Trafikverket

Condition measurements of reflection properties of road surfaces in Sweden

English Version of ”Tillståndsmätning av vägbeläggningarnas reflektionsegenskaper”, Malmö 2020-07-10

Translated by Kai Sørensen 2020-09-25

Condition measurements of reflection properties of road surfaces in Sweden

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Innehållsförteckning

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1. Introduction

1.1 Background

The reflection properties of the road surface are important when dimensioning a lighting system intended for road surfaces with luminance requirements. In Sweden, luminance requirements are applied to roads for motor vehicles where the visibility distance is more than 60 m. In practice, this applies to the vast majority of the Swedish Transport Administration's lighting installations.

Depending on the properties of a road surface, it is classified according to systems developed by the CIE (International Commission on Illumination). The classifications involve the lightness of the surface measured by the average luminance coefficient Q0 or the luminance coefficient in diffuse illumination Qd. Additionally, it involves the specularity of the surface measured by a specular factor S1.

In Sweden, ”Vägar och Gators Utformning” (translates to ”Design of roads and streets”) is a central document. It is referred to as the VGU in the following.

In the VGU, the most common types of road surfaces are divided into the classification systems N and W for respectively the dry and a wet condition. However, this division is based on only a number of laboratory measurements from the 60s and 70s. These measurements have, in line with increased focus on energy saving, being questioned to an increasing degree.

This is a dilemma, that also applies for the neighboring countries Finland, Norway and Denmark, and has repeatedly been discussed within NMF (Nordic meeting for improved road equipment). Therefore, a decision was made in 2016 to have a portable instrument developed for the measurement of the reflection properties of road surfaces. The development was co-financed by the four traffic authorities and was completed in the spring of 2017.

Since then, new measurements have been performed in Denmark (2017), Finland (2017) and Sweden (2019) and are planned to take place in Norway in 2020. The measurement results for Sweden are presented in this report.

At the same time, an EU project (SURFACE) is underway to compile the Union's collective knowledge in this field. The measurements in the Nordic countries will be a valuable addition to this project.

1.2 Purpose and goals

The purpose of the project is to replace the current standard values used for dimensioning road lighting installations with values based on actual measurement data. The goal is to be able to measure to a sufficient extent and geographical spread in order to cover all common types of pavements and stone materials.

1.3 Delimitations

The measurements have been limited to include only the three most common types of pavements, as these together represent more than 97% of the Swedish Transport Administration's paved roads (surface treatments excluded).

Delimitations were also introduced with respect to the age of the road surfaces. When a road surface is new, the stone material is covered by a film of black bitumen. However, this film wears away relatively quickly and the road surface gets its characteristic appearance, which it then retains throughout its life. The measurements in this study have, therefore, been performed only on asphaltic surfaces with visible stone material.

The measurements were geographically limited to the southern part of Sweden with Dalarna as the northernmost county. Within this area, there are quarries that represent the country's most common stone materials. Measurements further north were therefore not considered to add much further information, and were assumed to raise the costs of measurements significantly. For these reasons, priority was given to measurements in the above-mentioned area.

The study does not include the reflection properties of road surfaces in the wet condition.

2. Measurements

2.1 Measurement strategy

The VGU provides the reflection properties for the road surface types ABS (skeletal asphalt), ABT (dense asphalt concrete) and TSK (thin layer coating). To verify that these are still the dominant road surface types, a compilation was made of all major asphalt works in the last ten years. The data for this compilation were taken from the Swedish Transport Administration's PMSv3. See figure 1.

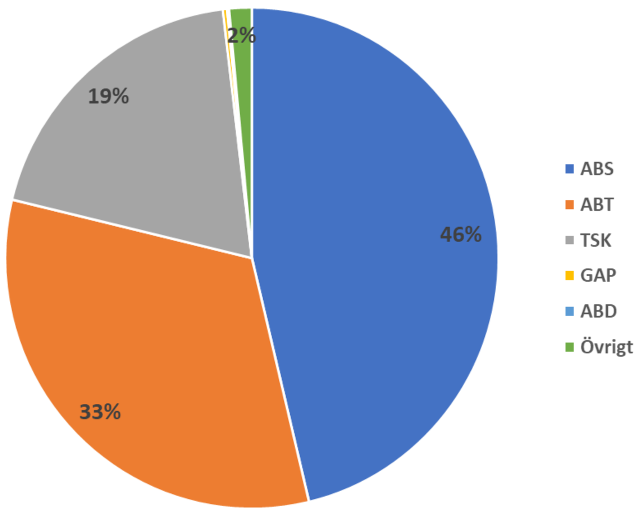


Figure 1, The most common types of road surfaces in Sweden

The compilation shows that the three road surface types ABS, ABT and TSK are still so dominant that it is not relevant to incorporate other road surface types in a revision of the VGU. Accordingly, this study also excludes other types of road surfaces.

In the VGU, the road surface types ABS and TSK have been equated with regard to the reflection properties in the dry condition. However, they have been divided into three subgroups depending on the stone material used. The division is as follows:

- Light granite or light quartzite
- Dark granite or dark quartzite
- Porphyry

As this division does not appear in the Swedish Transport Administration's database, it is not possibility to determine in advance, where each subgroup of stone material is used nor how common it is.

The measurement strategy was, therefore, in a first measurement round to measure the road surface reflection properties at a large number of objects with these road surface types, followed by a compilation per subgroup of stone material.

For a second round of measurement, the goal then became to fill up the measurement volume so that at least five, preferably ten, measurements are obtained per subgroup.

In a first measurement round, priority was given to measure easily accessible road surfaces. The most busy counties and roads were, therefore, avoided.

However, this strategy can give a skewed distribution between road surfaces with maximum stone sizes of 11 and 16 mm, compared with what it generally looks like on Sweden's road network. According to the VGU, however, the stone size of the constituent material should not be of any decisive importance, as the stone size is completely missing in today's tables.

Still, in order not to miss the possible impact of the stone size, this information was included in reports of possible measuring locations. In this way, the actual measuring locations were selected so that a desired spread of maximum stone size was obtained.

Possible combinations of road surface type, stone material and maximum stone size are then eight in number.

Road surface type	ABS orr TSK						ABT	
Stone material	Light granite or light quartzite		Dark granite or dark quartzite		Porphyry		All	
Maximum stone size	11 mm	16 mm	11 mm	16 mm	11 mm	16 mm	11 mm	16 mm
Combinations	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***
VGU	Average value		Average value		Average value		Average value	

Table 1, Eight combinations of road surface type, stone material and maximum stone size

Using data from the PMSv3, a number of locations were selected as potential measurement locations. The selection criteria were:
- Road surface types ABS, TSK or ABT
- Age 3 - 7 years
- Minimum length of 50 m
- Full coverage of the road
- Groove depth of maximum 8 mm
- ADT 1000 - 5000
- Counties E, F, G, H, K, M

The maximum wheel track depth was set to 8 mm for the reason that the instrument was suspected to be sensitive to irregularities in viwe of the small measuring angle (1,0° - 1,5°).

