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ROAD SURFACE MARKINGS' PERFORMANCE: MONITORING AND INNOVATION

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SUMMARY

The unit of Perugia of CIRIAF (Interuniversity Center of Research on Pollution by Physical Agents), in cooperation with the municipality of Perugia, has started a research project aiming at defining a modus operandi for in-situ measurements able to take into account the characteristics of the site of installation of road marking in order to:

- optimize the maintenance;
- give the municipalities a tool to verify the quality of the application, in order to assess if the requirements given in tenders are fulfilled.

The activity is performed within the framework of the EU co-funded project CIVITAS Plus "RENAISSANCE", involving five municipalities of five EU state members. The project aims at testing and developing innovative transport strategies in historic cities (see the website of the project www.civitas.eu).

The paper, after the first sections about the state of the art of materials used for road markings and the methodology for the evaluation of their performance, reports the results of a first experimental campaign carried out on several roads of the municipality of Perugia.

THE CIVITAS+ "RENAISSANCE" PROJECT

The Project "RENAISSANCE" (full title: "Testing Innovative Strategies for Clean Urban Transport for historic European cities") is co-funded by the European Union within the 7th Framework Programme CIVITAS Initiative (Plus edition 2008-2012).

The goal of the project RENAISSANCE is to develop a valid, reliable and integrated package of access and mobility measures for historic cities.

RENAISSANCE cities are five historic cities from across Europe, in the vanguard of sustainable development. The cities are in sites having in common strong reliance on heritage and tourism, which must combine environmental concerns, mobility and economic development.

The cities involved in the project are:

- Perugia (ITALY) – Project Leader (see fig. 1);
- Bath (UK);
- Szczecinek (Poland);
- Gorna Oryahovitsa (Bulgaria);
- Skopje (Republic of Macedonia).

Figure 1: logo of CIVITAS RENAISSANCE for the city of Perugia.

The activities are performed by the five cities in cooperation with other 25 partner companies and research organizations expert in the field of transport and mobility.

The 4-years project has started in September 2008.

Within the framework of the measure 5.2 of the project "Assessing the options for more efficient road pavement markings", the unit of Perugia of CIRIAF (Interuniversity Center of Research on Pollution by Physical Agents), in cooperation with the municipality of Perugia, has focused the research activities on the study of the performance of road surface markings.

The incidence of pavement marking on traffic safety and driving comfort is considerable.

Efficiency and durability of road horizontal marking are strongly required both from the users and the administrators. From the users' point of view pavement marking provides an optical path by means of an adequate contrast of colour and luminance with the road surface, while costs and performances influence the administrators' choices, especially as far as the planning of maintenance.

The activities of CIRIAF can be summarized as follows:

- survey on the state of the art on materials used for road markings;
- survey on the state of the art on methodology used for evaluating the performance of road markings;
- selection of the most suitable instruments for evaluating the performance of road markings;
- selection of the sites of measure along the road network of the municipality of Perugia, taking into account different types of material, asphalt and traffic flows;
- experimental campaign on the selected sites.

These activities aim at defining a modus operandi for in-situ measurement able to take into account the characteristics of the site of installation of road marking, in order to:

- optimize the maintenance;
- give the municipalities a tool to verify the quality of the application in order to assess if the requirements given in

tenders are fulfilled.

This second aspect is particularly important for public administrations: as a matter of fact the current evaluation of the performance of road surface markings performed by the Municipality of Perugia is made purely by verifying the products used in terms of quantity, and by visual judgment of the amount of paint used, without any experimental support.

PARAMETERS FOR THE EVALUATION OF ROAD MARKINGS' PERFORMANCE

In the European Union, the evaluation of the performance of road markings was introduced in August 1997, following the withdrawal of the English BS 3262.

The standards related to road markings are:

- EN 1436 – Road Marking Performance for Road Users;
- EN 1463 – Retro reflecting Road Studs;
- EN 1790 – Preformed Road Markings;
- EN 1824 – Road Trials;
- EN 1871 – Physical Properties;
- EN 1423 – Glass Beads, Aggregates and mixtures;
- EN 1424 – Premix glass beads.

