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Portuguese mainland road network safety performance indicator

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Abstract

Stepping away from traditional crash-based road safety measurements, several safety performance indicators (SPI) have been proposed in the past few years. SPI can incorporate quantitative and qualitative information on specific aspects that are known to have influence in the safety levels and, not only measure the influence of various safety interventions but also enable comparisons between different road systems. This paper presents the results of the application of a road network SPI to the entire Portuguese road network. This SPI aims at evaluating at the network level, if the connections between urban centres within a region are made by the adequate type of roads regarding generic safety criteria. To this end, the connections to be assessed were classified into pre-defined theoretical safety classes, based on the population of the connected urban centres. Then, the observed safety class of these connections was assessed according to the characteristics of their cross-section and associated road environment of the existing connection between the two urban centres. If the observed class is ensured by a road of higher or equal class than the pre-defined theoretical level in all its extension, the link is considered to be of the appropriate class. For each connection, the results of its evaluation are expressed as a binary value: 0 when the class is not appropriate; and 1 when it is appropriate. The evaluation results are weighted by the road length and aggregated by connection class and throughout the whole road network. The results show a satisfactory network configuration with an SPI of 94% connections with class equal to or higher than the adequate for the type of connection between urban centres they established. The above insights can help in the identification of potential operational inconsistencies that may require safety-related interventions and used for international benchmarks against existing SPI evaluations.

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1. Introduction

Road users, vehicles and infrastructure are key elements of the road transport system and their characteristics are important determinants in the overall road safety level of a region. Besides, the interactions between these elements

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greatly enhances the complexity of the whole phenomenon (Hermans et al., 2008) and to a large extent explain the wide spatial and temporal variations in crash frequency, risk and severity. This complexity explains the diversity of indicators that have been developed for monitoring, evaluating, and comparing the status and progress of road safety (Chen et al., 2016). The existence of several stages in road transport systems' development cycles (e.g., concept, planning, design, construction, operation and maintenance) further contribute to the variety of available indicators, some of them designed precisely for a specific stage.

A safety performance indicator (SPI) is defined as any variable which can be used to measure changes in the conditions of road traffic safety (Auerbach-Hafen et al., 2006). The SPI can incorporate quantitative and qualitative information on aspects that are known to have some influence in the safety levels and to measure the influence of various safety interventions and to enable comparisons between different road traffic systems (e.g. countries, regions, etc.). Small variations in such aspects can be identified, allowing to detect problems at an early stage, before accident's occurrence.

The development of a road network safety performance indicator was foreseen in scope of the National Road Safety Strategy defined by the National Road Safety Authority (ANSR, 2009 and ANSR, 2014). The proposed road network safety performance indicator is based on the methodology proposed by the consortium of the SafetyNet project, co-financed by the European Union under the 6th Framework Programme for Research and Development (Auerbach et al., 2007). This indicator was based on the Sustainable Safety approach (Koornstra et al., 1992, Weijermars and Wegman, 2011) and the indicator proposed by Dijkstra (2003).

The SafetyNet project aimed to provide a platform of knowledge at European level in the field of road accidents, including the creation of an observatory with relevant information to support the development of road safety policies. Under this project, several activities were carried out:

1. Congregation, under a common and independent structure, of existing data on road accidents and their consequences, to support the definition of plans and strategies for road safety.
2. Development of a common methodology for calculating performance indicators for road safety, suitable for use by each Member State;
3. Collection of relevant data to the use of safety performance indicators consistent with the proposal for a harmonized methodology.
4. Development of new tools for the collection and analysis of data related to road accidents.

Within the activity dedicated to Safety Performance Indicators, methodologies were proposed in order to obtain harmonized indicators regarding seven relevant aspects: alcohol and drugs; speeds; protective systems; daytime running lights; vehicle crashworthiness and passive safety; road infrastructure; and trauma management (Auerbach-Hafen et al., 2005; Auerbach-Hafen et al., 2006a; Auerbach-Hafen et al., 2006b; Riguelle et al., 2006; Auerbach-Hafen et al., 2007, Gitelman, at al., 2014).

Two types of safety performance indicators were proposed for road infrastructure: one focusing on network characteristics (Road Network SPI) and the other resulting from a combination of infrastructure characteristics which are known to influence the frequency and severity of accidents (Road Design SPI). The former is intended for application at the planning level; the latter is mainly useful at the design and operation levels.

