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Road Surface Reflection Properties

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Foreword

This publication presents the results of measurements of road surface reflection properties, conducted in Finland in 2017. The purpose of the measurements was to survey the reflection properties of the road surface materials currently in use in Finland. The results are intended for use in assessing whether the calculation principles presently in use for road lighting design should be updated in relation to the road surfaces' reflection properties.

The preparation of this report was supervised by Kari Lehtonen of the Finnish Transport Infrastructure Agency. The report was prepared by Aleksanteri Ekrias LiCon-AT Oy. Expert feedback was provided during the work by Kai Sørensen. The road surface measurements whose results are presented in the report were conducted by Elisa Kallio of LiCon-AT Oy.

Helsinki, May 2019

Finnish Transport Infrastructure Agency
Department/unit in charge

Contents

1 Introduction

1.1 Aims

The purpose of the measurements conducted for this report was to survey the reflection properties of the road surface materials currently in use in Finland, and to answer the following questions:

- What are the levels of average luminance coefficient (Q_0) and specular factor (*S1*) of the road surface materials currently used in Finland?
- How do the results differ from those of measurements conducted in Finland in the 1970s and 1980s?
- Should different road surface classes be used for roads and streets in outdoor lighting design?
- Should the road surface classes currently used in Finland in outdoor lighting calculations be updated?
- How do the average luminance coefficients (Q_0) and specular factors (*S1*) of the road surface on the wheel tracks differ from those off the wheel tracks?
- What regional differences exist between road surface types (e.g. in aggregate)?
- How does the type or age of the road surface affect the road's reflection properties?
- Can the same road surface classes be used in outdoor lighting design in all of the Nordic countries?

1.2 Source data

The road surface classes currently used in Finland for outdoor lighting design are based on measurements conducted in the 1970s and 1980s. Road surface materials have advanced in recent decades, however, and new types have been developed. Furthermore, the measurements carried out in the 1970s and 1980s had relatively small number of samples measured, and the aims of those studies differed from those of this study to some extent. The reflection properties of the road surface have a significant impact on the quality and cost-effectiveness of outdoor lighting. Therefore, this study was set up to investigate the present situation of road surfaces' reflection properties.

The source data for this study consist of the measurements of road surface reflection properties formerly carried out in Finland, whose results are presented in the following reports:

- *Tienpäällysteiden valonheijastusominaisuudet – Asfalttipäällysteen koostumuksen merkitys,* VTT Technical Research Centre of Finland, Research Report 179, 1980
- *Tienpäällysteiden heijastusominaisuudet – Jatkotutkimus, VTT Technical* Research Centre of Finland, Research Report 456, 1985

Appendix 1 to this study is a publication by Kai Sørensen, which explains the theory and principles behind the operation of the measurement device used for this study. Appendix 1 also presents the definitions and formulae for road surface reflection properties that are essential for this study. The above-mentioned information will not be repeated herein; instead, Appendix 1 will be referenced where necessary. Further information on the reflection properties of road surfaces and the standard road surfaces used by the International Commission on Illumination (CIE) can be found in the following publications:

- *CIE 47:1979 Road lighting for wet conditions,*
- *CIE 66:1984 Road surfaces and lighting,* and
- *CIE 144:2001 Road surface and road marking reflection characteristics*.

The measurements made for this study form part of a project funded by NMF (q Nordic co-operation group in the field of road equipment), in which the current road surface types used in the Nordic countries are examined using the portable measurement device developed by Kai Sørensen. Measurements were carried out in Denmark and Finland in 2017, and will take place in Sweden in 2020, and Norway possibly in 2021.

2 Visibility Impact of Road Surface Reflection Properties

2.1 Road Surface Reflection Properties

The road surface is one of the most significant factors affecting the end result of road lighting, because the reflection properties of the road surface determine how much of the light projected onto the road surface by luminaires is reflected from the road surface into the driver’s eyes.

The reflection properties of a road surface depend on the following factors:

- the structure of the road surface (aggregate, binder, filler, production method)
- the physical state of the road surface (cleanliness, moisture)
- the angle at which the light reaches the road suface, and the vehicle driver’s observation angle.

The International Commission on Illumination (CIE) adopted in 1976 the so-called Q_0 - *S1* description system, which today is still the recommended system and used all over the world for comparing and classifying road surface types.

The parameters of this system are called:

- for lightness: the average luminance coefficient Q_0,
- for specularity: the specular factor *S1*.

The numerical values of Q_0 and *S1* can be calculated from the reflection table (*r*-table). The *S2* variable is no longer used these days, so it is not considered in this document. The higher the average luminance coefficient Q_0, the longer the column spacing or lower the energy consumption for outdoor lighting. The higher the specular factor *S1*, the greater the specular reflection from the road surface. The specular factor has a great impact on the overall luminance uniformity U_o and longitudinal luminance uniformity U_l.

Appendix 1, section A.2 presents the definitions and formulae for road surface reflection properties that are essential for this study.

Reflection properties are defined separately for dry and wet road surfaces. Wet road surfaces were not measured in this study, nor will they be discussed in this document. More information can be found in the publication *CIE 47:1979*.

2.2 Road surface Types Used for Outdoor Lighting Design

Because there is a wide variety of road surface types, the International Commission on Illumination (CIE) has classified road surfaces for lighting design purposes into the categories R, N and C for dry surfaces, and W for wet surfaces. A theoretical standard road surface has been determined for each road surface class in the above-mentioned categories, which encompasses all of the road surface types having similar reflection characteristics to a sufficient degree of accuracy. The dry road surface classes are shown in Table 1. The *r*-tables of the standard road surfaces are presented in Appendix B to *CIE 144:2001*. From the perspective of outdoor lighting performance, a road surface class should be as small as possible, i.e. the road surface should be light but not specular.

Table 1. Dry road surface classification.

Road surface class	Specular factor *S1* range	Nominal value	
		S1	Q_0
C1	*S1* < 0.40	0.24	0.10
C2	*S1* ≥ 0.40	0.97	0.07
R1	*S1* < 0,42	0.25	0.10
R2	0.42 ≤ *S1* < 0.85	0.58	0.07
R3	0.85 ≤ *S1* < 1.35	1.11	0.07
R4	1.35 ≤ *S1*	1.55	0.08
N1	*S1* < 0.28	0.18	0.10
N2	0.28 ≤ *S1* < 0.60	0.41	0.07
N3	0.60 ≤ *S1* < 1.30	0.88	0.07
N4	*S1* ≥ 1.30	1.61	0.08

In Finland, the reflection properties of road surfaces have been measured in studies conducted in the 1970s and 1980s. The studies' results are presented in the reports *VTT:1980* and *VTT:1985*, and the conclusions were that most of the road surface types used in Finland belonged to the classes R1 and R2. The studies recommended the use of class R2 in the case of asphalt road surfaces and R1 for concrete road surfaces.

Today, the Finnish Transport Infrastructure Agency's code of practice for road lighting design *Maantie- ja rautatiealueiden valaistuksen suunnittelu 16/2015* requires that class R2 is used for dry road surfaces and class W3 for wet road surfaces. Out of Finland's municipalities, the City of Helsinki requires the use of classes R3 and W3 in its guidelines for outdoor lighting design (*Helsingin kaupungin ulkovalaistuksen suunnitteluohje 2017*). The reason behind using class R3 is that municipalities apply road surface types with a smaller aggregate size for the purpose of reducing road noise. Usually road surfaces with a smaller aggregate size have a slightly lower average luminance coefficient Q_0 value and a higher specular factor *S1* value than those with a larger aggregate size. All other Finnish municipalities besides Helsinki use the same road surface classes as the Finnish Transport Infrastructure Agency.

The following dry road surface classes are used in outdoor lighting design in the other Nordic countries:

- Sweden: N2
- Norway: C2
- Denmark: N2, where average luminance coefficient Q_0 = 0.09.

Similarly to Finland, the dry road surface classes used by the other Nordic countries are based on measurements carried out in the 1970s and 1980s.

