A New Framework to Evaluate Crash Risk for Road Traffic Safety Management System

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Abstract. Road safety issue is becoming increasingly important for both public administrations and road users. Therefore, tools for assessing and managing safety performance take on even more relevance.

Previous research has proposed different types of Road Safety Management Systems but, to the best of our knowledge, only a few of these studies have focused on recent road safety regulations such as the ISO 39001:2012.

This paper proposes a new framework that evaluates the crash risk for administrative areas according to ISO39001:2012. First, this framework identifies the safety factors. Next, it specifies the risk components in terms of frequency, severity and exposure factors that may affect road crashes. Then, combining these components in a risk crash function, it is possible to build a safety performance ranking for each administrative areas.

The viability of the proposed methodology was tested on the administrative areas of all Italian provinces, using over 500,000 road crashes data recorded by the Italian National Institute of Statistics ISTAT between 2015 and 2017, which were merged for the 107 Italian provinces. The results helped ranking the road safety of the Italian provinces according to a scale with four risk scores: maximum, high, medium and low.

The findings show how the implementation of the proposed framework could help public administrations in managing the safety performance of their road networks and, also, qualify them according to the recent safety norms.

Keywords: Road Safety · Smart city · Safety regulations · Risk · Safety performance

1 Introduction

During the last decade, road safety issue has assumed considerable importance for public administrations all over the world. Although considerable differences still remain

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among regions, more and more countries are adopting restrictive measures and international guidelines to reduce road traffic deaths and injuries [1]. The ISO 39001 [2] is one of the most important international norms for road safety of recent years and it is directed to all the organizations operating in and with the road traffic environment. The aim of this norm is the reduction of death and serious injuries caused by road traffic crashes by improving safety performance. According to [2], the improvement of the safety performance may be pursued by implementing a Road Traffic Safety Management System (RTSMS) organized in a Plan, Do, Check and Act (PDCA) cycle. In the Plan stage, the organization plans the goal, establishes roles and responsibilities, and identifies safety factors as well as risk exposure factors for the safety assessment. In the Do stage, the organization commits to achieve the safety objectives. In the Check stage, the organization establishes procedures to record crashes to monitor safety performance and periodically revises it. In the Act stage, the organization works towards a continuous improvement of its RTSMS. A key crucial point of ISO 39001 [2] is the implementation of a method to evaluate the crash risk, but no specific method is suggested.

Nevertheless, despite the literature is quite rich about road safety management systems, as far as we know, there are still few studies related to the ISO 39001 [2] and risk assessment methods in the domain of road safety.

During the last ten years, studies focused on three approaches to perform RTSMS models. The first approach is based on the conflict points assessment as safety management models. Many of these studies follow the Swedish Traffic Conflict Technique [3] and were implemented with new technologies (i.e. [4–8]). The second approach assesses the crash risk as a function of traffic flows ([9–11]). The last approach uses crash data to assess the risk associated within the reference context, and it is adopted in this study. Indeed, it is the most common in the road safety literature. Moreover, two different sub-approaches may be considered according to the size of the context: the former is focused on large administrative area as countries or regions ([12–19]), the latter tries to evaluate road safety performance on more restricted areas such as routes, intersection or districts ([20–24]). Despite this literature and as far as we know, no study has proposed a solid RTSMS that assesses road risk in terms of probability, consequence ad exposure of crashes. Therefore, there is not a mature scientific treatment about the implementation of ISO 39001 [2] on safety management models. Even outside of the scope of private transport (i.e., car based), there are few contributions. Porcu et al. ([25, 26]) focused on the evaluation of accident risk in public transport companies, whereas [27] in transport of dangerous good.

The objective of this paper is to develop a framework for the evaluation of the road safety encompassing the requirements of ISO 39001 [2] that combines safety factors of crash frequency and severity and exposure in one function. The proposed methodology adjusts the well-known risk index first introduced by [28] who considered the following three components: the potential crash consequence, the exposure factor and the probability factor. However, unlike [28] who used predefined numerical ratings for these components, our index is expressed by a mathematical relation among these components and uses real crashes data. Moreover, our index links together frequency and severity prediction models (or functions) to the exposure factors.

The viability of this framework was tested in Italy, using over 500,000 road crashes recorded by the Italian National Institute of Statistics (ISTAT), merged by province, between 2015 and 2017. More precisely, the results are provided in an aggregate form for each province and a focus is also reported for the Sardinian road safety performance situation, being the origin of most of the authors.

This paper aim to contribute to both theory and practice. From a theoretical perspective, this paper covers a research area that has not been fully addressed and provides useful outcomes for many applications. On the practical side, this framework helps implement a RTSMS for each administration interested in the monitoring of road safety performance and in the safety certification process according to [2].

The remaining paper is organized as follows. Section 2 presents a general framework to evaluate the crash risk. Section 3 illustrates the experimentation of this framework in all the Italian provinces and briefly discusses the results. Finally, Sect. 4 draws conclusions and research perspectives.

2 Methodology

The proposed framework builds on ([25, 26]) for the public transport and it describes each step for the crash risk assessment of the private transport, according to the safety factors introduced by the ISO 39001 [2]. A scheme of the framework is shown in Fig. 1.

