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A multi-criteria model to define intervention priority levels for traffic signs

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Abstract: - Traffic signs are only effective when they are visible and perceptible. Improving traffic safety cannot be achieved without properly applying and maintaining traffic signs. An integrated approach combining GIS-based multi-criteria analysis with risk assessment is proposed to evaluate the physical and operational characteristics of traffic signs and to define a level of intervention reflecting the need/urgency to improve their performance and compliance. The multi-criteria analysis is based on the identification and weighting of physical and operational criteria. One of the criteria, sign visibility, was evaluated through GIS tools. The method was applied in Guimarães, a Portuguese medium-sized city, by analysing the characteristics of 35 regulatory traffic signs. Results show that 51% of the signs analysed have physical and operational problems (level of intervention 2), requiring actions to improve their condition. Besides the compact urban structure, with narrow and non-linear streets, the trees planted on the pavements were identified as the main cause of obstruction. Since the obstructed signs are hardly visible within the braking and stopping distances, road users are exposed to significant accident risk. Removing and maintaining regularly the vegetation and replacing some signs are important actions to improve their physical and operational characteristics. The proposed method can help transportation entities in improving traffic safety.

Key-Words: Traffic signs, Visibility, Multi-criteria analysis, Intervention level, Ranking, GIS

1 Introduction

Traffic signs are a key element of a transportation system, providing critical safety-related information to road users and ensuring predictable, efficient and organised movements of drivers and other road users. Of all transportation infrastructures, traffic signs are the most common visual aids that provide safer traffic environments through regulating or warning drivers [1]. For that purpose, signs must be properly visible from moving vehicles and must be of a size, shape and colour that enable drivers to easily detect, read and understand the message, allowing them to act accordingly [2].

Visibility is generally understood as the degree to which different parts of an environment may be observed from various viewpoints [3]. However, the traffic sign visibility is an imprecise concept because it encompasses both sign detectability and legibility [4]. Sign detectability refers to the likelihood of a sign being found in the driving environment and is related with the capacity to attract the driver's attention. On the other hand, sign legibility describes the ease with which the textual or symbolic content of a sign can be read. Traffic signs must be visible to be detectable and readable by drivers. It implies that they have to be in good physical and operational characteristics and they must be appropriately mounted and placed. Borowsky et al. [5] argue that when signs are misplaced, they may cause crashes due to inappropriate design, rather than inappropriate driving. Moreover, to be suitably visible, traffic signs should be regularly monitored and maintained regarding their physical condition and level of compliance with standards [6,7].

While the design, placement, operation and maintenance have been analysed in the literature, the condition of the traffic signs has been less exploited [8]. To fulfil this gap, this paper presents and describes an innovative approach to evaluate the physical and operational characteristics of traffic signs and to define a level of intervention reflecting the need/urgency of intervention. The approach combines a GIS-based multi-criteria analysis with risk assessment. A generic and adjustable GIS-based multi-criteria model is presented identifying the criteria with impact on the signs' visibility, aggregating physical and operational issues. The multi-criteria model is adjustable as the weighting process is methodologically left open to be replicated and adapted in other contexts according to stakeholders' opinion and/or to spatial specificities. In this paper, the model was implemented taking into account weights defined by stakeholders from the Mobility Division of the municipality of Guimarães, Portugal. The level of intervention was estimated by defining a probable risk that reflects the signs' compliance with the standards and the exposure to risks.

The application in Guimarães was carried out with the purpose of testing the functionality and the utility of this methodology. This study is innovative in proposing an integrated approach to assess the physical and operational characteristics of traffic signs and to rank the interventions required according to the need/urgency to restore their compliance with national standards and guidelines.

2 Methodology

This paper proposes an innovative GIS-based multi-criteria analysis to classify the traffic signs according to an intervention level scale, considering their compliance with local and national standards and guidelines. The first step of the work consisted in collecting traffic signs data. This includes identifying, georeferencing and surveying all signs, namely about their size, colour, position, and condition. Road characteristics (type of road, maximum speed allowed, gradient, among others) need also to be collected. The collected data was, then, introduced into the ArcGIS software to assess the signs' visibility, taking into consideration the braking and stopping distances. All signs and elements which had interference in their visibility (trees, buildings, etc.) were mapped. Signs were represented by points while buildings and greenery were represented by polygons. Both buildings and trees have a height attribute. The height of the buildings was estimated by using the number of floors. Trees and shrubs were spatially represented by polygons. Vegetation also has a height attribute obtained by visual inspection. When the branches were taller than the signs, only the width of the trunks was considered as having an impact on the sign visibility.