3 Measurements

3.1 Measurement Device

Measurements were carried out using the portable measurement device designed by Kai Sørensen, displayed in Figure 1. The device consists of a measurement box, light sources, mirrors, a battery, internal wiring and a reference surface. The measurements were carried out with a TechnoTeam LMK Mobile Advanced portable imaging luminance photometer that can be attached to the measurement device.

The measurement device, its operation, its calibration and the processing of measurement data are described in further detail in Appendix 1.

Figure 1. The measurement device used for measuring road surface reflection properties.

3.2 Measurement Sites

Measurements were conducted in the regions of Southern Savonia, Southwest Finland, Lappeenranta, Tampere and Helsinki. The aim was to examine regional differences within the same road surface types, caused for instance by the use of local aggregate. Measurements were carried out at 46 different sites. These comprised 17 roads and 29 streets. The measurement sites and measured road surface types are presented in Table 2.

Table 2. Measurement sites and measured road surface types.

Road or street name	Road surface type	Road surface installation year	On wheel track	Off wheel track
Southern Savonia, roads				
Vt 13 Uusi Ristiinantie	SMA16 RC80	2013	X	X
Kt 62 Anttolantie	AC16 RC80	2016	X	X
Vt 13 Lappeenrannantie	AC16	2014	X	X
Kt 72 Pieksämäentie	AC16	2015	X	X
Southwest Finland, roads				
Vt 110 Valtatie	AC16	2013	X	X
Mt 2343 Alvar Aallon tie	AC16	2014	X	X
Mt 2340 Paimiontie	AC16 RC80	2015	X	X
Mt 12276 Alisippaantie	AC16	2016	X	X
Mt 12275 Loukinaistentie	AC16	2013	X	X
Mt 2200 Kaarinantie	SMA16	2014	X	X
Mt 2200 Kaarinantie	SMA16	2015	X	X
Mt 204 Säkyläntie	AC16 RC80	2014	X	
Mt 12264 Paattistentie	AC16 RC80	2016	X	X
Mt 181 Sauvontie	AC16 RC80	2016	X	
Mt 180 Saaristotie	AC16 RC80	2014		X
Helsinki and Espoo, roads				
Vt 1 Turunväylä	SMA16 RC80	2014	X	X
Vt 1 Turunväylä	SMA16	2016	X	X
Lappeenranta, streets				
Snellmaninkatu	SMA16	2014	X	X
Koulukatu	SMA16	2015	X	X
Tilsalankatu	AC16	2013	X	X
Terminaalinkatu	AC20	2015	X	
Taipalsaarentie	AC16	2013	X	X
Kirkkokatu	AC16	2016	X	X
Imatrantie	SMA16	2016	X	
Tampere, streets				
Pispankatu	SMA11	2016	X	
Sammon valtatie	SMA16	2014	X	X
Veisunkatu	AC16 RC100	2015	X	X
Hatanpäänkatu	AC16 RC100	2015		X
Tahmelan viertotie	AC16 RC70	2014	X	X
Mattilankatu	AC11 RC50	2016	X	X
Jänislahdenkatu	AC11 RC60	2014	X	X
Nikinväylä	AC22	2016	X	X
Mariankatu	SMA16	2015	X	X
Lempääläntie	SMA16	2016	X	X
Pispalanharju	SMA11	2016	X	X
Tohlopinranta	AC11	2015	X	
Helsinki, streets				
Maaherrantie	AC22	2013	X	X
Siltavoudintie	SMA11	2016	X	X
Isoniitynkatu	AC22	2014	X	X
Panuntie	SMA16	2013		X
Panuntie	AC22	2016	X	X
Kytkintie	AC16 RC50	2013	X	X
Malminkartanontie	SMA16	2015	X	X
Mäkitorpantie	SMA8	2015	X	X
Pirkkolantie	SMA11	2015		X
Viilarintie	AC22	2015	X	X

The measurement sites were chosen based on source data received from the road and municipal authorities. Source data on roads were obtained from the Road Register. Source data on streets were requested from the persons in charge of road surfaces at municipalities and consisted of the regions' paving programmes and current situation maps. The aim was to choose sites so that they would include as many different samples as possible of road surfaces of various ages and aggregate sizes, in various regions. The chosen road surface types were asphalt concrete (AC) and stone mastic asphalt (SMA), because they are the most commonly used road surface types on Finland's roads and streets. Measurement plans were drawn up for each region's sites prior to the measurements taking place. An example of such a measurement plan (for Southwest Finland) is included as Appendix 2.

The necessary permit applications were submitted to the municipal councils before measurements were carried out on streets. Municipal instructions were complied with in relation to traffic control arrangements.

Notifications of traffic-obstructing work were submitted to the relevant traffic management centres before measurements were carried out on roads. During measurements on roads, traffic arrangements were made according to the Finnish Transport Infrastructure Agency's guideline for construction site traffic (*Liikenne työmaalla – kunnossapitotyöt 3/2015*).

3.3 Measurement Method

Six measurements were taken at each site, as shown in Figure 2: three measurements on the wheel tracks and three off the wheel tracks. The measurements were taken by placing the measurement device at the measurement point and taking two images with the imaging luminance photometer, as described in Appendix 1. The total number of measurements taken for this study was 276, which involved the processing of 552 images at the analysis stage. The measurements were taken during August and September 2017.

The measurements for each site were merged into a single result by using the average of the three measurements according to formulae (1) and (2). This was done separately for the measurements on and off the wheel track.

$$Q_0 = \frac{Q_{0_1} + Q_{0_2} + Q_{0_3}}{3}, \quad (1)$$

$$S1 = \frac{S1_1 + S1_2 + S1_3}{3}, \quad (2)$$

Figure 2. At each site, three measurements were taken on the wheel tracks and three measurements off the wheel tracks.

At the analysis stage, it was found that some of the images taken during the measurement stage were not suitable for analysis. This is probably due to the following factors:

- The observation angle used for measurement is 1.0°, which makes the area available for processing of the measured sample very narrow (see Appendix 1). The wear and tear caused by traffic on the carriageway creates wheel tracks, which makes the measured sample uneven. In some cases, deep wheel tracks in the road surface caused the measured area to be too small, which made the imaging luminance photometer images unusable for analysis.
- Towards the end of the measurement period, one of the mirrors of the device had become slightly bent due to handling or transportation. The bending of the mirror further reduced the measured area of the sample, which made some images unusable for analysis.
- Some images were taken when the surface was damp, due, for instance, to night-time condensation.

4 Results

4.1 Average Luminance Coefficient and Specular Factor

Table 3 presents the results for all of the measured road surfaces. The results were obtained by analysing the images taken by the imaging luminance photometer (two per sample) with an Excel spreadsheet tool developed by Kai Sørensen. The Excel tool and the image analysis process are described in Appendix 1. The Excel tool was used to calculate the average luminance coefficient Q_0 value and specular factor *S1* value for each road surface sample.

Table 3. Results for all of the measured road surfaces.