In particular, EN 1436 specifies the performance for the road user of white and yellow road markings based on luminance (colour), day-time visibility, night-time visibility and skid resistance combined with durability. The specification also introduces the importance of wet-night visibility road markings. Furthermore, it also describes the methods of measuring the various performance characteristics.

The road marking characteristics are as follows:

1) Reflection in daylight or under road lighting Q_d.

Luminance is the property of the marking which describes the brightness of its colour.

Q_d measures, true to scale, the luminance (day visibility) of a road marking. The observation angle of 2,29° corresponds to the viewing distance of a motor car driver of 30 m under normal conditions (see fig. 2). The illumination is diffused light.

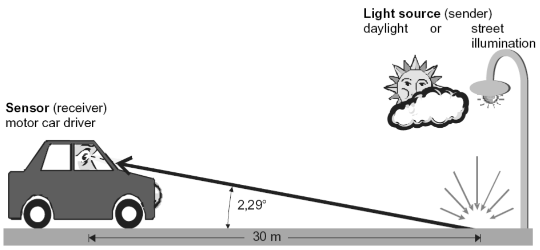

Figure 2: scheme of the measurement conditions for Q_d.

2) Retroreflection under vehicle headlamp illumination R_L.

Retroreflection is the ability of a road marking to reflect light from a vehicle's headlights back to the driving position of a vehicle. Initially it will be determined by the amount of glass beads spread on the line. The continuing performance of the line is determined by the amount and quality of glass beads included in the body of the road marking.

R_L measures, true to scale, the retroreflection (night visibility) of a road marking. The observation angle of 2,29° corresponds to the viewing distance of a motor car driver of 30 m under normal conditions. The illumination angle is 1,24° (see fig. 3).

R_L is measured in three different conditions of road markings: dry, wet and rain.

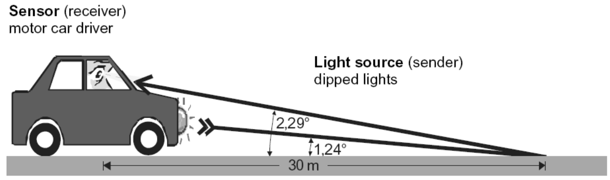

Figure 3: scheme of the measurement conditions for R_L.

3) Colour.

It is defined by the luminance factor β and chromaticity, defined as the co-ordinates to fall within a defined square on the chromaticity diagram (see fig. 4).

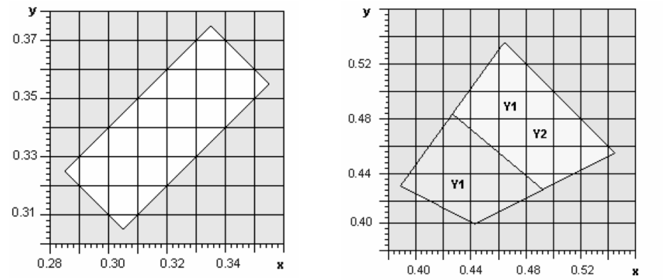

Figure 4: chromaticity vertexes defined by EN 1436 for white (left) and yellow (right) road markings

4) Skid Resistance SRT.

Skid resistance measurement on road markings is carried out using the standard British pendulum apparatus. The units of measurement quoted in EN 1436 are followed by the abbreviation SRT. The skid resistance of freshly applied road markings tends to increase in value due to the effects of trafficking and weathering. For skid resistance, emphasis is sometimes placed on those road markings which occupy a large percentage of the trafficked areas such as zebra crossings, arrows, transverse markings, text and symbols.

Table 1 reports the classes of performance for each parameter, as defined by EN 1436 for white and yellow on asphalt pavements; other values are referred to concrete surfaces.