As the visibility in ArcGIS can only be analysed using raster data, all the vectorised elements were transformed into a regular grid of cells (rasterization). Thus, the points were converted into a single cell surrounded by cells with other values (attributes), while the polygons originated several cells of equal value, which are surrounded by other different cells. The visibility was analysed by using the viewshed and visibility tools of ArcGIS that have been widely used in such approaches [9, 10]. Viewshed is a GIS tool used to detect surfaces that are visible (or not) from one or more observation locations [11].

After concluding the spatial analysis, the next step was to develop the multi-criteria analysis. Multi-criteria analysis is a widespread evaluation method for transport projects, including in road safety [12, 13]. Macharis and Bernardini [14] retrieved 276 publications regarding the application of multi-criteria analysis for transport projects, which were increasingly used over the last ten years. Multi-criteria analysis evaluates different alternatives criteria by using some qualitative and quantitative criteria with different weights [12, 14]. According to Ait-Mlouk et al. [13], the main advantages of this tool is the inclusion of decision makers' preferences and diversity of criteria.

The work started by selecting the criteria with impact on the signs' function and performance according to the literature review. The analysis was based on two groups of criteria, physical and operational characteristics of signs. The first group comprises the following criteria: (i) longitudinal placement: is related with the braking and stopping distances, meaning that the signs must be far enough in advance so that the driver can react and slow or stop the vehicle if necessary; (ii) Post height: the vertical distance from ground to underside of sign; (iii) lateral offset: the distance between the sign post and the curb, defining the lateral clearance; and (iv) size: the dimension, including the height and width of the signs that define their vertical clearance. As mentioned in the background, these physical issues have a direct impact on the operational performance of traffic signs, namely in their visibility [4, 15, 16, 17]. The second group aggregates operational issues and includes the following criteria: (i) presence of obstacles, understood in this study as temporary or easily removable elements, such as shop awnings, obstructing partially or totally the signs; (ii) sign visibility, considering permanent or long-term obstructions covering the signs. This item was obtained by GIS analysis; (iii) deterioration, including ageing and vandalism; and (iv) retroreflectivity to assess how reflective are the signs during nigh time. As described in the literature review, these operational issues also have a strong impact on the signs visibility [7, 18, 19, 20, 21, 22].

The model is proposed with two main focuses: a global evaluation module to assess traffic signs during day and night time conditions, which consists of eight criteria; and a daytime module comprising the same criteria excepting the retroreflectivity.

The next step was the risk analysis to obtain the level of intervention required to evaluate the physical and operational characteristics of signs. The study adopted the risk analysis approach initially proposed by Belloví and Malagón [23] and more recently used by other authors, such as Bessa et al. [18]. As shown in Figure 1, the level of compliance was evaluated considering four categories and the respective weights: very poor (10) when signs present serious problems, not respecting the standards; poor (6) when they show problems that must be solved to improve their visibility; insufficient (2) when they have minor problems that ideally should be solved; and suitable (0) when signs are in full accordance with the standards.

The level of exposure to risks was also based four categories with the following weights: permanent (4) when they are permanently exposed to damaging factors or events (e.g., polluting sources); frequent (3) when signs are cyclically exposed to some risks (e.g., climatic); occasional (2) when signs are irregularly exposed to some risks (e.g., loading and unloading); and unusual (1) when signs are only threatened by sporadic events.

Finally, the intervention index (II) was estimated by combining the probable risk with the multi-criteria evaluation as shown in equation (1).

Process to define the Level of Intervention

Level of Compliance (with standards) (LC)			
Very poor	Poor	Insufficient	Suitable
10	6	2	0

Level of Exposure (to risks) (LE)			
Permanent	Frequent	Occasional	Unusual
4	3	2	1

Probable Risk (PR_s) (LC×LE)			
Very high	High	Moderate	Low
[40-20]	]20-8]	]8-4]	]0-4]

Assessment Intervention Index (AII)

$$AII=\frac{\sum_{s=1}^{ns}(W_s \times PR_s)}{\sum_{s=1}^{ns} W_s} \qquad (1)$$

where: ns is the number of criteria assessed; PRs is the probable risk; Ws is the weight assigned

(1) - Urgent	(2) - Necessary	(3) - Desirable	(4) - Unnecessary
[40-20]	]20-8]	]8-4]	]0-4]

Source: Adapted from Belloví and Malagón [23].

Fig. 1 - Procedures and weights assigned to define the intervention index

By applying this methodology, the level of intervention can be represented by four categories, which indicates if a sign needs, or not, to be restored/replaced and what is the urgency of that action (Table 1). The higher the weight class, the more urgent should be the intervention. Thus, the signs scored in the class [40-20] are those where the intervention is more required and urgent (level 1), presenting problems related to their physical and operational characteristics.

