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A Methodology for the Network-Wide, In-Built Safety Assessment Of Primary Roads

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Abstract

Crash occurrence analysis may not be the best approach for assessing road infrastructure safety due to local conditions (e.g., safety culture, vehicle characteristics. In-built safety assessment allows for a proactive examination of the road infrastructure to detect safety deficiencies related to road design, operational and maintenance characteristics. This study focuses on the development of a new methodology for the network-wide, in-built safety assessment of primary roads, divided and undivided. The methodology considers ten design and operational parameters for the assessment of primary roads and uses a three-class ranking system, based on the estimated scoring. The outcome of this study is useful to policy makers and relevant road safety stakeholders as it introduces a proactive and effective road safety assessment process.

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1. Introduction

Safe road infrastructure for all users is one of the pillars of the Safe System. Road safety assessment has been based on the analysis of historic crash data however, this approach has several limitations, ranging from erroneous or unavailable crash records to the fact that crashes may not always be a good proxy of road infrastructure safety. Local factors and conditions such as human behaviour, safety culture, presence of enforcement, vehicle characteristics (e.g., percentage of heavy vehicles, vehicle age, etc.) affect crash occurrence and severity. Lastly, the analysis of crashes is a reactive approach in the sense that (unwanted) events need to occur to trigger safety assessment procedures.

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In addition to the in-built safety assessment of roads, another innovative concept is the network-wide assessment. This assessment allows for a high-level screening of the road to detect potential deficiencies and indicate which parts of the road should be further examined in a more detailed manner. The network-wide safety assessment aims in doing this screening in relatively faster way, using fewer resources compared to detailed processes like Road Safety Inspection (RSI).

A network-wide, in-built safety assessment methodology should achieve a good balance between validity and reliability on the one hand and data needs and cost of implementation on the other hand. This study presents the development of network-wide in-built safety assessment methodology for primary divided and undivided roads across the European Union. Section two presents the methodological framework for developing a network-wide, in-built safety assessment methodology while section three presents the proposed methodology. Conclusions and future extensions are discussed in the last section.

2. Methodology

2.1. Literature review

The first step in developing a network-wide, in-built safety assessment methodology was to understand the state-of-practice. An extensive review of the safety literature including research papers, project reports, national guidelines and manuals was conducted and identified ten methodologies for the in-built safety assessment of roads (Table 1). An in-depth analysis of the methodologies followed to understand their strengths and weaknesses, validity, transferability and generalizability. Additionally, it was indented to obtain a clear view of the ease of use of each methodology, focusing on data and expertise needed to implement it. For example, the Predictive Method developed by AASHTO (AASHTO, 2010) requires both advanced knowledge in statistical modeling and extensive data.

Table 1. Existing in-built safety assessment methodologies

Method	Use/Development	# Parameters	Scoring and Ranking
1. Road Safety Inspection	Internationally	> 60	Detailed scanning of a road section for the identification of deficiencies and recommendation of safety countermeasures
2. Highway Safety Manual Predictive Method (AASHTO, 2010)	Developed in the US, used internationally	37	Crash prediction models and crash modification factors for various road types. The assessment considers the average crash frequency at a site in comparison to other similar sites.
3. PRACT Models	Europe	25	
4. iRAP Star Rating Protocol	Internationally	48	Each section is assessed considering several parameters. Both methodologies produce a score accounting for crash risk and severity. Each section is classified in one out of five safety classes.
5. Australian National Risk Assessment Model	Australia	36	
6. Risk Identification Method (Brondie et al., 2009)	New Zealand	16	Quantitative assessment of sections based on road design characteristics. A five-class ranking system is considered.
7. Safety Ranking Method	Sweden	18	Qualitative assessment of sections and junctions based on road design characteristics and the speed limit. A four-class ranking system is considered.

8. Rural Road Safety Index (Mahgoub et al., 2011)	South Dakota, US	13	Quantitative assessment of sections based on road design characteristics. A four-class ranking system is considered.
9. Proactive Road Safety Program (de Leur & Hill, 2015).	British Columbia, Canada	25	Quantitative assessment of sections based on road design characteristics. There is no classification systems, sections are prioritized for improvements based on their score and funding availability.
10. SAMO method (Ambros et al., 2017)	Czechia	5	This method assesses horizontal curves considering several design characteristics in addition to speed limit and measured speeds. Curves are classified as safe or unsafe.

In-built safety assessment methodologies examine the quality of a set of road design and operational characteristics and then rank the road based on those characteristics. These can be lane width, the presence and design of horizontal curves, etc. For methodology it was analyzed the type of parameters used for the assessment and the way the safety level of each parameter is measured, e.g., in a binary way or qualitative/quantitative way. The ranking system of each methodology was also evaluated.