Figure 2 shows the possible measuring locations for the first round of measurements. Ramboll's PM system RAMS was used for display. The program provides information on the road number and location of the sections (according to NVDB) as well as the current pavement and maximum stone size. The program also allows display of the operator's position in real time, so that navigation to the locations can be facilitated.

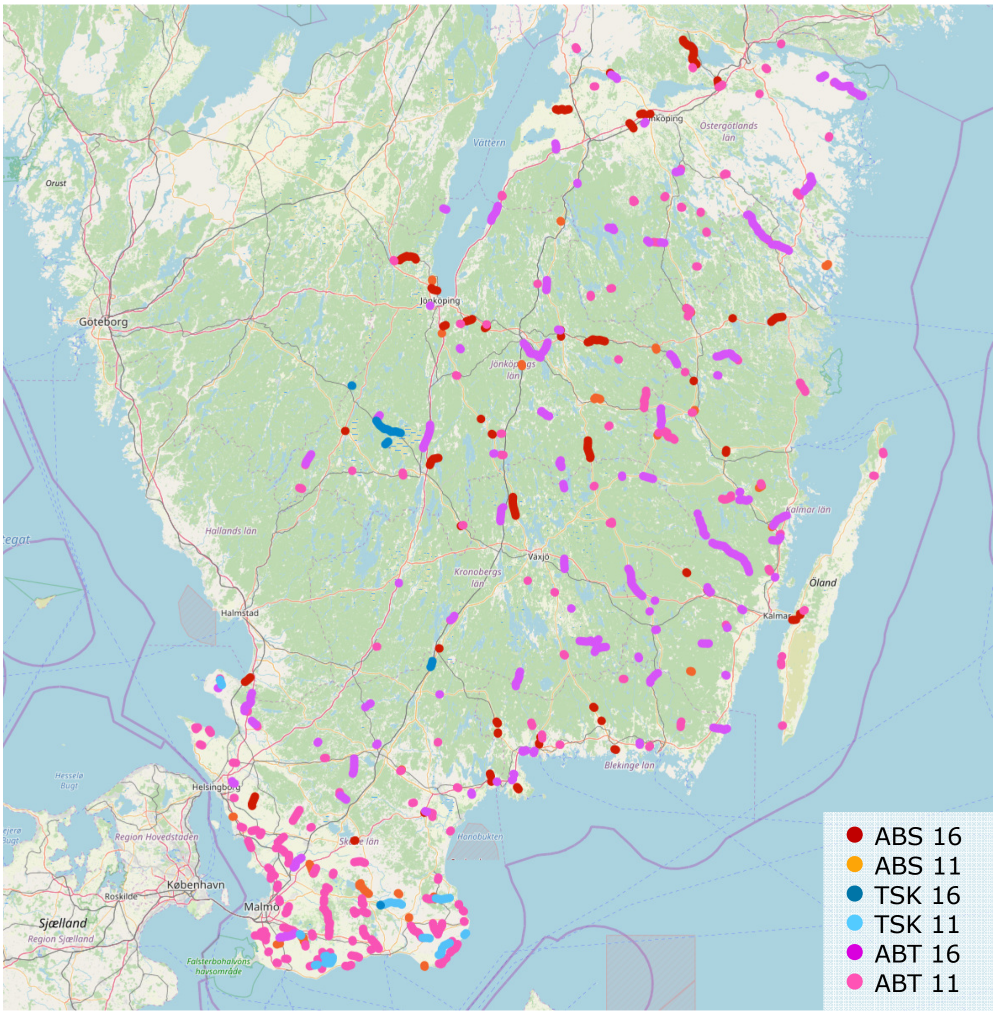


Figure 2, Candidate locations for the first round of measurements

In the following, measurement locations are called ”objects”

The measurements of the first round took place between 24 June - 3 July and resulted in the measurement of 108 objects.

Unfortunately, the data from more than half of the objects could not be analyzed with sufficient certainty. This was caused by changes of the setting of the camera (measurements are based on a calibrated luminance camera) and a small change of the measuring angle to less han 1,0° because of rough handling of the instrument. Sensitivity to the depth of wheel tracks is an additional factor.

However, the Qd value was measured in parallel with another instrument (LTL-XL), so for this parameter results were obtained for all objects.

The number of objects per parameter and combination is shown in table 2.

Road surface type	ABS or TSK						ABT		Total
Stone material	Light granite or light quartzite		Dark granite or dark quartzite		Porphyry		All		-
Max stone size	11 mm	16 mm	11 mm	16 mm	11 mm	16 mm	11 mm	16 mm	-
Number of measured Qd values	21	21	13	8	3	10	12	20	108
Number of measured Q0 & S1 values	12	7	1	2	1	4	4	8	39

Table 1, Number of objects for each combination of road surface type, stone material and maximum stone size at the first round of measurements

A second round of measurement took place between 13 - 21 July and 7 October. Now, some objects were re-measured in order to achive the desired volume for some combinations and new objects were added for other combinations.

This includes a number of objects in Dalarna and the surrounding area where the red porphyry that is abundant. As the porphyry is hard and durable, it is suitable for the top layer of the road surface.

The porphyry from this area is also exported to other parts of the country where it is used for roads with high traffic flows. The porphyry can also be mixed with other rocks, which is why different shades of red appear on roads in Sweden.

After measurement round two, the number of objects per parameter could be summed up as shown in table 3.

Road surface type	ABS or TSK						ABT		Total
Stone material	Light granite or light quartzite		Dark granite or dark quartzite		Porphyry		All		-
Max stone size	11 mm	16 mm	11 mm	16 mm	11 mm	16 mm	11 mm	16 mm	-
Number of measured Qd values	23	35	27	13	10	14	24	34	180
Number of measured Q0 & S1 values	14	21	10	7	7	8	16	18	101

Table 3, Final number of objects for each combination of road surface type, stone material and maximum stone size

A total of 180 objects were measured. For the different road surface types, the distribution is; 88 (49%) for ABS, 58 (32%) for ABT and 34 (19%) for TSK. This distribution agrees with the use of these types in Sweden.

2.2 Measuring instruments and measuring parameters

Two instruments have been used in this study. One is the NMF instrument and the other an LTL-XL from Delta. The NMF instrument provides the parameters Qd (the luminance coefficient in diffuse illumination), Q0 (the average luminance coefficient) and S1 (the specular factor).

The Delta instrument has been used only to supply complementary values of Qd.

Qd and Q0 are different measures of the lightness of road surfaces, while S1 is a measure of the degree of specular reflections. Qd and Q0 both have the unit $cd \cdot m^{-2} \cdot lx^{-1}$.

