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Dynamic Planning of Vertical Road Signs Maintenance: Operational Methodology

Antonio Pratelli[a], Lorenzo Brocchini[a,*], Pietro Leandri[a], Marco Del Carlo[a], Luca Martini[a]

[a]*College of Engineering, University of Pisa, Largo Lucio Lazzarino 2, 56122 Pisa, Italy*

Abstract

This article is the first of two papers on a topic gaining ground in traffic and transport engineering, namely Dynamic Planning of Vertical Road Signs Maintenance. In particular, this first paper describes the methodologies used in determining the current state, the position, the type, the state of conservation and the efficiency of vertical road signs in the city of Forte dei Marmi (Tuscany, Italy). The ultimate goal is to set up a dynamic GIS-based road vertical signs archive and subsequently develop a forecast model. Such an operational procedure can be seen as a useful tool for setting up a Dynamic Maintenance Plan for all vertical signs along the roads of the municipal area. The methodology followed is the following: once the area of interest has been defined, the retroreflection parameter of the 752 vertical signs present in the area was measured using a retroreflectometer, recording the georeferenced data in a specific GIS database. This hands-on approach allows for both adding and removing a given sign, as well as sorting all monitored signs by age and efficiency in a dynamic operational maintenance view. Hence, the development of the forecasting model has been done, however, for this part reference should be made to the second paper. In the final part of this article, the concluding chapter relating to the creation of a dynamic maintenance plan and the conclusions on the methodology used and on possible ideas for further research developments have been included.

Keywords: dynamic maintenance plan; retroreflection; GIS cadastre; retroreflectometer; operational methodology.

1. Introduction

First, to talk about Dynamic Maintenance Planning, it is appropriate to define what a maintenance plan/program is.

*Corresponding author. Tel.: +39-333-8313112
E-mail address: lorenzo.brocchini@unifi.it

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The maintenance program prescribes a series of checks and inspections to be carried out with predefined deadlines, with the aim of monitoring the state of health, functioning and performance of an asset. It is divided into three sub-programmes: the benefits sub-programme; the sub-programme of controls; the sub-program of maintenance interventions. Instead, the maintenance plan is the document that foresees, plans and schedules the maintenance activity of the work to maintain its functionality, qualitative characteristics and efficiency over time. In particular, the dynamic planning of vertical road signs maintenance has the purpose of maintaining the aforementioned characteristics relating to the road signs present in the territorial area under the jurisdiction of the administrative body which draws it up. One of the fundamental aspects for the correct design of a vertical signing system is the visibility of road signs; shape, appearance and size, in fact, must be consistent with the category of the road on which they are installed, given that the speed of passing vehicles strongly influences the sighting distance of the sign. The sighting distance of a road sign must always be guaranteed, day and night, in all weather conditions and cases of poor visibility. For this to be possible, road signs must be made with retroreflecting films; hence, the parameter chosen to evaluate the state of maintenance of vertical signs is retroreflection, i.e., the principle according to which a sign, illuminated by the headlights of a vehicle, reflects the incident light towards the driver.

Given the highly experimental nature of this topic, it was deemed necessary to carry out a preliminary investigation of case studies in the same disciplinary field to try to understand which approach had been used and therefore better clarify, by analogy, which were the best procedures to use. The most significant case study referred to is certainly the one developed in Croatia by Babić et al. (2017), which precisely concerns the analysis of the retroreflection of singling films aimed at creating a dynamic maintenance plan for road signs. Furthermore, another study, always closely related to the present research, but in terms of argumentative typology, is the one made by Banović (2016). The purpose of the aforementioned research works was to develop models that effectively allowed the retroreflection of road signs to be predicted in order to optimize the maintenance and replacement of road signs to increase road safety. Furthermore, in such researches, it is also well illustrated that road signs manage, regulate, inform and warn road users to ensure their safe movement through transport networks and consequently must be timely visible to all traffic participants in all conditions. This are the main motives, why this research started.