From the review it was concluded that current in-built safety assessment methodologies have some similarities with respect to the parameters used for the assessment. Most methodologies include cross-section characteristics (e.g., lane width, median presence, etc.), roadside characteristics (e.g., clear zone width, side slopes, etc.), the presence and design of horizontal curves, the condition of the road or the road elements (e.g., markings), junction characteristics and the assessment of facilities for bicyclists and pedestrians. Despite those similarities, there are great differences on how the safety level of each road element is measured and how the final safety scoring and ranking are facilitated. Through the review it was feasible to understand the workload as well as the expertise associated with implementing an in-built safety assessment methodology. Overall, a methodology should have a relatively low number of parameters for the assessment, as in the case of the Swedish methodology or the one developed in the New Zealand, and for validity purposes there should be a direct connection between the defined safety level of each parameter and risk, as in the case of the Highway Safety Manual Predictive Method and iRAP Star Rating Protocol. Additionally, it is evident that the methodology needs a quantitative assessment, using reference tables to indicate the way to assess the safety level of each road elements.

2.2. Conceptual framework

Based on the findings from the literature, it was decided to develop a new methodology for the assessment of roads instead of adopting and adjusting an existing one. The process of the proposed assessment is illustrated in Figure 1 in the form of steps.

After detecting the road type, a macroscopic data collection is needed to collect the following data types: (1) number of lanes, (2) horizontal alignment, (3) terrain type, (4) traffic volume preferably in Annual Average Daily Traffic (AADT), and (5) speed limits. This information is used for the network segmentation. The network is divided in smaller parts, noted as “sections”, that are roughly homogeneous in terms of number of lanes, horizontal alignment, terrain type, traffic volume and speed limits. Sections include both junctions (grade separated or at-grade) and road segments and should have a maximum length of 2km. For divided roads, sections are defined for each direction of traffic while for undivided roads, sections include both directions of traffic.

The network segmentation is followed by a second stage of data collection which is more detailed and aims to collect the needed road data to be used for the assessment of each section. The proposed methodology bases the assessment of roads on a set of ten parameters that correspond to road design and operational characteristics.

A score is estimated for each parameter per section and based on the scores for all parameters it is calculated the final score for the section. Based on the final score the section is classified as “high risk”, “intermediate risk” or “low risk”.

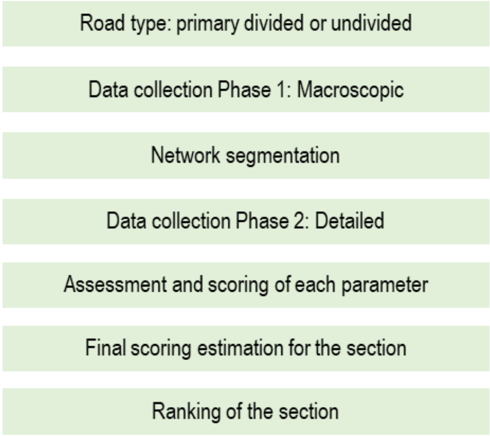

Figure 1. Flowchart of the proposed in-built safety assessment methodology.

3. In-built safety assessment methodology

There are three core aspect in the proposed methodology: the safety scoring formula, the way to measure the safety level of each parameter, and the definition of the thresholds for three safety classes.

Each parameter corresponds to a Reduction Factor (RF) that is equal to one if the respective road element is properly designed and maintained in the examined road section. A RF lower than one corresponds to a less safe design/condition. The final score for the road section i is given by formula (1) considering the RFs for the *n*-parameters used for the assessment. An ideally safe road section receives a score of 100 points.

$$Score_i = 100 \times RF_{1i} \times RF_{2i} \times \ldots \times RF_{ni} \quad (1)$$

Each section is evaluated based on ten parameters: lane width, roadside, curvature, density of property access points, junction type, conflicts between pedestrians/bicyclists and motorized vehicles, shoulder width and type, passing lanes, markings and signs and lastly, lighting. These parameters are used in most of the existing in-built safety assessment methodologies.

It was decided to quantify the safety level of each parameter using the concept of Crash Modification Factors (CMFs). CMFs describe the effect of a treatment or a road element on crash occurrence. For each one of the proposed ten parameters, an extensive review and synthesis of CMFs were conducted to identify the most appropriate and valid way to quantify its safety level. The review was focused on the American Association of State Highway and Transportation Officials (AASHTO) Highway Safety Manual (AASHTO, 2010), the meta-analysis conducted by Elvik et al., 2009, the iRAP Star Rating Protocol factsheets and accompanied research, the PRACT project deliverables, and multiple additional studies that were identified using the CMF Clearing House. Given that this study is tailored to the European roads, European road design guidelines were also taken into consideration when defining the safety levels for each parameter. For example, the lane widths listed in Highway Safety Manual (AASHTO, 2010) are wider compared to the average European standards and so, this information should be incorporated in the proposed CMFs.

