Safety Oriented Road Asset Management Methodology for Urban Areas

Mauro D'Apuzzo[1(✉)], Azzurra Evangelisti[1], Giuseppe Cappelli[1,2], and Vittorio Nicolosi[3]

[1] University of Cassino and Southern Lazio, Via G. Di Biasio 43, 03043 Cassino, Italy
{dapuzzo,giuseppe.cappelli1}@unicas.it
[2] University School for Advanced Studies, IUSS, Piazza della Vittoria n.15, 27100 Pavia, Italy
giuseppe.cappelli@iusspavia.it
[3] University of Rome "Tor Vergata", Via del Politecnico 1, 00133 Rome, Italy
nicolosi@uniroma2.it

Abstract. Modern cities require new engineered approaches to tackle the challenges related to smart, sustainable and safe urban mobility. In this connection, preserving the functional condition of road infrastructures is of paramount importance. Following the recent European Directive on Road Safety Management, in this paper a new safety-oriented methodology for road asset management system in urban areas has been developed and presented.

The proposed methodology is based on the results obtained from the accident analysis and the current road assets conditions gained by means of road safety inspections.

All the collected data are combined into an urban road management system model that is able to convert qualitative judgements into quantitative values in order to evaluate budget allocation and prioritization of road maintenance interventions basing on a global performance safety function.

In order to validate the proposed method, a 30 km long Italian urban road network has been examined and safety inspections have been carried out to gain information on asset conditions together with related traffic and accident data. Finally, according to a hypothesized triennial investment plan, the best three-years maintenance program has been identified accomplishing the principle of maximum reduction of accident rate.

Results obtained so far highlight that the proposed method may be a useful tool for municipal road agencies.

Keywords: Urban road asset management · Road safety · Budget allocation

1 Introduction

Transportation organizations have the responsibility and the challenging task to maintain, preserve and improve infrastructure assets for current and future generations since transport infrastructures play a critical role in the development of the modern communities' economic and social aspects.

© The Author(s), under exclusive license to Springer Nature Switzerland AG 2022
O. Gervasi et al. (Eds.): ICCSA 2022 Workshops, LNCS 13382, pp. 650–662, 2022.
https://doi.org/10.1007/978-3-031-10592-0_47

However, due to both economic (as funds deficiency) and environmental (as territory revaluation) aspects, in recent years, the main aim of transportation systems administrations has been the "*existing infrastructures' heritage maintenance*", implying the use of renewed approaches for resources optimization.

Therefore, engineering-economic procedures have been developed and implemented into proprietary tools with various purposes as: more efficient management of ordinary and extraordinary maintenance operations; rational support decision-making and road asset risk evaluation.

These tools are known as Asset Management Systems, AMS [1] which are usually composed by a GIS (Geographical Information System) architecture with database and, eventually, a decision support system. The new paradigm introduced by Asset Management represents a recent evolution of traditional maintenance approaches that are no longer be suitable to meet future business and political challenges.

The new framework already adopted in several countries has proved to provide a reliable response to various stakeholders' needs since it addresses "*demands of a nation's citizens and industry for greater accountability and transparency, more efficient use of funds, greater focus on customer expectations and more sustainable solutions*" [2].

In smart urban environment where most or individual mobility is still occurring, the recent instances related to sustainable development goals require a higher attention on transportation infrastructure preservation because of higher complexity of the transportation network systems and of multiple users (drivers as well pedestrian) and of the relationship between infrastructure assets.

On the other hand, it has to be reminded that every year 1.25 million people are killed and around 50 million are injured in road traffic crashes, providing the clear evidence that road safety is one of the most demanding health emergencies of our time [3].

In European Union, recent crash reports still highlight nearly one million of crashes resulting in injuries or death for 2019 year (pre Covid-19 pandemic period), with crashes involving vulnerable users (pedestrian and bicycles) that are almost three times higher in urban area with respect to rural one [4]. In the European area, as regards only the number of victims of road accidents, there was a significant reduction of -13% in 2020 and +5% respect 2020, in 2021 [5]. Unfortunately, it is mainly due to the strong mobility restriction caused by the Covid-19 pandemic and its effects.