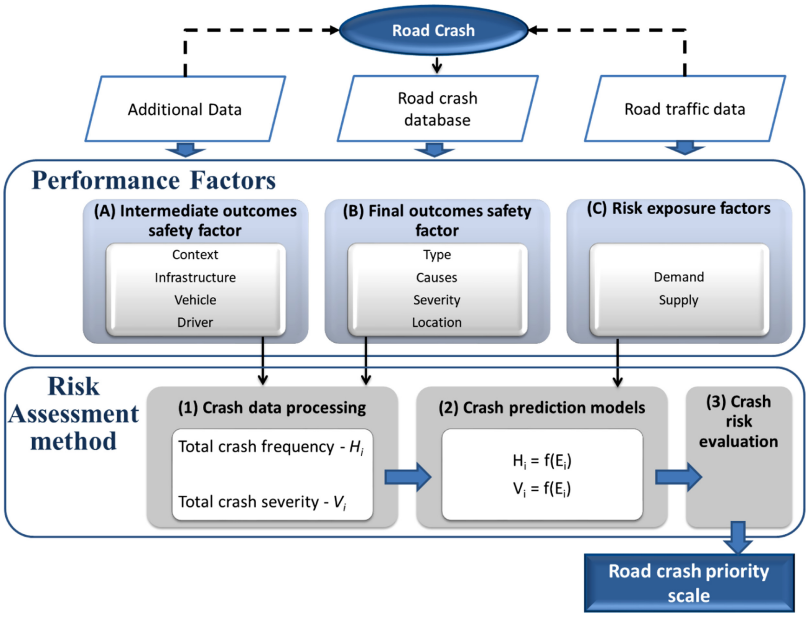


Fig. 1. Conceptual framework for road crashes risk evaluation

2.1 Performance Factors

According to [2], a performance factor is "*a measurable factor, element and criterion to the road traffic safety identified to cause road traffic crashes and road traffic incidents that lead, or have the potential to lead, to death and serious injuries of road users*". Other studies have already focused on identifying these factors, usually called variables or safety factors but their deepening is not the subject of this study (i.e., [26, 29–32]). From a practical viewpoint, there is no standard variable within each crash database. Moreover, usually the available database has a limited number of variables and it may contain factors that are difficult to implement in the methodology. Therefore, it is important to identify the different types of factors to better understand the available variable and its usefulness within the methodology.

Following the ISO39001 [2] directives, three classes of factors are distinguished: (A) intermediate outcome safety factors, (B) final outcome safety factors and (C) risk exposure factors.

(A) Intermediate Outcomes Safety Factors
The intermediate outcome safety factors are related to safe planning design and use of the road network, vehicle type, user safety equipment, fitness of drivers and so on. They are described by the ISO 39001 [2] as the condition or interventions that improve the final road traffic safety performance both in terms of occurrence and severity of crashes. In other words, intermediate outcome safety factors are the elements that can reduce (or increase) the number of crashes and/or the potential consequence of crashes. For example, the presence of well-signalized pedestrian crossings along the road could be the reason to the reduction of the number and severity of crashes because drivers tend to reduce speed and pay more attention to them. According to ([25, 26]) based on the scale and context of the analysis, it is possible to define different class of intermediate outcome safety factors. For the analysis of private transport, in this paper, we identified four types of intermediate outcome safety factor: the context, the infrastructure, the vehicle and the driver.

(B) Final Outcomes Safety Factors
The final safety outcomes include all factors that can be collected after a crash has occurred. These factors are recorded in specific crashes database by local authorities (i.e. local police) or other organization (e.g. insurance companies etc.). This class largely reflects the number and the severity of crashes in terms of deaths, serious injuries, and property damages; but also include other final safety outcome factors such as the crash type, the location etc. It is important to highlight that this framework focuses exclusively on road crashes intended as unwanted accidental events.

(C) Risk Exposure Factors
The risk exposure factors are related to the supply of road network and user demand. For this reason, we group the risk exposure factors into supply-oriented and demand-oriented factors. Supply oriented factors concern road characteristics (e.g., the length of the road) while demand oriented factors concern the use of the road network by users (e.g. the annual average daily traffic). However, despite the importance of such factors, they are

usually not recorded in the crash databases. Indeed, crashes will result by the interaction between the intermediate safety outcome factors and the risk exposure factors.

2.2 Risk Assessment Method

The methodology exposed in this paper is inspired by the well-known risk index introduced by [28], where the risk is computed as a combination of three components: Probability, Exposure and Consequence (or Vulnerability). Let R be the risk score, C the consequence, E the exposure factor and P the probability factor.

$$R = C \times E \times P \tag{1}$$

The consequences refer to the most probable results of a potential crash; exposure is described as the frequency of occurrence of the hazard-event (unsafe condition or potential source of an accident) while probability is the likelihood that an accidental event may arise from the hazard-event [28].

However, unlike [28] who assigned default values for the risk components, our index introduced a mathematical relation among these components which are evaluated through analytical functions as already applied in public transport ([25, 26]). Nevertheless, in this study, a methodology is proposed for the calculation of a risk index on homogeneous administrative areas, intended as a part of the road network where each contextual, infrastructural, vehicular and user characteristics remain constant.

Let:

- l be the homogeneous administrative area of interest;
- i be the index of the intermediate outcome factor (or the associated sub-factor);
- n be the total number of intermediate outcome factors;
- $H_{i,l}$ be the frequency of crashes occurrence on homogeneous administrative area l that can be evaluated as the total number of crashes in a predefined time interval (e.g., a year) in which factor i manifests itself;
- $V_{i,l}$ be the potential consequence of crash (in terms of severity of crashes) on homogeneous administrative area l, that can be evaluated as the total cost of crashes in a predefined time interval (e.g., a year) in which factor i manifests itself;
- $E_{i,l}$ be the exposure factor on homogeneous administrative area l associated with factor i.