The Road Network SPI helps to assess whether the existing road category linking two urban centres is adequate. At the aggregate level, this SPI is defined as the percentage of the total road network length with an adequate category. In this sense, "adequate category" means that the analysed road presents the minimum requirements to ensure an acceptable level of safety, based on the current road function and traffic volume. The sizes of the urban centres that are connected by a road are assumed to determine its function and the amount of traffic volume.

The applicability of this Road Network SPI was tested successfully through a pilot study in Portugal (Arsenio et al., 2008; Yannis et al., 2013), which only covered the national continental territory South of the Tagus River. Also, in that study spatial and demographic territorial data (e.g. geometry, population and number of houses) were collected at the parish administrative level, since no lower disaggregation was available. This paper presents the results of applying the methodology developed in the SafetyNet project to the entire Portuguese road network, thus considering all Portuguese mainland urban areas. A description of the method and the characteristics of the information used in the calculations are presented in Section 2. Section 3 presents the findings of the study and discusses relevant issues for improvement of the procedure.

2. Methodology and Results

The road network SPI allows to assess whether the road connection between two urban centres is appropriate from the road safety point of view. The initial concept was defined in German guidelines for road categories (FGSV, 1988). Dijkstra (2003) made an adaptation of this concept, with an application to the European context. The idea behind this concept is based on the definition of the minimum requirements that a road must comply with, based on its function and traffic volume, to ensure an acceptable level of safety. It was considered that the function and the traffic volume depend on the size of the urban centres that are connected by this road. It was assumed that higher traffic volumes are associated with more demanding geometric design requirements and that traffic volumes are higher when larger urban centres are linked. The minimum requirements that must be met by a road are related to the prevention of different types of conflicts. The aggregated road network SPI is defined as the percentage of roads with an adequate category.

The spatial data used to calculate the SPI was provided by Infoportugal S.A., which is a technology company specialized in Geographic Information Systems and Tourism (http://infoportugal.pt/). It includes the following descriptors:

- Limits of urban settlements;
- Administrative limits (parishes, municipalities, districts);
- Centroids of urban settlements;
- Land use;
- Road network.

The methodology used in the definition of the SPI applied to the Portuguese road network comprises seven steps, as presented in the following paragraphs.

STEP 1 - Calculation of the population for each urban area

The first step for the SPI definition concerns the calculation of the population in each urban area. Population data is available in the National Statistical Institute at various disaggregation levels: at the lower administrative boundary (parishes), for 2011; and at the municipality level, for 2012.

Thus, for 2012 the population by parish was estimated, based on the development of the population in the relevant municipality between 2011 and 2012, according to Equation 1.

$$\mathrm{Pop}_{2012}^{\mathrm{Parish}} = \mathrm{Pop}_{2011}^{\mathrm{Parish}} \times \left(1 + \frac{\mathrm{Pop}_{2012}^{\mathrm{Mun}} - \mathrm{Pop}_{2011}^{\mathrm{Mun}}}{\mathrm{Pop}_{2011}^{\mathrm{Mun}}}\right) \qquad (1)$$

The distribution of this population in each urban settlement was performed according to Equation 2.

$$\mathrm{Pop}_{\mathrm{urban\ settlement}} = \frac{\mathrm{Urban\ settlement\ area} \times \mathrm{Pop}_{\mathrm{Parish}}}{\mathrm{Parish\ urban\ area}} \qquad (2)$$

STEP 2 – Urban settlements definition

Many urban areas, although physically separated, present a rather small distance between them, meaning that they can be considered as belonging to the same urban centre. This assumption was applied to the calculation of the SPI through an aggregation of the polygons with distances of less than 200 meters between them (see Figure 1).

Fig. 1. Example of a proximity case in the urban settlements and its aggregation.

Since this procedure does not allow to distinguish any administrative boundaries (which in the case of large cities could create too large polygons with multiple municipalities), it was decided to respect the boundaries of the municipalities in these aggregations.

After this task, all urban centres with less than 100 inhabitants were excluded, since they would have a very low effect on the resulting SPI values.