In this connection, European Union, whose vision is to reduce to zero the crash related deaths by 2050, has helped the authorities, road managers and road safety professionals in making Europe's road infrastructure and management safer, by promulgating new regulations, and by promoting the adoption of guidelines concerning road safety impact assessments, road safety audits and inspections, safety rankings, management of the road network in operation [6].

Basing on these aforementioned premises, several authors proposed new methodological approaches for pavement maintenance in small municipalities [7] whereas other ones focused on infrastructure degradation modelling [8] or investigated on embedding risk into pavement management procedures [9] or resilience into asset management systems [10] but there is still a need to develop tailored urban transport infrastructures asset management procedures that may provide feasible tools for optimal budget allocation and intervention planning, as far as the impact to road safety of each maintenance action

(undertaken for the specific asset element) is concerned, in order to provide clear and transparent evidence of the management policy to the various stakeholders.

In this connection, ad innovative methodological approach that is able to combine a holistic urban transport asset management vision with the new approaches to be undertaken by safety inspections according to recent European Regulations on Road Safety Managements, is presented.

The framework of the methodology and a case study, where the original methodology has been applied, are conveniently reviewed in the followings.

2 Methodology - Model Framework

The framework of the model initially consists of two analyses of the network: the accident analysis and the current road asset condition analysis. Both of them are based on the detailed knowledge of the network, in terms of network geometry, operating speeds and traffic volumes (expressed as Average Daily Traffic, ADT).

In order to perform the analyses, the identification of homogeneous sections (specific nodes as intersections, roundabouts, etc. are not included), in terms of road layout features and percentage of occurred accidents is required and, according to the Italian guidelines [11], 100 m long road section (suggested for urban areas), has been chosen.

The core of the proposed model consists into the prioritization process which combines the previous analyses results by means of several matrixes and vectors in a series combination and obtaining a synthetic index able to identify critical assets of critical segments worthy of interventions and investments.

The output of the proposed simplified road asset management model, mainly aim to improve road safety and designed to act at network level, is the multi-year scheduling for ordinary maintenance interventions as [12, 13]:

- road pavement resurfacing;
- road markings painting;
- vertical signs substitution;
- drainages and side vegetation cleaning;
- safety barriers retrofit or substitution;
- streetlight devices improvement or substitution.

In Fig. 1, the framework of the simplified proposed model has been represented and in the following paragraphs a more detailed description of the model has been provided.