A measurement with the NMF instrument involves two digital images of the road surface, one with illumination perpendicular to the surface (0°) and one with illumination oblique from the front (63,4°). Each image, in addition to the road surface, includes a surface with known reflection properties. In this way, the values of the reduced luminance coefficients r_1 and r_2 are determined via image analysis, and the values of Qd, Q0 and S1 values are in turn calculated by:

$Q0 = (0{,}957 \times r_1 + 0{,}746 \times r_2 + 104{,}5)/10.000$
$Qd = (0{,}981 \times r_1 + 0{,}323 \times r_2 + 86{,}1)/10.000$
$S1 = r_2/r_1$

There is an illustration of the NMF instrument in figure 3.

There is a more detailed description of the NMF instrument in “A prototype instrument for the measurement of road surface reflection properties - version 21 April 2017”, from where images in figure 3 have been copied.

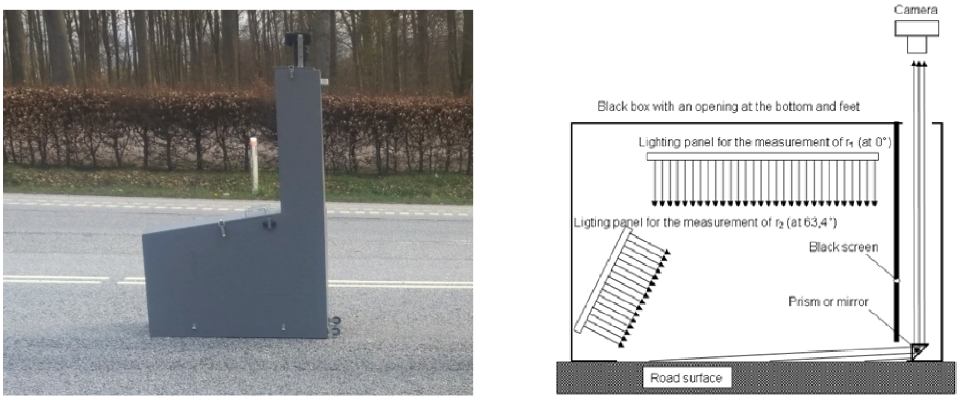


Figure 3, Photo and principle sketch of the NMF measuring instrument for the reflection properties of road surfaces

2.3 Measurement procedure

For each object, measurements were performed at six points, three in the right wheel track and three between the wheel tracks.

The NMF instrument provides two digital images at each point (refer to 2.2). In order to link these images to the points, the images were always taken in the predetermined sequence shown in figure 4.

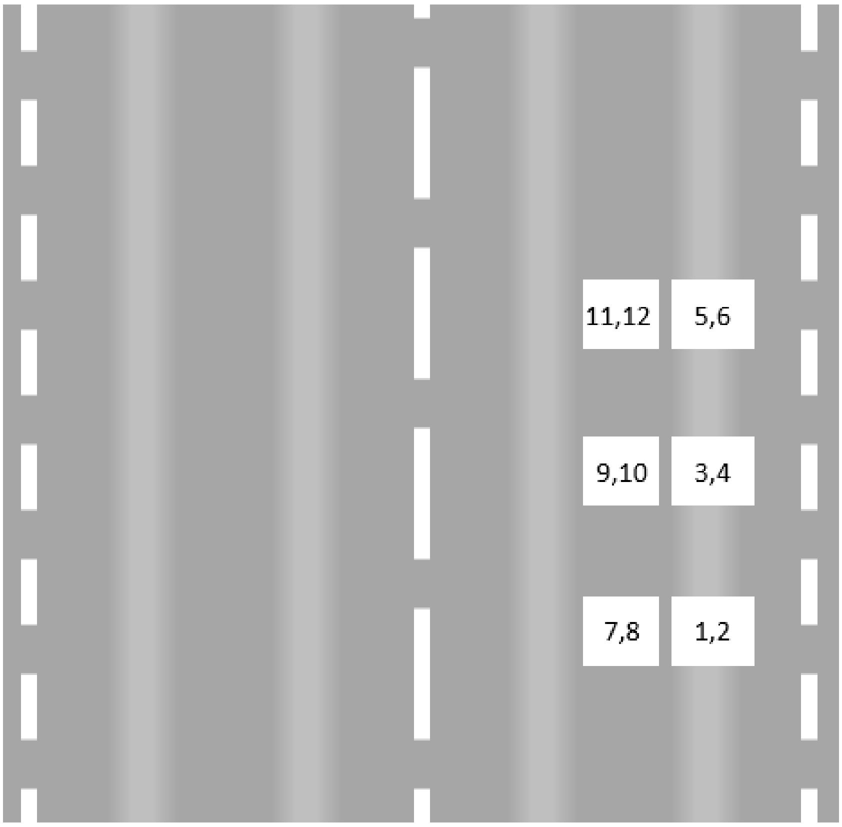


Figure 2, Sequence of images taken with the NMF instrument

Variations across the road are accounted for by the measurements in two lateral positions - in the right wheel track and between the wheel tracks. The wheel tracks are often slightly more light than elsewhere on a road surface, but it can also be the opposite. When averaging over a total of six measuring points, a representative picture of the entire road surface is obtained.

The Qd measurements with the LTL-XL were performed at the same six measuring points. However, this instrument was set to provide averages for the two lateral positions directly.

3. Analysis

3.1 System of classification of road surface reflection properties

CIE has classified the reflection properties of dry road surfaces into three categories called C, R and N. In the VGU, however, the classification according to the category N is applied. This category has four classes N1, N2, N3 and N4 with increasing degree of specular reflection.

The class of a road surface is determined on the basis of the specular factor (S1) as shown in table 4.

Class	Specular factor S1	Nominal values S1	Nominal values Q0
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
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	S1 ≥ 1,35	1,55	0,08
C1	S1 < 0,40	0,24	0,10
C2	S1 ≥ 0,40	0,97	0,07

Tabel 2, Classification in accordance with CIE

The diagram in figure 5 shows the ranges of S1 for the different classes. Additionally, the nominal values of the N-classes for S1 and Q0 are shown as points in the diagram.