Additionally, for some parameters, a different assessment is proposed depending on the road type (i.e., divided or undivided). This differentiation was evident in the reviewed CMF literature.

The RF is the calculated as the inverse of the respective CMF (RF = 1/CMF). This way it is ensured that all parameters are measured in the same scale with their values being positive and lower than or equal to one. Table 2 presents the parameters used for the assessment as well as the safety levels and the respective CMFs and RFs for each parameter.

For sections that a parameter changes across its length, it is proposed to estimate a weighted average CMF considering the length and then estimate the final, section-wide RF:

$$Weighted\ average\ CMF_j = \frac{\sum_k^n w_k CMF_{kj}}{\sum_k^n w_k} \quad (2)$$

Where CMF_{kj} is the CMF for the j parameter that corresponds to the condition k of the parameter w_k is the weight and is inserted in the equation as a percentage of the section's length. Therefore, the denominator in the above formula is always equal to one. corresponds to length.

The weighted average CMF will be then converted to RF based on formula (3). This is the final, section-wide RF.

$$RF_{section} = {}^{1}/_{Weighted\ average\ CMF} \quad (3)$$

Table 2. Proposed parameters and reduction factors for the assessment of motorways and primary roads.

Road Type	Parameter	CMF	RF
	1. Lane width		
Undivided	LW ≥ 3,40m	1,000	1,000
	3,15m ≤ LW <3,40m	1,050	0,952
	2,70m ≤ LW <3,15m	1,120	0,893
	LW ≤ 2,70m	1,190	0,840
Divided	LW ≥ 3,40m	1,000	1,000
	3,15m ≤ LW <3,40m	1,021	0,979
	2,70m ≤ LW <3,15m	1,080	0,926
	LW ≤ 2,70m	1,120	0,893
	2. Roadside		
Undivided	1	0,875	1,000
	2	0,935	1,000
	3	1,000	1,000
	4	1,069	0,935
	5	1,143	0,875
	6	1,222	0,818
	7	1,306	0,766
Divided	1	n/a	1,000
	2	n/a	1,000
	3	n/a	1,000
	4	n/a	0,968
	5	n/a	0,937
	6	n/a	0,909
	7	n/a	0,883
All	**3. Curvature**		
	Sections with tangents and curves with R≥1.000m	1,000	1,000
	Sections with curves with R<1.000m: $CMF = 1{,}00 + 0{,}7937 \times (0{,}09134\ V)^4 \times \frac{(0{,}9134\ V)^2}{32{,}2 \times (R/0{,}3048)^2}$	Formula	1/CMF

	4. Density of property access points (Points per km)		
All	0	1,000	1,000
	1	1,045	0,957
	2	1,093	0,915
	3	1,144	0,874
	4	1,197	0,835
	5	1,253	0,798
	6	1,312	0,762
	7	1,374	0,728
	8	1,439	0,695
	9	1,508	0,663
	10	1,581	0,633
	11	1,658	0,603
	12	1,739	0,575
	13	1,825	0,548
	14	1,916	0,522
	15 or more	2,000	0,500
	5. Junction type		
All	No junction	1,000	1,000
	Grade-separated	1,000	1,000
	Roundabout	1,000	1,000
	3-leg signalized with turn lane	1,000	1,000
	3-leg signalized without turn lane	1,044	0,958
	3-leg unsignalized with turn lane	1,130	0,885
	3-leg unsignalized without turn lane	1,391	0,719
	4-leg signalized with turn lane	1,000	1,000
	4-leg signalized without turn lane	1,420	0,704
	4-leg unsignalized with turn lane	1,515	0,660
	4-leg unsignalized without turn lane	2,178	0,459
	6. Facilities for pedestrians and bicyclists		
	(a) Pedestrians - crossing		
All	No pedestrian traffic	1,000	1,000
	Grade separated facility	1,000	1,000
	Signalized crossing with refuge - SL > 70km/h	2,500	0,400
	Signalized crossing without refuge - SL > 70km/h	3,100	0,323
	Unsignalized marked crossing with refuge - SL > 70km/h	9,500	0,105
	Unsignalized marked crossing without refuge - SL > 70km/h	12,000	0,083
	No facility for pedestrians crossing - SL > 70km/h	16,750	0,060