STEP 3 – Urban centres classification

In the methodology proposed by Auerbach et al. (2007), five types of urban centres were defined, based on the number of inhabitants. The number of inhabitants is used as a measure of the importance of a city and the amount of traffic that it is able to generate (or draw to). Type 1 corresponds to a big city; Type 5 to a village; and types 2 to 4 correspond to centres of intermediate classes as shown in Table 1. This classification was improved with land use information concerning traffic generators such as airports, hospitals or industrial areas (with more than one square kilometre). In the presence of these facilities the urban centre type was raised by one level. The total number of urban centres of each type is presented in Table 1.

Table 1. Urban centers classification by number of inhabitants.

Type	Number of inhabitants	Number of urban centres
Type 1	>200 000	12
Type 2	100 000 a 200 000	25
Type 3	30 000 a 100 000	33
Type 4	10 000 a 30 000	75
Type 5	<10 000	7610

STEP 4 – Centroid identification

After the definition of each urban centre it was necessary to locate the centroid of their corresponding polygon, which represents the beginning/end of the connections associated with it. Although there are tools to perform this procedure automatically, it was considered advantageous to use the centroids provided by Infoportugal, since they are already defined hierarchically (from 1 – small to 8 – high, according to the urban centre dimension).

The aggregation of several urban settlements in a single urban polygon makes these polygons to have several Infoportugal centroids (from the individual urban areas). The choice of the representative centroid for each polygon (represented by different colours in Figure 2) was made in accordance with the highest hierarchy. The final classification and spatial distribution of centroids for each urban centre is presented in Figure 3.

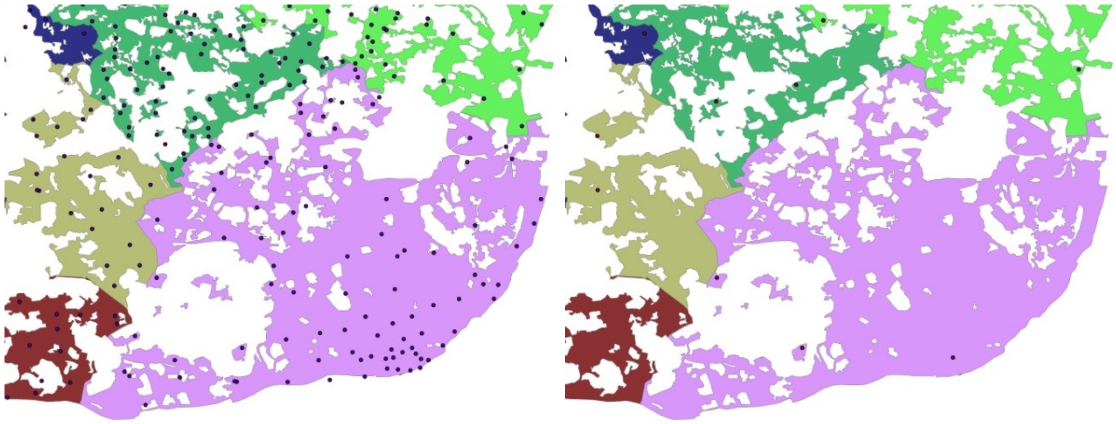

Fig. 2. Centroids identification for each urban centre.