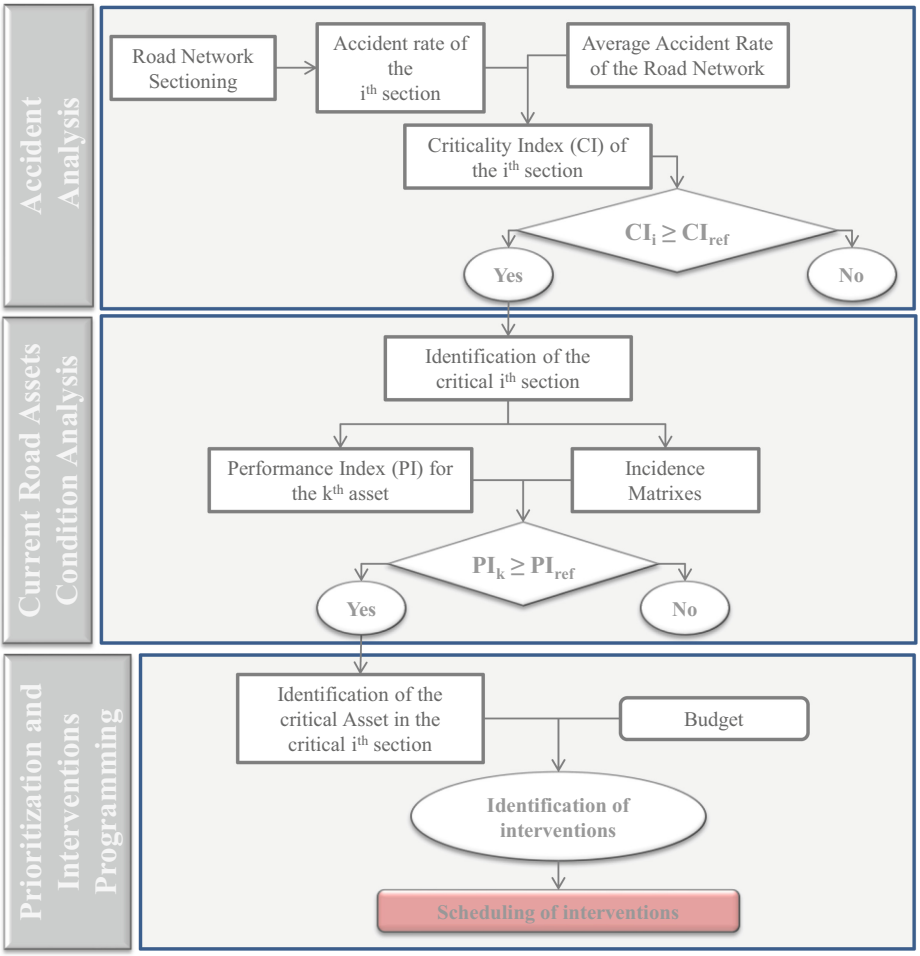

Fig. 1. Proposed model framework

2.1 Accident Analysis

The input data for the accident analysis consist on the accidents data occurred on the study road network. For each accident, the minimum requirement is the knowledge of the location, the type of accident, the day and hour, the severity of the accident (deaths, injuries, damage), the weather conditions and the pavement conditions.

These data are easily available for all the local agencies or municipalities which developed a customized accident database. On the same time, the National opensource database ISTAT [14] supplies these information with an acceptable level of precision.

The ISTAT database provides for the use of 12 different categories of accident types (see Table 1), and in the proposed model, an aggregation to 7 is performed (see Table 2).

Table 1. Categories of accident type and ISTAT code

ISTAT code	ISTAT definition of accident type
01	Head-on collision
02	Front-side collision
03	Side collision
04	Rear-end collision
05	Pedestrian involvement
06	Collision with vehicle in momentary arrest or stop
07	Collision with parked vehicle
08	Collision with accidental obstacle
09	Collision with train
10	Off-road
11	Sudden braking
12	Fall from vehicle

Table 2. Aggregation of accident types

Aggregation	ISTAT code
1	01–03
2	02
3	04–06
4	05–12
5	08
6	07–10
7	09–11

According to [15], for each road section and consequently for the overall road network, different Accident Rates (AR), depending on the daily period (night/day) and aggregation of accident type, could be evaluated. Thus 14 Average Network Accident-Type Rates that acts as reference values, have been calculated.

The accident analysis provides for the comparison of the accident rate, evaluated for each specific road section, with corresponding reference value, with the aim to identify accident-prone sections (with a Critical Index, CI, higher than the reference one) requiring a further investigation on road asset conditions.

2.2 Current Road Assets Condition Analysis

The analysis of the current conditions of the network is based on the evidences collected during the road network safety inspections which have the main aims to:

- identify road infrastructure problems that may constitute potentially dangerous situations;
- define a prioritization of corrective interventions in order to reduce number and severity of accidents;
- monitor in a continuous and systematic manner the safety conditions of the road network.

In particular the road network safety inspections, according to [6, 16, 17], consist into visual safety inspections of the roads in operation, by a team of experts, in different daily periods (day and night), during which fills technical sheets to describe the real conditions of the main road assets as: vertical road signs (replacement in case of aging or damage) and horizontal road signs (replacement in case of aging), streetlights (replacement of lamp or pole in case of damage), pavements (milling and remaking), hydraulics (lateral drainage gutter: cleaning or refurbishment/replacement in case of damage), roadside conditions (roadside greenery care) and safety barriers (replacement of road restraint systems in case of damage).