Table 1: requirements for white (a) and yellow (b) road markings' performance.

a)

R_L (dry conditions) mcd/ (m^2·lux)		R_L (wet conditions) mcd/(m^2·lux)		Q_D mcd/(m^2·lux)		SRT	
Class	Value	Class	Value	Class	Value	Class	Value
RO	NIL	RW0	NIL	Q0	NIL	SO	NIL
R2	≥ 100	RW1	≥ 25	Q2	≥ 100	S1	≥ 45
R3	≥ 150	RW2	≥ 35	Q3	≥ 130	S2	≥ 50
R4	≥ 200	RW3	≥ 50	Q4	≥ 160	S3	≥ 55
R5	≥ 300	RW4	≥ 75			S4	≥ 60
		RW5	≥ 100			S5	≥ 65
		RW6	≥ 150				

b)

R_L (dry conditions) mcd/(m^2·lux)		R_L (wet conditions) mcd/(m^2·lux)		Q_D mcd/(m^2·lux)		SRT	
Class	Value	Class	Value	Class	Value	Class	Value
R0	NIL	RW0	NIL	Q0	NIL	S0	NIL
R1	≥ 80	RW1	≥ 25	Q1	≥ 80	S1	≥ 45
R3	≥ 150	RW2	≥ 35	Q2	≥ 100	S2	≥ 50
R4	≥ 200	RW3	≥ 50	Q3	≥ 130	S3	≥ 55
		RW4	≥ 75			S4	≥ 60
		RW5	≥ 100			S5	≥ 65
		RW6	≥ 150				

MATERIALS AND TECHNOLOGIES: STATE OF THE ART

As previously said, the performance of road markings in terms of retro reflectivity is determined by the amount and quality of glass beads included in the material (see figure 5).

Glass beads have usually diameters around one-tenth, one-hundredth of millimeter; they can be pre-mixed in the marking material or post-sprayed on the surface of the material after its installation.

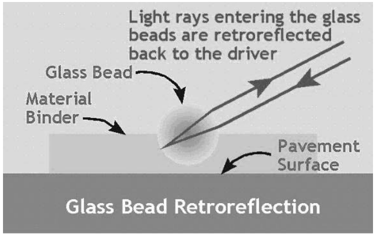

Figure 5: retroreflection of glass beads.

There are four basic road marking materials, all of them using glass beads to improve retro reflectivity properties.

Paint: it is the most used road marking system in the world. It does not require heating and can be applied very quickly at speeds up to 15 km/h, it has little build up and an affinity to glass beads. This road marking system can be applied generally from May until October because of the weather conditions. Traffic paints are available with a variety of solvents (alkyd resin, rubber, modified alkyd) and water-borne. Solvent-borne paints are very durable with respect to water-borne, but have an higher content of VOC (around 440 g/l vs. 150 g/L). Glass beads are either pre-mixed into paint or dropped while the paint is wet. Water-borne are much easier to handle than solvent paints but wear off rapidly and lose reflectivity quickly. Therefore paint are not suitable for high-volume roadways but for nondurable markings. Expected service life is around ½ to 1 year while retro reflectivity is within the range of 140-250 mcd/(lux·m^2).

Figure 6: installation of paint stripes.

Thermoplastic: it is a durable pavement marking material, composed of glass beads, pigments, binders (plastics and resins) and fillers. There are two types of thermoplastics: hydrocarbon and alkyd. Thermoplastic road markings are solid at ambient temperatures, so they must be melted for the application (at least at 200°C). They do not contain solvents and have an application speed of around 5 km/h and a thickness from 1.5 to 3 mm. A correct installation requires a proper surface cleaning, the removal of the moisture; it is recommended not to apply thermoplastic materials on cold pavements surfaces (poor adhesion may occur). Moreover these materials can be re-applied over older thermoplastic marking, they perform very well on all types of asphalt surfaces but a loss of material may occur from snow-removal operation. Expected service life is around 2 to 7 years (strongly depending on formulation and installation), while retro reflectivity is within the range of 80-120 mcd/(lux·m^2).

