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ROAD SURFACE REFLECTION PROPERTIES AND APPLICABILITY OF THE R-TABLES FOR TODAY’S PAVEMENT MATERIALS IN FINLAND

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ABSTRACT

The current road lighting recommendations are to a large extent based on values for road surface luminances and luminance distributions. The luminance of any point on the road surface is a function of the illuminance on the road and the reflection characteristics of the road surface. Road surface reflection characteristics depend on the nature of the surface (aggregate type, binding agent and manufacturing method, texture, etc.) and physical state (wearing, purity and moistness of the surface). Luminance on any point depends on the light incidence angle and the observation angle.

The average luminance coefficient $Q_0$ and a table of reduced luminance coefficients ($r$-table) are characterised by the reflectance properties of road surface. Each surface material has a unique average luminance coefficient and $r$-table which change over time. CIE has also standardised [1] road surfaces into different classes for dry and wet conditions. All these classes are generalisations of various pavement materials that have similar reflection characteristics.

The standard $r$-tables are based on pavement materials and measurements made in the 1960’s and 1970’s. However, new pavement materials have been introduced since then. Recent studies made in the Netherlands and France indicate that pavement materials have become darker and standard $r$-tables are no longer representative of today’s road surface reflection properties.

In this paper several pavement samples of different types and aggregate size were studied. The samples represented current pavement materials generally used on Finnish roads. Complete $r$-tables were measured and reflection coefficients ($Q_0, S1, S2$) were calculated for each sample. In conclusion road surface classifications were made.

**Keywords:** road surface luminance, luminance distribution, average luminance coefficient, $r$-table, pavement materials

1. INTRODUCTION

The purpose of road lighting is to increase the safety of road users. With proper lighting people, vehicles and objects on the road are made visible so that they can be detected. Road lighting standards in Europe [2, 3, 4] give values for average road surface luminance, overall luminance uniformity ratio and longitudinal luminance uniformity ratio. The luminance of any point on the road surface is a function of the luminous flux falling on the surface and the reflection characteristics of the surface.

Road surface reflection properties depend on its nature and physical state [5]. Furthermore, the luminance of a surface depends on the direction of the illumination and direction of observation. The pavement reflection characteristics depend on the aggregate type, colour and lightness, binding material, texture of the surface and method of construction of the surface. Furthermore, the prevailing conditions affect the reflection properties of the road surface. Road surface reflection properties change due to wearing and different weather conditions. In countries where studded tires are used, the wear of the road surface is considerable during the winter season. When the surface is wet or moist the specular
The reflection properties of a road surface can be described using the average luminance coefficient $Q_0$, for the lightness and specular factors $S1$ and $S2$ for the specularity. The average luminance coefficient is defined by

$$Q_0 = \frac{1}{\Omega_0} \int_0^\Omega q d\Omega,$$

where $q$ is the luminance coefficient and $\Omega_0$ is the solid angle, measured from the point on the surface, containing all those directions from which light is incident that are taken into account in the averaging process [5].

The specular factor $S1$ is defined as a ratio of reduced luminance coefficient which is generally large for specular reflection ($\beta = 0^\circ$, $\tan \gamma = 2$) to a factor which is generally large for diffuse reflection ($\beta = 0^\circ$, $\tan \gamma = 0$), i.e.

$$S1 = \frac{r(0,2)}{r(0,0)},$$

Similarly, specular factor $S2$ is a ratio of the average luminance coefficient to a reduced luminance coefficient ($\beta = 0^\circ$, $\tan \gamma = 0$)

$$S2 = \frac{Q_0}{r(0,0)}.$$
The pavement quality requirements are based on European standards [14] and Finnish weather and wearing conditions. In Finland the mostly used pavement types are asphalt concrete (AB), soft asphalt (PAB) and stone mastic asphalt (SMA) [14, 15]. Also porous asphalt and mastic asphalt are used in some special situations. Asphalt concrete, soft asphalt and stone mastic asphalt are all mixtures of bitumen, aggregate and some additive agent. However, the proportion, bitumen and additive materials’ type, and grading curve of the aggregate change [14].

In Finland the pavement materials and their quality requirements are defined by PANK, which coordinates the road construction industry [9]. The pavement quality requirements are based on European standards [14] and Finnish weather and wearing conditions. In Finland the mostly used pavement types are asphalt concrete (AB), soft asphalt (PAB) and stone mastic asphalt (SMA) [14, 15]. Also porous asphalt and mastic asphalt are used in some special situations. Asphalt concrete, soft asphalt and stone mastic asphalt are all mixtures of bitumen, aggregate and some additive agent. However, the proportion, bitumen and additive materials’ type, and grading curve of the aggregate change [14].