Following the inspections, for each asset and sub-asset, the qualitative judgments, are converted into quantitative values, which are appropriately weighted and combined in order to evaluate, for each road section and daily period (night/ day), the corresponding Performance Indexes (PI) related to the main road assets summarized in Table 3.

Table 3. Main assets identified for describing the current conditions

Asset		PI
Horizontal road signs	HS	PI_{HS}
Vertical road signs	VS	PI_{VS}
Hydraulics conditions	HC	PI_{HC}
Safety barriers	SB	PI_{SB}
Streetlights	SL	PI_{LS}
Pavements conditions	PC	PI_{PC}
Roadside conditions	RC	PI_{RC}

2.3 Prioritization and Interventions Programming

As previously mentioned, the core of the proposed method consists into the combination, by means of several matrices and vectors in series, of the results of the preceding analyses.

In particular, can be defined:

- the *Condition State Vector* which, for each segment and for each asset, contains the judgments of the safety inspectors;
- the *Accident-Type Risk Matrix*, one for each Accident-type aggregation, and conceived according to technical-scientific literature with the aim to identify which assets may affect occurrence and effects of a specific accident type;
- the *Risk Matrix*, one for each road segment, which is the combination of the latest two and provides the identification of the critical road segments.

Then, for each critical road segment, the Synthetic Index, defined in the Eq. 1 as function of traffic exposition, CI, AR and PI, can be calculated and their ascending order guarantees the evaluation of the maintenance interventions prioritization.

$$SI_{k,i} = \frac{ADT_i}{ADT_{max}} \left(W_d \sum_{AT} \frac{AR_{an,d,AT}}{AR_{an,d,AT_{Tot}}} \mathrm{PI}_{d,AT} \mathrm{CI}_{d,AT} + W_n \sum_{AT} \frac{AR_{an,n,AT}}{AR_{an,n,AT_{Tot}}} \mathrm{PI}_{n,AT} \mathrm{CI}_{n,AT} \right) \quad (1)$$

Where:

$SI_{k,I}$ = Synthetic Index for the kth asset and the ith critical road segment;
ADT_i = Average Daily Traffic of the ith critical road segment;
ADT_{max} = Maximum Average Daily Traffic of the network;
$AR_{an,d/n,AT}$ = Diurnal/Nocturnal Average Network Accident Rate for the specific Accident Type (AT) aggregation;
$AR_{an,d/n,ATTot}$ = Total Diurnal/Nocturnal Average Network Accident Rate for the specific AT aggregation;
$PI_{d/n,AT}$ = Diurnal/Nocturnal Performance Index for the specific AT aggregation, of the ith critical road segment;
$CI_{d/n,AT}$ = Diurnal/Nocturnal Critical Value for the specific AT aggregation, of the ith critical road segment;
$AR_{an,n,AT}$ = Nocturnal Average Network Accident Rate for the specific AT f aggregation;
$AR_{an,n,ATTot}$ = Total Nocturnal Average Network Accident Rate for the specific AT aggregation;
$PI_{n,AT}$ = Nocturnal Performance Index for the specific AT aggregation, of the ith critical road segment;
$CI_{n,AT}$ = Nocturnal Critical Value for the specific AT aggregation, of the ith critical road segment;
$W_{d/n}$ = Diurnal/Nocturnal Accident Weight, evaluated by means of the Eq. 2 and Eq. 3 respectively;

$$W_d = \frac{\sum_d \mathrm{AR}_{an,d,AT}}{\sum_{d+n} \mathrm{AR}_{an,AT}} \quad (2)$$

$$W_n = \frac{\sum_n \mathrm{AR}_{\mathrm{an,n,AT}}}{\sum_{d+n} \mathrm{AR}_{\mathrm{an,AT}}} \tag{3}$$

Finally, in order to improve the safety conditions of the critical road sections, by means of a prioritization of maintenance interventions, an effective budget allocation has to be performed.