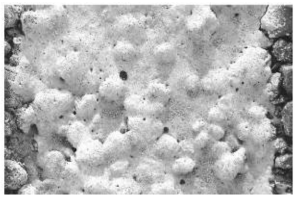

Figure 7: thermoplastic road marking.

Two-components: these materials are produced on site through the reaction of two chemical reactants. The first component contains epoxy resin, pigment, extenders and fillers, while the second component acts as a catalyst to accelerate setting time. Epoxy resin may be substituted with polyester, polyurea or methacrylate. All these materials have a low VOC content. Epoxy-based marking materials have a service life until 4 years, but discolour with age; they have a drying time in most cases higher than 40 minutes. Methyl Methacrylate-based markings have to be applied slowly (5 km/h) and need a cure time of about 30 minutes; nevertheless this system has a very high retro-reflectivity and a service life up to 10 years. Polyurea-based marking materials have a faster drying time, need a short cure time (3 to 8 minutes); they may be also applied at low pavement surface temperatures (as low as 0°C) and are not affected by humidity.

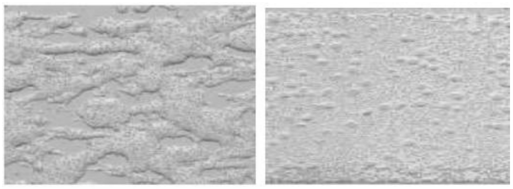

Figure 8: two-components road markings: methacrylate (left) and polyurea (right) based materials.

Preformed road markings or Tapes: these materials are available in several performance levels and types, both permanent and temporary. The marking can be applied to existing pavement rolled into hot surfaces, or placed in prepared grooves. It needs a proper pavement surface preparation, a slow application and has a cost which is 5 to 10 times higher than thermoplastic. Glass beads are incorporated into material during factory manufacturing. Nevertheless tapes have a service life longer than others marking systems and an excellent retro-reflectivity (300-1000 mcd/(lux·m^2)).

Figure 9: road marking tape

MEASUREMENT SET-UP

The optimal measurement set-up and conditions have been defined after a in-depth survey on the state of art of laboratory and in situ measurements for the characterization of the optical properties of road markings. It has allowed to pick and choose the most suitable instrumentations complying to the European standards. The equipment is described in the following sections.

<u>Retroreflectometer Zehntner ZRM6013 R_L+Q_d</u>

The Zehntner-retroreflectometer ZRM 6013 measures the night visibility (R_L) of road markings as seen by a vehicle driver with dipped headlight. The illumination simulates the dipped headlights of a vehicle. The day visibility (Q_d) of road markings under typical or average daylight or under street lighting is measured with diffused illumination. This makes an objective determination of night (R_L) and day visibility (Q_d) of road markings in compliance to EN 1436, of ambient temperature as well as of relative humidity in dry or wet condition, at any given time of day or night, on the road or in the laboratory for all types of road markings paints, marking tapes, thermoplastic and cold plastic materials - whether smooth, textured, profiled, coloured, with or without aggregates and reflective beads.

Figure 10: Retroreflectometer

<u>Road marking control kit Zehntner ZMK5051</u>

The kit includes the complete range of measuring and testing instruments required for control checks on road markings:

- 1 thickness gauge, 100 µm to 950 µm, in steps of 25 µm;
- 1 insertion thermometer, -10°C to +200°C;
- 1 hygrometer, 25% to 95% relative humidity;
- 1 electronic balance, 0 g to 2’000 g;
- 1 magnifying glass, 6x magnification with scale;
- 1 digital marking gauge for measuring the dry film thickness of road markings.

<u>Portable Skid Resistance Tester Zehntner SRT 5800</u>

The instrument, which is direct reading, gives a measure of the friction between a skidding tyre (a rubber slider mounted at the end of the pendulum arm) and a wet road surface. The quantity measured with the portable tester has been termed "Skid-resistance" and this correlates with the performance of a vehicle with patterned tyres braking with locked wheels on a wet road at 50 km/h. It can be used in laboratory or in field measurements.