Table 1 - Intervention level according to the sign characteristics

Intervention level	Intervention Index	Description
1	[40 – 20]	Critical situation. Take immediate action
2	]20 – 8]	Correcting actions are necessary
3	]8 – 4]	Improve if possible
4	]4 – 0]	Intervention not required

Source: Adapted from Belloví & Malagón [23].

In turn, level 2 comprises signs where the problems are not so critical but where some actions must be taken to improve their standard characteristics. The signs grouped in level 3 showed some minor problems that ideally should be solved, while the signs of level 4 do not require any specific action.

3 Case Study

The described method was applied in Guimarães, a medium-sized city with 51,900 inhabitants [24], located in northern Portugal. The city of Guimarães differs in terms of the quality of the architectural and cultural heritage of its historical centre, which has been included in the UNESCO World Heritage List since 2001. In this area, the roads are generally narrow and irregular and buildings typically with two or three floors maintain the original identity.

In order to test the practicability and feasibility of the approach, various streets near the historical centre of Guimarães were selected. To check if the signs were physically and operationally in compliance with the legal specifications, the streets selected covered diverse urban areas with different traffic points of conflict. The streets selected were: D. João I, Camões, Dr. Bento Cardoso, Liberdade, Manuel Saraiva Brandão and in the S. Gonçalo roundabout. As the aim was to test the functionality of the approach, the analysis was limited to the regulatory signs. The selected area contains 35 regulatory signs.

On the other hand, weights were determined using Saaty's Analytic Hierarchy Process (AHP) [25, 26]. Since Guimarães is a medium-sized city, the process was conducted through direct interviews to the Mobility Division of the municipality (headers, engineers and planners), which is responsible for managing road infrastructures and traffic. Table 2 shows the weights obtained by applying AHP, where it can be seen that the criterion *sign visibility* was largely considered as the most important.

In this study and due to the lack of equipment (retroreflectometer) to measure the retroreflectivity, this criterion was not evaluated. Consequently, the subsequent analysis is based on the daytime module.

Table 2 - Criteria weights

Criteria	Daytime module Weights	Global module Weights
Size	0.04	0.04
Longitud. placement	0.06	0.06
Post height	0.06	0.06
Lateral offset	0.04	0.04
Obstacles	0.18	0.14
Sign visibility	0.44	0.40
Deterioration	0.18	0.13
Retroreflectivity	-	0.13

Table 3 exemplifies the calculation process carried out to estimate the intervention level, using a sign (ID 34-H7) located in Avenida S. Gonçalo. Besides the permanent exposure to external risks, this sign is in compliance with almost all the physical requirements, except the lateral offset, which is insufficient (LC=2) because the post is located closer than that recommended by law (at least 0.50 meters).

Table 3 - Level of intervention calculated for the 34-H7 sign

Group	Criteria	LC	LE	PR_s (LCxLE)	wPR_s	II ($\sum wPR_s$)	IL
Physical characteristics	Size	0	4	0	0	18.92	(Level 2) Necessary
	Longitudinal placement	0	4	0	0		
	Post height	0	4	0	0		
	Lateral offset	2	4	8	0.32		
Operational characteristics	Obstacles	10	3	30	5.4		
	Sign visibility	10	3	30	13,2		
	Deterioration	0	4	0	0		

$wPR_s = PR_s x W_s$; II = Final Intervention Index.

The main problem was related to operational issues, especially due to vegetation obstructing the drivers' line of sight and, consequently, the sign visibility under the braking and stopping distances. Thus, the level of intervention of the sign 34-H7 (level 2 - required) was essentially influenced by the deficient *sign visibility*, which was the criteria most valued by the stakeholders.
In a broader analysis, results showed that more than half of the signs (18) obtained an intervention level 2, requiring actions to improve their physical and operational characteristics (Figure 2). The remaining signs obtained an intervention level 4, meaning that no intervention is required. However, only three signs obtained a final intervention index (II) equal to zero (a value that means that all the criteria analysed are fulfilled). The remaining have small problems that do not affect their characteristics (II $\leq$ 4). As shown in Figure 4, the signs which needed some kind of intervention are widespread by the study area. Signs with an intervention level of 2 globally have one or more problems that is mostly related with the compact urban structure, that causes obstructions or makes signs more difficult to read. In other cases, visibility is affected by trees and greenery that partially or totally cover the signs.