Road or street name	Road surface type	Road surface install. year	On wheel track		Next to wheel track	
Southern Savonia, roads			Q_0	*S1*	Q_0	*S1*
Vt 13 Uusi Ristiinantie	SMA16 RC80	2013	0.119	0.417	0.115	0.308
Kt 62 Anttolantie	AC16 RC80	2016	0.100	0.370	0.079	0.764
Vt 13 Lappeenrannantie	AC16	2014	0.102	0.312	0.109	0.605
Kt 72 Pieksämäentie	AC16	2015	0.109	0.669	0.104	0.400
Average values	Q_0 **= 0.105**	*S1* **= 0.481**				
Southwest Finland, roads			Q_0	*S1*	Q_0	*S1*
Vt 110 Valtatie	AC16	2013	0.097	0.325	0.098	0.305
Mt 2343 Alvar Aallon tie	AC16	2014	0.085	0.427	0.083	0.386
Mt 2340 Paimiontie	AC16 RC80	2015	0.093	0.361	0.097	0.553
Mt 12276 Alisippaantie	AC16	2016	0.085	0.723	0.081	0.826
Mt 12275 Loukinaistentie	AC16	2013	0.092	0.564	0.099	0.423
Mt 2200 Kaarinantie	SMA16	2014	0.108	1.242	0.092	0.743
Mt 2200 Kaarinantie	SMA16	2015	0.099	0.623		
Mt 204 Säkyläntie	AC16 RC80	2014	0.097	0.344	0.089	1.004
Mt 12264 Paattistentie	AC16 RC80	2016	0.090	0.516	0.096	0.384
Mt 181 Sauvontie	AC16 RC80	2016	0.095	0.789		
Mt 180 Saaristotie	AC16 RC80	2014			0.091	0.508
Average values	Q_0 **= 0.093**	*S1* **= 0.581**				
Helsinki and Espoo, roads			Q_0	*S1*	Q_0	*S1*
Vt 1 Turunväylä	SMA16 RC80	2014	0.095	0.762	0.110	1.397
Vt 1 Turunväylä	SMA16	2016	0.105	1.483	0.069	0.698
Average values	Q_0 **= 0.095**	*S1* **= 1.085**				
Lappeenranta, streets			Q_0	*S1*	Q_0	*S1*
Snellmaninkatu	SMA16	2014	0.108	0.696	0.093	0.513
Koulukatu	SMA16	2015	0.096	0.688	0.097	0.548
Tilsalankatu	AC16	2013	0.105	0.628	0.103	0.495
Terminaalinkatu	AC20	2015	0.109	0.713		
Taipalsaarentie	AC16	2013	0.116	0.720	0.134	0.437
Kirkkokatu	AC16	2016	0.103	0.561	0.099	0.794
Imatrantie	SMA16	2016	0.130	0.536		
Average values	Q_0 **= 0.108**	*S1* **= 0.611**				
Tampere, streets			Q_0	*S1*	Q_0	*S1*
Pispankatu	SMA11	2016	0.082	1.724		
Sammon valtatie	SMA16	2014	0.106	1.801	0.069	0.795
Veisunkatu	AC16 RC100	2015	0.086	0.438	0.087	0.287
Hatanpäänkatu	AC16 RC100	2015			0.073	0.848
Tahmelan viertotie	AC16 RC70	2014	0.099	0.606	0.074	0.575
Mattilankatu	AC11 RC50	2016	0.064	1.059	0.061	0.697
Jänislahdenkatu	AC11 RC60	2014	0.071	1.078	0.062	0.828
Nikinväylä	AC22	2016	0.073	0.800	0.056	0.981
Mariankatu	SMA16	2015	0.086	1.232	0.095	1.761
Lempääläntie	SMA16	2016	0.091	1.514	0.078	1.000
Pispalanharju	SMA11	2016	0.086	1.590	0.085	1.196
Tohlopinranta	AC11	2015	0.082	1.106		
Average values	Q_0 **= 0.079**	*S1* **= 1.044**				
Helsinki, streets			Q_0	*S1*	Q_0	*S1*
Maaherrantie	AC22	2013	0.092	1.108	0.079	0.756
Siltavoudintie	SMA11	2016	0.094	0.842	0.110	0.637
Isoniitynkatu	AC22	2014	0.085	0.525	0.086	1.255
Panuntie	SMA16	2013			0.099	0.408
Panuntie	AC22	2016	0.100	1.400	0.086	0.639
Kytkintie	AC16 RC50	2013	0.088	0.585	0.085	0.724
Malminkartanontie	SMA16	2015	0.099	1.284	0.082	1.441
Mäkitorpantie	SMA8	2015	0.085	0.752	0.094	0.950
Pirkkolantie	SMA11	2015			0.096	1.049
Viilarintie	AC22	2015	0.094	1.403	0.101	1.325
Average values	Q_0 **= 0.092**	*S1* **= 0.949**				
Averages of all measurements			Q_0 **= 0.093**		*S1* **= 0.800**	

Figure 3 displays all the measured road surfaces on a graph, where the x axis represents specular factor *S1* and the y axis average luminance coefficient Q_0. The measurement results are indicated as blue dots. There are separate dots for the results on and off the wheel track. The CIE standard road surfaces presented in Table 1 are shown in Figure 3 as grey dots highlighted with different colours. The standard road surface classes used in Finland, R2 and R3, are highlighted in green, and the other standard road surfaces in yellow. The average of all the measurements is indicated with a red dot.

Figure 3. All measured road surfaces (blue dots), their average (red dot) and the CIE standard road surfaces.

Figure 3 shows that the reflection properties of the road surface types used in Finland vary greatly depending on the site. This is a highly typical outcome of road surface measurements. Further, Figure 3 indicates that the reflection properties of the road surface types used in Finland correlate fairly poorly with the CIE standard road surfaces.

4.2 Comparison with Earlier Measurements from Finland

Figure 4 shows all of the measured road surfaces and the results of the measurements conducted in the 1970s and 1980s. The results of this study are shown with blue dots, and those of the measurements from the 1970s and 1980s, with black dots. The CIE standard road surfaces presented in Table 1 are shown as grey dots highlighted with different colours. The standard road surface classes used in Finland, R2 and R3, are highlighted in green, and the other standard road surfaces in yellow. The average of the measurements made for this study is indicated with a red dot, while the average of those made in the 1970s and 1980s is indicated with a purple dot.

Figure 4 shows that the average luminance coefficient Q_0 value of today's road surface types is, on average, on a par with that of the road surfaces measured in the 1970s and 1980s. In contrast, the specular factor values are significantly higher for the modern road surfaces than the earlier ones. This is partly explained by the following factors:

- The studies in the 1970s and 1980s focused solely on roads, whereas in this study, only 38% of the measurements came from roads.
- The measurements from the 1970s and 1980s mostly came from road surface types consisting of asphalt concrete (AC), whereas this study measured both asphalt concrete (AC) and stone mastic asphalt (SMA) road surfaces.