The crash risk index on homogeneous administrative area l (R_l) may be defined as:

$$R_l = \sum_{i=1}^{n} \left(H_{i,l} * V_{i,l} * E_{i,l}\right) \tag{2}$$

Each individual component of (2) is better explained in the following steps.

(1) Crash Data Processing

The estimate of $H_{i,l}$ and $V_{i,l}$ needs a preliminary crash data processing, in which the total number of crashes and the severity are computed from the raw crashes database. More precisely, for each intermediate outcome safety factor i, the occurrence frequencies and associated economic costs are counted.

Let:

- j be the index of the crash;
- m be the total of number of crashes;
- h_{ijl} be a binary variable related to the crash occurrence, which is 1 if crash j occurred on homogeneous administrative area l, due to factor i, 0 otherwise.
- $v_{ijl}{}^{dm}$, $v_{ijl}{}^{f}$, $v_{ijl}{}^{d}$ be ordered variables related to the crash severity due to damages (dm), injuries (f) and dead (d), respectively, according to a numerical scale. Although several scales may be adopted for this purpose (e.g., [33]), in this paper we adopt the average cost related to the severity of damage computed as sum of costs for material damage (C_m), injured (C_f) or dead (C_d).

Thus, the total frequency of crashes and the associated severities may be computed as follows:

$$\boldsymbol{H_{i,l}} = \sum_{j=1}^{m} \boldsymbol{h_{ijl}} \; \forall i = 1, \ldots, n; \forall l = 1, \ldots, L \tag{3}$$

$$\boldsymbol{V_{i,l}} = \sum_{j=1}^{m} (\boldsymbol{v_{ijl}^{dm}} * \boldsymbol{C_m} + \boldsymbol{v_{ijl}^{f}} * \boldsymbol{C_f} + \boldsymbol{v_{ijl}^{d}} * \boldsymbol{C_d}) \; \forall \, i = 1, \ldots, n \; ; \; \forall \, l = 1, \ldots, L \tag{4}$$

(2) Crash Prediction Models

In the second step the frequency and the severity of crashes are computed by bivariate models, one for each intermediate safety outcome factor i, where $H_{i,l}$ and $V_{i,l}$ are the response variables, and the predictors are represented only by the exposure factor $E_{i,l}$. Although this choice impedes analysis of the correlations between intermediate safety outcome factors, the simple formulation of bivariate models enables to easily evaluate the impact on risk assessment of each factor singularly. Thus, differently from multivariate models, this choice helps compute the risk exposure factors value for each i. In other words, each bivariate model can have a different risk exposure factor according to the intermediate safety outcome factor. For instance, if i is daylight, then the exposure factor could be the average daily traffic during the daylight hours.

According to [34], road crashes are random, rare and non-negative integer events. Therefore, we decide to use the Generalized Linear Modelling approach that assumes a negative binomial structure to predict the frequency of crashes. However, there is a non-linear relationship between the frequency of crashes and traffic exposure factors (e.g., [35]). Moreover, exposure $E_{i,l}$ refers to a variable that when it assumes zero value, the frequency of crashes and severities must be zero. Therefore, according to (e.g., [35, 36]), a power function regression is a viable solution. Let:

- α_{1i}, α_{2i}, β_{1i}, β_{2i} be the coefficients to be estimated in the model.

The prediction of $\widehat{H_{i,l}}$ and $\widehat{V_{i,l}}$ is performed as follows:

$$\widehat{\boldsymbol{H_{i,l}}} = \boldsymbol{\alpha}_{1,i,l} * \boldsymbol{E}_{i,l}^{\alpha_{2,i,l}} \tag{5}$$

$$\widehat{V_{i,l}} = \boldsymbol{\beta}_{1,i,l} * \boldsymbol{E}_{i,l}^{\boldsymbol{\beta}_{2,i,l}} \tag{6}$$

(3) Crash Risk Calculation and Risk Priority Scale
The estimation of crash prediction models $\widehat{H_{i,l}}$ and $\widehat{V_{i,l}}$ enables us to computing the crash risk index for each homogeneous road section by adjusting Eq. (1) as follows:

$$R_l = \sum_{i=1}^{n} \left(\widehat{H_{i,l}}(E_{i,l}) + \widehat{V_{i,l}}(E_{i,l})\right) = \sum_{i=1}^{n} \left(\left(\alpha_{1,i,l} * E_{i,l}^{\alpha_{2,i,l}}\right) * \left(\beta_{1,i,l} * E_{i,l}^{\beta_{2,i,l}}\right)\right) \ \forall\, l = 1, \ldots, L \tag{7}$$

Results of Eq. (7) enables us to classify roads according to a predefined risk scale to prioritize the road safety improving actions. In this paper, a simple risk priority scale for homogeneous administrative area l is proposed according to the following criterion: we divide the range lower, middle and upper quartiles ($Q_1 = 25$th percentile, $Q_2 = 50$th percentile and $Q_3 = 75$th percentile) and classify each road as follows:

- $R_1 \rightarrow R > Q_3$ - Maximum risk (8)
- $R_2 \rightarrow Q_2 > R > Q_3$ - High risk (9)
- $R_3 \rightarrow Q_1 > R > Q_2$) - Average risk (10)
- $R_4 \rightarrow (R < Q_1)$ - Low risk. (11)

This risk classification helps identify the roads that require greater safety measures to apply the risk mitigation measures. First, it is important to understand the reasons for poor performance safety on this road sections by using a detailed analysis of the crashes and the severity; next, the actions to for the risk mitigation should be searched. This may be pursued by prevention and/or protection actions that act on the terms of Eq. (7). Prevention actions aim to reduce level $\widehat{H_{i,l}}(E_{i,l})$, whereas protection actions aim to reduce the level of $\widehat{V_{i,l}}(E_{i,l})$.