As concern the current regulations, retroreflective films are divided into 3 Classes, based on their level of performance: Class 1, Class 2 and Class 2 Microprismatic. The retroreflective performance of Class 1 Films is guaranteed for 7 years, while those of Class 2 and Class 2 Microprismatic Films are guaranteed for 10 years. The purpose of this work is to create a forecast model to evaluate a possible warranty extension for each type of film. In detail, in this first paper, the study method and the field data collection are described with a final chapter about the setting up of the dynamic maintenance plan. Instead, as regard the data analysis and the consequently emerging statistic refer to the second paper. In any case, both the conclusions on the methodology used herewith, and other feasible ideas for further research developments have been included shortly also at the end of this paper.

2. Study Method

Similarly, to what was done in the previously mentioned studies, the parameter chosen to evaluate the state of conservation of vertical signs is retroreflection; that is, the principle according to which a sign, illuminated by vehicle headlights, reflects the incident light in the direction of the driver. The calculation of the retroreflection coefficient, also called coefficient of the luminous intensity per unit area (R'), of retroreflective films is based on the following measurements:

- Area of the useful surface hit by the light beam;
- Illuminance of the sample (measured orthogonally to the direction of the light);
- Illuminance on the detector, to obtain the light intensity emitted by the sample.

For the measurement of the luminous intensity coefficient per surface unit, in addition to the typical laboratory equipment which requires the preparation of a photometric gallery, a series of portable instruments are available on the market, called retroreflectometers, which allow the measurement of the retroreflection parameter of the vertical signage on the construction site. This instrumentation is based on the typical parameters of the retroreflection phenomenon. These parameters include:

- Observation, also named divergence, angle (α): the portion of the plane included between the semi-line representing the direction of the light beam and the semi-line passing through the observer's eye, both originating in the centre of the retroreflector;
- Illumination angle (β): the portion of the plane included between the ray representing the direction of the light ray and the ray normal to the surface of the retroreflector, both originating in the centre of the same.

To measure the luminous intensity per unit of weight of vertical signs in place, the UNI EN 12899-1:2008 standard establishes the need to refer to values of α = 0,33° (20') and β = 5°. There is a geometric and photometric relationship whereby the retroreflection coefficient, R', increases as the angle of observation decreases; the latter, in turn, is a function of the distance that separates the observer from the sign. Therefore, by carrying out the measurements with a retroreflectometer, it is possible to correlate the value of R', detected at a certain angle of observation, to the distance at which the hypothesized medium is located concerning the illuminated sign. To carry out this correlation it is necessary to assume average values of the height between the observer's eye and the centre of the vehicle's headlights, for the main vehicle categories: cars: 0,55 m; MPV: 0,82m; trucks: 1,48m. With the above hypotheses, the distances between the light sign and the observer, corresponding to the various angles of divergence and the various types of vehicles, are summarized in the table below (Table 1).

Table 1. Relative Distance [m] function of Divergence Angle α.

Divergence Angle	Relative Distance [m]		
α	Cars	MPV	Truck
12’	158	235	424
20’	95	142	257
2°	16	23	42

From the able it can be deduced that, for example, the user of the minivan traveling at an average speed of 25 m/s (90 km/h) intercepts the three angles of divergence in about 8,5 seconds; in this short period the user will have to read the sign, understand its meaning and act accordingly. The sign sighting phase, on the other hand, has already taken place; it depends on the distance of perception of the sign in night conditions, which varies depending on the case between 300 and 600 m. The graph (Fig. 1) shows the variation of distance from the sign as a function of the variation of the observation angle, in the interval 0°÷2°, every 0,05°, for the 3 vehicles to which we referred previously.

