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 to ensure adequate road luminance is adequate and visibility for road users and traffic safety, as well as, lowering energy consumptions in accordance with current EN standards. The project results have provided the necessary groundwork for a metrological infrastructure and supported the European standardisation process by developing validated, optimised and reliable geometrical conditions for instrument calibration, along with reference data that is representative of current road pavements. Thus, ensuring more efficient, sustainable and safer road lighting design. In addition, SURFACE completed a full evaluation of the energetic impact of current road lighting design procedures based on reference outdated r-tables. The optimized measurement geometries outlined by the project addressed the needs of different road user (e.g. drivers, cyclists and pedestrians) while taking into account their viewing distance, actual traffic conditions, velocity and road environment. In terms of traffic safety, the project established new observation angles, homogeneous with actual users' viewing conditions, leading to road lighting systems with visually improved safety performances. Key project outputs such as an initial version of a portable instrument for road marking characterization, the developed RM and CRM, and the uncertainty evaluation software (Lumcorun), 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 As such, normative technical committees (TCs), lighting designers and road authorities now have access to reliable luminance coefficient data describing the behaviour of contemporary road surfaces.

Need

Across 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) are 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 the 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 due to 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, the project focussed on improving *q* reference data and reference geometries through a large metrological research review of basic concepts and metrological capabilities. After the 1st CIE international symposium on Road Surface Photometric characteristics (Torino, 2008), the revision of CIE TR 144 was set up in 2009, however no significative advances were made due to the lack of focused research, NMI involvement, and of collaborative approach within all involved figures. Owing to the project's achievements, CIE TC4-50 is finally able to attain its task. A new CIE TR144 has been planned in for the next years and will based on the SURFACE pre-normative guidelines and results.

Objectives

The goal of this project was 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 project 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 were:

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. The reference directions cited in the current standards, 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 geometries 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 and actual metrological capabilities of measuring devices and community needs. 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 and a very difficult geometrical requirement to achieve on site with significative accuracy.

Available commercial measurement devices for measuring luminance, lack a clear assessment of photometric and geometrical performance. Furthermore, measurement guidelines are not available so the reliability of measurements is unknown and the uncertainty difficult to evaluate. The project provided patented, Certified Reference Materials (CRMs) that were based on IoT and produced by 3D printing. Also, the project developed Open Access Software (LUMCORUN) for uncertainty evaluation of measurement, which is able to model the material behaviour and to calculate the main systemic errors due to apertures, as well as to evaluate the alignment random error.

The CIE Community and in particular CIE TC4-50 stated that no guidelines on measurement methods and sample management were currently available. Without standard approach and measuring device performances knowledge the reliability of measurements is unknown and their measurement uncertainty difficult to evaluate. Therefore, the project provided research results and guidelines on the photometric characterisation of road surfaces, a software for the study of measurement uncertainty, and reference materials. *SURFACE* guidelines provided the necessary reference to community and ensure CIE TC 4-50 will finally (CIE TC4-50 is one of the oldest CIE TC) achieve its goal of revision of TR 144. New revisions and future editions of the EN road lighting standard series will take advantage of the SURFACE findings that extend the scenario of aspects to be included in road lighting, including new geometries and reference data for calculation to achieve higher Energy Saving and Road Safety and to reduce the Environmental Impact of road lighting systems.

Results

Optimised measurement geometries (Objectives 1)

The project proposed a new set of geometries representative of the directions of illumination and observation that are most useful and significant for actual road users' needs, for Solid State Lighting (SSL), adaptive lighting design, glare evaluation and for new vision models. Such advanced situations required 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 was evaluated: the spectrum of the new CIE LED Reference Illuminant was also included, due to the project's effective collaboration with CIE Division 2. The new geometries, were published in an open access paper and presented during the 3rd International Road Characterization Symposium. The proposal contained 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. For an urban environment, the project partners suggested a viewing angle of 2,29° (viewing distance 37m), this choice supported the dissemination of portable measurement devices with low production cost and higher accuracies, harmonized with road-marking measurement conditions, thus ensuring viewing conditions which were useful for pedestrians and drivers in urban traffic. Also, it increased the accuracy of on-site measurements during compliance verification. The observation angle for extra-urban environment is 1° (viewing distance 86 m), enabled traceability and harmonization with available results and suitable for viewing distances of extra-urban and ADAS (Advanced Driver Assistance System). An additional proposal of 5° was deemed suitable for pedestrian, cyclist and diffuse smart mobility systems (scooters).

This objective has been fully met since the project's approach towards observation angles satisfied the actual viewing conditions of road users. Thereby ensuring improving road safety of all users (e.g. drivers, cyclists and pedestrians). Going beyond the project's lifetime, two different proposals (10° and 20°) are under consideration for defining a viewing condition that can describe the boundary diffusing-specular behaviour which will be useful for applications like Smart Lighting with luminance camera in high position.

