Publishable Summary for 16NRM02 SURFACE
Pavement surface characterisation for smart and efficient road lighting

Overview

The knowledge of the so-called luminance coefficient *q* (ratio between the luminance of the road surface and the illuminance on it for given directions of illumination and observation) is an unavoidable requirement for designing road lighting installations able to ensure that road luminance is adequate to ensure visibility for road users and traffic safety, as well lowering energy consumptions in accordance with current EN standards. SURFACE will provide the necessary metrological support to the European standardisation process with validated, optimised and reliable geometrical conditions for the measurement of *q* as well as reference data representative of current road pavements, useful for smart and efficient road lighting system design.

Need

Presently in Europe about 40 % of the 5.5 million kilometres of roads have lighting. Current EU standards on road lighting (i.e. EN 13201 series) seek to establish road luminance values able to satisfy quantitative and qualitative performances in terms of safety, visual appearance, and energy consumption. Thus, the weighting and spacing of a road lighting system (i.e. luminous flux installed per kilometre) is calculated accordingly to comply with the suggested luminance values of the assigned road class that warrant the visibility for road users safety. Usually the design of such lighting systems (e.g. the definition of installation layout, luminous intensity, distribution of luminaires, and luminous flux installed per kilometre or power density indicator) considers reference weighted *q* data (*r*-tables) of the road surface.

In the EN 13201 Road lighting Standard series, *r*-tables provide values only for the necessary incident and view directions for traditional lighting installation (i.e. installation luminaires height greater than 10 m and columns inter-distance of about 30 m) and the *q* data, representative of the road surface behaviour, for those directions are missing. Road lighting designers adopt as de facto standard values, the *r*-table or the equivalent *q* values published in CIE documents. However, these data are based on measurements performed on concrete samples more than 40 years ago without traceability and uncertainty evaluation. Recent studies have shown that the use of CIE data as reference leads to large errors (on average over 30 %, but up to 50 % in worst case) on expected road luminance. Moreover, the photometric properties of road materials have changed over time considering new material components and laying techniques as well as the road lighting systems (i.e. LED sources, adaptive systems and smart lighting systems, and luminaires installed at lower heights). Such an evolving situation requires the definition of new values of *q* and an upgrade of the reference directions for its measurement. To ensure EU targets on Energy Saving and Road Safety are met it is now time to improve *q* reference data and reference geometries through a large metrological research review of basic concepts and metrological capabilities.

Objectives

The goal of this project is to address the current deficiencies in European Standards regarding (i) the definition and characterisation of the road surface photometry, (ii) traceable measurement and characterisation methods for road surface characteristics and (iii) traceable reference data for photometric tables useful in the design process of road lighting installations. The results will be used by CEN TC169/WG12 in the next revision of EN 13201 series, and by CIE TC4-50 in the revision of pertinent CIE publications.

The specific objectives are:

1. To develop optimised measurement geometries for the characterisation of photometric quantities for road surface materials to support EN 13201 ‘Road Lighting’ and its future revisions.

2. To produce technical and metrological specifications for instruments used to measure luminance and reduced luminance coefficients of road surfaces in laboratories or on-site, including methodologies for calibration, establishing traceability and evaluating the measurement uncertainty.
3. To develop pre-normative guidelines for measurement methods and procedures, for the future evolution of European standards to include aspects such as mesopic visual conditions (CIE191:2010), reduced obtrusive light and reduced light pollution of road lighting installations.
4. To develop pre-normative guidelines for photometric characterisation of road and pavement surfaces, including factors such as aging of road surfaces, wet conditions, spectral properties, diffusion of adaptive lighting systems (smart lighting), luminaire luminous intensity distribution and effects of measurement uncertainty in tolerance calculations.
5. To contribute to the standards development works of the technical committees CEN TC169/WG12 and CIE TC4-50 through the provision of data, methods, guidelines and recommendations. In particular traceable data related to new geometries and materials for inclusion in updated photometric tables of pavements in the international CIE database shall be provided. To ensure that the outputs of the project are aligned with their needs, results will be communicated quickly to those developing the standards and to those who will use them (e.g. lighting engineers, road designers), and in a form that can be incorporated into the standards at the earliest opportunity.