<u>Spectrophotometer Konica Minolta CM-2500c</u>

The spectrophotometer CM-2500c, with 45/0° geometry, is a portable, hand-held spectrophotometer designed to measure, match and control the color of small, irregular surfaces as well as substrates with grain, texture or directional characteristics. It is used to measure the chromatic coordinates of road markings.

Figure 11: Portable Skid Resistance Tester

Figure 12: spectrophotometer

<u>Infrared camera FLIR B360</u>

An infrared camera is a non-contact device that detects infrared energy (heat) and converts it into an electronic signal, which is then processed to produce a thermal image on a video monitor and perform temperature calculations. Heat sensed by an infrared camera can be very precisely quantified, or measured, allowing to not only monitor thermal performance, but also to identify and evaluate the relative importance of heat-related problems.

The emissivity of road marking materials is generally different from the one of the road surface (asphalt or concrete). Being the emissivity an intrinsic property of the material, it changes with the thickness of the road marking film, showing differences in films’ thickness and problems of uniformity of application not visible to the naked eye.

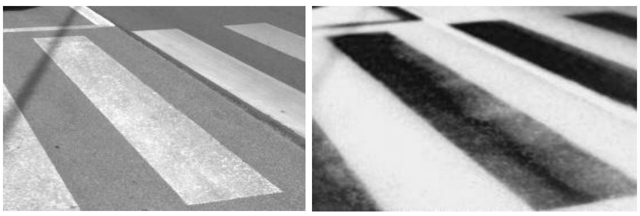

Figure 13: picture of white stripes shot with a normal camera (left) and with an infrared camera (right).

ROAD SURFACE MARKINGS’ PERFORMANCE MONITORING

Municipality’s territory is crossed by high intensity traffic routes with 1000 vehicles per hour, but also by local streets with lower traffic density and street surfaces range from smooth pavement to cobblestones. Furthermore several materials are used as road markings (paints, thermoplastics, preformed tapes, etc).

The unit of Perugia of CIRIAF will execute measurements in selected places, representative of the whole municipality of Perugia, in order to extend the results on its entire territory. So the selected locations of measurements have to take into account all the most representative surfaces which can be found throughout the whole territory of Perugia Municipality.

A wide range of horizontal marking materials will be considered, both standard (paint, thermoplastic, two-components, preformed) and innovative, in order to compare their performance.

A total number of 36 sites have been selected, taking into account three main factors:

- traffic flow (high, medium, low);
- street surface (smooth, rough, other like cobblestone);
- road marking materials.

The parameters have been chosen in order to guarantee the upscaling of the procedure in other cities.

The parameters to be evaluated are:

- R_L Retroreflectivity in dry and wet conditions;
- Q_d Reflection in daylight;
- Colour;
- Skid resistance.

The infrared camera will be used in all sites for a preliminary test, in order to put in evidence problems of uniformity.

The experimental campaign will start in Spring; in the meanwhile a preliminary measurements campaign is being carried out, in order to define the measurement procedure to be applied in the 36 planned sites.

PRELIMINARY EXPERIMENTAL CAMPAIGN

Three sites have been chosen for the preliminary experimental campaign. Such locations have in common low traffic flows (to guarantee the operators' safety) and differ by the material used for the marking.

In the first site the analyzed material is a preformed tape laid on a smooth road surface. In order to obtain a more representative information, 8 different measurements in different points of the stripes were carried out (fig. 14).

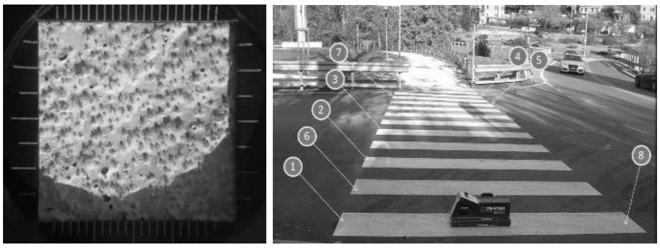

Figure 14: Pictures of white stripes tested

The average values of R_L in dry conditions, R_L in wet conditions and Q_d are respectively 598, 55 and 198 mcd/(lux·m^2), higher than the prescription of UNI 1436. Moreover SRT is 42, lower than the minimum value required by the standard (45). These results were expected because of the large amount of glass beads included in the tape (see fig. 14).