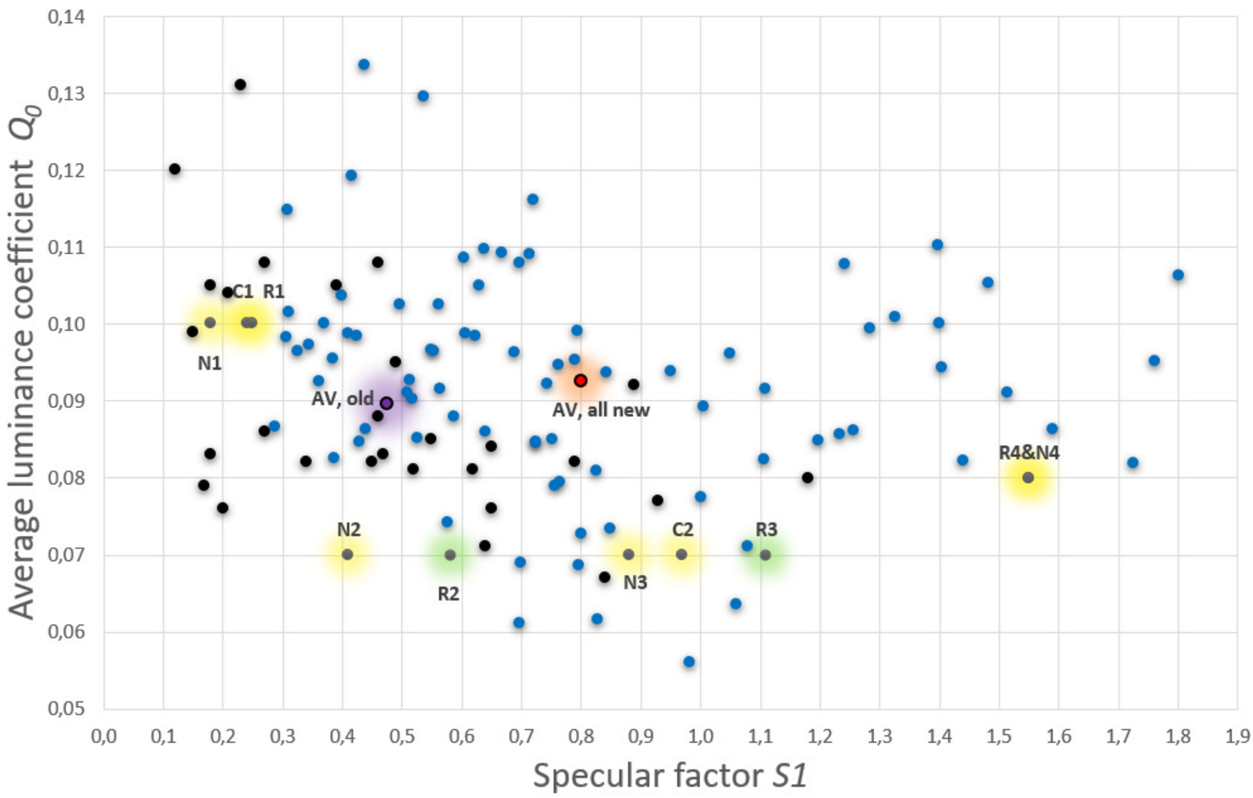

Figure 4. All the road surface measurements made for this study (blue dots), road surface measurements made in the 1970s and 1980s (black dots), their average values, and the CIE standard road surfaces.

Figure 5 presents measurement results for highway sites whose road surface type was asphalt concrete. The results of this study are shown with blue dots, and those of the measurements from the 1970s and 1980s, with black dots. The average of the measurements made for this study is indicated with a red dot, while the average of those made in the 1970s and 1980s is indicated with a purple dot.

Figure 5 shows that if streets and SMA road surfaces are excluded from the results, the measurements made for this study correlate well with those from the 1970s and 1980s.

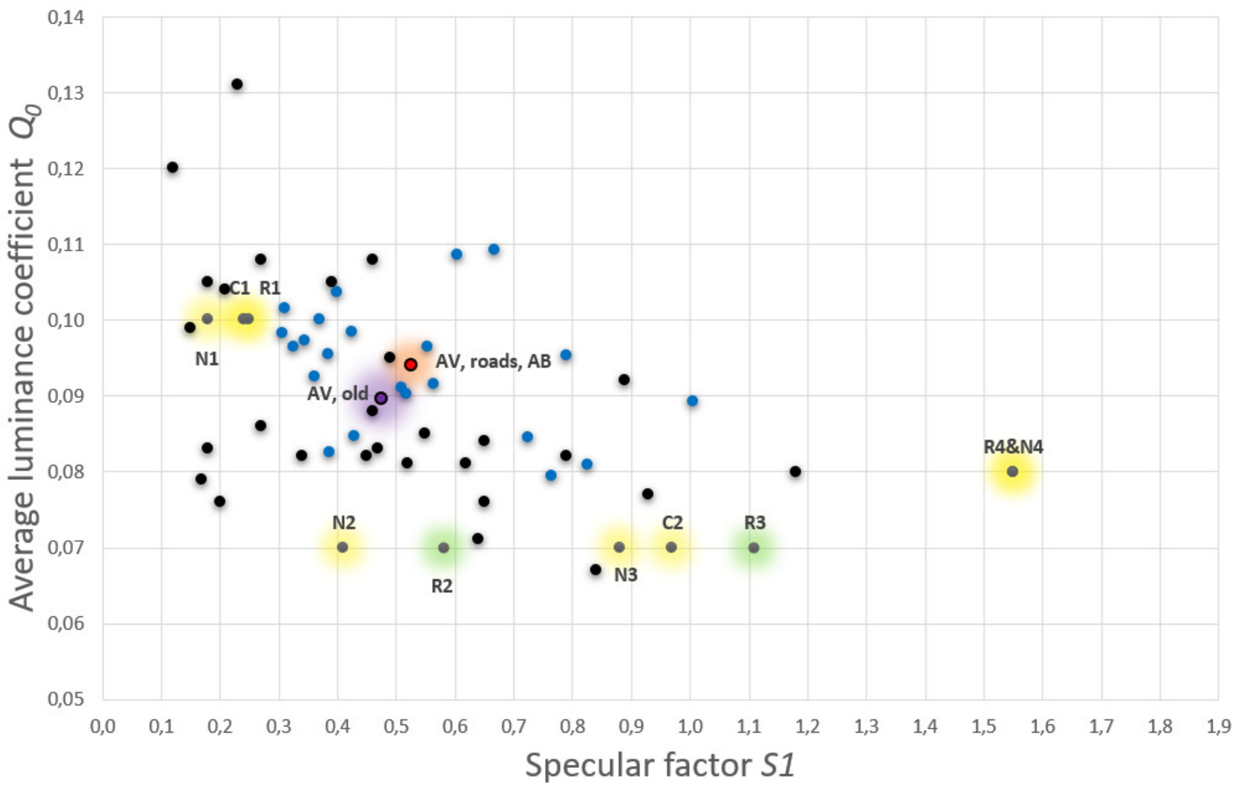

Figure 5. *All the asphalt concrete (AC) road surface measurements made for this study (blue dots), road surface measurements made in the 1970s and 1980s (black dots), their average values, and the CIE standard road surfaces.*

4.3 Comparison between Roads and Streets

Figure 6 differentiates between the road surfaces measured for this study, depending on whether they came from roads or streets. The results for roads are indicated with blue dots, and for streets with red dot, and those of the measurements from the 1970s and 1980s, with black dots. The CIE standard road surfaces presented in Table 1 are shown as grey dots highlighted with different colours. The standard road surface classes used in Finland, R2 and R3, are highlighted in green, and the other standard road surfaces in yellow. The average of the measurements made on roads is indicated using blue dot highlighted with a blue circle, whilst the average for streets is indicated using red dot highlighted with a red circle. The average for the measurements made in the 1970s and 1980s is shown with a purple dot.