Progress beyond the state of the art

Although the luminance coefficient, *q,* is a quantity for characterising the spatial reflectance behaviour of a material, the measurement of *q* of a road surface for all possible directions of illumination and view is not necessary for a Road Lighting Standard, but a sub-set of useful directions for current and future smart lighting systems shall be clearly established. Actually, the available reference directions were established at the time of measurement of the reference data, based on the luminaire, traffic conditions and design approaches of that age. Therefore, this project tackles the need for the new directions of illumination and view that are most significant and useful in the design of road lighting systems with Solid State Lighting (SSL), in adaptive lighting, for improved glare evaluation, as well as considering new vision models, the complexity of traffic conditions and obtrusive lighting. Moreover, the prescribed direction of observation is 1°, the corresponding observation distance is around 85 m in front of the driver: an obviously unrealistic visual condition in urban environment both for driver and pedestrian.

Available commercial measurement devices for measuring luminance lack a clear assessment of photometric and geometrical performance. In addition, measurement guidelines are not available; the reliability of measurements is unknown and the uncertainty difficult to evaluate. The development of reference materials will establish traceability and provide an opportunity to verify measurement procedures and uncertainty calculations. These reference materials will allow the performance of the first comparison on measurement of luminance coefficient in the last 20 years and to ensure the traceability of the road characterisation metrology infrastructure in the EU.

New revisions and future editions of the EN road lighting standard series need to enlarge the scenario of aspects to be included in road lighting in order to achieve higher Energy Saving and Road Safety and to reduce the Environmental Impact of road lighting systems. The project will provide research results and guidelines about the influence of road surface ageing (installation over dimensioning), spectral properties (mesopic vision), and wet/dry conditions (adaptive systems). The CIE Expert Symposium on Road Surface Photometry and CIE TC4-50 stated that no guidelines on traceable measurement methods and sample management and alignment are currently available. Without standard measurement guidelines the reliability of measurements is unknown and their measurement uncertainty difficult to evaluate. *SURFACE* guidelines will also describe measurement methods and handling as well as specifications for new vision models, tolerance analysis and quality parameters.

An analysis of current NMIs involvement on road surface characterisation was carried out via the BIPM (Bureau International des Poids et Mesures) website on the KCDB database devoted to intercomparisons (Key Comparison Database) and gave no results about road surface intercomparison. In KCDB only eleven Key Comparisons are ascribed to materials properties, nine of them belong to regular transmittance and two to diffuse reflectance, none of which are of use for road surface characterisation.

The planned intercomparison will stress and improve the measuring capabilities of NMI goniometers to materials very different from usual metrology applications (e.g. ceramic tiles or lambertian surfaces).

Results

The joint research project *SURFACE* is developing the necessary metrological research and infrastructure, i.e. measurement methodologies, reference data, new geometries and reference materials for instrument calibration to achieve more efficient, more sustainable and safer road lighting design.

To achieve objectives and provide data of surfaces and measurements devices really representative of actual situations of different countries and laboratories, the consortium launched different calls for contributions on *r*-tables and instruments description, among the communities of stakeholders and collaborators, SDO, lighting designers, lighting engineering, road administration authorities, ...

The calls have been spread extensively at international road lighting congresses (CIE mid term session 2017 and Lux Europa 2017 congress), CIE symposium (CIE New advance on road Visibility 2018) and other events (CIE division 4 and TC meetings in 2017 and 2018, national lighting congresses).

Optimised measurement geometries

This project selects a new set of geometries representative of the directions of illumination and views that are most useful and significant for Solid State Lighting (SSL), adaptive lighting design, glare evaluation and for new vision models. These advanced situations require spectral investigation on the photometric properties of asphalts: in the first part of the project, the impact of different lighting source spectrum on available *q* data have been evaluated: the spectrum of the new CIE LED Reference Illuminant is also included, thanks to the strong consortium connections with CIE DIV2.