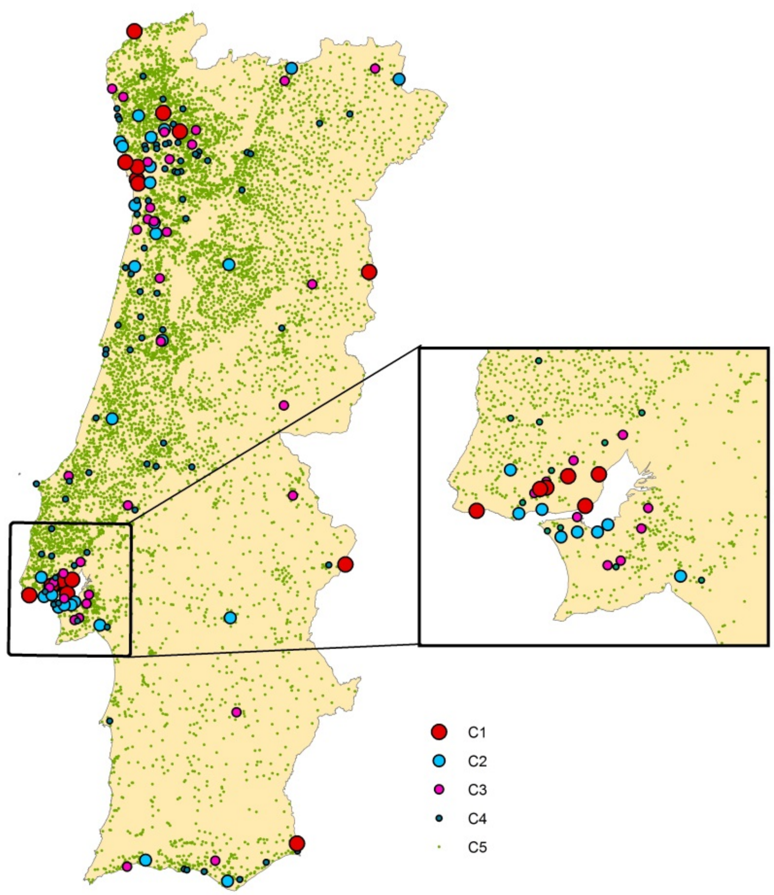

Fig. 3. Centroids location by type.

STEP 5 - Identification of theoretical connections between urban centres

Following the centroids definitions it is possible to identify their interconnections. For this purpose, searching circles (buffers) were defined around the centroids of all urban centres. This methodology was proposed in the SafetyNet project and involves the creation of a buffer for each centroid where the search for the other centroid to connect is made. The radius of this buffer is determined by the distance to the nearest centroid of the same type, as indicated in Table 2 (see also Figure 4).

Table 2. Buffer radius for connection identification.

Initial Centroid	Buffer radius - Distance to:	Identification of connections between:
Type 1	Closest type 1	1 and 1, 1 and 2, 1 and 3
Type 2	Closest type 2	2 and 2, 2 and 3, 2 and 4
Type 3	Closest type 3	3 and 3, 3 and 4
Type 3	Closest type 4	3 and 5
Type 4	Closest type 4	4 and 4, 4 and 5
Type 5	Closest type 5	5 and 5

The methodology proposed by SafetyNet project has some limitations in the establishment of the theoretical connections for the Portuguese territory, as regards the connections between major urban centres that are very far away from each other. Thus, the set of connections detected by the algorithm previously described had to be complemented by connections added manually, necessary to ensure that all centroids of a given level were dully connected.