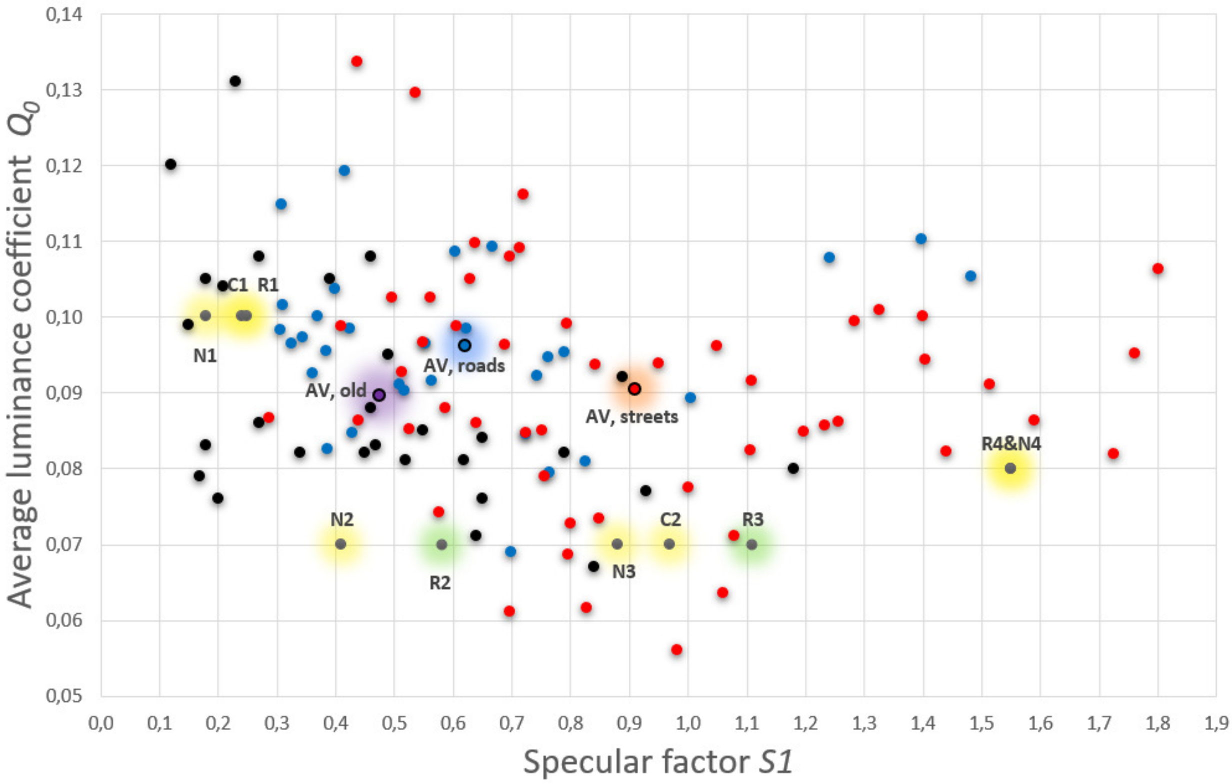

Figure 6. *Road surface measurements for roads (blue dots) and streets (red dots) made in this study, road surface measurements made in the 1970s and 1980s (black dots), their average values, and the CIE standard road surfaces.*

Figure 6 shows that the road surface types used on streets display a greater dispersion in the values for average luminance coefficient Q_0 and specular factor *S1* than those used on streets. The results also show that the Q_0 value for streets is slightly lower than that of roads. In contrast, the *S1* value is significantly greater for streets than for roads.

The maximum aggregate size for the measured road surfaces on roads was greater than for streets. Road surface types on streets included AC11, SMA11 and SMA8, among others. The results indicate that as the aggregate size grows, the average luminance coefficient value Q_0 increases, while the specular factor value *S1* decreases. This observation is in line with the conclusions of the report *VTT:1980*.

4.4 Effect of the Wheel Track on the Reflection Properties of a Road Surface

Figure 7 displays the measurements from this study according to whether they were made on a wheel track or off the wheel track. The results for on wheel track measurements are indicated with blue dots, and for off wheel track measurements with red dots. The CIE standard road surfaces presented in Table 1 are shown as grey dots highlighted with different colours. The standard road surface classes used in Finland, R2 and R3, are highlighted in green, and the other standard road surfaces in yellow. The average of the measurements made on the wheel track is indicated using blue dot highlighted with a blue circle, whilst the average of the measurements made off the wheel track is indicated using red dot highlighted with a red circle.

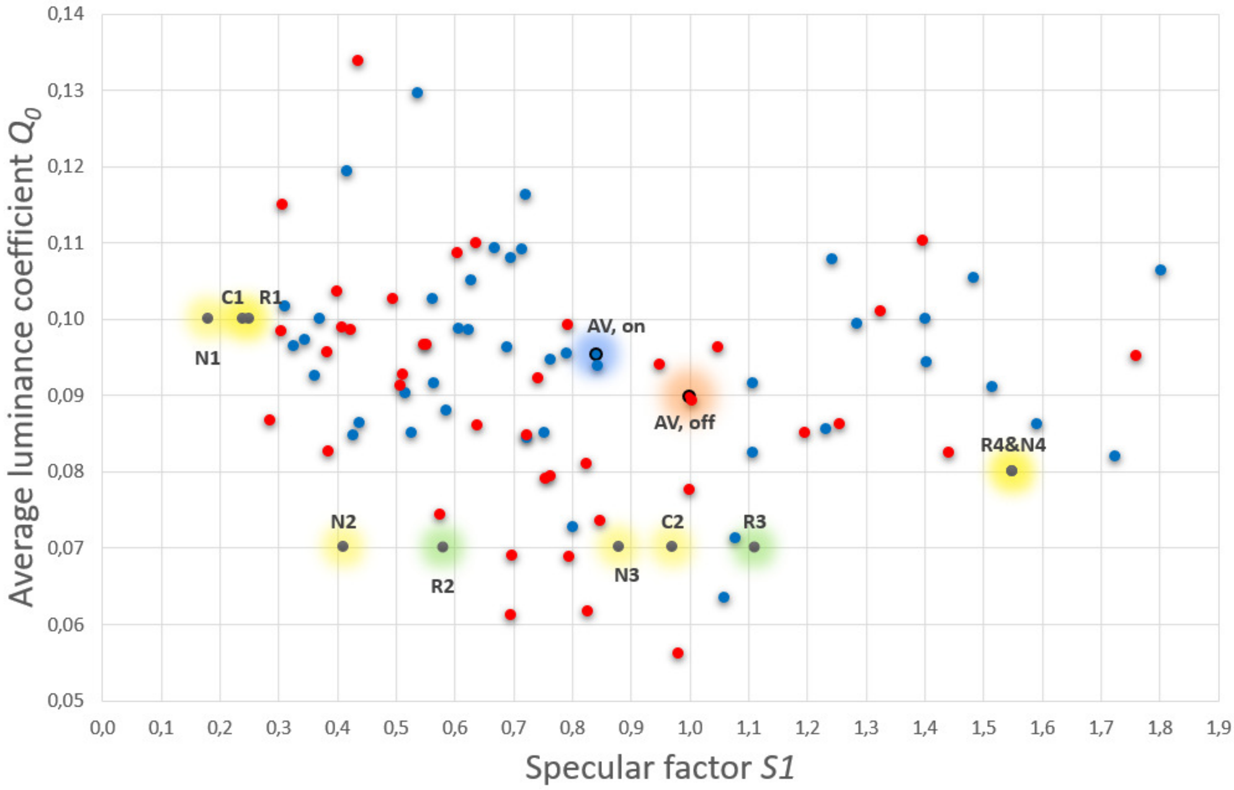

Figure 7. *Road surface measurement results on the wheel track (blue dots) and off the wheel track (red dots), their average values and the CIE standard road surfaces.*

Figure 7 shows that the road surface on the wheel track has a slightly higher average luminance coefficient Q_0 value and a slightly lower specular factor *S1* value than the road surface off the wheel tracks. This is mostly explained by the coarsening of the surface, the loosening of small aggregate granules and the wearing of the bitumen on the wheel tracks. This is known to slightly increase the average luminance coefficient and slightly reduce the specular factor.

4.5 Regional Differences

Figure 8 presents the measurement results distributed by region. The results for roads in Southern Savonia are indicated with black dots, in Southwest Finland with yellow, and in Helsinki and Espoo with green. For streets, Lappeenranta is indicated with purple dots, Tampere with red and Helsinki with blue. The average for each region is indicated with the same colour dot highlighted with the same colour circle. The CIE standard road surfaces presented in Table 1 are shown as grey dots highlighted with pink.