A first draft proposal on new geometry has been prepared and discussed among consortium members and presented at the first stakeholder meeting in Berlin (May 2018), and was well accepted. The proposal contains three different observation angles, representative of the different needs of road users in different situations like: urban environment (vehicle drivers and pedestrians), extra-urban environment (vehicle drivers), and road surface boundary reflectance diffusing-specular behaviour.

The geometries proposed by the consortium, have been made explicit during the second stakeholder meeting in Washington at the 29th CIE quadrennial session and at CIE TC4-50 meeting (June 2019). The observation angle for urban environment is 2,29°, this choice helps the dissemination of portable measurement devices, harmonizes with road-marking measurement conditions and ensures viewing conditions useful for pedestrians and drivers in urban traffic. The observation angle for extra-urban environment is 1°, the previous established one, this allows traceability and harmonization with results so far available and is suitable for viewing distances of extra-urban and of ADAS (Advanced Driver Assistance System). Two different proposals (10° and 20°) are under consideration for defining a viewing condition useful for describing the boundary diffusing-specular behaviour.

Guidelines

The project provides specific guidelines on: metrological requirements (objective no. 2) for instruments, measurement procedures (including sampling and handling), calibration and uncertainty evaluation, and methods (objective no.3) for evaluating the influence of ageing, of spectral properties and of wet conditions.

These advanced situations require spectral investigation on the photometric properties of asphalts: in the first part of the project, the impact of different lighting source spectrum on available *q* data have been evaluated. Investigations on spectral impact considering the most common lighting sources, LEDs included both for instrument and road lighting have been considered. The road surface spectral behaviour shows its impact on mesopic calculation for tunnel lighting visibility and ADAS camera calibration and performance evaluation.

One of the aforesaid calls was to catalogue existing measurement devices (for in laboratory and on-site measurements), and review their performances for setting up the intercomparison protocol and future guidelines on instrument specifications and performance (objective no.2) as well as for an initial version of the proposed portable measuring device. Twenty-two different measuring devices from across Europe have been classified; fifteen of them are laboratory instruments. All portable instruments belong to consortium partners or to those within the stakeholder group. Indeed, road lighting and road surface characterisation is a worldwide

need, so ten additional devices from outside Europe have also been classified, most of them are the same instruments developed in Europe and installed abroad, with the exception of goniometers developed in USA and China.

A second call was launched to establish the actual distribution of road surfaces families across Europe, to provide reference data on the most relevant actual roads to technical committees (objective no. 5). In the call for information, qualitative and descriptive data are also requested to classify the performance from the ageing point of view.

Collaboration between the NMIs and the planned intercomparison, the first one ever carried out on luminance coefficient, will ensure the necessary traceability and uncertainty of the European Metrology Infrastructure and instrument manufacturers. A dedicated Creative Commons (CC) open source software for uncertainty calculations will also be tested and provided to the community. The measurement intercomparison will be based on Reference Materials (RM) fabricated by means of 3D printing, representative of asphalt photometric performances. Several 3D printable materials have been characterised for their photometric performances, while two different RM have been designed to be used during the intercomparison based on given photometric performances and given artefact attributes. After prototyping and deep metrological characterization of photometric performances, the consortium has chosen to produce RM of given artefact attributes. Two different sets of 3D printed RM are used during the intercomparison: one set is based on flat materials of given reflectance with matte and glossy behaviour, the other set is based on artefacts with attributes similar to a road surface with matte and glossy behaviour. Different measuring challenges related to geometrical attributes have been identified. Both sets will be used during the planned intercomparison. The measurement method report of each laboratory attending the intercomparison will be useful to the measurement guidelines.

Planar irregularities of the road surface under test on site affect the actual geometries of measurements: a special portable device for the evaluation of surface irregularities, necessary for the selection of measurement area on site, has been developed and a prototyped by 3D printing.

Continuous contacts with the community of laboratories doing measurements on road surface photometric properties, showed that laboratories are unaware of the Guide to uncertainty measurement calculation (GUM) approach in the evaluation of the measurement uncertainty on *q* values. SURFACE defined measurement models for the evaluation of the uncertainty on *q* values of simple application in industrial laboratory and will be tested during the intercomparison. At the end of the project the EU market will benefit of a software for the uncertainty evaluation.

