A prototype instrument for the measurement of road surface reflection properties - version 9 May 2017

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Background

Road surface reflection properties are input to dimensioning calculations of road lighting on traffic roads and are in practise represented by standard assumptions that are old and have not been verified by measurements since the early 1980's.

There were some portable instruments for in situ measurement of road reflection properties in use during the 1970's and 1980's, but they were, with one exception, basicly unreliable. The exception was the LTL 200, which was developed at the Danish lighting laboratory at about 1980 and produced in a small number. These were a bit complex in use and expensive to produce, and none of them are probably in practical use to-day. A later type of instruments, Memphis®, may well have had virtues, but worked in an indirect manner and is no longer in use.

This situation gave cause to an idea of a simple instrument for the measurement of road surface reflection properties, which emerged on an NMF meeting in the Autumn of 2015. At this meeting, the author was instructed to outline such an instrument and, at further NMF meetings during 2016, this instruction was extended to include first a description of the optics of such an instrument and next to actually build a prototype instrument.

Note: NMF stands for Nordic Meeting For improved road equipment.

1. Introduction

In annex A it is explained that the two values of the reduced luminance coefficient, r_1 and r_2, of a road surface can lead to both of the characteristic values for the reflection properties of road surfaces. These are the specular factor S1 and the average reflection - measured by either the average luminance coefficient Q0 or the luminance coefficient under diffuse illumination Qd.

S1 is the ratio r_2/r_1, while Q0 and Qd are derived by means of these linear expressions in r_1 and r_2:
Q0 = (0,957×r_1+ 0,746×r_2 + 104,5)/10.000,
Qd = (0,981×r_1+ 0,323×r_2 + 86,1)/10.000.

It is recommended that Qd is used as the measure of average reflection for these reasons:
* the Qd value is determined with a smaller uncertainty than the Q0 value (refer to the above-mentioned note),
* reference Qd of samples can be determined by diffuse illumination as obtained in a photometric sphere, while it is very difficult to obtain reference Q0 values,
* Qd is probably a better measure of the average reflection of road surfaces in road lighting conditions, in particular for road lighting with cut-off luminaires.

The reduced luminance coefficient is defined by:
r = q×$\cos^3$(γ)×10.000,
where   q is the luminance coefficient,
and   γ is the entrance angle.

The multiplications with 10.000 and $\cos^3$(γ) are conventional and serve to provide convenient numerical values.

As also accounted for in annex A, r_1 is defined by illumination perpendicular to the road surface and can be measured with fairly large angular spreads of illumination, while r_2 is defined by illumination from the front at an entrance angle γ of 63,4° (tanγ = 2). The value of r_1 can be measured with fairly large angular spreads of illumination, while the value of r_2 must be measured with angular spreads of a few degrees only.

The measurements are carried out at an observation angle of 1°, which is measured between the central direction of measurement and the road surface.

This note describes a prototype instrument, which is intended for the measurement of the values of r_1 and r_2, of the road surface on which it is placed.

The measured field and the measuring system are introduced in section 2, the illuminations systems in section 3, stability of measurements in section 4, calibration in section 5, handling images from the camera in section 6, the cabinet in section 7 and use of the prototype instrument in section 8.

The measuring system of the prototype instrument is based on a luminance camera; the LMK mobile advanced from the German company TechnoTeam.

The use of a camera has the disadvantage that a fairly long optical measuring distance is needed. This has been provided by means of a "tower" protruding from the cabinet on which the camera is mounted.

However, use of the camera also has some advantage, in particular that the length of the measured field can be adjusted and that the position of the camera on top of the "tower" can be changed. This allows for measurement of fairly short samples, and also for setting the observation angles in the range from 1° to 3°.

It is foreseen that a possible commercial version of the instrument will use a collimating luminance meter, which allows for more easy use of the instrument and smaller dimensions. In particular, the "tower" can be avoided.

A new cabinet will also be needed. However, this should not be too difficult as all the necessary measures are supplied in this report.

The prototype instrument has so far been used for the samples listed in table 1.

Table 1: Values obtained for some samples.

Samples	Description	r_1	r_2	S1	Qd	Q0
Asphalt concrete	Thin asphalt on local road	380	206	0,542	0,053	0,062
HS route antiskid black	Black thermoplast	215	190	0,885	0,036	0,045
HS route antiskid grey	Grey thermoplast	648	396	0,611	0,085	0,102
LTL No. 83	White stones in the surface	1021	151	0,147	0,114	0,119
LTL No. 289	Dark worn asphalt concrete	318	680	2,139	0,062	0,092
White panel	White	1980	256	0,129	0,211	0,219
AC-O-4	Grey, worn	429	696	1,622	0,073	0,104
SMA-O-3	Dark, worn	278	388	1,394	0,048	0,066
AC-N-1	Dark, new	239	378	1,580	0,044	0,062

The sample HS route antiskid black is a black thermoplast with a relatively strong texture and black antiskid aggregates in the surface.