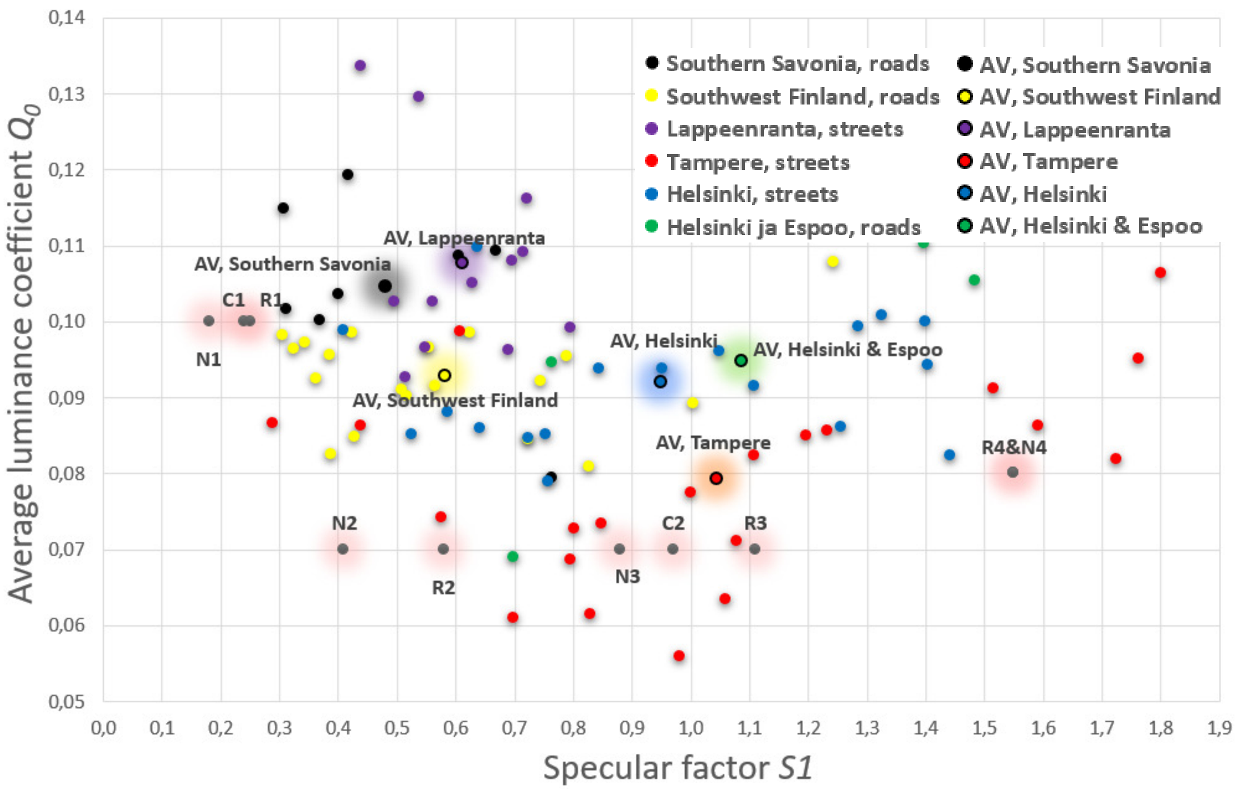

Figure 8. Road surface measurement results distributed by region. The average for each region is indicated as "AV [region name]".

Figure 8 demonstrates that there are significant differences between the reflection properties of road surfaces in different regions in Finland. The differences are mostly due to the aggregate size, to the type and colour of the chosen aggregate, and to the filler type. The larger the aggregate size, the higher the average luminance coefficient Q_0 and the lower the specular factor *S1*. Particularly significant are aggregate granules that are visible to drivers at an observation angle of 1.0°. The colour of the aggregate is significant for the road surface's Q_0 value, in that road surfaces made of red or grey aggregate lead to higher Q_0 values than ones made, for instance, of a dark aggregate type. No correlation could be demonstrated to exist between aggregate colour and the *S1* value in this study.

4.6 Effect of Road surface Type and Age on Road surface Reflection Properties

Figure 9 presents the measurement results by road surface type. The graph only shows the average Q_0 and *S1* values for each road surface type. Calculations were only made for the road surface types AC16 and SMA16, which had the largest sampling (cf. Table 2). The average values for road surface types AC16 and SMA16 used on roads are indicated with blue dots highlighted with a blue circle. The average values for road surface types AC16 and SMA16 used on streets are indicated with red dots highlighted with a red circle. The CIE standard road surfaces are shown as grey dots highlighted with green and yellow.

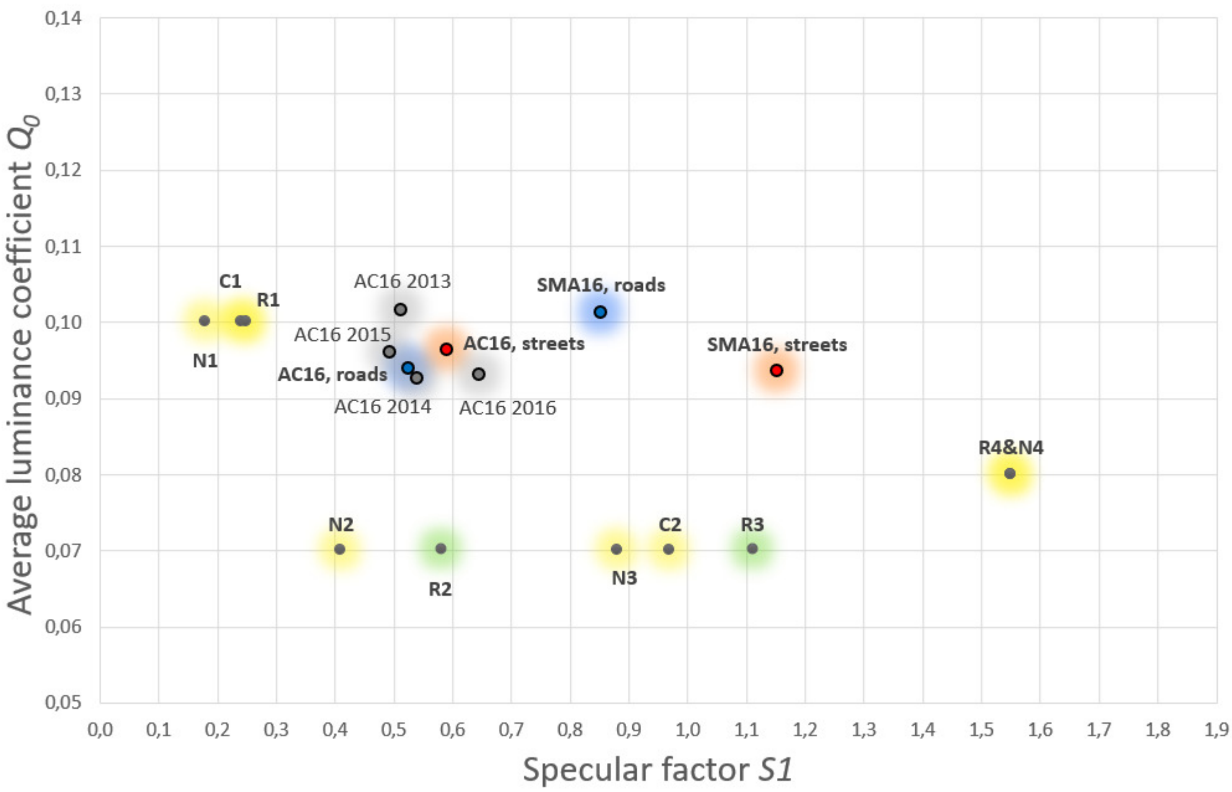

Figure 9. *Road surface measurement results by road surface type. For the AC16 road surface type there are also data on the effect of age on the road surface reflection properties.*

Figure 9 demonstrates that as a road surface type, stone mastic asphalt (SMA) has significantly higher specular factor (higher *S1* value) than asphalt concrete (AC). There were no great differences between the average values for roads and streets with an AC road surface, whereas in the case of SMA, the *S1* value for streets was higher than for roads. This may be due to the aggregate type and colour, as well as the filler used in the road surface. The wearing of the road surface also differs between roads and streets due, among other things, to driving speeds.

In this study, the AC16 road surface type was separately analysed in relation to the road surface's installation year. This was done for AC16 because:

– the largest number of measurement results were obtained in the study for the AC16 road surface type, and
– no great differences were observed between the average values for roads and streets paved with AC16.

Figure 9 presents the average values for road surface type AC16 by the year of installation. The results are indicated with grey dots highlighted with grey circles. Figure 9 indicates that as a road surface ages, its Q_0 value increases slightly, while its *S1* value decreases slightly. This is probably due to changes in the coarseness of the surface and the lightness of the aggregate as the road surface wears down.

4.7 Comparison with Results from Other Nordic Countries

Figure 10 presents all the measurement results obtained in this study together with the measurements obtained for roads in Denmark in 2017. The Danish measurements were made using the same measurement device and method as those employed in this study. The Finnish results are indicated as blue dots, with the average for all measurements shown as blue dot highlighted with a blue circle. The Danish results are indicated as yellow dots, with the average for all measurements shown as yellow dot highlighted with a yellow circle. There are separate dots for the results on and off the wheel track.