The reflectance properties of the currently used pavement materials have been studied in France, United Kingdom and the Netherlands [10, 11, 12, 13]. The reflectance properties of the currently used pavement materials have been studied in France, United Kingdom and the Netherlands [10, 11, 12, 13]. In the Netherlands three types of road surfaces were measured for their reflectance properties: closed asphalt concrete (DBA), stone mastic asphalt (SMA) and very open asphalt concrete (ZOAB). The reflectance properties of DBA and SMA were very

### Table 1. Classification system for road classes R, N, C and W and the standard values of $Q_o$ and $S_1$ [5]

<table>
<thead>
<tr>
<th>Standard table</th>
<th>$S_1$-limit</th>
<th>$S_1$ of standard</th>
<th>Normalised $Q_o$ value</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1</td>
<td>$S_1 &lt; 0.42$</td>
<td>0.25</td>
<td>0.10</td>
</tr>
<tr>
<td>R2</td>
<td>$0.42 \leq S_1 &lt; 0.85$</td>
<td>0.58</td>
<td>0.07</td>
</tr>
<tr>
<td>R3</td>
<td>$0.85 \leq S_1 &lt; 1.35$</td>
<td>1.11</td>
<td>0.07</td>
</tr>
<tr>
<td>R4</td>
<td>$1.35 \leq S_1$</td>
<td>1.55</td>
<td>0.08</td>
</tr>
<tr>
<td>N1</td>
<td>$S_1 &lt; 0.28$</td>
<td>0.18</td>
<td>0.10</td>
</tr>
<tr>
<td>N2</td>
<td>$0.28 \leq S_1 &lt; 0.60$</td>
<td>0.41</td>
<td>0.07</td>
</tr>
<tr>
<td>N3</td>
<td>$0.60 \leq S_1 &lt; 1.30$</td>
<td>0.88</td>
<td>0.07</td>
</tr>
<tr>
<td>N4</td>
<td>$1.30 \leq S_1$</td>
<td>1.61</td>
<td>0.08</td>
</tr>
<tr>
<td>C1</td>
<td>$S_1 &lt; 0.40$</td>
<td>0.24</td>
<td>0.10</td>
</tr>
<tr>
<td>C2</td>
<td>$S_1 \geq 0.4$</td>
<td>0.97</td>
<td>0.07</td>
</tr>
<tr>
<td>W1</td>
<td>$S_1' &lt; 9.6$</td>
<td>5.8</td>
<td>0.088</td>
</tr>
<tr>
<td>W2</td>
<td>$9.6 \leq S_1' &lt; 26.5$</td>
<td>16</td>
<td>0.091</td>
</tr>
<tr>
<td>W3</td>
<td>$26.5 \leq S_1' &lt; 73$</td>
<td>44</td>
<td>0.097</td>
</tr>
<tr>
<td>W4</td>
<td>$73 \leq S_1' &lt; 200$</td>
<td>121</td>
<td>0.104</td>
</tr>
</tbody>
</table>

where $S_1 \_w$ and $Q_{0w}$ are those for the wet conditions. For $S_1 \_w \leq 1 \ SI' = S_1 \_w$.

By accepting a certain tolerance [5, 7], each class can be assigned one standard reflection table assumed to be representative of the reflection properties of the respective class. All these tables are generalisations of various pavement materials that have similar reflection characteristics.

Standard $r$-tables are based on pavement materials and measurements made in the 1960’s and 1970’s [6, 8]. However, new pavement materials have been introduced since then. Economical, environmental and wear resistance aspects have affected the development of new road surface materials [9]. Albeit road surface material affects the performance of road lighting, its reflection properties has not been an issue in developing new materials. The new pavement materials are darker and standard $r$-tables are no longer representative of these materials [10, 11, 12, 13]. Thus, more light and energy are needed to achieve the same luminance level on the road surface.