Technical and metrological specifications for instruments used to measure luminance (Objectives 2)

The project provided specific guidelines on metrological requirements for instruments, measurement procedures (including sampling and handling), calibration and uncertainty evaluation, and methods (Objective 3) for evaluating the influence of ageing, of spectral properties and of wet conditions. These advanced situations required spectral investigation on the photometric properties of asphalts: 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 the guidelines on instrument specifications and performance. 22 different measuring devices from across Europe have been classified; fifteen of them are laboratory instruments. All portable instruments belonged to project partners or to those within the stakeholder group. Indeed, road lighting and road surface characterisation is a worldwide need, so 10 additional international devices 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 full review of road surface photometry characterization methods and metrological features of available devices was also published in an open access paper.

Furthermore, collaboration between the NMIs and the planned intercomparison; which was the first one ever carried out on luminance coefficient; ensured the necessary traceability and uncertainty of the European Metrology Infrastructure and instrument manufacturers. A dedicated Creative Commons (CC) open source software for uncertainty calculations was provided to the community and tested by the project partners. The measurement intercomparison was based on Reference Materials (RM) fabricated by means of 3D printing, representative of asphalt photometric performances. An intercomparison KIT made of two different sets of 3D printed RM was used: to test different measuring challenges related to geometrical attributes. The measurement method report of each intercomparison attending laboratory was also useful to the measurement guidelines. This objective was been met.

Pre-normative guidelines for measurement methods and procedures, for the future evolution of European standards (Objective 3)

SURFACE engaged with relevant standardisation organisations, in particular with CIE to disseminate and raise awareness of key project outputs such as: new reference data for *q* of actual road surface, the evaluation of the impact of their usage, new geometries, a detailed investigation on instruments performances for on-site and laboratory evaluation of photometric road surface characteristics, a reference test set to compare lighting performances of systems and road surfaces, and two detailed practical guidelines for direct implementation in the standard. All of these project results will provide the basis for the new revision of CIE TR144 and EN lighting standards. This objective has been met.

Pre-normative guidelines for photometric characterisation of road and pavement surfaces (Objective 4)

This objective has been fully met. Guidelines produced during the project contained fundamental background on road surface parameters, detailed metrological requirements for portable and laboratory instruments with an emphasis on measurement parameters and geometries, and how these contribute to the measurement uncertainty. Regarding measurement procedures, both laboratory and on-site measurement procedures were detailed along with sample extraction, marking and handling, alignment, and documentation on laboratory measurements. For on-site measurements, the guidelines detailed: area selection, a description of a particular device for the evaluation of surface irregularities (that affects the most measurement geometries) designed and prototyped during the project, and data analysis. Additional aspects such as dirt, traffic, and spectral properties of the pavement and light sources, were also considered along with the measurement uncertainty and the influence of the various parameters is described. Furthermore, continuous engagement with the community of laboratories that perform measurements on road surface photometric properties, showed that the laboratories are unaware of the Guide to uncertainty measurement calculation (GUM) approach in the evaluation of the measurement uncertainty on *q* values. For this reason, SURFACE defined measurement models for the evaluation of the uncertainty on *q* values of simple application, which were tested by industrial laboratories during the intercomparison to ensure reliability and traceability of the results.

Contributions to standard development (Objective 5)

The objective has been met. A 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). 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, including the data base description.

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 have been regularly 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; and by Laboratory Accreditation System. Moreover, all guidelines fulfilled through Objectives 2,3 and 4 were made fully available to CIE TC4-50.

Impact

SURFACE has produced 10 open access, peer-reviewed publications. The partners provided regular progress updates and presented project results to relevant standardisation bodies (such as CIE, ISO, UNI, AFNOR, GFSV and SIS) at TC meetings. Furthermore, the partners organised 10 workshops and training courses to promote key project findings and outputs to an external audience. Highlights include: the '*Too Smart, Too Light'* workshop on smart lighting, which was organized in March 2019, at Politecnico di Torino for 20 students, where a presentation of the results was also given to an audience of more than 200 people. Also, a symposium was organised on road surface characterisation which was held at the CIE Mid Term Session in Korea, allowing the project to enlarge the stakeholder committee and to raise awareness of the project results internationally. An additional symposium was planned near the end of the project for further dissemination of project results again under the aegis of CIE, during the CIE DIV4 meeting in May 2020. Due to the COVID-19 pandemic travel restrictions, SURFACE successfully organized 4 open access live webinars for the scientific and stakeholders communities instead. These webinars are available on the project website which was created in July 2017 and has been continually updated as new public information becomes available. It also contains a member's area with restricted access for project partners and collaborators.

Impact on Industrial and other user communities

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, was strengthened by the use of Creative Commons Policy and Open Access for the dissemination of all relevant materials and results and by the involvement of an IT company in the consortium. In June 2019, a joint meeting was organized with the EMPIR project x BiRD where BiRD project partners presented the file format for BRDF (Bidirectional Reflectance Distribution Function) data sharing to ensure a common European Approach to luminance coefficient and BRDF data presentation. Furthermore, interest in the production of RM and the concept of IoT RM for luminance coefficient has steadily grown due to the promotion of key project outputs and outreach activities undertaken by the project (such as the largest Energy Saving event in Italy, Ecomondo 2017 and the exposition A&T (Automation and Testing) in Torino in 2018, 2019 and 2020). The design and usage of RM produced in SURFACE is one of the first actual applications of IoT to metrology and has attracted the interests of accreditation bodies (such has ACCREDIA, the Italian Body for accreditation) as tangible application of normative on RM producers and future approach to RM based on IoT. The RM kit and design have been patented. More exploitation opportunities are related to additional investigations on printable materials properties, production process and printing accuracy vs material and printer. Further developments can be related to new opportunities for building a large funded action on Metrology of 3D Printing to investigate additional IoT applications of RM, and validation processes. Since the SURFACE RM kit has been used for the measurement intercomparison, the EU market benefits now of Certified Reference Material (CRM) for calibrating road surface measuring instruments.