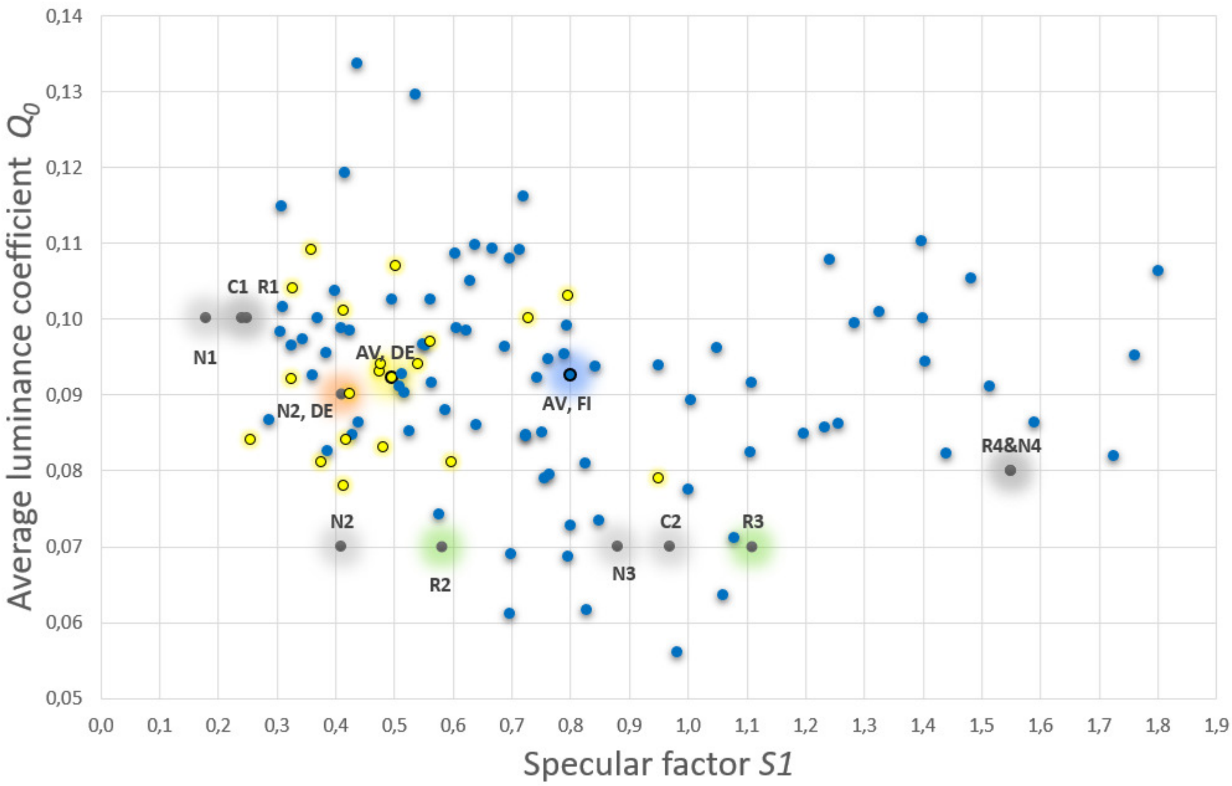

Figure 10. *Road surface measurements from Finland (blue dots, roads + streets), road surface measurements from Denmark (yellow dots, roads), their averages, and the CIE standard road surfaces.*

The CIE standard road surfaces are included in Figure 10 as grey dots highlighted with different colours. The standard road surface classes used in Finland, R2 and R3, are highlighted in green, and the other standard road surfaces in grey. The standard road surface class used in Denmark, N2 with Q_0 = 0.09, is highlighted in red. Figure 10 shows that the measurements obtained for Danish roads correspond very well to the standard road surface class used there for outdoor lighting design.

The average luminance coefficient Q_0 value obtained for the road surface types used in Finland is, on average, in line with that of the Danish road surface types. In contrast, the specular factor *S1* value of the Finnish road surfaces was higher than that of the Danish ones. This is to some extent explained by the fact that the Danish study focused solely on road surfaces used on roads, whereas in this study only 38% of the measurements came from roads. The difference becomes much less significant if the comparison includes only measurements from roads (cf. Figure 11). Based on these results, the same standard road surface class could be adopted for use in outdoor lighting design in Finland and Denmark.

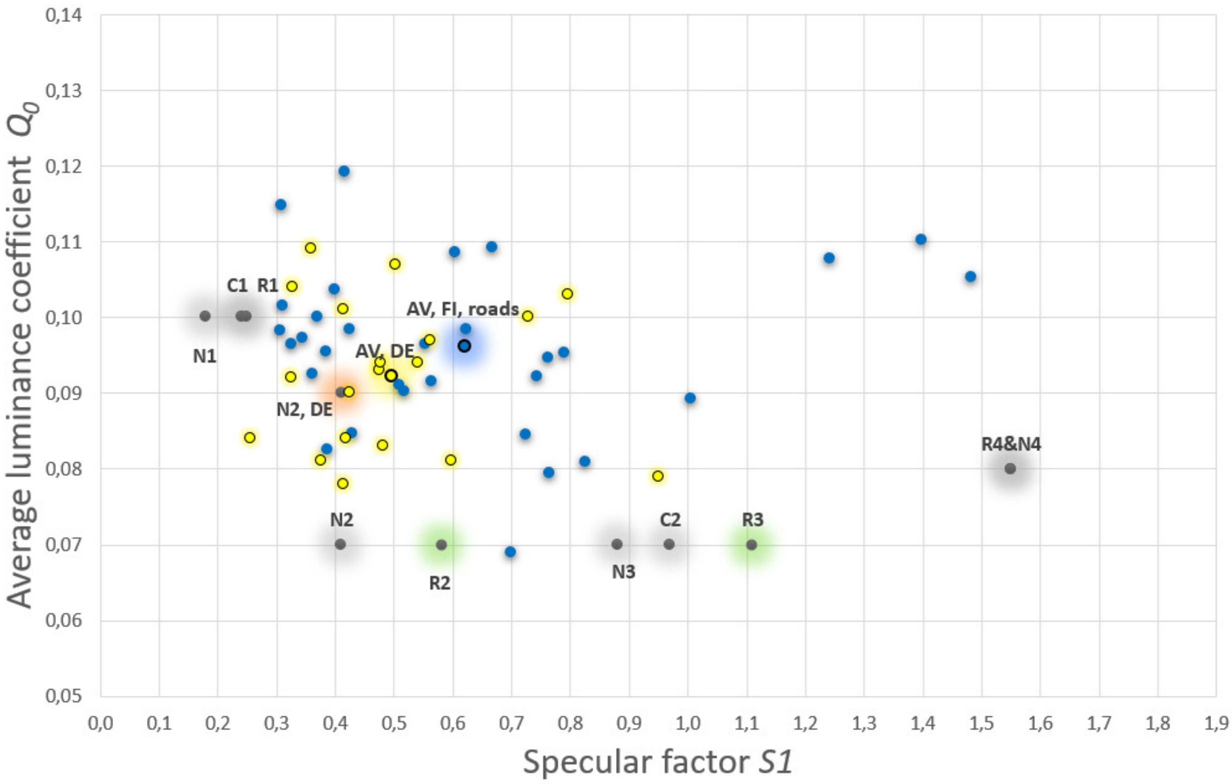

Figure 11. *Road surface measurements from Finland (blue dots, roads), road surface measurements from Denmark (yellow dots, roads), their averages, and the CIE standard road surfaces.*

5 Conclusions

What are the levels of average luminance coefficient (Q_0) and specular factor (S1) of the road surface materials currently used in Finland?