Contributions to standard development

At the end of the three years *SURFACE* will provide to Standardisation Organisations and to CIE, new reference data for *q* of actual road surface, with an uncertainty statement, for current EN 13201 *q* reference geometries and for future reference geometries.

Presently, the SURFACE database of current road surfaces includes about 250 different types of road surfaces. Data have been classified in clusters, and a champion for each cluster was used as reference for road lighting calculations. The results highlight the differences among current road surfaces and published road data, especially in terms of LED road lighting systems.

The project defined, in accordance also with EN 13201-5 suggestions, a reference set (called SURFACE *test set*), to compare performances of road surfaces and lighting systems. The SURFACE *test set* includes: 5 different reference road surfaces selected from the SURFACE database, a reference road profile and lighting class, a reference lighting system of given geometrical and photometrical characteristics. Based on this reference set, energetic and visibility performances of different actual road surfaces have been compared to reference CIE road surface currently used in standard. The results highlight the impact of the SURFACE achievements in term of energy savings and visibility as improvement to safety conditions.

The results are constantly disseminated to relevant International and National Standardization Organizations, and mainly used:

- by CEN TC169/WG12 in the next revision of EN 13201 series (mainly part 3) or as an addendum;
- by CIE TC4-50 and TC4-51, for improving reference tables and guidelines;
- by National Standards Organisations, like the Italian UNI GL5 for standard UNI 11248, AFNOR for France, EVS for Estonia, SIS for Sweden and SNV for Switzerland.

- by Laboratory Accreditation System

Impact

Impact on Industrial and other user communities

The initial version of a portable instrument, the development of Certified Reference Material as well as the software for uncertainty evaluation will push forward the market for developing new and adequate laboratory and portable measuring instruments for the characterisation of road surface as requested in EN 13201 standard series and never implemented due to an actual lack in metrological infrastructure.

The assimilation of the file format of luminance coefficient data and the data of *r*-tables of SURFACE database by the lighting engineering community and designers, will be ensured by the use of Creative Commons policy for the dissemination of relevant material and results and by the involvement of an IT company in the consortium. A joint meeting was organized during the Consortium meeting in June 2019, with member of the BiRD project consortium to share details on the file format selected by BiRD for BRDF (Bidirectional Reflectance Distribution Function) data sharing.

The interest in the production of CRMs has grown up and the idea of CRMs for a luminance coefficient has been shared on several occasions, and promoted by ACCREDIA, the Italian Body for accreditation, including at the largest Energy Saving event in Italy, Ecomondo 2017 and the exposition A&T (Automation and Testing) in Torino in April 2018 and February 2019. The manufacturing of RM is one of the first actual applications of IoT to metrology and has attracted the interests of Accreditation body as tangible application of normative on RM producers and future approach to RM based on IoT.

At the end of the project the EU market will benefit of Certified Reference Material (CRM) for calibrating road surface measuring instruments.

Three different European stakeholders and collaborators are attending the intercomparison on *q* values based on RM: this will ensure reliability and traceability of the results made by industrial laboratories.

In December 2018 a delegation of the stakeholder Panasonic visited INRIM and Cerema for a technical meeting focused on portable instruments development and their introduction to Japan.

A workshop on Smart lighting *(Too Smart, Too Light)* was organized in March 2019 for students in design of the Politecnico di Torino; attendance about 20 students, then a presentation of the results was given to an audience of more than 200 people.

The project attracted interest of the ADAS (Advanced Driver Assistance Systems) producers community: SURFACE representative is among IEEE P2020 (Automotive Image Quality) group, and invited to the largest European event on ADAS (September 2019, AutoSens) to attend a panel on the optimization of roads for vehicle perception applications through improvement on road design, characterization, and maintenance.