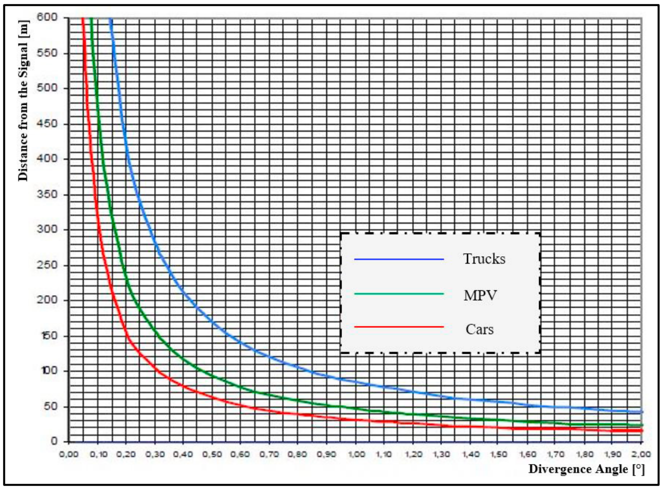

Fig. 1. Graph of the variation of distance from the sign function of the variation of the observation angle.

The retroreflectometer device reproduces the illumination condition of the sign in a standardized way during the measurement phase and detects the amount of retroreflected light from the investigated sign.

The one used in this discussion is the Retroreflectometer Zehntner ZRS 6060 (Fig. 2), a high-precision portable instrument for measuring the luminous intensity R' coefficient value per unit area of vertical traffic signs, according to three different observation angles at the same instant. The retroreflectometer has a magnetic front panel, also called an illumination angle adapter, which ensures that measurements are taken at the desired illumination angle; in our case, as previously described, we carried out the measurements with an illumination angle $\beta = 5°$, using the appropriate front panel. The internal part of the front panel contains the calibration standard, used to calibrate the periodic instrument, with a frequency that can be chosen by the user. The front panel can be mounted on the front of the instrument in two positions: the measurement position, to carry out the measurements of the retroreflection coefficient, and the calibration position, by turning the angular adapter upside down, to carry out the periodic calibration of the instrument. One of the most important functions of the Zehntner ZRS 6060 is the multimedia mode; in fact, it allows one to carry out several measurements of R' in different points of the same colour of the film. The instrument stores every single measurement and also returns the average value relating to all the measurements taken. Finally, the ZRS 6060 also offers the possibility of storing the GPS coordinates associated with the measurement.

Fig. 2. Retroreflectometer Zehntner ZRS 6060 and its extension pole.

From a constructive point of view, the Zehntner ZRS 6060 consists, like all retroreflectometers, of the so-called "optical head" which contains the precision optics, the light source, the correction filters, the shutter, the detector and the controller, which includes the power supply and display. The instrument is also equipped with an internal camera, whose optics are positioned in the upper part of the retroreflectometer. Therefore, each measurement carried out can be associated with a photo of the corresponding road sign. Through the use of the instrument described above, we then proceeded to measure the retroreflection coefficient, of the vertical signs present in the chosen area, considered more representative, of the City of Forte dei Marmi (Tuscany, It.).

3. Field Data Collection

To carry out the survey of the retroreflection of the permanent vertical signs of the City of Forte dei Marmi (Tuscany, It.), it was necessary to choose a significant sample section on which to carry out the measurements; given the logistical impossibility of extending these measures to the entire municipal area. Considering the geomorphological characteristics of the territory and the presence of the sea, the representative area was chosen as the one most exposed to the erosive action created by the brackish water against the permanent vertical signs placed near the bathing area. Therefore, the representative stretch includes the seaside avenues of the municipal area, which are: Viale Italico; Viale della Repubblica; Viale Franceschi.

Overall, the stretch of seaside avenues extends for a length of approximately 5 km and it spans from North to South, joining the small town of Montignoso to Pietrasanta, respectively.