In December 2018, a delegation of the collaborators Panasonic and Nexco-RI visited INRIM and Cerema for a technical meeting focused on portable instruments development, SURFACE new geometries and their introduction to Japan. It was the starting point of an active with engagement of Japanese collaborators in the consortium activities and subsequent involvement in the SURFACE Webinar. Indeed, that was an additional sign of the EU leadership in the field of road surface metrology: the state of art of research, measurement methods and devices (large majority of currently available instruments are in EU, and the few available outside EU, most have been developed in EU). The project attracted interest of the ADAS (Advanced Driver Assistance Systems) testing and producers communities: 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 characterisation have led to connections between global descriptors or reflective properties of road marking and road surface. This will ensure future development of a new portable measuring device on the market and support the implementation of EN13201 on-site *q* measurements.

Impact on the metrology and scientific communities

At the beginning of the project, an analysis of actual 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 on road surface intercomparison. In the KCDB only eleven Key Comparisons have been ascribed to materials properties, nine of them belong to regular transmittance and two to diffuse reflectance, none was about luminance coefficient evaluation. The software for uncertainty evaluation developed during the project along with the intercomparison results will improve the metrological capabilities of NMI and stakeholders (collaborators) goniophotometers and portable devices for road surface characterisation and, by consequence, the European metrological services on road lighting and material characterisation. It is anticipated that the EU market will benefit from the uncertainty evaluation software that has been developed and validated during the project.

Impact on relevant standards

The project supported CIE TC4-50 in the revision of TR 144 and contributes to the standards development works of the technical committees CEN TC169/WG12.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, May 2020 and the TCs members strongly supported the TCs involvement. The CEN TC169/WG12 Chairperson attended the project live webinar and invited consortium member to present achievements on new geometries and road surface database at the first meeting of TC169/WG12 for EN 13201 revision.

During the project, at each CIE DIV4 meeting (October 2017 in Jeju, May 2018 in Berlin, June 2019 in Washington) the project results were discussed. Meanwhile at CIE TC4-50 meetings held concurrently, project actions were constantly planned and integrated with the CIE TC4-50 document revision. On 25th of May 2018, at Berlin TU University, after the CIE Workshop “A new Vision of Visibility in Roadway Lighting” the consortium organised the first stakeholder meeting. Around 20 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 organised to present key project 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.

The optimised geometries (Objective 1) were presented and acknowledged during the second project stakeholder meeting in Washington, USA (which coincided with the 29th CIE quadrennial session) and at CIE TC4-50 meeting (in June 2019).Although, the CEN TC169/WG12 was not active due to the revision of the current standard EN13201 which should have started in 2020, in October 2019 they met to resolve some discrepancies in EN 13201-3. During this meeting the SURFACE research results were presented and the EN TC community were informed of the expected achievements. In June 2020, the CEN TC169/WG12 Chair attended the SURFACE Webinar and the continued interest in the project’s outputs was affirmed, as a result a project partner was invited to next available CEN TC169/WG12 meeting.

Longer-term economic, social and environmental impacts

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 ensuring 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. Additionally, the proposed geometries are actually based on the different road-users and their needs, viewing conditions, road typologies (urban road, extra-urban road) and the related stopping distance. This will provide the basis for future investigations based also on subjective testing and ensures that the road luminance design and evaluation is made accordingly to actual users’ needs with an effective road safety increase.

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, compared to using current (and old) CIE database. The energy saving can go up to more than 50% with the concurrence of new pavement installation and of Smart Light controllers for ensuring the compliance to normative visibility requirements in case of new pavement installation on existing lighting systems.

List of publications

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F. Valpreda, P. Iacomussi, Innovative design and metrological approaches to smart lighting. https://doi.org/10.25039/x46.2019.PO192

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

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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. https://doi.org/10.25039/x46.2019.OP75

P.Iacomussi, Metrology impact for ADAS, Imaging IS&T 2020 conference. https://doi.org/10.2352/ISSN.2470-1173.2020.16.AVM-202

This list is also available here: https://www.euramet.org/repository/research-publications-repository-link/

Project start date and duration:		1 July 2017, 42 Months
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Internal Funded Partners: 1. INRIM, Italy 2. AALTO, Finland 3. LNE, France 4. METROSERT, Estonia 5. RISE, Sweden	External Funded Partners: 6.CEREMA, France	Unfunded Partners: 7. METAS, Switzerland 8. OPTIS, France 9. ZEHNTNER, Switzerland
RMG: -		