In Finland the pavement materials and their quality requirements are defined by PANK, which coordinates the road construction industry [9]. The pavement quality requirements are based on European standards [14] and Finnish weather and wearing conditions. In Finland the mostly used pavement types are asphalt concrete (AB), soft asphalt (PAB) and stone mastic asphalt (SMA) [14, 15]. Also porous asphalt and mastic asphalt are used in some special situations. Asphalt concrete, soft asphalt and stone mastic asphalt are all mixtures of bitumen, aggregate and some additive agent. However, the proportion, bitumen and additive materials’ type, and grading curve of the aggregate change [14]. In Finland a few experimental roads have been constructed with concrete pavement [16, 17]. Due to high construction costs, problems in maintenance and ground frost, no plans for future construction of concrete roads exist.

The reflectance properties of the currently used pavement materials have been studied in France, United Kingdom and the Netherlands [10, 11, 12, 13]. In the Netherlands three types of road surfaces were measured for their reflectance properties: closed asphalt concrete (DBA), stone mastic asphalt (SMA) and very open asphalt concrete (ZOAB). The reflectance properties of DBA and SMA were very
One sample was taken from the verge of a road. The samples represent different pavement types typical for Finnish roads (Fig. 1). Asphalt concrete (AB) and stone mastic asphalt (SMA) pavements are mainly used on roads carrying heavy traffic. Soft asphalt (PAB-V) is used on roads that have less traffic. Also Hilja, noise reducing quiet asphalt, was measured. In Finland the use of studded tires in winter time wears the pavement surface. Hence, the samples were mostly from roads paved two years ago. Table 2 lists all the pavement samples, their type and age, which is the time it has been worn. Average daily traffic (ADT) is the average number of vehicles passing the road in a 24-hour period [15].

Road surface reflection characteristics measurements were done in a laboratory with a gonioreflectometer (Fig. 2). The measurement set-up consists of a fixed table, where the pavement sample is set. A spot luminance meter Prichard 1980 A is fixed to the pavement sample. The luminance meter is set at the observation angle of 1°. The area where the luminance is measured is delimited by shield plates. The luminance is measured through a gap in shield plates. The measuring area is defined by the aperture of the luminance meter and the size of the gap between the shield plates.

A metal halide lamp is set at constant distance from the sample and it is moved over an arc about the sample. The light source is at the bottom of a 3 m long arm in a case, which purpose is to eliminate ambient light. A lens gathers up the light towards the top of the arm, where a mirror reflects it to the center

Table 2. Pavement samples (Average daily traffic (ADT) of the road, pavement type, pavements wearing time (age) and place of extraction of the sample)

<table>
<thead>
<tr>
<th>Sample</th>
<th>ADT</th>
<th>Type</th>
<th>Age</th>
<th>Extraction of the sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>121</td>
<td>PAB-V</td>
<td>2</td>
<td>wheel track and between wheel tracks</td>
</tr>
<tr>
<td>2</td>
<td>229</td>
<td>PAB-V</td>
<td>2</td>
<td>wheel track and between wheel tracks</td>
</tr>
<tr>
<td>3</td>
<td>77</td>
<td>PAB-V</td>
<td>2</td>
<td>wheel track and between wheel tracks</td>
</tr>
<tr>
<td>4</td>
<td>271</td>
<td>PAB-V</td>
<td>2</td>
<td>wheel track</td>
</tr>
<tr>
<td>5</td>
<td>9255</td>
<td>SMA</td>
<td>3</td>
<td>wheel track and between wheel tracks</td>
</tr>
<tr>
<td>6</td>
<td>290</td>
<td>SMA</td>
<td>5</td>
<td>wheel track and between wheel tracks</td>
</tr>
<tr>
<td>7</td>
<td>6489</td>
<td>Hilja</td>
<td>1</td>
<td>wheel track and between wheel tracks</td>
</tr>
<tr>
<td>8</td>
<td>2931</td>
<td>AB</td>
<td>2</td>
<td>wheel track and between wheel tracks</td>
</tr>
<tr>
<td>9</td>
<td>1959</td>
<td>AB</td>
<td>2</td>
<td>wheel track and between wheel tracks</td>
</tr>
<tr>
<td>10</td>
<td>1959</td>
<td>SMA</td>
<td>2</td>
<td>verge of the road</td>
</tr>
</tbody>
</table>

close to the earlier results, even if these results were about 40 years old [12]. However, the measurements for ZOAB resulted in lower reflection than used in the design state.

Measurements made in France indicate that for very thin asphalt concrete (VTAC) the reflection properties change from the very specular reflection to slightly specular or even diffuse due to wearing. On the other hand, surface dressing (SD) is very diffuse at first and changes to specular with aging. According to photometric properties of VTAC and SD pavement materials it was concluded that the standard r-tables are no longer representative of the road surface materials in France. Similar results of the CIE classification system C have been found in the United Kingdom [13].