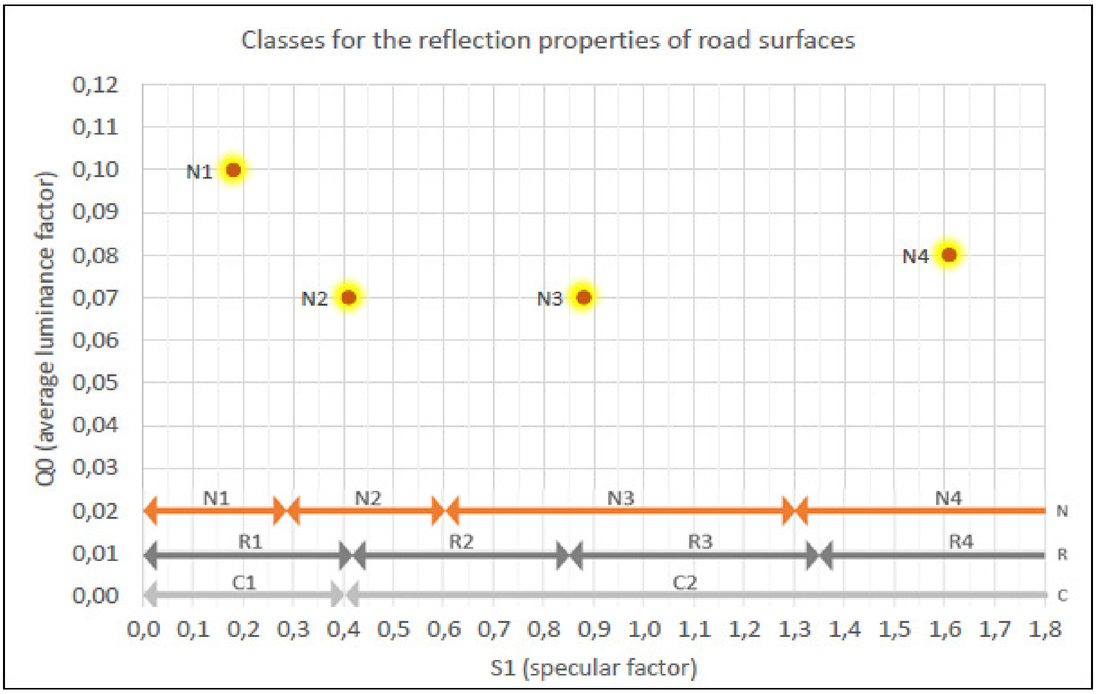


Figure 3, Ranges of S1 for the different classes and the nominal Q0 values of the N-classes

3.2 Verification of assumptions

The tables in the VGU are based on certain assumptions, for example that the roa surface types ABS and TSK have similar reflection properties as long as they contain the same stone material. Another assumption is that the maximum stone size has no decisive significance for the reflection properties in the dry condition. There is no reason to distrust these assumptions from previous studies and this project also has no focus on testing them. However, within the framework of data collected, comparisons between ABS and TSK and a maximum stone size of 11 and 16 mm are reported below.

3.2.1 Road surface types ABS and TSK

For the road surface types ABS and TSK with granite and quartzite stone material, there is a sufficient amount of data for reporting the median value for each type. The strongest basis is for the light stone materials, which are the subject of figure 6, while dark stone materials are the subject of figure 7.

In both cases it can be stated that the difference between road surface types ABS and TSK is marginal and that there is no trend for a natural separation between them. Therefore, it is not considered meaningful to separate those two road surface types and classify them individually. These measurements, therefore, support the assumptions from previous studies that the road surface types ABS and TSK can be merged.