3 Real World Experiment

This section shows the application of the methodology. The crash database was acquired by ISTAT. This database contains crashes data occurred on Italian roads (from 2015 to 2017), which are merged for the 107 Italian provinces for this experiment. The characteristics which have been analyzed and processed are shown in Table 1.

ISTAT only collects road crashes data recorded by law enforcement agencies in which at least one person is injured or dead. Therefore, property damage only road crashes are missing.

Moreover, since the data on accidents provided by ISTAT are aggregated by province, the risk index was calculated at the provincial level, considering all the roads of the single province- together. The Automobile Club Italia (ACI) and other ISTAT databases (not crashes) are used for the computation of exposure factors data.

Table 1. Intermediate outcome factor

Factors	Sub-factors	Exposure factors
Type of vehicle	Passengers car [**C**] – Bus [**B**] - Commercial Vehicles [**CV**] – Motorcycles [**M**] – other [**O**]	N° of vehicles by province
Type of road	Motorway [**Mw**] - State Road [**Sr**] - Provincial Road [**Pr**]	Km of road typology by province
Gender of the driver	Male [**gM**] – Female [**gF**]	N° of male and female drivers by province
Age class of the driver	14/17 [**a1**] - 18/29 [**a2**] – 30/54 [**a3**] – 55/64 [**a4**] - + 65 [**a5**]	N° of drivers for age classes by province

In brackets the acronyms of the sub-factors are reported. They help reading results in Table 2

Therefore, following the steps indicated in Fig. 1, the total frequency of crashes and the associated severities are calculated by applying Eqs. (3) and (4). It should be noted that for the calculation of the latter, the average cost associated with each event was taken from [37]. The reference values are: € 1,503,990.00 for the average annual cost for road deaths and € 42,219 for the injured.

Next, by Eqs. (5) and (6) we predicted $\widehat{H_{i,l}}$ and $\widehat{V_{i,l}}$ for each Italian province. More precisely, the frequency and the severity of crashes are computed by bivariate models, one for each intermediate safety outcome factor *i*, where $H_{i,l}$ and $V_{i,l}$ are the response variables, and the predictors are represented only by the exposure factor $E_{i,l}$. Coefficients α_i e β_i were estimated by a power function regression. In addition, estimating a vulnerability value for the type of vehicle factors was not possible owing to the aggregated data provided by ISTAT.

Next, each model was evaluated by different goodness-of-fit measures: F-test, the Pearson correlation coefficient (R), R^2 and the adjusted-R^2. In addition, the sign and the significance of the coefficient are evaluated for each model.

Table 2 reports the results of these estimations. Generally speaking, all models provide a good data fit.

As expected, all models give evidence that by increasing exposure factor $E_{i,l}$, $\widehat{H_{i,l}}$ and $\widehat{V_{i,l}}$ increase as well.

As for vehicles, motorcycles have the highest H compared to the other types of vehicles. This result is probably related to the high speeds and the relatively poor safety conditions of motorcyclists, who are still considered as vulnerable road users for their few protection devices.

Focusing on infrastructure factors, the motorway is the safest type for high exposure values. This unexpected result can be explained as follows: at the same traffic volumes, the high standards of highway design provide the highest levels of safety.

Lastly, as for the driver factors, males aged 18 to 29 have the highest values of $\widehat{H_{i,l}}$ and $\widehat{V_{i,l}}$. Inexperience and recklessly behavior may have significantly influenced this result.