The investigations on the improvements necessary to adapt a road marking commercial measuring device to road surface characterization lead to establish connections between global descriptors or reflective properties of road marking and road surface. It will entail the introduction of a new portable measuring device on the market to help in the EN13201 implementation of on-site *q* measurements.

Impact on the metrology and scientific communities

The guidelines on measurement uncertainty and measurement methodologies, and the planned comparison will improve the measuring capabilities of NMI goniophotometers for road surfaces and the European metrological services on road lighting and material characterisation.

A special portable device for the evaluation of surface irregularities, useful for the selection of measurement areas on site, has been developed and a prototyped by 3D printing. The device is described in the guidelines.

The scientific community will receive new contributions via CIE TC4-50 and TC4-51.

The first of two planned workshops on road surface characterisation were held at the CIE Mid Term Session in Korea, allowing the project to enlarge the stakeholder committee and to raise awareness of the EMPIR programme and the project to eastern countries communities. The second planned workshop near the end of the project to disseminate the results under the aegis of CIE, is going to be organized during the CIE DIV4 meeting in May 2020.

Several papers on the results of the project will also be published in target end user journals and presented at scientific conferences. The ongoing activities in the project are reported on the project website: www.surface-nrm02.eu. The website was set up in July 2017 and is continually updated as new public information becomes available. It also contains a member's area with restricted access for project partners and collaborators.

The project and its results are constantly shared with the road lighting and lighting design communities giving presentations and publishing at international and national conferences. Indeed, these two communities are deeply rooted to communications through conferences instead of publication on journals. Therefore, consortium partners gave several presentations and published papers at the main lighting conferences: LuxEuropa 2017, CIE 2017 mid-term congresses, CIE 2018 road visibility workshop, CIE 2019 quadrennial session, Autosens Bruxelles, and the National lighting engineering congress of Italy and France.

Impact on relevant standards

The project supports EN 13201 'Road Lighting' and its future revisions, and contributes to the standards development works of the technical committees CEN TC169/WG12 and CIE TC4-50.

The project has been introduced to CIE Division 4 and CIE TCs TC4.50, TC4.15,TC 4.51 at the CIE-meeting in October 2017, May 2018, June 2019 and the TCs members strongly supported the TCs involvement. At SDO the project was presented to CEN TC 169, and several other TC and WG at National and International meetings.

At each CIE DIV4 meeting during the project duration (October 2017 in Jeju, May 2018 in Berlin, June 2019 in Washigton) the project results so far are discussed within the members. Meanwhile at CIE TC4-50 meetings held concurrently, project actions are constantly planned and integrated with the CIE TC4-50 document revision. On May 25 2018, at Berlin TU University, after the CIE Workshop "A new Vision of Visibility in Roadway Lighting" the consortium organised the first stakeholder meeting. About 20 different stakeholders attended the event. Stakeholders acknowledged the main results presented by the consortium: new geometry for road surface characterisation based on three different observation angles (instead of only one as in the current reference documents), new reference source for spectral calculations of road surface behaviour (available reference documents do not consider spectral peculiarities) and RM for the planned intercomparison. On June 2019, at CIE quadrennial session in Washington, the second stakeholder meeting was organized to present main consortium achievements: the database of the *q* values of current road surfaces, the SURFACE *test set* and their impact on the energy saving and visibility, a preliminary version of RM set was also presented to stakeholders community.

CEN TC 169 is not active because the revision of the current standard EN13201 will start in 2020, but in October 2019 the TC will meet to resolve some discrepancies in EN 13201-3. During this meeting the SURFACE research results will be presented and the EN TC community get the occasion to tune in advance on the expected achievements of 2020.

Longer-term economic, social and environmental impacts

This research project will provide the groundwork (e.g.: metrological infrastructure, measurement methodologies, reference data, new geometries, reference materials for calibration, and portable measuring device) for a more efficient, more sustainable and safer road lighting design to be acknowledged in future standards for the benefit all EU night-time road users.