The samples LTL No. 83 and LTL No. 289 are samples surviving from a large collection at the former Danish lighting laboratory. Their measured values are found in the LTL report No. 10 "Road surface reflection data", the Danish lighting laboratory 1975.

The white panel is mentioned in section 5. It was intended for calibration, but turned out not to have suitable properties for that.

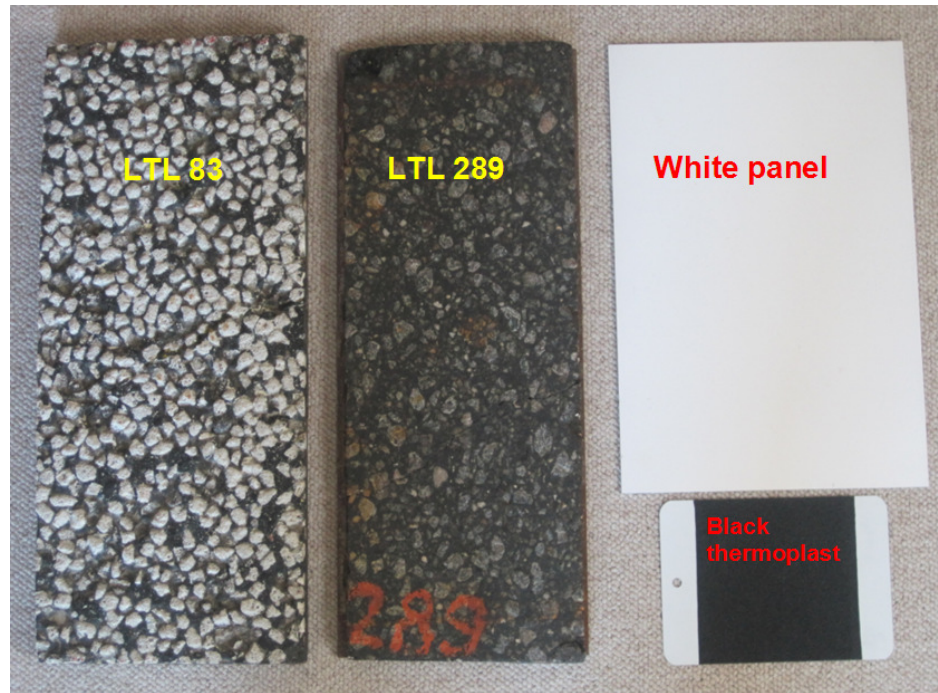The above-mentioned samples are shown in figure 1.

Figure 1: Four samples.

Note 1: The measured values for the samples LTL No. 83 and LTL No. 289 are given below. As these data were measured more than 40 years ago, the properties of the samples may have changed so that is it not reasonable to compare to the values in table 1.

Samples	Description	r_1	r_2	S1	Qd	Q0
LTL No. 83	White stones in the surface	1058	135	0,13	0,119	0,13
LTL No. 289	Dark worn asphalt concrete	338	351	1,04	0,057	0,083

The other samples were made available by Xu Zeng, Philips in China with the purpose of comparing measured values.

Note 2: Xu Zeng has himselves obtained the following values.

Samples	Description	r_1	r_2	S1	Qd	Q0
AC-O-4	Grey, worn	370	516	1,40	-	0,090
SMA-O-3	Dark, worn	218	302	1,38	-	0,053
AC-N-1	Dark, new	213	230	1,08	-	0,048

The only measured values in table 1 are r_1 and r_2. S1 is the ratio r_2/r_1. Qd and Q0 are derived by the above-mentioned linear expressions in r_1 and r_2.

The r_1 and r_2 values provided in table 1 are measured for the standard value of the of the observation angle of 1,0°. These values have also been measured for an observation angle of 1,5°. The two sets of values are fairly close to each other.

The author thinks that the principles of the prototype instrument are sound and that it is ready for use. It has been planned to circulate it for measurements of selected road surfaces in the Nordic countries of Denmark, Finland, Norway and Sweden. This will probably take place during the Spring of 2017.

2. The measured field and the measuring system

The prototype instrument has feet that define a plane containing a measured field, whose size and position is defined by the measuring system. The feet and the measuring system need to be held firmly into position relative to each other in order to maintain the size and the position of the measured field. This applies also for the illumination systems introduced in the next section.