Table 2: Regression coefficients

Pattern	F-Test	R	R^2	Adjusted R2	t-stat (p value)
Type of vehicle					
$H_C = 0,002E_C^{1.097}$	483,271	0,906	0,822	0,820	$\alpha_2 = 21.983$ (<.001)
$H_B = 0.019E_B^{0.967}$	83,051	0,666	0,444	0,439	$\alpha_2 = 9.113$ (<.001)
$H_{CV} = 0.002E_{CV}^{1.062}$	150,621	0,768	0,589	0,585	$\alpha_2 = 12.273$ (<.001)
$H_M = 0.0001E_M^{1.393}$	881,235	0,945	0,894	0,893	$\alpha_2 = 29.686$ (<.001)
$H_O = 0.0005E_O^{1.282}$	263,450	0,846	0,715	0,712	$\alpha_2 = 16.231$ (<.001)
Type of road					
$H_{Mw} = 0.00003E_{Mw}^{0.915}$	213,768	0,843	0,711	0,707	$\alpha_2 = 14.621$ (<.001)
$V_{Mw} = 7.749E_{Mw}^{0.863}$	109,805	0,747	0,558	0,553	$\beta_2 = 10.479$ (<.001)
$H_{Sr} = 0.002E_{Sr}^{0.698}$	139,680	0,757	0,573	0,569	$\alpha_2 = 11.819$ (<.001)
$V_{Sr} = 382.920E_{Sr}^{0.668}$	108,489	0,715	0,511	0,506	$\beta_2 = 10.416$ (<.001)
$H_{Pr} = 0.00004E_{Pr}^{0.911}$	151,729	0,770	0,593	0,589	$\alpha_2 = 12.318$ (<.001)
$V_{Pr} = 4.785E_{Pr}^{0.907}$	131,084	0,747	0,558	0,553	$\beta_2 = 11.449$ (<.001)
Gender of the driver					
$H_{gM} = 0.002E_{gM}^{1.092}$	652,176	0,929	0,863	0,861	$\alpha_2 = 25.538$ (<.001)
$V_{gM} = 316.365E_{gM}^{1.008}$	699,106	0,933	0,871	0,869	$\beta_2 = 26.441$ (<.001)
$H_{gF} = 0.002E_{gF}^{1.050}$	460,165	0,903	0,816	0,814	$\alpha_2 = 21.451$ (<.001)
$V_{gF} = 92.673E_{gF}^{1.044}$	435,729	0,899	0,807	0,806	$\beta_2 = 20.874$ (<.001)
Age class of the driver					
$H_{a1} = 0.012E_{a1}^{0.907}$	242,745	0,837	0,700	0,697	$\alpha_2 = 15.580$ (<.001)
$V_{a1} = 423.802E_{a1}^{0.944}$	197,782	0,810	0,655	0,652	$\beta_2 = 14.063$ (<.001)
$H_{a2} = 0.003E_{a2}^{1.070}$	552,234	0,917	0,842	0,8400	$\alpha_2 = 23.500$ (<.001)
$V_{a2} = 316.141E_{a2}^{1.028}$	492,398	0,909	0,826	0,8239	$\beta_2 = 22.190$ (<.001)
$H_{a3} = 0.001E_{a3}^{1.090}$	601,736	0,923	0,853	0,8512	$\alpha_2 = 24.530$ (<.001)
$V_{a3} = 110.376E_{a3}^{1.073}$	561,478	0,919	0,844	0,8422	$\beta_2 = 23.696$ (<.001)
$H_{a4} = 0.002E_{a4}^{1.049}$	394,841	0,890	0,792	0,7895	$\alpha_2 = 19.871$ (<.001)
$V_{a4} = 268.136E_{a4}^{0.978}$	286,069	0,856	0,733	0,7308	$\beta_2 = 16.914$ (<.001)
$H_{a5} = 0.001E_{a5}^{1.040}$	355,403	0,880	0,774	0,7714	$\alpha_2 = 18.852$ (<.001)
$V_{a5} = 299.085E_{a5}^{0.971}$	309,698	0,865	0,749	0,7462	$\beta_2 = 17.598$ (<.001)

Finally, by Eq. (7), for each province has been calculated the crash risk index R_I. Since the index values are very high, the scale was obtained considering their logarithm. The results are ranked in decreasing order of risk and are shown in Figs. 2, 3, 4 and 5. They show the general risk scale (Fig. 2) and the detailed scale for each R_I risk classification (Figs. 3, 4, 5 and 6, respectively). For sake of clarity, the black lines in Fig. 2 represent the threshold of the lower, middle and upper quartiles, which define the risk classes.