	Signalized crossing with refuge - SL ≤ 70km/h	2,000	0,500
	Signalized crossing without refuge - SL ≤ 70km/h	2,500	0,400
	Unsignalized marked crossing with refuge - SL ≤ 70km/h	8,000	0,125
	Unsignalized marked crossing without refuge - speed limit ≤ 70km/h	10,000	0,100
	No facility for pedestrians crossing - SL ≤ 70km/h	12,000	0,083
All	*(b) Pedestrians - along*		
	No pedestrian traffic	1,000	1,000
	Segregated - protected pedestrian path	1,000	1,000
	No facility for pedestrians walking along	20,000	0,050
All	*(c) Bicyclists - along*		
	No bicycle traffic	1,000	1,000
	Segregated bicyclist path	1,000	1,000
	Dedicated bicyclist lane on roadway	12,000	0,083
	Wide paved shoulder (width > 1m)	17,000	0,059
	No facility for bicyclists	20,000	0,050
	7. Shoulder width (SW) and type		
Undivided	Paved SW ≥ 1,83	1,000	1,000
	1,23 ≤ Paved SW < 1,83	1,063	0,941
	0,91 ≤ Paved SW < 1,23	1,097	0,912
	0,61 ≤ Paved SW < 0,91	1,127	0,887
	0,00 ≤ Paved SW < 0,60	1,211	0,826
	Unpaved SW ≥ 1,83	1,017	0,983
	1,23 ≤ Unpaved SW < 1,83	1,077	0,929
	0,91 ≤ Unpaved SW < 1,23	1,106	0,904
	0,61 ≤ Unpaved SW < 0,91	1,136	0,880
	0,00 ≤ Unpaved SW < 0,60	1,211	0,826
Divided	Paved SW ≥ 2,44	1,000	1,000
	1,83 ≤ Paved SW < 2,44	1,040	0,962
	1,23 ≤ Paved SW < 1,83	1,090	0,917
	0,91 ≤ Paved SW < 1,23	1,110	0,901
	0,61 ≤ Paved SW < 0,91	1,130	0,885
	0,00 ≤ Paved SW < 0,61	1,180	0,847
	Unpaved SW ≥ 2,44	1,025	0,976
	1,83 ≤ Unpaved SW < 2,44	1,058	0,945
	1,23 ≤ Unpaved SW < 1,83	1,104	0,906
	0,91 ≤ Unpaved SW < 1,23	1,119	0,894
	0,61 ≤ Unpaved SW < 0,91	1,139	0,878
	0,00 ≤ Unpaved SW < 0,61	1,180	0,847
	8. Passing lanes		
	Divided road	n/a	1,000

	Undivided multi-lane road	n/a	1,000
	Undivided 2-lane road with:		
	slope <4%, or slope >4% for length<500m	n/a	1,000
	slope >4% for more than 500m - passing lane in both directions	1,000	1,000
	slope >4% for more than 500m - passing lane in one direction	1,149	0,870
	slope >4% for more than 500m - No passing lanes	1,502	0,666
All	**9. Markings and signs**		
	In place, high quality, good condition	n/a	1
	In place, medium or poor quality and/ or require maintenance	n/a	0,95
	Are missing	n/a	0,90
All	**10. Presence of lighting**		
	Lighting	1,000	1,000
	No lighting	1,068	0,936

Using the information provided in Table 2 one can estimate the RF for each one of the ten parameters. The final safety score of a section is based on formula (1). Based on the safety score, the section is classified as:

- Low Risk - class 1: score ≥ 80%,
- Intermediate Risk - class 2: 50% ≤ score < 80%,
- High Risk - class 3: score < 50%.
    - if the road sections within the lowest 15% in terms of AADT, are classified (initially) as high risk, they will be automatically re-classified as intermediate risk.

4. Conclusions

This study focused on the development of a network-wide, in-built safety assessment methodology for primary roads, divided and undivided. The developed methodology considers ten parameters related to road design and operational characteristics to assess and rank a road section. The study contributes to the existing literature by introducing a framework for the proactive assessment of roads, i.e., without relying on historic crash records, in a cost-effective and user-friendly manner. It also contributes to the road safety literature by providing the steps and concept for creating a similar methodology that could better fit the needs of a country or national road authority.

The developed methodology is not yet in its final format. It will be tested in various road networks across Europe before being finalized. The pilot studies aim at validating the methodology using historic crash data. Additionally, the pilot studies aim to evaluate and improve the transferability and generalizability of the methodology. At the same time, the pilot studies will shed light to issues related to the actual implementation of the methodology, for example issues related to the network segmentation. Detecting and addressing those issues will improve the acceptance and adoption of the methodology and in turn, opening the way to road infrastructure safety improvements.

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