For convenience, the section just described has been divided into 4 zones, listed below:

- *Viale Italico (Zone 1)*, which extends from the beginning of Viale Italico, near the border with Montignoso, at the crossroads with Via Versilia;
- *Viale Italico (Zone 2)*, which goes from the intersection with Via Versilia to the end of Viale Italico;

- *Viale della Repubblica (Zone 3)*, which runs from the beginning of Viale della Repubblica to the end of Viale Franceschi, a limited-traffic avenue parallel to Viale della Repubblica;
- *Viale della Repubblica (Zone 4)*, which goes from the end of Viale Franceschi to the end of Viale della Repubblica, near the border with Pietrasanta.

Each of the areas has also been further divided into "Seaside" and "Inner side", to differentiate the part of signs on the side of the roadway closest to the sea from that on the opposite side of the road. The measurement of the retroreflection coefficient, was carried out with the Zehntner ZRS 6060 retroreflectometer, extensively described previously. For each area surveyed, a database was created, with the name corresponding to the section analysed, to facilitate the stages of archiving and subsequent processing of the surveyed data; in the name of the database, from time to time, the words "Seaside" or "Inner side" have been added depending on the side of the roadway detected. On each permanent vertical road sign, the value of the retroreflection coefficient R' was measured for each colour present on the film of the sign; for each colour, 3 measurements of R' were carried out in sufficiently distant and representative points. Taking advantage of the mean mode of the instrument, both the single values and the corresponding mean value were recorded, the latter value used as a representative of the retroreflection characteristics of that colour. This procedure is similar to that reported in the previously mentioned studies carried out in Croatia. Note that the retroreflectometer returns the luminous intensity coefficient to the observer in the same unit of measurement in which the minimum reference standards to be respected are indicated in the regulations $[cd/lux \cdot m^2]$.

Fig. 3. Survey field stages on Viale Franceschi (Forte dei Marmi, Tuscany, Italy).

During the field survey stages (Fig. 3), a very important and delicate phase was of identifying the film category of the vertical sign under investigation. In fact, to be able to carry out the subsequent checks, it is essential to know which norm to refer to. Each film must bear a wording on the visible face indicating the code relating to the Class to which the film belongs (Class 1, Class 2, Class 2 Microprismatic); only in the presence of such labelling is it possible to establish with certainty the type of film. During the field measurements, it is very often encountered a lack of the aforementioned labelling, which made it difficult to classify the films.

However, making use of the information that can be received from the visual aspect of the same and using small comparison samples of the various types of films, it has been possible to catalogue all the films observed according to the respective Class they belong to. Another fundamental phase, no less important, was the identification of the year of manufacture of the road sign; in fact, this is fundamental information to create the statistical forecasting model. Also in this phase, some difficulty in identifying the year of manufacture was encountered, which was often absent, difficult to read or completely discoloured. In the aforesaid cases, the determination of the age of the sign was carried out by analogy with similar road signs, both in terms of type and state of maintenance; also making use of the fact that a vertical signage installation logic was found according to which the signs relating to the same disciplinary area (for example pedestrian crossing signs or signs relating to the cycle/pedestrian lane) were all installed in the same year. In the phase immediately following the measurement of the retroreflection coefficient on a vertical sign, this measurement was modified by interacting with the instrument thanks to the aid of a portable keyboard.

By accessing the section relating to the measurement just carried out via the display, we have entered the following information in the appropriate fields: location; street; orientation of the sign; kind of film; sign name; sign conditions; year of manufacture. The Zehntner ZRS 6060 instrument associates the measurements made with geospatial coordinates according to the global geodetic geographic coordinate system WGS84, also known as EPSG: 4326. Zehntner supplies, together with the instrument, software for the geospatial management of the measurements made, called Mapping Tools. The databases that are created during the investigation phases can be downloaded and processed with this software. However, since it is a closed proprietary software of the manufacturing company, it was necessary to export the reports generated in an Open-Source application. The application used is QGIS™, open-source software that allows you to analyse and modify spatial data and generate cartography and that supports various data formats, such as vector or raster, as well as major spatial databases. Once the databases have been loaded in this application, its related *shapefiles* (.shp) have been created by the "export" function. The recorded data restitution of the dynamic GIS, i.e., Geographic Information System, cadastre relating to the vertical signs investigated took place precisely through this file format. Such an output file is now readable in Open-Source mode through any GIS-based software, as well as editable and continuously updatable. This tool will be very useful to the City of Forte dei Marmi (Tuscany, It.) to update, modify and dynamically expand its road vertical sign archive performing subsequent survey operations and scheduled maintenance, complete and referable to the entire set of the municipal area permanent vertical signs (Fig. 4).