The proposed budget allocation strategy, follows the principle of maximum reduction of accident rate produced by different assets [18] and it is based on the Global Safety Performance Index (I_{GSP}) evaluation, for the entire road network, which can be defined as follows:

$$I_{GSP} = \frac{1}{M} \sum_{i=1}^{M} \mathrm{GAR}_n \left(1 - \sum_{k=1}^{J_i} RF_{k,i}\right) \tag{4}$$

Where:

I_{GSP} = Global Safety Performance Index of the road network;
M = Total number of road sections;
GAR_n = Global Average Network Accident Rate of the ith critical road segment, before the maintenance interventions;
J_i = number of maintained assets within the ith critical road segment;
RF_{ki} = Accident Reduction factor due to the maintenance action on the kth asset, of the ith critical road segment.

Through this synthetic index, the local agencies and municipalities, on one hand can set the performance target to be achieved and the related needed budget and on the other hand, evaluate the performance level that can be reached with a fixed budget.

3 Case Study

A sample of over 30 km (15 bidirectional km), belonging to 4 urban areas located in the central Italy has been selected for the application of the method previously presented. In Fig. 2, the location of the study areas can be seen.

As specified in the previous paragraph, the nodes of the network have been excluded from analysis and 312 homogeneous sections have been identified.

According to the accident analysis, for the overall road network and for each specific road section, the accident rates have been evaluated. By way of example, the 14 Average Network Accident-Type Rates obtained have been summarized in Table 4.

At the same time, safety inspections have been carried out and the current conditions of each asset and sub-asset have been collected. A three member crew employing video-camera has been involved in the inspection task that has been carried out at normal travel speed and at reduced speed with help of law enforcement assistance. According to the current road assets condition analysis, for each road section, the relative Performance Indices (PI), one for each asset (see Table 3), have been assessed.

For example, the results, in terms of Performance Indices, obtained for the "Horizontal Signage" asset have been represented in Fig. 3. As it is possible to see, according to the



Fig. 2. Road network study areas (Source: Esri topographic base-map, [19]).

Table 4. Percentage of the Accident Type Incidence for each aggregation (columns 2 and 3) and Average Network Accident-Type Rates (columns 4 and 5) for the overall urban areas.

Accident Aggreg.	ISTAT code	% Incidence ISTAT cat.	Daily Period	
			Day	Night
Aggr. 1	01–03	32,5–67,5	0,00529	0,00878
Aggr. 2	02	100	0,02032	0,01421
Aggr. 3	04–06	89,6–10,4	0,00901	0
Aggr. 4	05–12	66,7–33,3	0,00068	0,00128
Aggr. 5	08	100	0,00109	0,0027
Aggr. 6	07–10	0–100	0,02189	0,00892
Aggr. 7	09–11	50–50	0	0
TOT			0,05827	0,04562

inspectors' evaluation, the conditions of the horizontal markings were on average compromised and severely compromised, within nocturnal and diurnal safety inspections respectively.

The application of the two analyses, allowed to identify the critical segments, in terms of both accident rate and current asset performance index and, for each for each asset of each critical segment, according to the assets performance levels detected within the safety inspections, the best maintenance strategy has to be identified, with the aim to improve safety aspects.