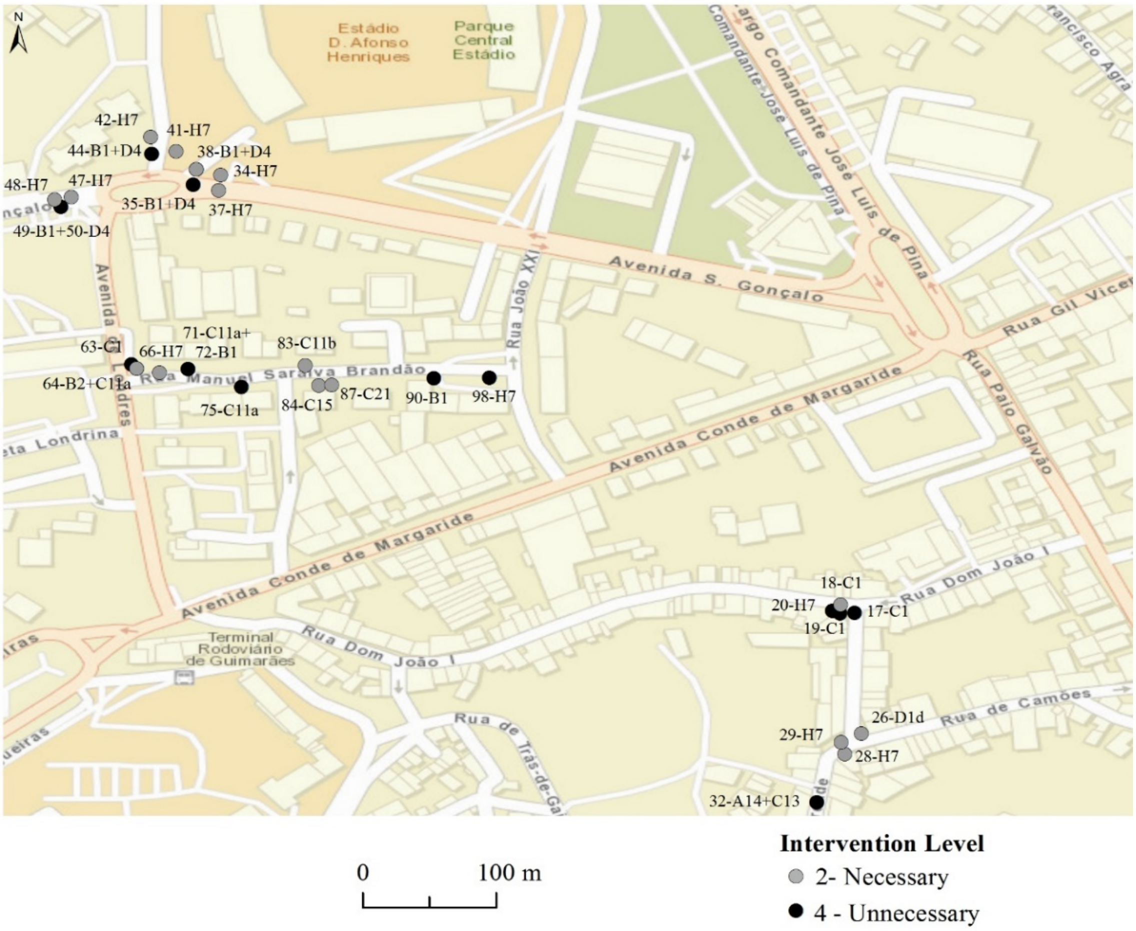

Fig. 2- Signs classified according to the level of intervention

4 Conclusion

This paper describes a methodological approach to evaluate the physical and operational characteristics of traffic signs by assessing a set of criteria and defining a level of intervention reflecting the need/urgency to restore their function and compliance with standards. The methodology uses a GIS-based multi-criteria model and a risk analysis approach to define the required level of intervention. The intervention level was grouped in four levels according to the need/urgency to improve the signs' physical and operational characteristics.
This approach was adopted in various streets near the historical centre of Guimarães, Portugal. Results showed that more than half of the 35 signs analysed obtained an intervention level of 2, requiring actions to improve their condition. This conclusion matches similar studies carried out in other European countries where a significant proportion of traffic signs do not respect the regulatory requirements for

the products' performances [27]. In Guimarães, most of the problems are related with the presence of trees and vegetation that obstructs the traffic signs. This is a common problem already identified by other researchers [22, 28]. The undesirable impact of vegetation can be solved by removing it and maintaining and trimming it regularly or, even more radically, by replacing some signs. The narrow and non-linear streets are also a problem as some signs can only be seen at a distance shorter than the stopping distance. In these cases, signs could be replaced or additional signs should be installed, so that drivers can have an available safety distance to brake and stop the vehicles.

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