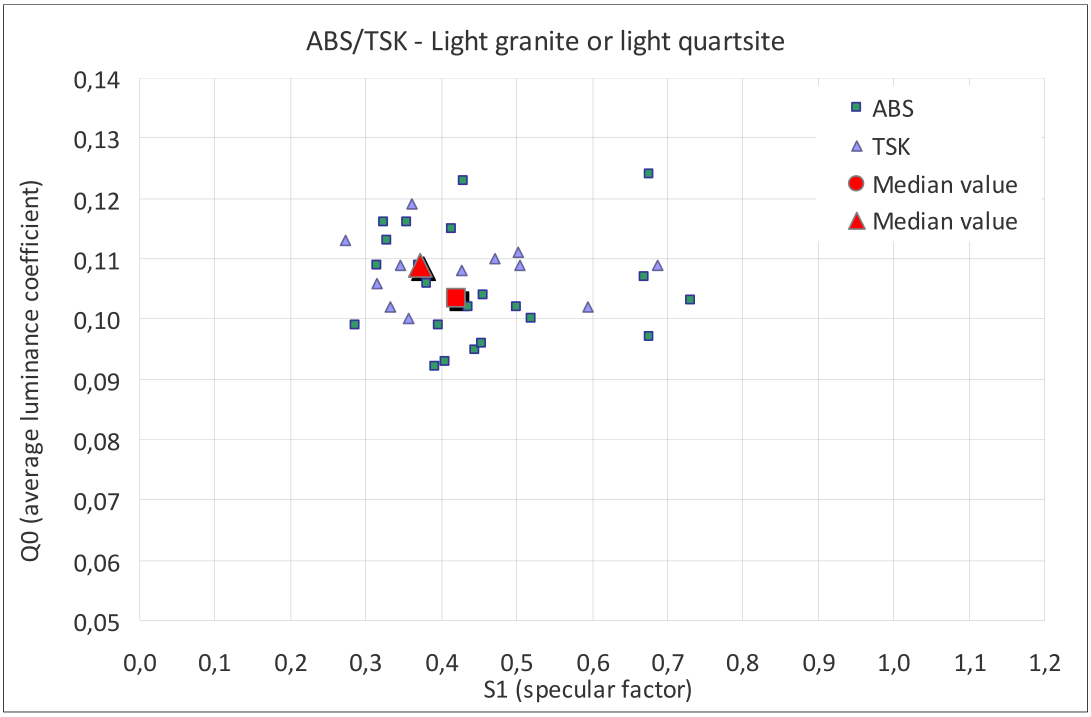


Figure 4, Road surface types ABS and TSK with light granite or light quartsite

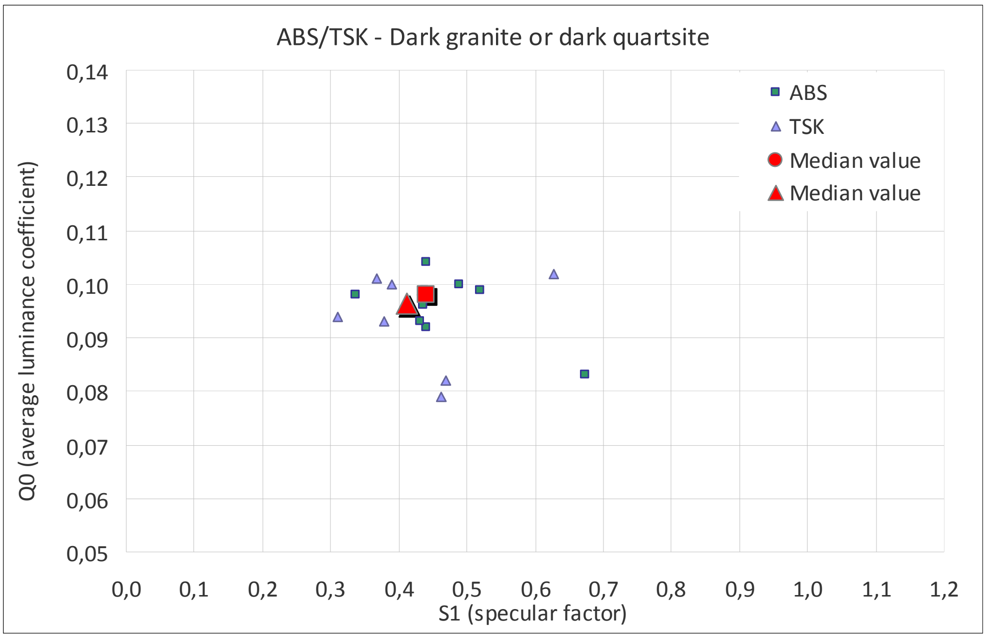
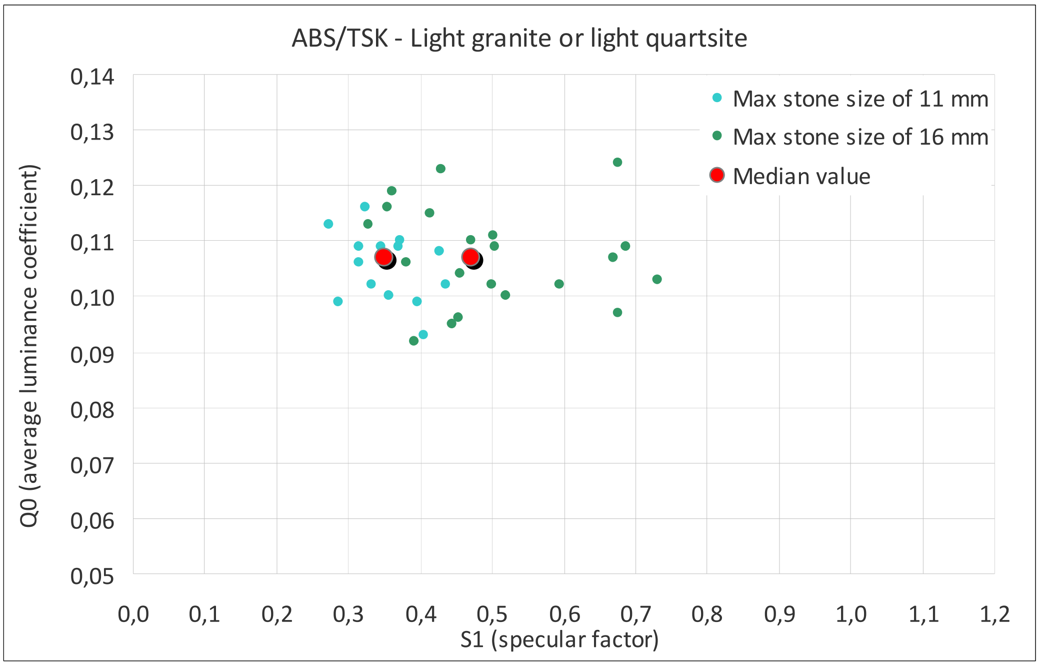


Figure 5, Road surface types ABS and TSK with dark granite or dark quartsite

3.2.2 Stone size

It seems that the maximum stone size of 11 or 16 mm generally does not play a major role for the reflection properties. An exception is possibly that the road surface types ABS/TSK with light stone material show some difference in the specular factor S1 for the two stone sizes.



Figur 6, Road surface types ABS and TSK with light stone materials, but different stone sizes (11 or 16 mm).

3.3 Road surface types according to the VGU

Light stone materials seems to be the dominant in Sweden. In accordance with this, the road surface types ABS/TSK with light stone material cover the highest number of objects.

However, the boundary between light and dark road surfaces is not clearly defined and the stone material often consists of a mix of different materials with varying brightness and colour.

In total, in many situations it can be difficult for the human eye to decide whether a road surface should be classified as light or dark, when there are no references. Additionally, the age and wear of a road surface, plus the directionaly of the lighting, can affect an assessment.

Figure 9 shows a light and a dark ABS surface as well as two surfaces with mixed stone materials.