In Finland the R and W classes is in use and road lighting is designed using standard tables R1, R2, W1 and W2 [18]. Road surface reflection measurements have been made earlier in Finland in the 1980’s and 1990’s [19, 20, 21]. In these studies the samples were cut from the road surface; from the wheel track, between the wheel track and the verge of a road. Some samples were also made and worn at the laboratory. According to these results most surfaces belong to road classes R1 and R2.

2. METHODS

The measurements were done for road surface samples extracted from roadways in the southern part of Finland. Two samples were taken from each road: from the wheel track where the wearing is the highest and in between the wheel tracks. One sample was taken from the verge of a road. The samples represent different pavement types typical for Finnish roads (Fig. 1). Asphalt concrete (AB) and stone mastic asphalt (SMA) pavements are mainly used on roads carrying heavy traffic. Soft asphalt (PAB-V) is used on roads that have less traffic. Also Hilja, noise reducing quiet asphalt, was measured. In Finland the use of studded tires in winter time wears the pavement surface. Hence, the samples were mostly from roads paved two years ago. Table 2 lists all the pavement samples, their type and age, which is the time it has been worn. Average daily traffic (ADT) is the average number of vehicles passing the road in a 24-hour period [15].

Road surface reflection characteristics measurements were done in a laboratory with a gonioreflectometer (Fig. 2). The measurement set-up consists of a fixed table, where the pavement sample is set. A spot luminance meter Prichard 1980 A is fixed to the pavement sample. The luminance meter is set at the observation angle of 1°. The area where the luminance is measured is delimited by shield plates. The luminance is measured through a gap in shield plates. The measuring area is defined by the aperture of the luminance meter and the size of the gap between the shield plates.

A metal halide lamp is set at constant distance from the sample and it is moved over an arc about the sample. The light source is at the bottom of a 3 m long arm in a case, which purpose is to eliminate ambient light. A lens gathers up the light towards the top of the arm, where a mirror reflects it to the center.
The measured value is in fact the luminance coefficient $q$, from which the reduced luminance coefficient can be derived using equation 2. Since $q$ is defined as the ratio of the luminance to the illuminance, the $q$ values can be obtained from a series of luminance and illuminance measurements. Using relative calibration method it is possible to calibrate the measuring set-up in such a way, that only luminances need to be measured.

In a relative calibration method a diffuse surface with a known reflection coefficient $\sigma$ is set perpendicular to the angle of light incidence and the luminance $L_0$ of the reference surface is measured. Lumi-
nance coefficient \( q \) for the corresponding luminance \( L \) and angle \( \gamma \) is then equal to

\[
q = \frac{\sigma L}{\pi L_0 \cos \gamma}.
\] (7)

The accuracy of the luminance meter Pritchard 1980 A is \( \pm 4\% \) [22]. The accuracy of the measuring device is \( 5\ldots15\% \) depending on the roughness of the pavement sample [23]. The inaccuracy is caused by setting up the pavement sample and the luminance meter, the pavement sample and the luminance meter itself, turning the arm to obtain angles \( \beta \) and \( \gamma \), the light source and the calibration method.

3. RESULTS

The \( r \)-tables were measured for each pavement sample. The calculated values for \( Q_0, S1 \) and \( S2 \) value are presented in Table 3. The results were calculated for each pavement sample and for each road an average was taken from the respective wheel track sample and the sample between the wheels tracks.

Fig. 3 presents the \( Q_0 \) and \( S1 \) values of the samples. The normalised values for \( Q_0 \) and \( S1 \) for reflection tables R1 and R2 are also plotted on the graph. Most of the samples, except the one taken from the verge of the road, have \( S1 \) values close to that of the standard class RI value. \( S1 \) values for the two samples taken from the same road do not vary significantly. The \( S1 \) values are also close to the normalised value of \( S1 \) of the R1 class. In addition, there is no significant difference of \( S1 \) value between different pavement materials. Sample 6 has the highest \( S1 \) value in both of the samples and the wheel track sample belongs to road class R2. The sample extracted between the wheel tracks is classified to road class R1. However, the \( S1 \) value is close to the limit of road class R2. The sample taken from the verge of the road has \( S1 \) value that is in the middle of the limits of road class R2.