In a final version of the instrument, the measuring system would be a collimating luminance meter with a mirror at the bottom close to the road surface. Such luminance meters are used in for instance retroreflectometers for road markings such as the LTL-X produced by DELTA Light & Optics.

It is a characteristic of a collimating luminance meter that it is placed close to the measured field so that dimensions of the prototype instrument can be relatively small. It is another characteristic that the lens of the luminance meter must be larger that the width of the measured field.

However, the measuring system of the prototype instrument is based on a luminance camera; the LMK mobile advanced from the German company TechnoTeam. This camera cannot be used as a collimating luminance meter, as the lens – rather the entrance pupil of the lens – is not sufficiently large. The camera must therefore be placed at a sufficient optical distance from the measured field in order to keep the angular spreads of measurement within acceptable limits.

The measuring system includes a mirror close to the road surface with an inclination of approximately 45°. The camera is placed above the mirror and aims at the road surface through the mirror.

The camera is used with these settings:
   a. full zoom corresponding to a focal width of 50 mm, so that there is a high resolution of the road surface,
   b. manual focus on the road surface at a distance of a bit less than 2 m so as to obtain a good sharpness of the image at the road surface,
   c. the maximum aperture number of 22, so that the entrance pupil of the camera lens is small and leads to a good depth sharpness of the image,
   d. manual mode with a setting of the exposure time to 1/8 second in order to obtain a proper exposure of the image,
   e. an exposure delay of 2 seconds to avoid that the image is shaken.

Settings a. and b. are to be checked for each exposure as handling the camera easily leads to changes.

Note: The camera is used for other purposes with an additional setting to full dynamic range, which leads to the exposure of three images with respectively 0,25, 1,00 and 4,00 times the requested exposure time. These images are later turned into a single image with a dynamic range that is 16 times the dynamic range of a single image. However, the dynamic range obtained in a single image of approximately 1:2000 is sufficient for this purpose.

The camera has 4.525.752 pixels placed in 1738 rows and 2604 columns. At full zoom with a focal width of 50 mm, the angular spacing between the pixels is 0,01028°. In total, the rows cover an angular range of approximately ±8,5°, while the columns cover an angular range of approximately ±13°

The measured field shows up as a small field within the camera image. The measured value is the average value of the pixels within this field.

The mirror is a hard coated front side mirror with a width of 72 mm and a height of 42 mm. It has been supplied by DELTA Light & Optics.

The total optical length from the camera lens to the centre of the measured field is approximately 175 cm.

The camera is aligned so that the direction to the centre of the measured field is 1°. With a length of the measured field of 20 cm, the measuring angle varies from 1,06° at the front end down to 0,95° at the back end. This means that the measured field in the camera image shall be only 11 pixels high.

This is actually the basis for aligning the camera and the mirror. The prototype instrument is placed on a panel with a white area of a length of 20 cm. Camera positions in the longitudinal directions are tried until the white area has a height of 11 pixels.

Figure 2 shows the camera image of a such a panel. The broad field is the main field that covers the measured field, while the small field is an additional field that has been introduced for the purpose described in section 4. The main field does fit into the length of 20 cm with a height of 11 pixels.

Figure 2: A panel with a white field.

The width of main field of the camera image determines the width of the measured field. A width of 140 pixels provides a width of the measured field of approximately 4,4 cm. The side angle within this width varies by $\pm 0,72°$

3. The illumination systems

There are individual illumination system for the two r-values, r_1 and r_2.

Both illumination systems use halogen low voltage reflector lamps of the type 12V/20W/GU 5.3 from Philips. These are probably the standard lamps with the most narrow beam on the market and have the advantages that they are driven by an ordinary 12 V sealed lead battery, and that the spectral composition is close to the standard illuminant A as prescribed for measurements of road reflection properties.

The use of these lamps was supposed to be intermediate until suitable LED panels could be obtained. However, it seems to be difficult to find suitable LED panels, and the halogen lamps are used in a manner - as described in the following - that can serve as a permanent solution.

The illumination system for r_1 has five lamps aimed vertical downwards in a longitudinal row directly above the centre line of the measured field at a height of 50,2 cm above the road surface (measured to the fronts of the lamps). The spacing between the lamps is 98 mm and the position is so that the middle lamp is placed at a small distance of 3,6 cm in front of the centre of the measured field.

As the nominal beam width is 8°, it was thought that the lamps would provide an illumination of the measured field with an acceptable uniformity.

However, the illumination pattern did actually show isolated spots from each of the lamp. Additional non-uniformity is caused by differences in the aims of the lamps, as the aims are not firmly fixed by the sockets.