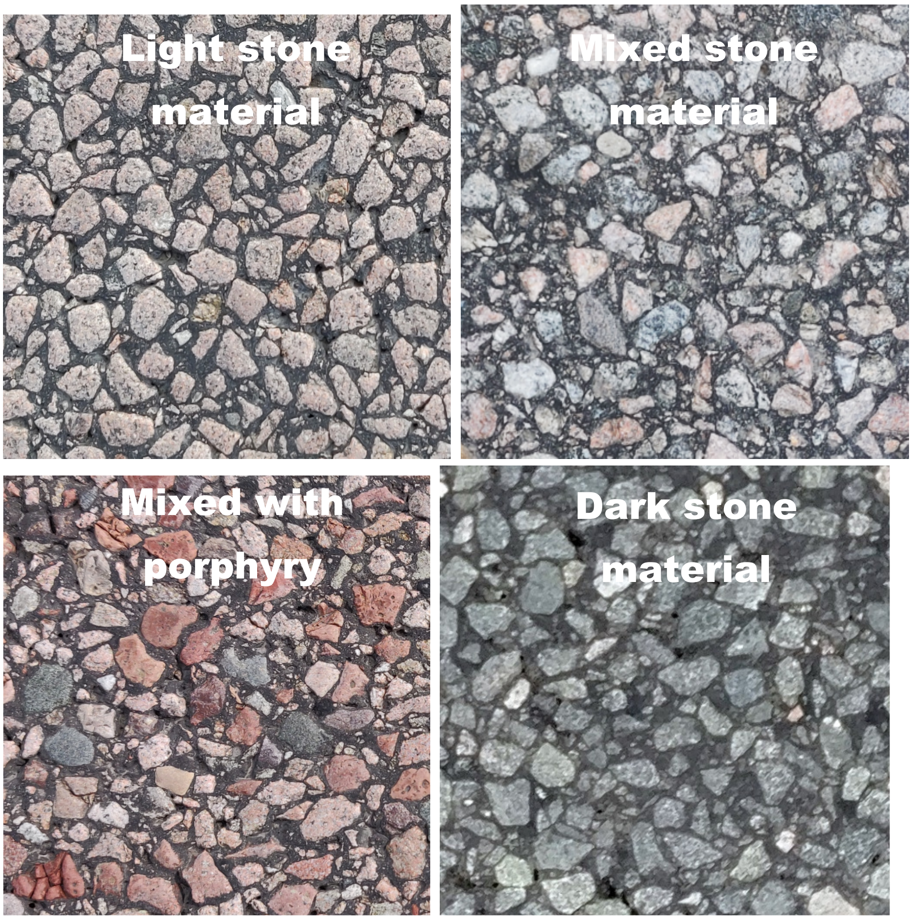


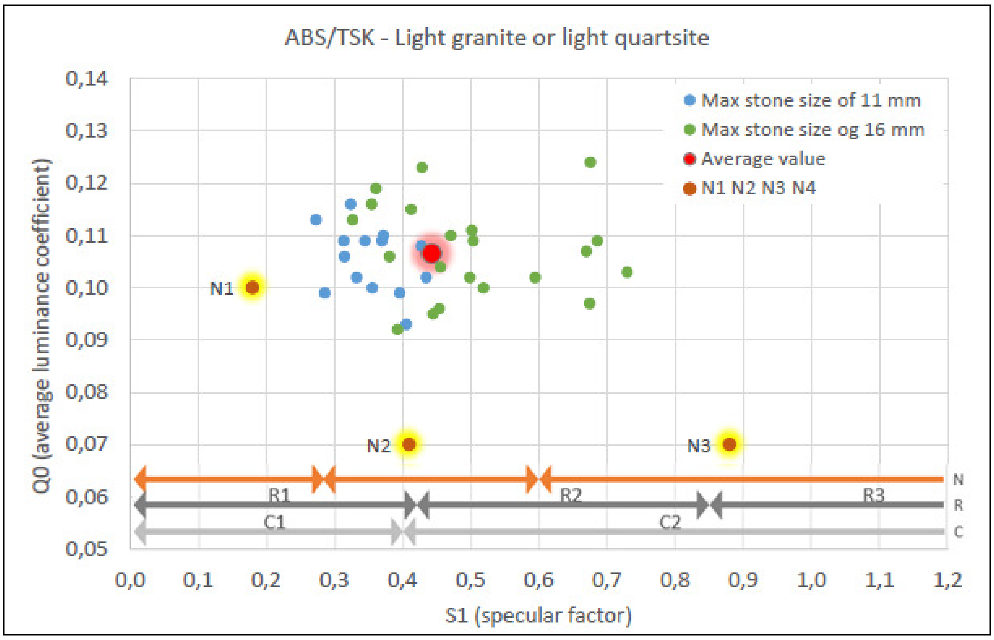
Figure 7, The stone material mostly is a mix of rocks with different colours.

In the following subsections, diagrams with average values of Q0 and S1 are presented for each road surface type.

3.3.1 ABS/TSK - Light granit or light quartzite

The S1 values show that the these road surfaces has the best match to class N2. The average value is 0,44 with a standard deviation of 0,12. Of the 35 objects, 30 fall within the range of N2 (0,28 – 0,59). Four objects, all with a maximum stone size of 16 mm, show values above 0,59, while one object show a value below 0,28.

The average of Q0 is 0,107 cd·m^{-2}·lx^{-1} with a standard deviation of 0,008 cd·m^{-2}·lx^{-1}. The values for Qd are respectively 0,093 and 0,008 cd·m^{-2}·lx^{-1}.



Figur 8, ABS/TSK - Light granite or light quartzite

Table 5 provides additional values for this type of road surface, and also nominal values of the N2 class.

Parameter	Average values				Class N2	
	In wheeltracks	Between wheeltracks	Average	Standard deviation	Nominal values	Percent within N2
S1	0,418	0,487	0,443	0,124	0,41	83%
Q0	0,110	0,103	0,107	0,008	0,07	
Qd	0,096	0,089	0,093	0,008		

Table 3, Average values for ABS/TSK - Light granite or light quartzite

3.3.2 ABS/TSK – Dark granite or dark quartzite

The S1 values show that most of these road surfaces are well within class N2, with only 2 values above the range for the class. The average value is 0,45 with a standard deviation of 0,007.

The average of Q0 is 0,095 $cd{\cdot}m^{-2}{\cdot}lx^{-1}$ with a the standard deviation of 0,007 $cd{\cdot}m^{-2}{\cdot}lx^{-1}$. The corresponding values for Qd are respectively 0,082 and 0,007 $cd{\cdot}m^{-2}{\cdot}lx^{-1}$.

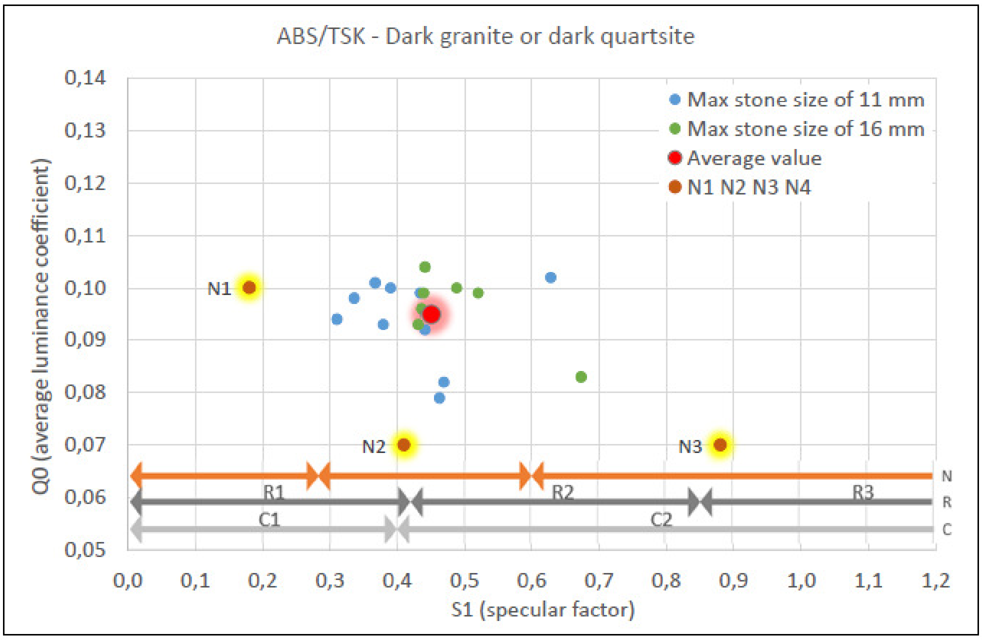


Figure 9, ABS/TSK – Dark granite or dark quartzite

Table 6 provides additional values for this type of road surface, and also nominal values of the N2 class.

Parameter	Average values				Class N2	
	In wheeltracks	Between wheeltracks	Average	Standard deviation	Nominal values	Percent within N2
S1	0,466	0,443	0,450	0,093	0,41	88%
Q0	0,101	0,089	0,095	0,007	0,07	
Qd	0,087	0,078	0,082	0,007		

Table 4, Average values for ABS/TSK - Dark granite or dark quartzite

3.3.3 ABS/TSK – Porphyry

The S1 values for porphyry reaches from approximately 0,35 to 1,0 with a center of gravity at about 0,7.