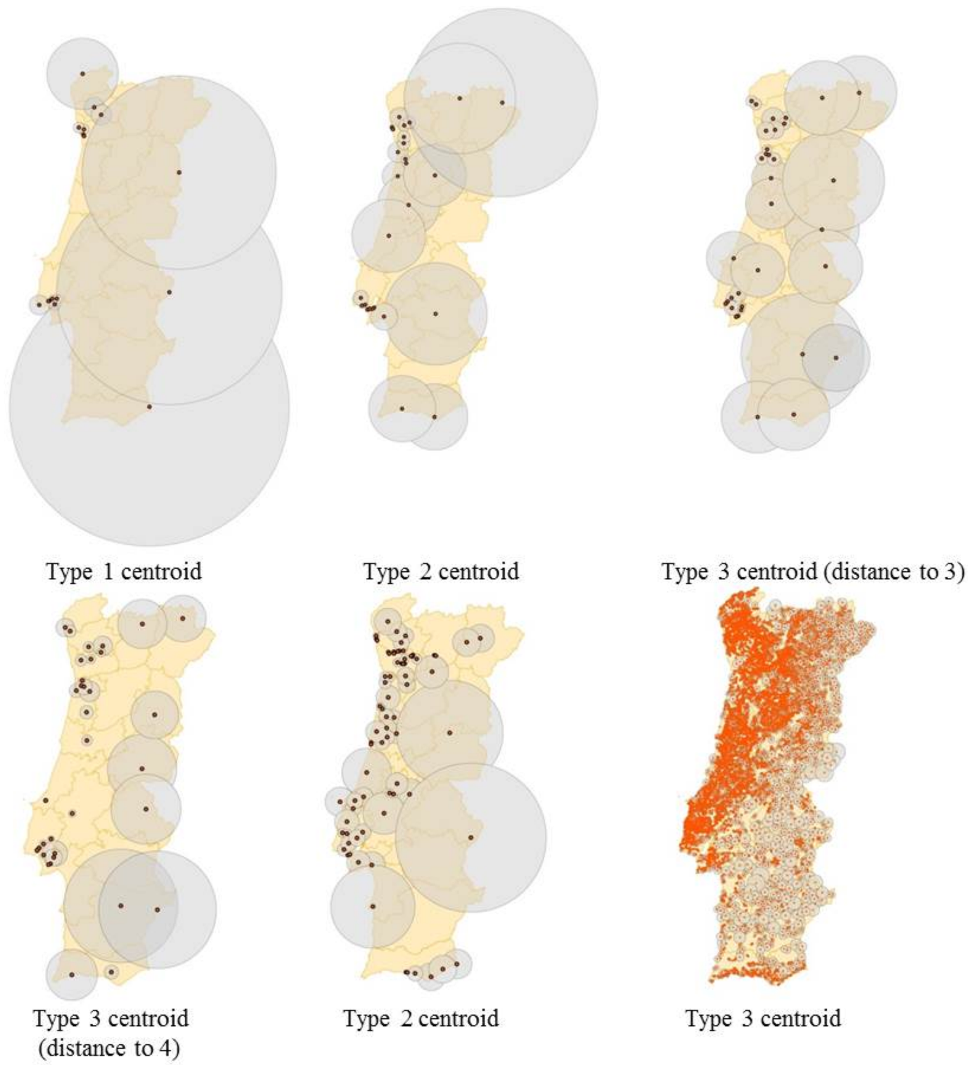

Fig. 4. Types of centroids and their buffers.

A total of 18 396 connections were identified, corresponding to 405 553 kilometres. Each of these connections was then classified (from AAA to C – see Table 4) according to the criteria presented in Table 3 (see also Figure 5). In the SafetyNet project methodology the classification of connections between different types of urban centres does not include connections of type A (single carriageway express roads), since it is considered that, from the road safety point of view, such connections – with high speeds – should correspond to dual carriageways roads.

Table 3. Classification of connections between different types of urban centres

Urban centre type	Type 1	Type 2	Type 3	Type 4	Type 5
Type 1	AAA – 17	AAA – 34	AA – 40	Indirect	Indirect
Type 2		AA – 32	AA – 38	BB – 90	Indirect
Type 3			BB – 34	BB – 86	B – 2794
Type 4				B – 75	B – 7229
Type 5					C – 7917

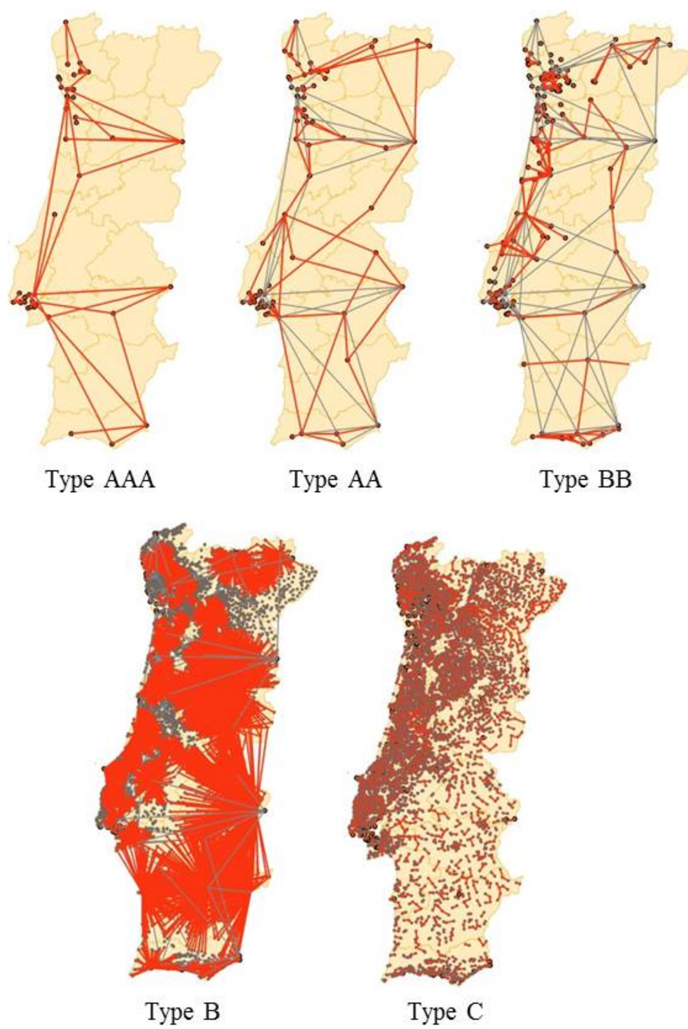

Fig. 5. Schematic representation of the connections by urban centre type

Note: The grey lines represent the connections at higher levels and the red lines represent the connections of the indicated level.