Both of these problems are solved in the way shown in figure 3. The fronts of the lamps are brought into contact with a glass that introduces a spread of the light of approximately $\pm 5°$. The contact dictates the aim, and the spread softens the illumination pattern. The glass does cause a raise of the beam width, but there is sufficient tolerance for this when measuring r_1.

5 mm raw glass with texture on the upper face (Pilkinton English)
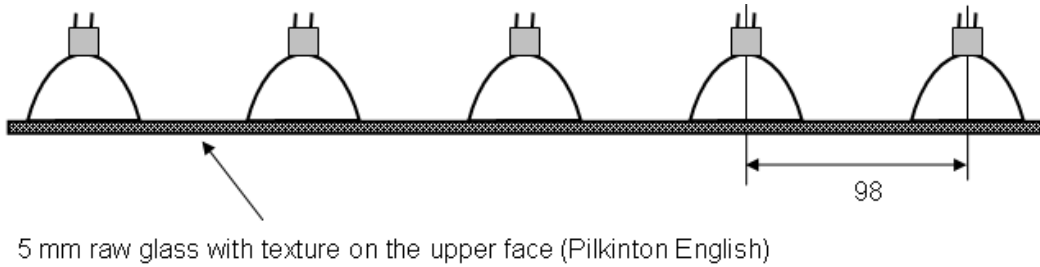
Figure 3: Illumination system for the measurement of r_1.

The illumination system for he measurement of r_2 is shown in figure 4.

20 mm wide brackets bent to the indicated angle
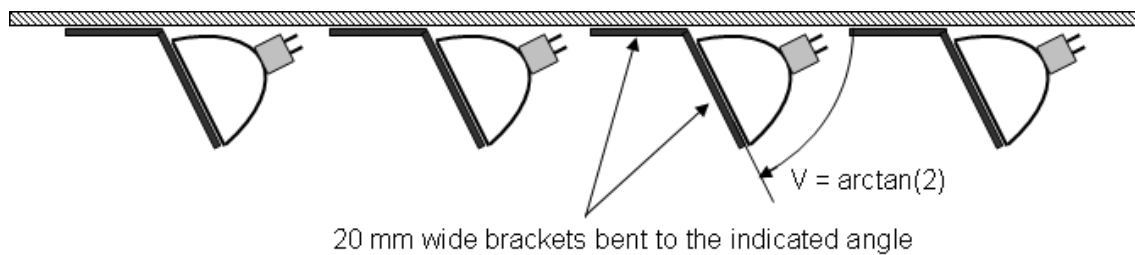
Figure 4: Illumination system for the measurement of r_2.

This illumination system has four lamps aimed at the proper angle in a row at a height of 53 cm above the road surface (measured to the centre of the fronts of the lamps). The spacing of the lamps is 11,2 cm.

The aim of the lamps is secured by contact with brackets which also – because of their width – secures that the aim lies the vertical plane.

The brackets hide a substantial part of the fronts of the lamps and, thereby, reduces the luminous output. This on the other hand, causes a strong reduction of the beam width in the vertical plane, actually from the nominal $\pm 8°$ down to $\pm 2°$ or $\pm 3°$. This makes the illumination suitable for the measurement of r_2.

The lamps in the illumination system for r_2 illuminate the measured field by means of a mirror that sits at the front of the prototype instrument and is rotated by $5°$ about a vertical axis. This mirror is an ordinary mirror; it has a height of 30 cm and a width of 10 cm. Its centre is 24 cm above the road surface and 45,7 cm in front of the centre of the measured field.

Because of the rotation of the mirror, the lamps are placed in a line that is turned $10°$ relative to the direction of measurement.

Accordingly, the lamps do lie in the vertical plane through the direction of measurement when viewed through the mirror. The optical distances from the centre of the measured field are respectively 93,2; 104,4; 115,6 and 126,8 cm. This can be compared to the above-mentioned distance to mirror of 45,7 cm and shows that the mirror allows a reduction of the length of the prototype instrument by more than 80 cm.

The aims of the lamps, as seen though the mirror, meet the centre line of the measured field at -12,8; -14; 10,0 and 21,3 cm relative to the centre (minus means to the back and plus to the front of the centre). The average of these values is 4,3 cm. Accordingly, both of the two lighting systems provide illumination that is not symmetrical about the centre, but shifted a bit in the forward direction.

This is on purpose, as the illumination must have some reserve in the longitudinal direction for the reason that curve and texture of the road surface, and small particles on the road, tend to cause lifts and tilts of the prototype instrument. As an example, a lift of the prototype instrument of 1 mm would make the measured field move 5,7 cm forwards.