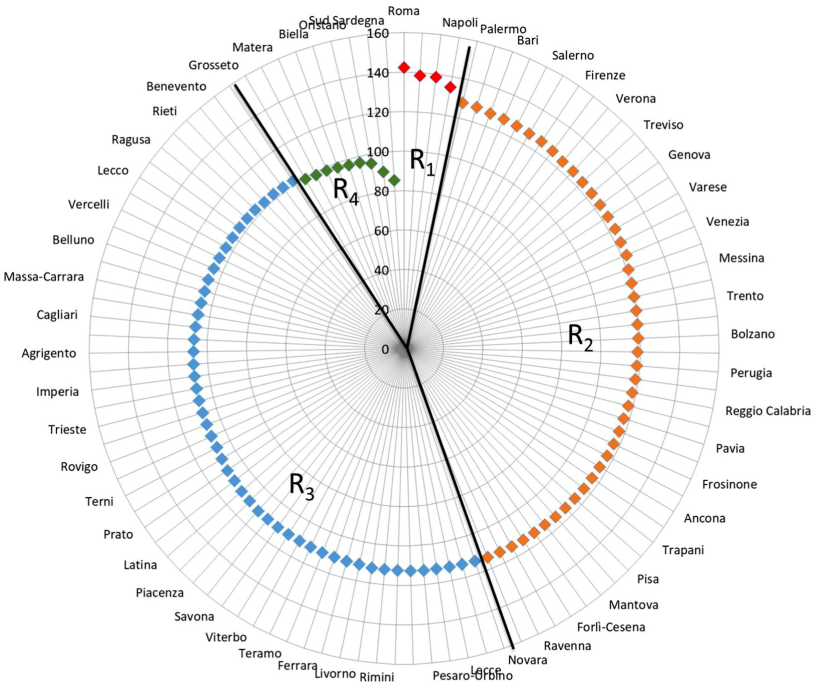


Fig. 2. Risk scale

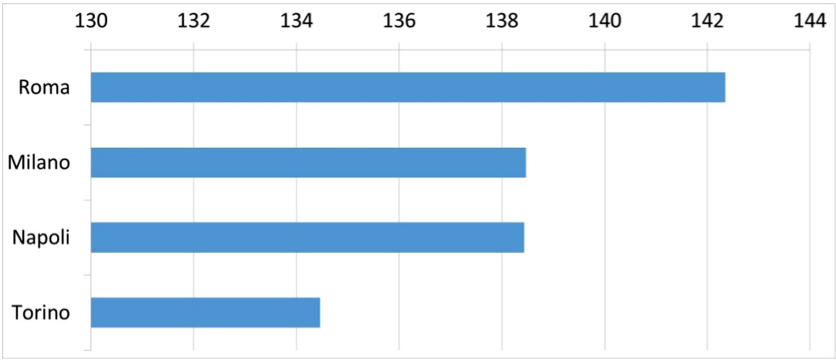


Fig. 3. Risk scale R_1 – maximum risk

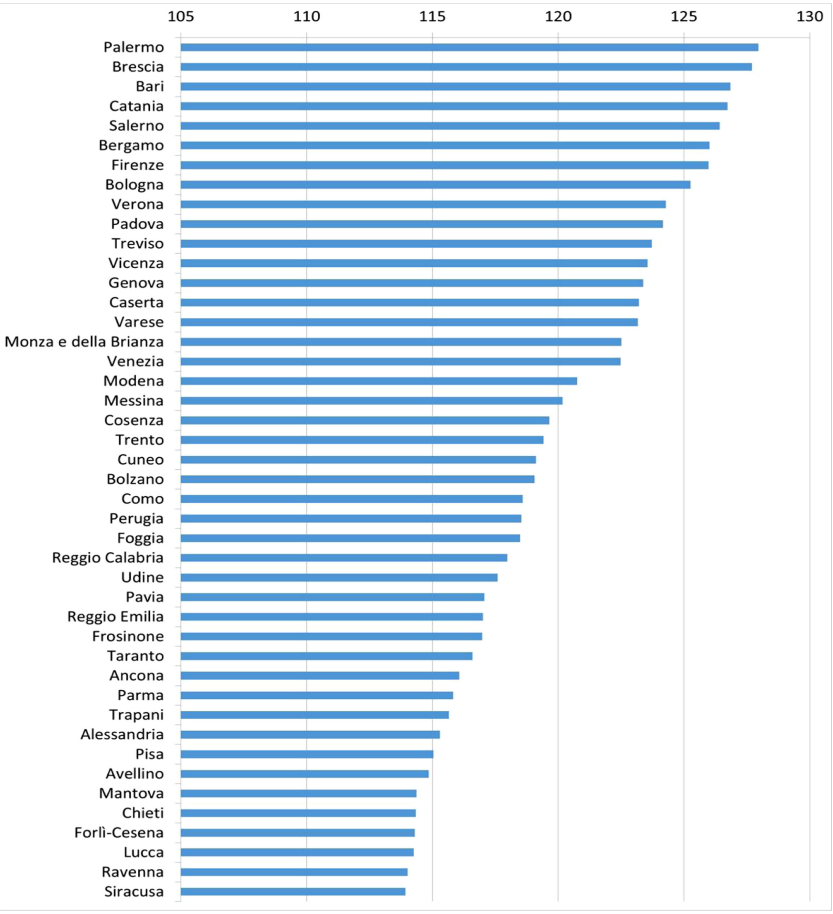


Fig. 4. Risk scale R_2 – high risk

Considering the results at the national context, the provinces ranked as R_1 (i.e., Roma, Milano, Napoli and Torino – Fig. 3) are also four of the largest and important Italian cities, which have very high population densities and a large number of road links. Therefore, due to these conditions, the exposure values are higher than in the other provinces. Conversely, the risk index classifies the Sardinian provinces (marked in yellow) at a medium (Fig. 5) - low risk (Fig. 6). This can be explained in absolute terms by considering the low demand values of the provinces of the island compared to the levels of the remaining Italian provinces.

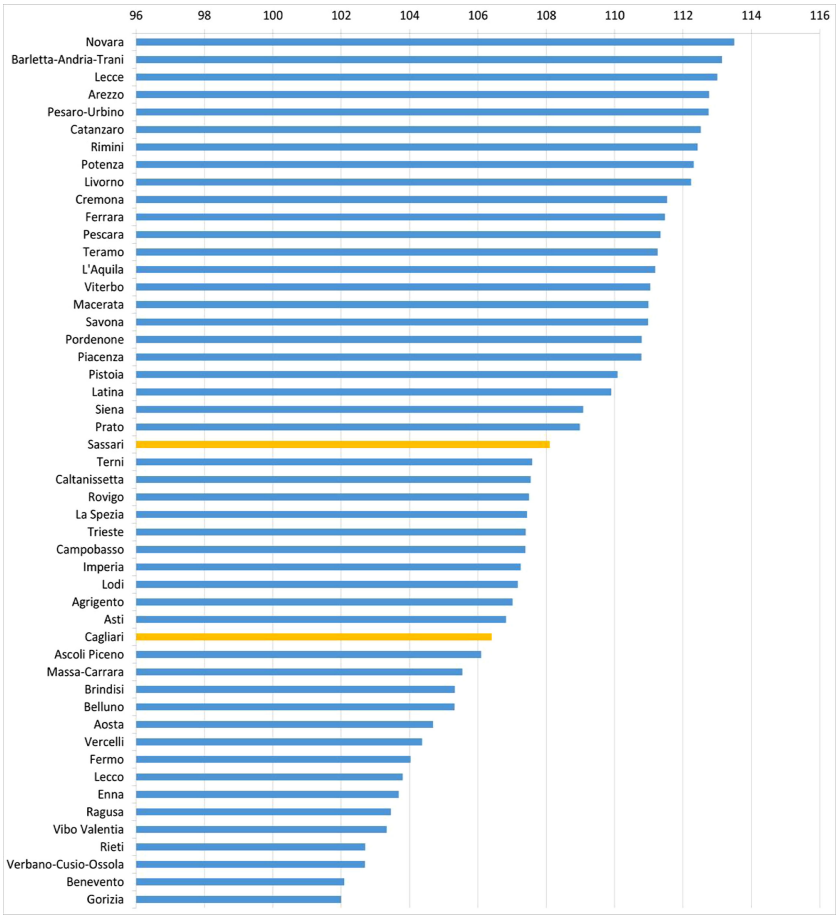


Fig. 5. Risk scale R_3 – average risk

A small-scale analysis, such as the road section, with a disaggregate crashes database, will enable to carry out a more detailed analysis and will enable to look for prevention and/or protection actions for risk mitigation. However, this case study was developed for testing the methodology according to the available data.