STEP 6 - Identification of real connections between urban centres

To identify and qualify the actual connections between each pair of urban centres a categorization of roads is necessary. In the SafetyNet project a road classification was defined, which was adapted to the Portuguese case study, presented in Table 4. Roads are divided into six classes ranging from AAA to C. Unfortunately, in Portugal there is currently no official database for the geometrical characteristics the National Road Network. Alternatively we used the data provided by Infoportugal on road characteristics (also presented in Table 4), namely:

- Street name
- Section length
- Number of lanes
- Number of ways
- Average speed (estimative)
- Road functional class assigned by Infoportugal (1- high to 8 – low; obtained from sampled point observations from Infoportugal's route guidance services).

Table 4. Road classification

SafetyNet road classes	AAA	AA	A	BB	B	C
Road functional classes	1	2	3	4	5	6, 7, 8
Road category	Motorway	A-level road 1	A-level road 2	Rural distributor road 1	Rural distributor road 2	Rural access road
Carriageway	Dual	Dual	Single	Dual	Single	Single
Lane configuration	2x2 or more	2x1, 2x2, (2x3)	1x2, 1x3	2x1, 2x2	1x2, 1x3, (1x4), (1x1)	1x2, 1x1

The route for each connection was obtained by applying the Dijkstra's algorithm (Dijkstra, 2003), which identifies the minimum path cost from a starting to an ending point (source and target) through a network. For each connections node-pair, the Dijkstra algorithm was applied in both directions and using the full network graph. In order to take into account not the shortest path, but the fastest, the average speed was considered together with the length of each road section for the algorithm's edge cost computation. This was made due to the fact that, in the first case, the results would be biased (with a lower SPI) compared to what is expected in normal route choice. Users tend to choose the fastest routes, rather than the shortest, to reach their destinations (Ramos et al., 2012).

STEP 7 – SPI determination

The final step to determine the SPI corresponds to the comparison between the classes of real connections (Step 6) and the desired theoretical classes (Step 5). The process was carried out for all 18 396 connections, resulting in the calculation of a SPI value for each connection (see Table 5).

Table 5. Percentages and kilometres of road class in each connection class and SPI

Theoretical connection class	Road class												SPI
	AAA	km	AA	km	A	km	BB	km	B	km	C	km	
AAA	82%	3546	8,0%	2908	5,6%	285	1,6%	198	1,5%	56	1,4%	52	82%
AA	65%	6356	17%	4111	10%	1053	4,5%	644	2,0%	288	2,1%	127	81%
A	0%	-	0%	-	0%	-	0%	-	0%	-	0%	-	-
BB	45%	5723	11%	2602	19%	622	12%	1062	7,2%	689	5,8%	414	87%
B	29%	366477	11%	105368	22%	41474	17%	81964	14%	63119	6,1%	52361	94%
C	1,2%	23450	1,5%	282	8,6%	340	19%	2006	33%	4367	37%	7820	100%

Total	405 553

Table 5 shows that: 82% of all roads that should be AAA are indeed of class AAA; 17% of all roads that should be AA are in reality AA and 65% of all roads that should be AA belong in fact to class AAA; 87% of all roads that should be BB, are in reality BB or higher (56% are from AA or AAA classes); 94% of all roads that should be B are in reality B or higher (40% are from AA or AAA classes); and 63% of the connections of type C correspond to higher class roads (2.7% of AA and AAA classes).

The existence of roads from lower classes in the higher connection classes (AAA and AA) is not unexpected since the beginning and end of each connection corresponds to the centroid of the urban centre, and therefore it is inevitable to use short road stretches from the lower classes to reach the upper classes roads.

Considering the total length analysed (405 553 km), it was concluded that 380 783 km presented an adequate (or higher than needed) road class, resulting in a global SPI for the entire road network of 94%.