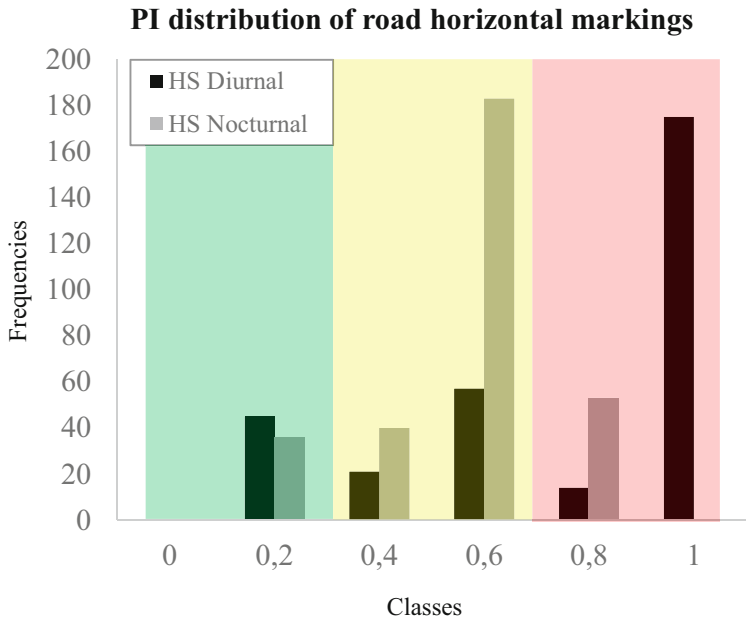

Fig. 3. PI distribution of the current condition of the asset HS.

For this reason, for each asset, three maintenance interventions with increasing cost have been proposed and, by way of example, the types of intervention suggested for the pavement maintenance strategy, have been reported in Table 5.

Table 5. Type of interventions for the asset PC.

Level of intervention	Type of intervention
Light	Milling and remaking of wear layer
Medium	Milling and remaking of wear and binder layers
Heavy	Milling and remaking of overall layers

It is worth to be highlighted that, in order to obtain the best multi-year ordinary maintenance strategy, the ordinary life cycle of each asset intervention has been taken into account (i.e. cleaning drainages and gutters and cleaning side vegetation two times for year or painting road markings one time every two years).

A plausible triennial investment plan has been hypothesized and summarized in Table 6.

Table 6. Hypothesis of triennial investment plan.

Year	Budget
1	110.779,67 €
2	204.735,33 €
3	204.735,33 €

Finally, according to the principle of maximum reduction of accident rate produced by different assets [18], the best three-years maintenance program has been identified and its results have been summarized in Table 7.

Table 7. Maintenance strategy according to the hypothesized budget

	Asset	HS	VS	HC	SB	SL	PC	RC
Total Critical Sections		180	180	186	46	218	218	204
Year 1	Maintained sections	180	148	104	25	35	3	99
	Used Budjet [€]	3.324	11.994	13.663	36.530	14.908	10.733	14.785
	Rest [€]	0	62	23	951	372	3.392	44
Year 2	Maintained sections	mc	32	186	21	137	15	204
	Used Budjet [€]	0	2.633	24.687	29.532	57.273	56.525	30.740
	Rest[€]	0	0	0	0	251	3.095	0
Year 3	Maintained sections	180	mc	186	mc	46	14	204
	Used Budjet [€]	3.324	0	24.687	0	19.712	125.920	30.740
	Rest [€]	0	0	0	0	0	353	0
Total Maintained sections		180	180	186	46	218	32	204

mc = maintenance completed.

4 Conclusions

In this paper a simplified road asset management system for Local Agencies and Municipalities has been proposed. The main aim of this method is to improve road safety combining traffic and accident data with current performance conditions of the network. The output of the method is the multi-year scheduling for ordinary maintenance interventions on the main road assets.

The method has been applied on 312 homogeneous sections, corresponding to more than 30 km of urban road network, in central Italy. In order to fulfill the principle of maximum reduction of accident rate, based on a plausible hypothesized triennial investment plan, the most effective multi-year ordinary maintenance strategy has been evaluated.

Relevant points in favor of the proposed method are resumed the followings: the input data of the model can be easily collected from public database and from safety

inspections, furthermore, the methodology itself can be simply implemented in a conventional spreadsheet. Given the great flexibility of the method, it can also be applied to suburban or rural areas, without losing validity. The results obtained by the application of the simplified road asset management system, seem to provide evidence that the method can be considered an effective tool for Local Road managers.

Acknowledgements. Authors wish to thanks Lazio Highway Agency (ASTRAL) for their support in this research.