For the \( Q_0 \) value there are more variations between the values of the wheel track sample and the sample taken between the wheel tracks. The differ-
ence within the pavement type remains close to constant, but between different pavement materials the difference varies. Pavement sample 3 has the same $Q_0$ value in both samples. The road has very low traffic. Therefore, wearing of the surface has been negligible. In most cases, the $Q_0$ value is larger for the wheel track value where the wearing is the most. More aggregate, which is lighter than binding material bitumen, emerge due to wearing.

All the measured samples belong to road class R1 except one SMA 11 sample taken from the wheel track and SMA 16 sample taken from the verge of the road. The average values calculated from the wheel track and between the wheel tracks classifies all the samples to road class R1. The normalized values for road class R1 are $Q_0 = 0.10$ and $S1 = 0.25$. There is no significant difference between the average measured values for the specular factor $S1$ and the normalized value of the R1 class. All the samples have $S1$ value close to the normalised value except sample 6, which has $S1$ value close to the upper limit of the road class R1. The average luminance
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is projected to a plane where $\gamma = 0^\circ$ and $\beta = 0^\circ$. Figs. 4–10 show the reflection indicatrix of the pavement samples. The figs. show results of the wheel track and between wheel tracks samples for each pavement type according to their average luminance value $Q_0$. In addition, the reflection indicatrix of the standard r-table is presented in each graph. The $r$-table $Q_0$ values, on the other hand, differ from the normalised value of the road class R1. The average values for $Q_0$ are those for the road classes R2, R3 and R4.

The results of the measured r-tables are presented in two dimensional reflection indicatrices. In these graphs the three dimensional reflection indicatrix is projected to a plane where $\gamma = 0^\circ$ and $\beta = 0^\circ$. Figs. 4–10 show the reflection indicatrix of the pavement samples. The figs. show results of the wheel track and between wheel tracks samples for each pavement type according to their average luminance value $Q_0$. In addition, the reflection indicatrix of the standard r-table is presented in each graph. The r-ta-
Table 4. Results of the three samples measured two times, calculated values for $Q_0$, $S_1$ and $S_2$ for each sample and an average of the two measurements

<table>
<thead>
<tr>
<th>Sample</th>
<th>1 measurement</th>
<th>2 measurement</th>
<th>average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$Q_0$</td>
<td>$S_1$</td>
<td>$S_2$</td>
</tr>
<tr>
<td>3</td>
<td>0.08</td>
<td>0.25</td>
<td>1.33</td>
</tr>
<tr>
<td>8</td>
<td>0.07</td>
<td>0.22</td>
<td>1.46</td>
</tr>
<tr>
<td>6</td>
<td>0.07</td>
<td>0.35</td>
<td>1.56</td>
</tr>
</tbody>
</table>

Fig. 8. Sample 3 ($Q_0=0.08$, $S_1=0.30$) and sample 9 ($Q_0=0.08$, $S_1=0.29$) taken between the wheel tracks, standard $r$-table R1 is rescaled according to $Q_0=0.08$

The shape of the reflection indicatrices for PAV, SMA and AB represent reflection tables R1 and R2 to a large degree except for the noise reducing pavement Hilja (Fig. 4). However, rescaling the standard $r$-table to match the $Q_0$ value of the measurements does not produce a good fit between these reflection indicatrices. Most of the differences compared to standard tables occur at small beta angles. That is they are more specular than standard R1 reflection. However, the reflection has a tendency to change towards class R2 reflection. There are also some differences at large $\beta$ angles. Standard $r$-table seems to underestimate the diffuse reflection.

The volume contained within the indicatrix represents the level of total reflectivity and the shape characterizes the degree of specularity [5]. Thus, the volume of the indicatrix is same at the same $Q_0$ value. According to these measurements, in most cases the standard $r$-table appears to be enclosed inside the measured indicatrices. Therefore, for high angles of incidence, the standard $r$-table seems to overestimate the reflection and for low angles of incidence underestimate the reflection.

The noise reducing pavement material Hilja (Fig. 4, sample 7), on the other hand, has a unique reflection indicatrix that does not correspond to standard class R1 or any other standard classes. The standard reflection table overestimates the specular reflection and underestimates the diffuse reflection.

Three samples were measured two times. Results of both of the measurements are in Table 4. Figs. 11–13 show the reflection indicatrices of the samples of the respective measurements.

The results of the comparison test vary substantially. However, the classification of the pave-
ment samples to road classes remains. The pavement samples cut from the road should be measured as soon as possible before surface changes take place due to drying out. The time span between the measurements were approximately two months, so changes in surface could explain some of the differences between the two measurement results. Also bending of the sample and uncleanliness of the sample may explain the differences. In addition the surface roughness and the orientation of the sample affect the measurement results which may cause that the luminance was not measured exactly from the same direction and at same area in the two measurements.