Type B connections are the most numerous (10 096 connections of a total of 18 338 - about 55%) and also correspond to a greater extension (approximately 366 500 km or 90% of the total network length). A large proportion of these connections are higher than theoretically required (80%), which contributes to the high value of the global SPI.

The above insights can help in the identification of potential operational inconsistencies that may require safety-related interventions. For example, the 19% class BB, B and C roads that were theoretically assigned an AA class, should be further analysed and local road safety performance indicators obtained; the single (BB, B and C) vs. dual carriageway (AA) configuration may be affecting any local safety performance weaknesses for the observed traffic conditions. This is a known safety issue, namely in some suburban roads such as EN 6 and EN 6-4, in the Lisbon Metropolitan Area. On the other hand, the roads that were overclassified can also be further analysed for potential re-evaluation of infrastructure development policies. Finally, the proposed nation-wide classification can be used for international benchmark and for inclusion in traveller's information systems, as proposed in Gitelman et al. (2014) and Yannis et al. (2013).

3. Conclusions

Throughout the whole road transport life cycle, opportunities exist for effective and efficient road safety interventions. At the planning stage, decisions regarding the road class for each road network element have a significant impact on important general geometric road and roadside characteristics. Under a safe system approach, roads should be self-explaining which means that road hierarchy and road function distributions ought to match univocally. Ideally, in a correctly ranked road network each road stretch belongs to a category fitting its function; which is clearly showed to road users by its design characteristics, so that they may easily recognize it and seamlessly adapt their behaviour accordingly (ETSC, 2001). There is a need for tools to assess the quality of road networks hierarchies and their strengths and weaknesses, from a road safety point of view.

Any variable which may be used to measure changes in road safety operational conditions can be considered as a potential SPI. Several SPIs have been proposed for different road safety issues, mainly in relation to driving behaviour and vehicle performances; however, SPIs addressing road network and design issues are not yet widespread. This paper presents the application of the method proposed in the SafetyNet project for determining the road network SPI for entire Portuguese road network, for the year 2012. At the aggregate level, through this SPI, the existing road network is compared to the theoretically required one, defined as the one which meets the minimum road safety requirements.

Furthermore, the SPI computation is mediated by the calculated disaggregate values (per connection) that may be used to assess the strengths and weaknesses of each network connection, helping decision makers to identify those requiring priority interventions.

The presented methodology is best applied through a GIS application and requires the development of automatic calculation procedures for determining the SPI. A modified Dijkstra algorithm was used to make these calculations, which considers the fastest path, rather than the shortest.

The SPI calculation involves several tasks: calculating the population for each urban settlement, aggregation of urban settlements in urban centres, identification of each urban centres centroids, classification of urban centres, classification of theoretical and real connections between urban centres, and finally computation of the road network SPI. In the presented work, the SPI calculation process was fully automated and extended from previous applications mostly by considering urban roads, a more detailed urban classification and applied to an entire national network. The obtained SPIs provided insight into the safety quality of the Portuguese network as a whole and of individual roads, allowing for international comparison using the same methodologies (Yannis et al., 2013).

This study confirms that the SafetyNet Road Network SPI may be applied to several contexts, even though adaptations may be required, mostly due to data availability and format. In the reported study, adaptations were necessary in order to establish the theoretical connections for the Portuguese territory, namely:

- manual definition of the AAA and AA connections between the urban centres that are very far apart from each other (distance larger than the radius of each search area);
- adaptation of Infoportugal road network characteristic descriptions to the classification proposed within the project SafetyNet.

The results revealed a network configuration with several road sections of equal or higher class than the desired theoretically, and an overall SPI of 94%.

Mention must be made to the importance of updating the population and road network characteristics database, since they are of evolving nature, which means that the various basic parameters of the method have to be recalculated when significant changes occur. Given the predictable stability in the short and medium term of the configuration of the road network for Portugal, this SPI is expected to be updated once every two years.

Future updates of this SPI are envisioned, namely by exploring more complex methods for connection identification, considering the most economical route and the existence of tolls and the corresponding value. Also, the SPI computation could be sensitive to known multi-modal alternatives and not unduly penalise connections that already have a high share of non-road transport. Indeed, connections may have lower class if its expected demand is largely satisfied by a preferred train, sea or air connection. In these cases, the theoretical connections estimation step may be improved to accommodate those multi-modal layouts.

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