The r_1 illumination system provides illumination of more that 10.000 lx, while the r_2 illumination system provides approximately 2.000 lx.

4. Stability of measurements

The levels of illumination by the two illumination systems will not remain constant for a number of reasons – in particular because of changes in the voltage of the battery that feeds the lamps.

Therefore, a white plate has been introduced at the bottom of the prototype instrument next to the measured field. This plate – as well as the measured field itself – is illuminated and its luminance is used as a measure of the level of illumination. The camera image has an additional field for that as seen in figure 1.

Accordingly, the measured value is the ratio between the luminance of the main field and the luminance of the additional field. The r value, either r_1 or r_2, is obtained as this ratio multiplied by a calibration factor.

The plate is a thin steel plate painted on the upper face with a white matt paint. The upper surface is approximately 2 mm above the road surface. It is located as shown in figure 5.

Figure 5: Location of a white plate next to the measured field.
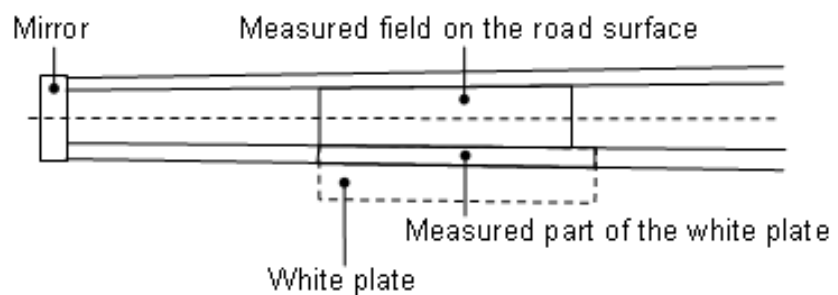
In spite of the matt finish of the paint of the steel plate, it turns out that the surface has a fairly strong specular reflection at the low angle (a bit less than 1°) at which its luminance is measured. This causes some disadvantage in the sense that the luminance varies over the measured part, depends on the actual angle of measurement and may be variable over time.

Therefore, an opal plastic plate of a thickness of 2 mm has been placed over the steel plate forming a wedge as shown in figure 6. Additionally, the sides of the wedge have been closed by white walls as also shown in figure 6.
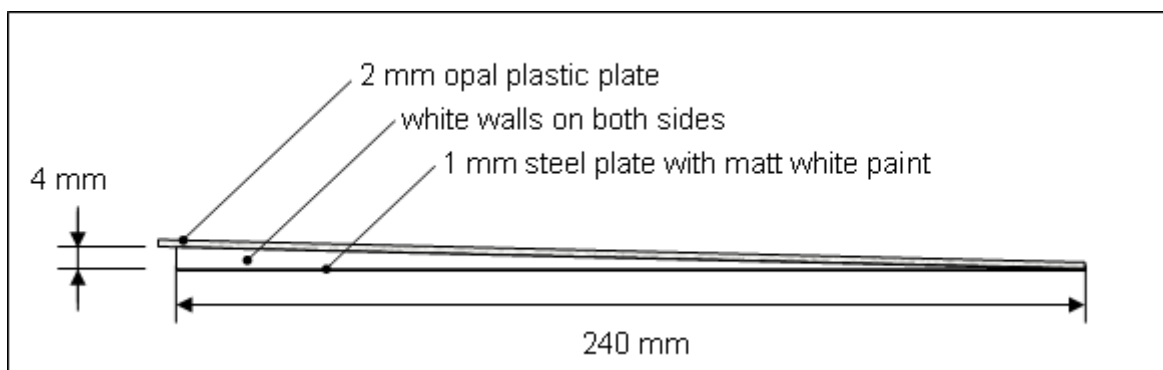
Figure 6: Wedge formed by a white steel plate and an opal plate.

The opening of the wedge does not show any specular reflection, and has a uniform luminance in a durable manner.

The wedge is fixed to the right hand side of the cabinet by means of two right angle brackets each held by two machine screws. It can be dismounted by removing these screws.

5. Calibration

5.1 General

The prototype instrument needs to be calibrated for both of the two measurements, of r_1 and r_2, that it performs.

The luminance coefficient of the road surface or sample to be measured is given by:
$q = L/E$

where   L is the luminance of the measured field,
and   E is the horizontal illuminance on the measured field.

Once the value of the luminance coefficient has been determined, the value of the reduced luminance coefficient can be determined by means of its definition $r = q{\times}\cos^3(\gamma){\times}10.000$. This gives:
$r_1 = 10.000{\times}q$,
$r_2 = 894{\times}q$.