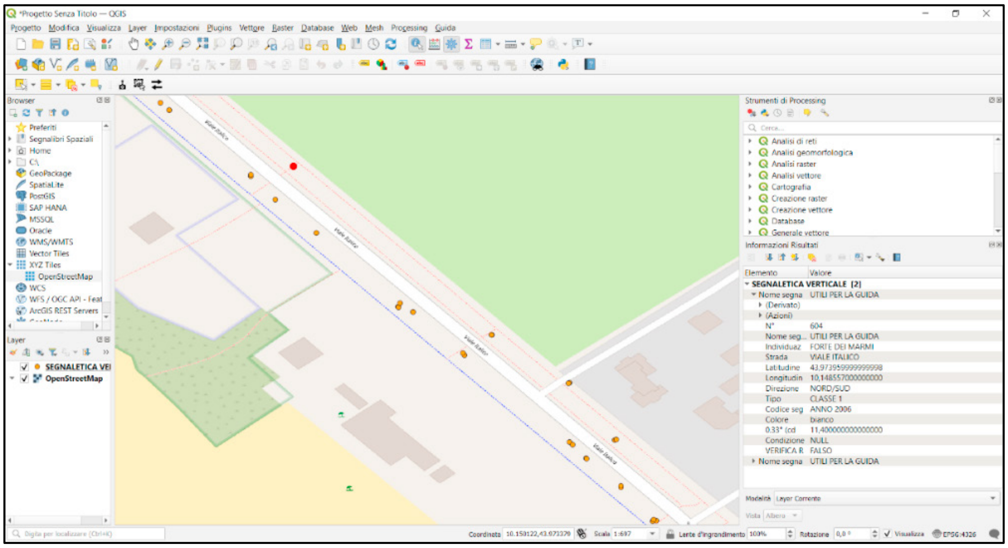

Fig. 4. Screenshot instance of the dynamic GIS-based road vertical signs archive.

Before concluding this chapter, a summary diagram of the phases described above is provided for greater clarity (Fig. 5):

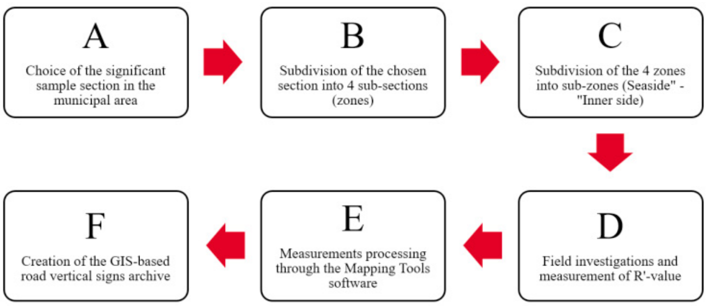

Fig. 5. Summary diagram of the phases described.

4. Setting up the Dynamic Maintenance Plan

At this point, once created the dynamic GIS-based road vertical signs archive. The next step was the development of the forecasting model through the analysis of data and statistical emergencies. However, considering the amount of data, the authors decided to go into detail of this part separately, in a second paper. In any case, it was deemed appropriate to include in this chapter, the summary of the phases of the Dynamic Maintenance Plan development with some general conclusive considerations on it which will in any case be detailed better in the second paper. As regards the implementation phases of the Dynamic Maintenance Plan, they can be summarized as follows:

- Phase 1: Selection of the most representative area;
- Phase 2: Measurement of retroreflection values;
- Phase 3: Creation of the GIS cadastre of signs;
- Phase 4: Preparation of the database necessary for the development of the model;
- Phase 5: Statistical elaboration;
- Phase 6: Development of the Model for the Dynamic Maintenance Plan.