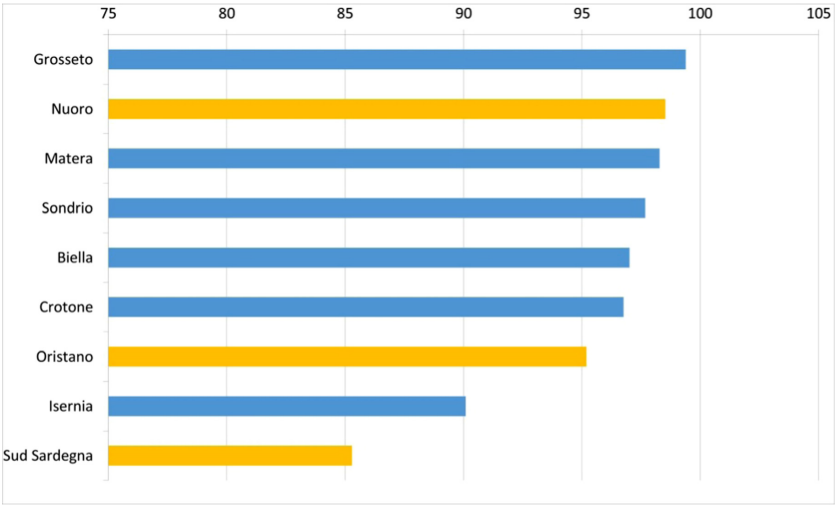


Fig. 6. Risk scale R_4 – low risk

4 Conclusions

In recent years, road safety issue is becoming increasingly important for both public administrations and road users. In this context, the tools for assessing and managing safety performance become even more important. However, to our knowledge, there is a gap in the literature on the assessment of the crash risk in private transport encompassing the requirements of ISO 39001 [2] by considering the frequency and the severity of the crash as a function of exposure factors.

This paper covers this gap by proposing a framework to assess the crash risk in the private transport by integrating safety factors, prediction models of frequency and severity to exposure factors and a risk assessment method. This framework was experimented in a real case study using over 500,000 road crashes data recorded by the Italian National Institute of Statistics ISTAT between 2015 and 2017, which were merged for the 107 Italian provinces. These results helped ranking the road safety of the Italian provinces from a maximum risk score (4 provinces) to a lower risk one (9 provinces) passing through intermediate values of high risk (44 provinces) and average risk (50 provinces). Indeed, this was helpful in identifying areas that require further attention in terms of road safety so that specific strategies can be developed.

Further developments of this research may follow: first, it could be of interest the evaluation of the risk of crashes for road sections using a disaggregate road crashes database, to better analyse the criticalities of this road network. Second, a complex bivariate (frequency and severity) risk model with all intermediate outcome factors and exposure factors will be developed. This model could help derive a compact set of significant factors to explain the frequency and severity of crashes to measure the crash risk for each administrative area, road, or road section.

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References

1. World Health Organization. Global status report on road safety 2018 (2018). Geneva, Switzerland, WHO (2019)
2. ISO 39001. Road Traffic Safety (RTS) Management Systems: Requirements with Guidance for Use. Geneva: International Standards Organisation (2012)
3. Hydén, C.: The development of a method for traffic safety evaluation: The Swedish Traffic Conflicts Technique. Bulletin Lund Institute of Technology, Department, vol. 70 (1987)
4. Vasconcelos, L., Neto, L., Santos-Pólo, R.L.R., II., Seco, Á.M., Silva, A.B.: Validation of the ssam technique for the assessment of intersections safety. Meet. Transp. Res. Board **38**, 39 (2014)
5. So, J., Hoffmann, S., Lee, J., Busch, F., Choi, K.: A prediction accuracy-practicality tradeoff analysis of the state-of-the-art safety performance assessment methods. Transp. Res. Procedia **15**, 794–805 (2016)
6. Giuffrè, T., Trubia, S., Canale, A., Persaud, B.: Using microsimulation to evaluate safety and operational implications of newer roundabout layouts for European Road networks. Sustainability **9**(11), 2084 (2017)
7. Astarita, V., Festa, D.C., GiofrÃ, V.P.: Microsimulation and the evaluation of safety levels in the presence of roadside obstacles. Eur. Transp. Trasp. Eur. **77**, 1–12 (2020)
8. Tesoriere, G., Campisi, T., Canale, A., ZgrabliÄ, T.: The surrogate safety appraisal of the unconventional elliptical and turbo roundabouts. J. Adv. Transp. **2018**, 1–9 (2018)
9. Yannis, G., et al.: Road safety performance indicators for the interurban road network. Accid. Anal. Prev. **60**, 384–395 (2013)
10. Lynam, D, Sutch, T., Broughton, J, and Lawson, S.D.: European road assessment programme, pilot phase technical report. AA Foundation for Road Safety Research, Farnborough, UK (2003).
11. Lynam, D., Hummel, T., Barker, J., Lawson, S.D.: European road assessment programme, EuroRAP! Technical report. AA Foundation for Road Safety Research, Farnborough, UK (2004)
12. Jamroz, K.: The impact of road network structure and mobility on the national traffic fatality rate. Procedia Soc. Behav. Sci. **54**, 1370–1377 (2012)
13. Khorasani, G., Yadollahi, A., Rahimi, M., Tatari, A.:.Implementation of MCDM methods in road safety management. In: International Conference on Transport, Civil, Architecture and Environment engineering (ICTCAEE'2012), pp. 26–27 (2012)
14. Jamroz, K., & Smolarek, L.: Road safety management tools for country strategic level. In: 16th International Conference Road Safety on Four Continents. Beijing, China (RS4C 2013), 15–17 May 2013 (2013)
15. Gitelman, V., Vis, M., Weijermars, W., Hakkert, S.: Development of road safety performance indicators for the European countries. Adv. Soc. Sci. Res. J. **1**(4), 138–158 (2014)
16. Hughes, B.P., Anund, A., Falkmer, T.: System theory and safety models in Swedish, UK, Dutch and Australian road safety strategies. Accid. Anal. Prev. **74**, 271–278 (2015)