In practice, calibration leads to a calibration constant C. In the following subsections, it is discussed how the calue of C can be derived in different calibration procedures. This value has eventually to be multiplied by either 10.000 or 894 for respectively r_1 and r_2, so that the r values are obtained directly.

5.2 A fundamental method of calibration

The definition of the luminance coefficient points to an obvious way to provide a calibration, namely to assure that the values of the luminance L and the illuminance E are both determined in calibrated manners.

The luminance L is provided by the main field in the camera image. The camera itself is calibrated, but as the image is seen through the 45° mirror at the bottom of the prototype instrument, the calibration has to be redone taking the loss in the mirror reflection into account.

The procedure is then to measure the illuminance E with a calibrated luxmeter. When doing this, is it practical that the prototype instrument is laying on the left side.

Shortly thereafter, before the illuminance changes, an image is exposed with the relevant illumination system turned on. In this image, the luminance of the additional field covering the opening of the wedge described in the previous section is dermined. This luminance is called $L_{wedge\ initial}$ in the following.

In later measurements the illuminance E may have changed to a different value called $E_{current}$. Simultaneously, the luminance of the additional field have changed in the same proportion to $L_{wedge\ current}$. Accordingly, $E_{current}$ can be determined by:

$E_{current} = E{\times}L_{wedge\ current}/L_{wedge\ initial}$

The luminance coefficient is determined by:

$q = L/E_{current} = (L_{wedge\ initial}/E){\times}(L/L_{wedge\ current}) = C{\times}(L/L_{wedge\ current})$

In this expression C is the calibration constant that does not depend on the actual illuminance (both terms in C are initial values), while the ratio $L/L_{wedge\ current}$ may be considered as the measured value.

This method has been used a couple of times. It has the difficulty that the camera has to be recalibrated – which is not easy. Additionally, the illuminance is not perfectly uniform over the measured area, so that E has to be derived as the average over a number of locations within the measured field – which has to be done quickly or the values will start decreasing. Further, the method is time-consuming and, therefore, not well suited for retesting of the calibration.

5.3 Calibration by means of a panel with known r_1 and r_2 values

If a panel with known values of r_1 and r_2 is available, calibration is quite easy.

The method is to take two images of the panel, with either r_1 or r_2 illumination. For each of the images, the ratio $L/L_{wedge\ current}$ is determined and the calibration constant C is set so that $C \times (L/L_{wedge\ current})$ results in the known value of either r_1 or r_2.

One attempt to establish such a panel has been to apply paint of the type used for the interior of photometric spheres in several layers on an aluminium substrate. The purpose is to achieve a panel with ideal diffuse reflection to the degree that the luminance coefficient is independent of the directions of illumination and measurement.

However, at small values of the observation angle, the luminance does decrease gradually with the actual value of the observation angle. This shows that the panel does not have the desired property of ideal diffuse reflection. The author doubts that it is possible at all to produce such a surface.

Note: The above-mentioned panel is the white panel, whose measured values are provided in table 1. The reflectance in the 45/0 geometry is 0,88, so that diffuse reflection would result in the value of r_1 of $0,88 \times 10.000/\pi = 2801$, a value of r_2 of $r_1 \times \cos^3(\arctan(2)) = r_1 \times 0,0894 = 251$ and a value of S1 of 0,089.

The values indicated in table 1 are respectively 2080, 180 and 0,089 and correspond to diffuse reflection with a reflectance of only 0,65.

The reason for this loss is probably that the measuring beam is partly reflected below the lamps in a kind of specular reflection. This in itself is a deviation from diffuse reflection, which makes the measured values depend on the observation angle.

5.4 Calibration by means of a wedge

An additional wedge like the one shown in figure 6 has been made. This wedge has the width of the normally applied measured field of 4,5 cm and a length of 24 cm. The height of the opening is 12 mm. This wedge - as seen in the camera image - is shown in figure 7 together with the in-built smaller wedge.

Figure 7: A large wedge as seen in the camera image with a field placed over the bottom plate of the wedge.