A thermoplastic signal has been tested in the second site, characterized by a smooth road surface. Ten measurements were carried out.

The average values of R_L in dry conditions, R_L in wet conditions, Q_d are respectively 132, 36 and 136 mcd/(lux·m^2); SRT is equal to 63. All the parameters show values complying to the requirements of UNI 1436. Nevertheless, in particular for R_L, the values are deeply influenced by the point of measure, ranging from 43 to 238 mcd/(lux·m^2) (see fig. 15). Results clearly evidence the effect of the crossing of tires on the stripes, that dirty the surface and remove a portion of glass beads.

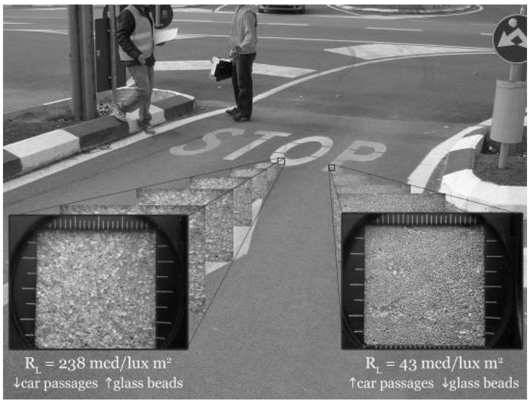

Figure 15: Effect of tires on road markings

The last site is a bus lane with yellow paint recently installed. In this case, while the performance concerning SRT and Q_d are satisfying (respectively 50 and 126 mcd/(lux·m^2)), the retroreflectivity is much lower than the requirements, both in dry (R_L= 27 mcd/(lux·m^2)) and wet (R_L= 18 mcd/(lux·m^2)) conditions. This results from the total absence of glass beads, as shown in figure 16.

Finally, the results concerning the chromatic coordinates of road markings in all the sites comply to those required by the standard.

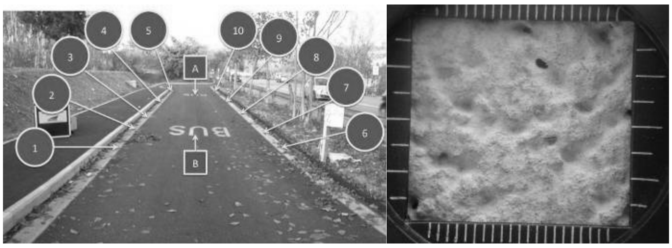

Figure 16: Bus lane with yellow paint

FUTURE DEVELOPMENTS

Waiting for the start of experimental campaign, the CIRIAF team of Perugia is developing an innovative indicator in order to give an efficient tool to rate the quality of the pavement marking of the roads managed by the municipality. This indicator, that will have adimensional values from 0 to 100, will take into account all the parameters characterizing the performance of a road marking:

- luminance Coefficient in day conditions Q_d;
- retroreflectivity in night conditions R_L (dry, wet);

- skid resistance SRT;
- colour;
- type of material for the pavement markings;
- volume of traffic;
- characteristics of pavement;
- ageing.

All the results will be weighted according to the importance of the parameters and averaged for the different condition of measurements, in order to have a realistic picture of the condition of the pavement markings installed on the road managed by the municipality.

The indicators will be evaluated for white and yellow (not considering temporary markings) stripes separately.

The analysis of the results obtained from the experimental campaign and the use of the developed indicator could help to give the outline of the situation of road marking quality and suggests actions to improve the performance.

Finally, a protocol reporting the procedures for in situ evaluation of road pavement marking properties will be developed. This protocol will be a powerful tool to verify the quality of the application of road markings in order to assess if the requirements given in tenders are fulfilled.

The protocol will also be extended to the other cities involved in the project.

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