As anticipated, therefore, for the sake of completeness, some concluding considerations regarding the Dynamic Maintenance Plan are reported, which however will be explored in the second paper relating to this work:

1. It is possible to conclude that Class 1 vertical signs can satisfy the minimum retroreflection requirements imposed by the legislation for some time at least approximately 12 years, with a probability of 96,07% that this forecast is accurate; therefore, the risk of error in this assessment is 3.93%, which is why the considerations made are considered sufficiently dependable;
2. Conversely, the average age relating to vertical signs that do not comply with the minimum regulatory standards, equal to approximately 18 years, should not be considered equally reliable. The percentage relative to the accuracy of this forecast is 64,43% with a probability of error equal to 35,57%. These percentages allow us to state that, from the experimental evidence we have found, is unable to establish when a Class 1 vertical sign will surely exhaust its retroreflection properties.

The information just reported can be used by the municipal administration to choose the maintenance strategy it deems most effective. In this direction, two approaches could be employed:

- In consideration of the fact that, up to the age of 12, Class 1 road signs almost certainly maintain the minimum requirements of the luminous intensity coefficient per area, it is considered not to carry out any checks until this age is reached, for then program checks of the retroreflective instrumentation with a high sampling frequency beyond this period;
- Taking advantage of the same assumptions referred to in the previous point, it is chosen not to carry out any checks on the same category of signs, until the end of the guarantee period, established by the legislation equal to 7 years. From this age onwards, periodic sampling of Class 1 vertical signs is carried out until the signage reaches 12 years of age, to then increase the frequency of checks from that age onwards.

5. Conclusion remarks

As repeatedly stated, this article is the first of two papers on a topic that is gaining traction in traffic and transportation engineering, namely Dynamic Planning of Vertical Road Signs Maintenance. Being the first of the two articles, the introductory part was more in-depth compared to this concise concluding part since the conclusions will be better explained and explored in the second article. That said, it is possible to affirm that the entire work carried out, and in particular the development of the forecast statistical model, will allow the municipal administration of Forte dei Marmi to prepare a maintenance plan for vertical signs in its area. Furthermore, without talking about the forecasting model (deepened in the second paper), if we stop at phase 3 described in the previous chapter, it would already be possible to obtain an excellent result. In detail, the creation of the GIS cadastre of signage can be already considered an excellent result for the administrations as it can be used as a "virtual warehouse" of continuously updatable vertical signage. Returning instead to the experimental evidence, it should be noted that what emerged from the calculations made and the relative conclusions reached are limited to this chosen sampling area; to evaluate possible areas of application to similar urban contexts it would be necessary to perform all the operations carried out concerning a much larger sample of dataset than the one analysed by the Authors.

The values of the luminous intensity coefficient were measured without considering other potentially influencing factors such as exposure, temperature, humidity and any atmospheric conditions. So, for example, this could be considered one of the possible ideas for further and future research developments. In detail, a new campaign of measurements can therefore be carried out on the same portion of the selected territory, or even on a larger portion, integrating it by taking into account the aforementioned additional factors. After talking about the possible ideas for research developments, it is also appropriate to mention its limits. In particular, the biggest limitation encountered during the work is that linked to the time it takes to carry out the surveys in the field. On a generic stretch of road, especially if you are in an urban area, the number of vertical signs is enormous; therefore, carrying out the measurements requires a lot of time for the operators. In any case, even this drawback could be better investigated, and possibly overcome, through further future research developments. Finally, for the other conclusions regarding the data analysis and the related emerging statistics, please refer to the second paper where further conclusions will be drawn regarding the type of film (Class 1 Film, Class 2 Film and Class 2 Microprismatic Film), the various colours and then the prediction model.

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