A field placed over the bottom plate of the wedge

Large wedge   Small in-built wedge with its own field
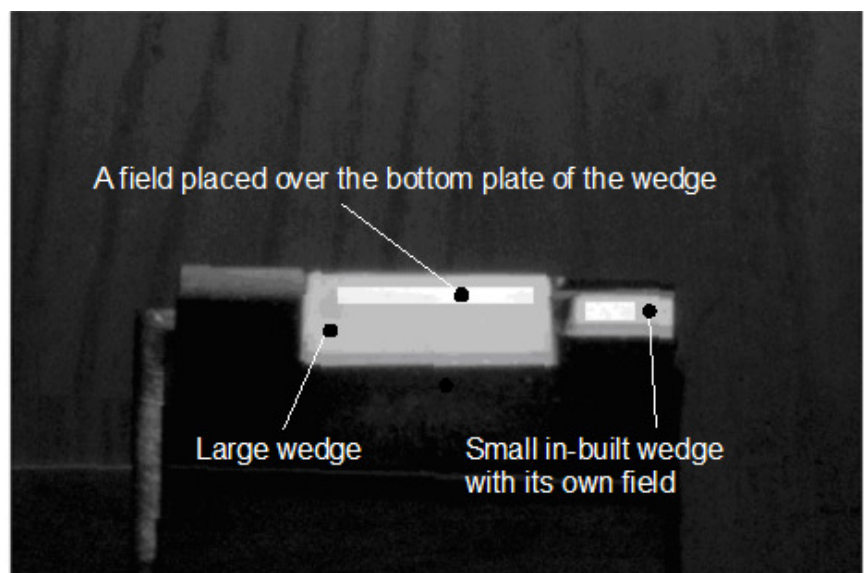
Note: The image in figure 7 is shown with an orientation as if facing forwards and looking into the mirror from the top of the "tower" of the prototype instrument.

In the mirror image, upwards is seen as downwards and vice versa. This is why the bottom plate of the large wedge is seen at the upper part of the mirror.

Additionally, the small in-built wedge is placed with its bottom plate approximately 2 mm higher that the bottom plate of the large wedge and is, therefore, seen at a lower position in the image. The height difference is approximately 8 pixels.

This wedge has the advantage that the bottom plate shows a luminance with a high degree of uniformity and with little variation with the actual observation angle.

The luminance of the bottom plate can, therefore, be measured with a luminance meter to a good accuracy at a convenient observation angle of for instance 2° or 3° and applied also for the observation angle of 1°. Additionally, the horizontal illuminance at the location of the bottom plate is measured with a luxmeter.

The ratio between the luminance and the illuminance is the luminance coefficient of the wedge. This luminance coefficent has been determined to be 0,248 for the illumination direction of r_1. Accordingly, the wedge has an r_1 value of $r_1 = 0{,}248 \times 10.000 = 2480$.

The value of r_2 can in principle be determined in the same manner. It would become $r_2 = \cos^3(\arctan(2)) \times r_1 = 0{,}08944 \times 2480 = 222$ if the same value of the luminance coefficient could be used for the r_2 illumination. However, the actual value of the luminance coefficient is lower for the r_2 illumination.

Therefore, the luminance coefficient would have to be measured for the r_2 illumination as well. This turns out to be difficult unless laboratory facilities are available.

Instead, the average illuminance values of the measured field for both illumination systems in the prototype instrument have been determined and used to determine the calibration value for r_2. It turns out to be 210.

Some details are as follows. The two q values are given by:
$q_1 = L_1/E_1$
$q_2 = L_2/E_2$
      where q_1 and q_2 are the luminance coefficients of the wedge in the two illuminations,
               L_1 and L_2 are the luminance values of the opening of the wedge in the two illuminations,
      and E_1 and E_2 are the average illuminance values in the two illuminations.

The ratio between the two equations is:
$q_2/q_1 = (L_2/L_1) \times (E_1/E_2)$

Which leads to:
$q_2 = q_1 \times (L_2/L_1) \times (E_1/E_2)$

In this equation, q_1 is known.

The values of L_1 and L_2 appear in the camera images. It is best to determine these values twice, first in the sequence L_1 - L_2 and then in the sequence L_2 – L_1 and use the average values of each. The advantage of this procedure is that compensates for a gradual loss of voltage from the battery.

The ratio E_1/E_2 has also to be determined.

To do that, a number of locations within the measured field are selected. The luxmeter is held at the first location, the r_1 illumination is turned on, the illuminance is measured, the r_1 illumination is turned off, the r_2 illumination is turned on, the illuminance is measured, and the r_2 illumination is turned off.

This is done for all the locations, and the E_1 value is determined as the average of the illuminance values for r_1 illumination, while the E_2 value is determined as the average of the illuminance values for r_2 illumination.

The advantage of this procedure is that E_1 and E_2 values are determined shortly after each other, so that the ratio is not much influenced by gradual loss of voltage from the battery. In practice, the number of locations can be small.

6. Handling images from the camera

Images are converted to tables of pixels values as described in "Bilag A: Optagelse af billeder med et digitalt luminanskamera og fremstilling af en måletabel" in the note "Et regneark til beregning af luminans, blænding og lysstyrke", Kai Sørensen, 9. februar 2016 (in Danish, available on nmfv.dk). The table can then be inserted into an excel file and analyzed as also described in the note.