One possible explanation is that the hard porphyry can be polished by the traffic and thus causes a more specular surface over time. Another possible explanation for the spread is that the porphyry can occur in a mix with other rocks. In total, the majority of the objects fall within class N3 (71%). If comparing to other categories of classes, classes C2 and R2 also fit well with the result for this type of road surface. The average value for S1 is 0,69 with a standard deviation of 0,18.

The average of Q0 is 0,089 $cd \cdot m^{-2} \cdot lx^{-1}$ with a standard deviation of 0,012 $cd \cdot m^{-2} \cdot lx^{-1}$. The corresponding values for Qd are respectively 0,073 and 0,008 $cd \cdot m^{-2} \cdot lx^{-1}$.

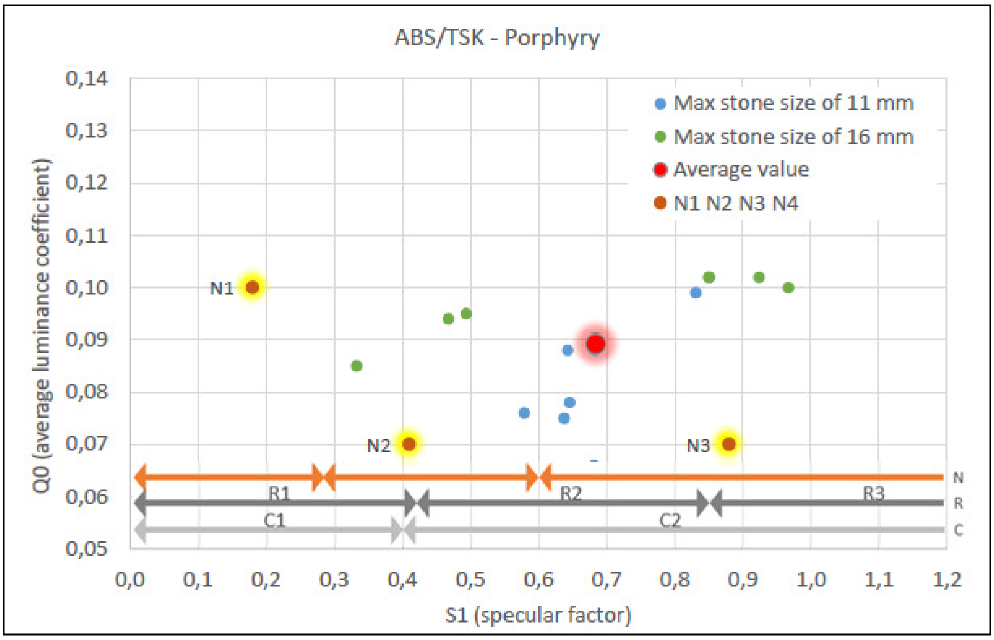


Figure 10, ABS/TSK – Porphyry

Table 7 provides additional values for this type of road surface, and also nominal values of the N3 class.

Parameter	Average values				Class N3	
	In wheeltracks	Between wheeltracks	Average	Standard deviation	Nominal values	Percent within N3
S1	0,642	0,760	0,685	0,183	0,88	71%
Q0	0,096	0,083	0,089	0,012	0,07	
Qd	0,079	0,067	0,073	0,008		

Table 5, Average values for ABS/TSK – Porphyry

3.3.4 ABT

The S1 values for the ABT are mainly within, or in close proximity to, class N2. The highest values in the group can be linked to road surfaces where the stone material was not yet completely free of asphalt, despite an age of several years. The explanation for this is that ABT is often placed on roads and streets with low traffic volumes. The average value for S1 is 0,47 with a standard deviation of 0,18.

The average of Q0 is 0,092 cd·m^{-2}·lx^{-1} with a standard deviation of 0,014 cd·m^{-2}·lx^{-1}. The corresponding values for Qd are respectively 0,080 and 0,012 cd·m^{-2}·lx^{-1}.

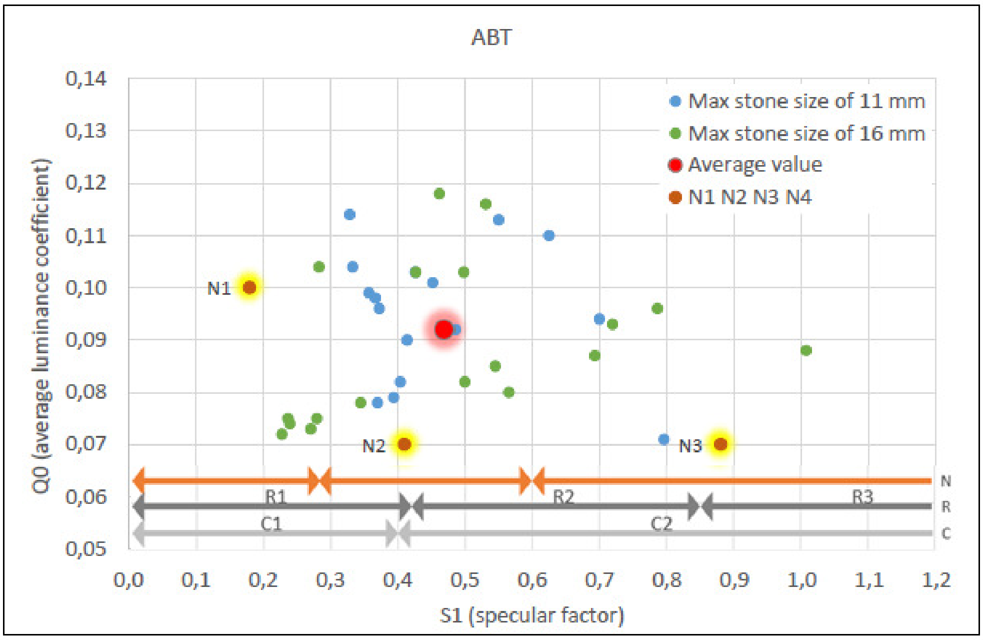


Figure 11, ABT

Table 8 provides additional values for this type of road surface, and also nominal values of the N2 class.

Parameter	Average values				Class N2	
	In wheeltracks	Between wheeltracks	Average	Standard deviation	Nominal values	Percent within N2
S1	0,435	0,519	0,470	0,183	0,41	68%
Q0	0,096	0,088	0,092	0,014	0,07	
Qd	0,084	0,075	0,080	0,012		

Table 8, Average values for ABT

3.3.5 Correction of average Q0 values based on additional objects

Figure 14 shows a diagram with average Q0 values for each road surface type. The average values are based on objects measured with the NMF measuring instrument. This is a measurement volume A of 101 objects.

There is an additional measurement volume B with 79 objects assigned Qd values measured with the LTL-XL. As Qd is also included in the measurement volume A, the total measurement volume A + B for Qd has 101 + 79 = 180 objects. Based on this, a correction of Q0 values has been derived for each of the road surface types by comparison of Qd values from measurement volume A against Qd values from the total measurement volume A and B.