The most significant differences between the measurements occur when the \( \beta \) angle is close to 0 degrees or 180 degrees. The sample was set to the sample holder at \( \beta = 0^\circ \) or \( \beta = 180^\circ \). Part of the differences may be caused by inequalities of the measurement set-up and positioning the pavement sample to the sample holder. Another reason is the changes in the sample due to drying.

Fig. 9. Sample 1 (\( Q_0 = 0.09, S1 = 0.19 \)) taken between the wheel tracks and sample 7 (\( Q_0 = 0.09, S1 = 0.24 \)), sample 8 (\( Q_0 = 0.09, S1 = 0.18 \)), and sample 9 (\( Q_0 = 0.09, S1 = 0.20 \)) taken from the wheel track, standard r-table R1 is rescaled according to \( Q_0 = 0.09 \)

Fig. 10. Sample 6 (\( Q_0 = 0.07, S1 = 0.4 \)) taken from the wheel track and sample 10 (\( Q_0 = 0.06, S1 = 0.68 \)) taken from the wedge of the road, standard r-table R2 is rescaled according to \( Q_0 = 0.06 \)
For the AB 16 (sample 8) the first measurement gives arbitrary values at \( \tan \gamma = 0 \) and \( \tan \gamma = 0.25 \). There are not just few abnormal values but all the values for \( \tan \gamma = 0 \) and \( \tan \gamma = 0.25 \) behave somewhat unexpectedly. For the rest of the measurement the results give values as expected for class R1 reflection. For the second measurements no abnormal behaviour was detected. The area where the luminance is measured is constant for all combinations of angles \( \beta \) and \( \gamma \). The abnormal behaviour is rather linear for each angle of \( \beta \) and \( \gamma \). Most likely cause for these results is the sample structure.

### 4. CONCLUSIONS

In this study the photometric properties of PAB-V, SMA and AB, which are common pavement materials on Finnish roads, were measured. In comparing the results to CIE standards it was found that they do not fulfill the requirements of the road classes R1 and R2. The standard \( r \)-table reflection indicatrices give adequate fit for the degree of specularity but not to the degree of lightness. However, the measurements were made only of a small number of pavement samples from a specific part of Finland, where the aggregate used comes from the neighbouring area. Hence, only a few of samples of each pavement type were measured and there were only two samples (wheel track and between wheel tracks) per road. Furthermore, there was only one sample.
of Hilja, the noise reducing pavement material and one SMA 16 sample taken from the wedge of the road. According to the measurements of Hilja, the wheel track sample behaves like the standard R1 reflection, but the sample taken between the wheel tracks does not behave like the standard R1 table. The SMA 16 sample, on the other hand, behaves like R2 reflection table.

The reflection properties of the actual road surface do not fit to the rescaled standard r-table. The specular lobe and the diffuse lobe of the reflection indicatrix of the actual road surface are overrated compared to the rescaled standard r-table. Also, for low angles of incidence, the reflection of the actual road surface is overrated and for high angles of incidence the reflection is underrated compared to the rescaled r-table. However, for the degree of specularity adequate fit is attained.

According to these measurements the pavement materials used on Finnish roads are diffuse and somewhat dark. Most of the $SI$ values are close to the $SI$ of standard (Table 1) of road class R1. The average luminance coefficient value $Q_0$, on the other hand, is closer to the normalised $Q_0$ value for road classes R2, R3 and R4. All the measured road surface samples belong to road class R1. However, the road lighting design is made using standard tables R1 and R2.

The measured pavement samples were from a small region in southern Finland. More measurements are needed for samples from other parts of Finland, as the used aggregate type and colour vary and it is highly dependent on regional availability. Also there were no wheel tracks samples of SMA 16, which is used on roads that have heavy traffic. More samples from different parts of the road (near the centre and the verge of a road) and different road sections should also be taken.

The repeatability of the measurements was not complete. In measuring the same samples on different days the results classified the samples to belong to the same road class. However, the reflection indicatrices show different behaviour. All these differences cannot be explained by the changes in samples caused by drying, dust, etc. The crooked pavement sample, sample orientation and the luminance measuring area as well as the drift of the luminance meter all contribute the measurement results. In order to verify the results of the comparison tests, measurements with other measuring facilities should be made.

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