References

1. ISO 55000. Asset management - Management systems - Requirements. Standard for Asset Management. International Standards Organization. Geneva (2014)
2. World Road Association (PIARC). "Asset Management Manual". https://road-asset.piarc.org/en. Accessed Mar 2022
3. World Health Organization. Global status report on road safety 2015. Geneva, Switzerland (2015). World Health Organization. https://www.afro.who.int/sites/default/files/2017-06/9789241565066_eng.pdf. ISBN 9789241565066. Accessed Mar 2022
4. European Commission: "European Road Safety Observatory, Annual statistical report on road safety in the EU 2020" Road safety thematic report – Fatigue. European Road Safety Observatory. Brussels, European Commission, Directorate General for Transport (2021)
5. European Commission: Directorate-General for Mobility and Transport. "Road safety in the EU: fatalities in 2021 remain well below pre-pandemic level" (2022). https://transport.ec.europa.eu/news/preliminary-2021-eu-road-safety-statistics-2022-03-28_en. Accessed May 2022
6. EU Directive 2008/96/EC of the European Parliament and of the Council of 19 November 2008 on road infrastructure safety management
7. D'Apuzzo, M., Evangelisti, A., Nicolosi, V., Di Silvestro, A.: Pavement maintenance of small municipalities: evaluation of the quality evolution for different budget scenarios. In: Pavement and Asset Management: Proceedings of the World Conference on Pavement and Asset Management (WCPAM 2017), Baveno, Italy, 12–16 June 2017, vol. 1, pp. 293–300 (2019). https://doi.org/10.1201/9780429264702. ISBN 9780429264702
8. Nicolosi, V., D'Apuzzo, M., Evangelisti, A.: Cumulated frictional dissipated energy and pavement skid deterioration: evaluation and correlation. Constr. Build. Mater. **263**, 120020–120029 (2020). https://doi.org/10.1016/j.conbuildmat.2020.120020. ISSN 0950-0618
9. Nicolosi, V., Augeri, M., D'Apuzzo, M., Santos, L.P., Evangelisti, A., Santilli, D.: Economic risk evaluation in road pavement management. In: Gervasi, O., et al. (eds.) ICCSA 2021. LNCS, vol. 12950, pp. 394–410. Springer, Cham (2021). https://doi.org/10.1007/978-3-030-86960-1_28. ISBN 978-3-030-86959-5. ISSN 0302-9743
10. Nicolosi, V., Augeri, M., D'Apuzzo, M., Evangelisti, A., Santilli, D.: A probabilistic approach to the evaluation of seismic resilience in road asset management. Int. J. Disaster Risk Sci. **13**, 114–124 (2022). https://doi.org/10.1007/s13753-022-00395-5
11. Italian Ministerial Decree of May 2nd, 2012, according to Legislative Decree n° 35 of March 15th 2011
12. Italian Legislative Decree n°163/2006 – for implementation of European directives 2004/17/CE and 2004/18/CE
13. Italian Legislative Decree n° 50 of April 18th, 2016 - for implementation of European directives 2014/23/UE, 2014/24/UE and 2014/25/UE

14. Italian National Institute of Statistics. http://dati.istat.it/. Accessed Mar 2022
15. Italian Ministerial Circular n° 3699 of Jun 8th, 2001. Ministry of public works and transport
16. Italian Legislative Decree n° 35 of March 15th, 2011 - for implementation of European directive 2008/96/CE
17. Publication No. FHWA-SA-06-06. Road Safety Audit Guidelines. Synectics Transportation Consultants Inc. Center for Transportation Research and Education (CTRE), Iowa State University Pennsylvania State University. Kittelson & Associates, Inc. Science Applications International Corporation (SAIC) (2006)
18. Elvik, R., Vaa, T., Hoye, A.: The Handbook of Road Safety Measures (2009)
19. QGIS.org. QGIS Geographic Information System. QGIS Association (2022). http://www.qgis.org