17. Persia, L., et al.: Management of road infrastructure safety. Transp. Res. Procedia **14**, 3436–3445 (2016)
18. Sakhapov, R.L., Nikolaeva, R.V., Gatiyatullin, M.H., Makhmutov, M.M.: Risk management model in road transport systems. J. Phys. Conf. Ser. **738**(1) 012008 (2016)
19. Wegman, F., Berg, H.Y., Cameron, I., Thompson, C., Siegrist, S., Weijermars, W.: Evidence-based and data-driven road safety management. IATSS Res. **39**(1), 19–25 (2015)
20. Sumaila, A.F.: Road crashes trends and safety management in Nigeria. J. Geogr. Regional Plan. **6**(3), 53 (2013)
21. Costescu, D., Raicu, S., Rosca, M., Burciu, S., Rusca, F.: Using intersection conflict index in urban traffic risk evaluation. Procedia Technol. **22**, 319–326 (2016)
22. Bonera, M., Maternini, G.: Methodology for the application of predictive method for road safety analysis in urban areas the case study of Brescia. Transp. Res Procedia **45**, 659–667 (2020)
23. Mahmud, S.S., Ferreira, L., Hoque, M.S., Tavassoli, A.: Micro-level safety risk assessment model for a two-lane heterogeneous traffic environment in a developing country: a comparative crash probability modeling approach. J. Safety Res. **69**, 125–134 (2019)
24. Wu, P., Meng, X., Song, L., Zuo, W.: Crash Risk Evaluation and crash severity pattern analysis for different types of urban junctions: fault tree analysis and association rules approaches. Transp. Res. Rec. **2673**(1), 403–416 (2019)
25. Porcu, F., Olivo, A., Maternini, G., Barabino, B.: Evaluating bus accident risks in public transport. Transp. Res. Procedia **45**, 443–450 (2020)
26. Porcu, F., Olivo, A., Maternini, G., Coni, M., Bonera, M., Barabino, B.: Assessing the risk of bus crashes in transit systems. Eur. Transp. **81**, 4 (2021)
27. Conca, A., Ridella, C., Sapori, E.: A risk assessment for road transportation of dangerous goods: a routing solution. Transp. Res. Procedia **14**, 2890–2899 (2016)
28. Fine, W.T.: Mathematical evaluations for controlling hazards. J. Safety Res. **3**, 157–166 (1971)
29. Ma, J., Kockelman, K.M., Damien, P.: A multivariate Poisson-lognormal regression model for prediction of crash counts by severity, using Bayesian methods. Accid. Anal. Prev. **40**(3), 964–975 (2008)
30. Moghaddam, F.R., Khiavi, M.P., Moghaddam, T.R., Ghorbani, M.A.: Crash severity modeling in urban highways using backward regression method. J. Civil Eng. Arch. **4**(6), 43–49 (2010)
31. Rosolino, V., et al.: Road safety performance assessment: a new road network risk index for info mobility. Procedia. Soc. Behav. Sci. **111**, 624–633 (2014). https://doi.org/10.1016/j.sbspro.2014.01.096
32. Casado-Sanz, N., Guirao, B., Attard, M.: Analysis of the risk factors affecting the severity of traffic accidents on Spanish crosstown roads: the driver's perspective. Sustainability **12**(6), 2237 (2020)
33. AAAM.: The Abbreviated Injury Scale, 1990 revision. Des Plaines, IL: Association for the Advancement of Automotive Medicine (1990)
34. Mannering, F.L., Bhat, C.R.: Analytic methods in accident research: methodological frontier and future directions. Anal. Methods Accid. Res. **1**, 1–22 (2014)
35. Cheung, C., Shalaby, A., Persaud, B., Hadayeghi, A.: Models for safety analysis of road surface transit. Transp. Res. Rec. **2063**, 168–175 (2008)
36. D'Agostino, C.: Reliability-based assessment of benefits in roadway safety management. Transp. Res. Rec. J. Transp. Res. Board **2513**, 1–10 (2015)
37. Ministero delle Infrastrutture e dei Trasporti, M.D.I.: Studio di valutazione dei Costi Sociali dell'incidentalità stradale (2010)