Road lighting consumption is about 6-7% of a country's total electrical consumption, but for a given municipality can be as high as 50% of the whole electrical consumption: more efficient lighting design based on SSL (Solid State lighting) and Smart Lighting can potentially save up to 70% on lighting energy, lowering the CO_2 impact, and allow the development of smart cities. These results can be achieved only with better design based on more reliable data on road surface characteristics harmonized with current road lighting standards, in order to provide higher visual quality assuring safety conditions to all road users.

The *SURFACE* reference data of actual (and upcoming) road materials will allow lighting designers to meet the normative energy savings and quality parameters as per the EU's commitment to cut energy consumption by 20 % by 2020. It will also strengthen the turnover of old lighting luminaires into new SSL luminaires and the introduction of adaptive and smart lighting systems allowing bigger energy savings.

EU Road Safety Programme aims to cut road deaths in Europe between 2011 and 2020 by about 40%. The *q* reference data of actual road surface are an unavoidable need for the design of safer roads and the

implementation of EU Road Safety Action trough the improvement of EU road Infrastructures, including intelligent and Smart roads and road assessment.

The SURFACE *test set* demonstrated the impact on visibility and energy saving when using actual road surfaces of the SURFACE database, instead of outdated data represented by CIE *r*-tables. The use of actual SURFACE database *r*-tables and LED lighting system highlights the relevance of pairing light road surfaces and smart lighting system to achieve the best results in energy saving and visibility. The use of SURFACE data can lead to energy savings that for bright pavements can be up to 27% in brand new lighting systems or more than 50% for new pavement installation, with reference to current (and old) CIE database, and the concurrence of using Smart Light controllers for ensuring the compliance to normative visibility requirements in case of new pavement installation on existing lighting systems.

List of publications

The project plan to produce pre-normative guidelines:

- for photometric characterisation of road and pavement surfaces including measurement methods and procedures, aging of road surfaces, wet conditions, spectral properties
- for applications in road lighting, including effects of measurement uncertainty in tolerance calculations, contribution to obtrusive light and light pollution of road lighting installations considering the road reflectance, mesopic visual conditions, and adaptive lighting systems (smart lighting).

The project plan includes the publication of at least three papers in open access peer review journals describing the intercomparison results, metrological characteristics of instruments for road surface measurements and the new database of road surface characteristics. Training materials in the form of a brochure on measurement difficulties when applying EN 13201 in real life situations will be also disseminated in different EU languages to stakeholders and road authorities, under CC policies.

The following publications have been published on open access:

Journal:

G. Rossi, P. Iacomussi, M. Zinzi, Lighting implications of urban mitigation strategies through cool pavements: energy savings and visual comfort Climate journal DOI: 10.3390/cli6020026

Gidlund, H., Lindgren, M., Muzet, V., Rossi, G. & Iacomussi, P. (2019) Road Surface Photometric Characterisation and Its Impact on Energy Savings. Coatings journal DOI: 10.3390/coatings9050286

Conference proceedings:

F. Valpreda, P. Iacomussi, G. Rossi, Innovative design and metrological approaches to smart lighting, DOI: 10.25039/x46.2019.PO192

P. Iacomussi, G. Rossi, Influence of material characterization in the design of tunnel lighting installations, DOI: 10.25039/x46.2019.OP74

P. Iacomussi, G. Rossi, , The veiling luminance in tunnel lighting installation, DOI: 10.25039/x46.2019.PP28

V. Muzet, M. Colomb, M. Toinette, P. Gandon-Leger, J.P Christory, Towards an optimization of urban lighting throug a combined approach of lighting and road building activities, DOI 10.25039/x46.2019.PP23

Muzet V, Greffier F, Vemy P, Optimization of road surface reflections properties and lighting: learning of a three year experiment, DOI 10.25039/x46.2019.OP72

Greffier F,Muzet V, Boucher V, Fournela F, Dronneau R., Use of an imaging luminance measuring device to evaluate road lighting performance at different angles of observation DOI 10.25039/x46.2019.OP75

1. INRIM, Italy 2. AALTO, Finland 3. LNE, France 4. METROSERT, Estonia 5. RISE, Sweden	6.CEREMA, France	7. METAS, Switzerland 8. OPTIS, France 9. ZEHNTNER, Switzerland