The reflection properties of road surfaces vary significantly depending on the road surface type. In practice it can be stated that every road surface is an individual with its own reflection properties. Figure 3 gives a good example of this. The greatest factors affecting road surface reflection properties are the road surface type, the aggregate size, the aggregate type and colour, the binder and the filler. The average luminance coefficient value of the road surface types included in this study was Q_0 = 0.093 and the average specular factor was $S1$ = 0.80. These averages correspond fairly poorly to the CIE standard road surface classes used in Finland for outdoor lighting design. The values of the standard road surface classes used generally on Finland's roads and by municipalities, R2, are Q_0 = 0.07 and $S1$ = 0.58. The values of the standard road surface class used by the City of Helsinki, R3, are Q_0 = 0.07 and $S1$ = 1.11.

How do the results differ from those of measurements conducted in Finland in the 1970s and 1980s?

The measurements made in the 1970s and 1980s only applied to road surfaces used on roads and only to ones made of asphalt concrete (AC). If all the measurements related to streets and to stone mastic asphalt (SMA) road surfaces are omitted from the results of this study, the results correlate very well with those obtained in the 1970s and 1980s. Based on this comparison, the conclusion could be drawn that the reflection properties of asphalt concrete (AC) road surfaces have remained fairly constant in the last decades.

Should different road surface classes be used for roads and streets in outdoor lighting design? Should the road surface classes currently used in Finland in outdoor lighting calculations be updated?

The average luminance coefficient level of the roads measured in this study was on average Q_0 = 0.096, and the specular factor was $S1$ = 0.62. The measured specular factor values correspond well, on average, to the value of the R2 standard road surface. In contrast, the average Q_0 value was 37% higher than that of the R2 standard road surface. This has a significant impact on the performance of outdoor lighting. Based on the results of this study, it is recommended to consider whether an updated version of the standard road surface class R2 should be adopted for roads in Finland, where the average luminance coefficient value would be updated to Q_0 = 0.09. Alternatively, Finland could consider adopting the same road surface class for highways as that used by Denmark, which is the standard road surface class N2 with an average luminance coefficient value of Q_0 = 0.09.

The road surface types used on streets displayed a greater dispersion in the values for average luminance coefficient Q_0 and specular factor $S1$ than those used on roads. The average Q_0 value of the road surface types used on roads included in this study was Q_0 = 0.09 and the average $S1$ value was $S1$ = 0.91. These values diverge significantly from those of the standard road surface class R2 used by Finnish municipalities for outdoor lighting calculations (Q_0 = 0.07 and $S1$ = 0.58). Based on the results of this study, the lighting calculations of outdoor lighting would correspond better to real conditions if they were calculated using the standard road surface class R3, whose values are Q_0 = 0.07 and *S1* = 1.11. Raising the average luminance coefficient level to Q_0 = 0.08 should also be considered. If the standard road surface class N2 with an average luminance coefficient value of Q_0 = 0.09 is adopted for roads, then for streets Finland could adopt the standard class N3 with Q_0 = 0.080. The specular factor value of the standard class N3, *S1* = 0.88, provides, on average, the best match for the road surfaces measured on streets in this study.

The road surface is coarsened by the use of studded tyres over the winter season, which slightly increases the road surface's average luminance coefficient and reduces its specular factor level. During the summer, traffic and higher ambient temperatures cause some smoothing of the surface, which conversely reduces the road surface's average luminance coefficient and increases its specular factor level. Because the measurements were taken in August and September, one can consider the time of year to have been unfavourable in terms of outdoor lighting.

With regard to outdoor lighting design, it is relatively easy to update the code of practice concerning the standard road surface classes to be used for roads and streets. Additionally, in Finland the distinction is clear enough, because at the design stage it is almost always known whether the traffic route in question is a road or a street.

How do the average luminance coefficients (Q_0) and specular factors (S1) of the road surface on the wheel tracks differ from those off the wheel tracks?
The results of this study show that the road surface on the wheel track has a slightly higher average luminance coefficient Q_0 value and a slightly lower specular factor *S1* value than the road surface off the wheel track. This is mostly explained by the coarsening of the surface, the loosening of small aggregate granules and the wearing of the bitumen on the wheel tracks. Due to the fact that road lighting calculations are done according to the standard EN 13201-3 for the entire carriageway, whose reflection properties are considered to be in accordance with a single standard road surface class for the entire area of interest, it is very challenging to take into account the aforementioned differences in reflection properties.

What regional differences exist between road surface types (e.g. in aggregate)?
The results of this study demonstrate that there are significant differences between the reflection properties of road surfaces in different regions in Finland. The differences are mostly due to the aggregate size, to the type and colour of the chosen aggregate, and to the filler type. In order to optimise the outdoor lighting performance, it is recommended that lighting calculations always make use of the reflection properties of local road surface types (e.g. the standard road surface class that best suits the region), if they are known. If they are not known, the lighting calculations should utilise the aforementioned generic division between roads and streets. It is recommended that measurements similar to those of this study should be carried out also in other parts of Finland, in order to investigate further the regional differences between road surface types.

How does the type or age of the road surface affect the road's reflection properties?

The results of this study show that as a road surface type, stone mastic asphalt (SMA) has a significantly higher specular factor *S1* value than asphalt concrete (AC) road surfaces. There were no great differences between the average values for roads and streets with an AC road surface, whereas in the case of SMA, the *S1* value for streets was slightly higher than for roads. This may be due to the aggregate type and colour, as well as the filler used in the road surface. The wearing of the road surface also differs between roads and streets due, among other things, to driving speeds.

In order to optimise the performance of outdoor lighting, it is recommended to always use the reflection properties of exactly the road surface type that will be laid or has been lain at the site. For example, in relation to the road surface type AC16, the standard road surface class R2 with the average luminance coefficient value Q_0 = 0.09 could be used, and in relation to SMA16, the standard class R3 with Q_0 = 0.09 could be used. Generally, however, the road surface type is not known at the design stage, or it may change during the outdoor lighting installation life cycle, which makes the road surface type impractical as a parameter for optimising outdoor lighting.

It can be concluded from the results of this study that as a road surface ages, its Q_0 value increases slightly, while its *S1* value decreases slightly. This is probably due to changes in the coarseness of the road surface and the lightness of the aggregate as the road surface wears down. The differences that were observed are minor, however, and the sampling used in the comparison is relatively small. It is not recommend accounting for the age of the road surface in outdoor lighting calculations and design.

Can the same road surface classes be used in outdoor lighting design in all of the Nordic countries?

Based on the results of this study, the same standard road surface class could be adopted for use on roads in Finland and Denmark. Alternatives include, for example, the standard road surface class R2 with the average luminance coefficient value Q_0 = 0.09, or the standard class N2 with Q_0 = 0.09. Before making a decision, however, Finland should wait for measurement results to come in from Sweden and Norway. Similar measurements to the Finnish and Danish ones will be carried out in Sweden probably in 2020, and in Norway possibly in 2021.

Bibliography

CIE 47:1979 Road lighting for wet conditions, CIE (Commission Internationale de l'Eclairage), Publication No. 47, 1979

CIE 66:1984 Road surfaces and lighting, CIE (Commission Internationale de l'Eclairage), Publication No. 66, 1984

CIE 144:2001 Road surface and road marking reflection characteristics, CIE (Commission Internationale de l'Eclairage), Publication No. 144, 2001

Helsingin kaupungin ulkovalaistuksen suunnitteluohje 2017, Guidelines for outdoor lighting design in City of Helsinki, 2017

Liikenne työmaalla – kunnossapitotyöt 3/2015, Guidelines for construction site traffic, Finnish Transport Infrastructure Agency, Publication No. 3/2015, 2015

Maantie- ja rautatiealueiden valaistuksen suunnittelu 16/2015, Finnish national code of practice for lighting of road and railway areas, Finnish Transport Infrastructure Agency, Publication No. 16/2015, 2015

Tienpäällysteiden valonheijastusominaisuudet – Asfalttipäällysteen koostumuksen merkitys, VTT Technical Research Centre of Finland, Research Report 179, 1980

Tienpäällysteiden heijastusominaisuudet – Jatkotutkimus, VTT Technical Research Centre of Finland, Research Report 456, 1985