This is defendable in view of a strong correlation between Q0 and Qd and the number of values included in the average values.

The corrected Q0 values are shown in figure 15. A comparison between figures 14 and 15 shows that the corrections are fairly small.

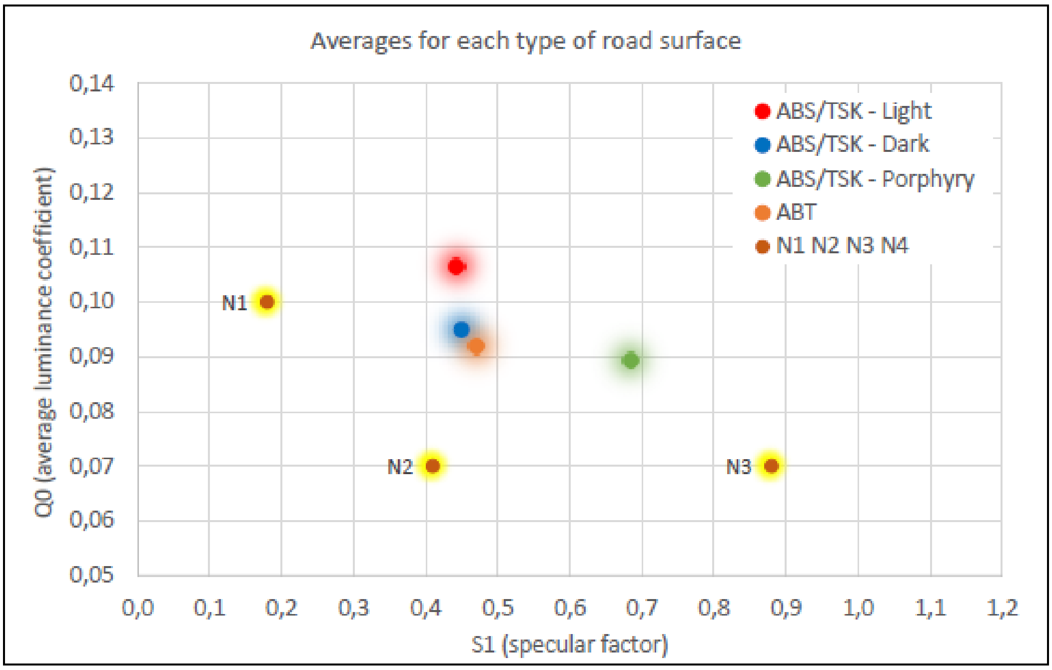


Figure 12, Average Q0 values for each road surface type (measurement volume A)

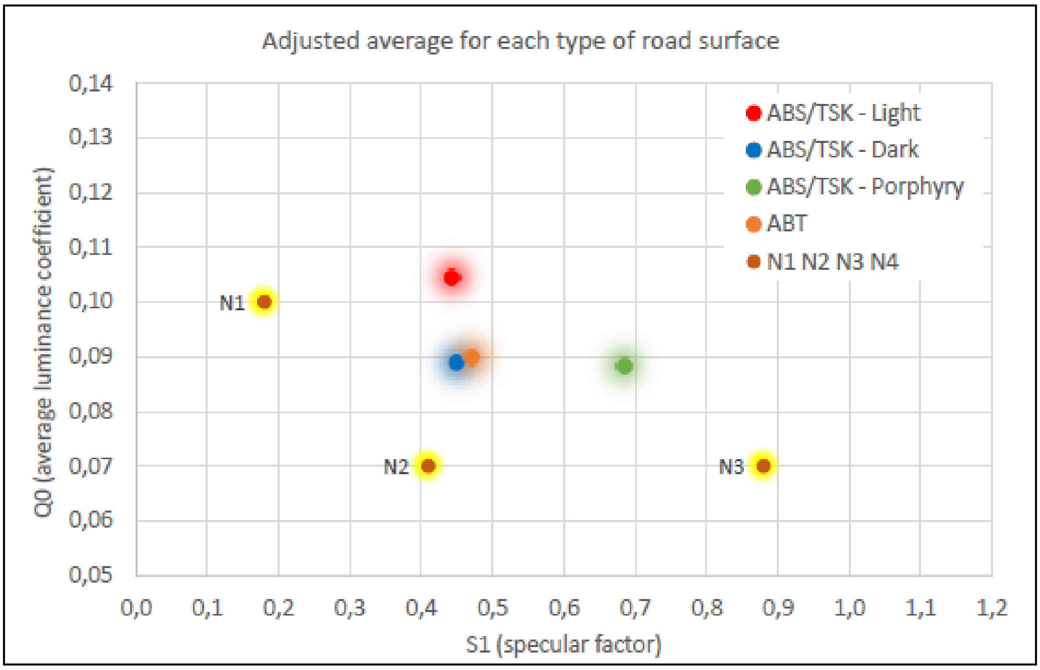


Figure 13, Adjusted average Q0 values for each road surface type (measurement volumes A and B)

4. Results

Table 9 shows measured reflection properties for road surface types according to definitions in the VGU.

Type of road surface	Stone material	Q0	S1	Qd
ABS or TSK	Light granite or light quartzite	0,105	0,443	0,091
ABS or TSK	Dark granite or dark quartzite	0,089	0,450	0,076
ABS or TSK	Porphyry	0,088	0,685	0,072
ABT	-	0,090	0,470	0,078

Table 6, Measured reflection properties

With the values for S1 in table 9, the road surface types fall into the N-classes as shown in table 10.

Type of road surface	Stone material	N-Class
ABS or TSK	Light granite or light quartzite	N2
ABS or TSK	Dark granite or dark quartzite	N2
ABS or TSK	Porphyry	N3
ABT	-	N2

Tablel 7, N-classes for the road surface types

4.1 Proposal for updating the guidelines in the VGU

Table 11 presents a proposal for future guideline values for the calculation of road surface luminance.

Typ of road surface	Stone material	N-Class	Q0	Qd
ABS or TSK	Light granite or light quartzite	N2	0,11	0,09
ABS or TSK	Dark granite or dark quartzite	N2	0,09	0,08
ABS or TSK	Porphyry	N3	0,09	0,07
ABT	-	N2	0,09	0,08

Table 8, Proposal for future guideline values in the VGU

Compared to the current VGU, the N-class for ABS or TSK with porphyry is changed from N2 to N3. All values for Q0 are also adjusted upwards by 0,01. Qd for ABT and ABS/TSK dark granite or dark quartzite is also adjusted upwards by 0,01.

References

A prototype instrument for the measurement of road surface reflection properties, version 21 April 2017 – Kai Sørensen

VGU – Vägar och Gators Utformning,
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version 25 juni 2014 – Trafikverket

Road lighting
version 2014 – Wout van Bommel