The above-mentioned note concerns an excel file that can be used in combination with the camera to provide values of luminance, glare and luminous intensity in road scenarios. This excel file has been modified for this purpose in the sense that matters relating to glare, luminous intensity and some aspects of luminance have been deleted, while a second field has been introduced in addition to the main field as accounted for in section 4.

The main page of this excel file is shown in figure 8.

Figure 8: Main page of the excel file.

The page has two images, one for overview and one for detail. The image for detail has the full pixel resolution and is the one to pay interest to.

This image shows two fields that are being promoted by having a higher luminance. The wide field is the main field (field 1) that defines the measured field, while the smaller field is an additional field (field 2) intended to be placed on the bottom plate of the in-built small wedge.

Additionally, a number of values can be set:
  a. The value for zoom should generally be 1, meaning that the camera is used at full zoom (a focal width of 50 mm).

b. The values for grey scale do not have any influence of the results, but can be modified in order promote various aspects of the images.

c. Changes of the values for "move up/right" cause the detail image to move relative to the two fields. An increase of the "move up" value, makes the detail image move up, while an increase of the "move right" value makes it move right. The values should be selected so that the additional field (field 2) fits into the upper left part of the opening of the in-built wedge, which is normally easily to discriminate in the image. The location of the main field (field 1) should then be accepted.

d. The values for "width/height" decide the dimensions of the main field (field 1). The values should normally be 140 and 11. However, the value for the height needs to be reduced, when measuring samples of a length less than 20 to 25 cm. Additionally, if the camera has been moved in the longitudinal direction so as to produce a higher observation angle, the value for the height can be raised accordingly, so as to keep the length of the measured field.

e. The value for "move up" of the additional field (field 2) determines the height location of this field relative to the main field (field 1). This value should normally be -8, as this places the measured field on a surface in the plane defined by the feet of the prototype instrument safely within the illuminated field. It may be considered to change this value, if the road surface or sample is not in this plane – for instance because of curve of a road surface. If so, the "move up" value has to be modified to bring the additional field (field 2) back into the proper height location.

f. The normal value for "rotation" is 270°, but can be changed a bit if this makes the image fit better to the pattern of the fields.

Note: Figure 8 shows the surface of the sample LTL No. 83 with white stones in the surface, refer to table 1. For this particular sample, the measured value depends on the observation angle, because a black bottom between the white stones becomes increasingly visible at higher observation angles.

This is clearly seen in the detail image of figure 8, where the black bottom takes up more of the area at short distances (upper parts of the image corresponding to an observation angle slightly above 1°) than at long distances (lower parts of the image corresponding to an observation angle slightly below 1°).

However, when the sample surface is located in the plane defined by the feet of the prototype instrument, an average value of the observation angle of 1° is obtained if keeping the "move up" value mentioned in item e. at -8.

Most surfaces do not show such variation with the observation angle.

The dimensions of the additional field (field 2) cannot be changed and it cannot be moved sidewise relative to the centre of the main field, as this should not normally be necessary. However, changes can be set in a different page.

It is practical to open and work in two excel files, one for r_1 and the other for r_2, so as to ensure that the pattern of the fields are placed in the same manner in both excel files (the "move up/right" values should be the same).

For this reason, the excel file exists in two versions, for r_1 and r_2. Each of these has the relevant calibration factor and supplies the relevant value of r_1 or r_2 in addition to the average values of the two fields. These output values are given with a red font.

7. The cabinet of the prototype instrument

The cabinet is built in 9 mm plywood of a good quality. It is a box with the modifications mentioned below.

The front is turned 5° about a vertical axis, so that the mirror in the illumination system for r_2 can be mounted directly on the inside.

The top has some slope so as to provide space at the back for the 12 V sealed lead battery that feed the lamps. The top is a hinged lid with a handle and a buckle bracket. It serves as an entry to the battery and a horizontal panel just below the lid with the illumination systems on lower face and electrical wires on the top face.

The battery has a capacity of 3 Ah, while the illuminations systems for r_1 and r_2 use respectively 8,3 and 6,7 A. This does not leave much time with the light on, but is sufficient as a measurement takes a few seconds only. The battery should be fully charged before a series of measurement.

The back part of the box has a "tower", on which the camera is mounted in a well defined position. The "tower" serves only to provide enough optical distance for the camera and is not needed if the camera is replaced by a collimated luminance meter in a final version of the instrument.

The feet of the prototype instrument are strong right angle brackets in stainless steel that are mounted with bolts and stick approximately 1 mm down under the cabinet. One is at the back, and serves also as a mount for the mirror in the measuring system. The other two are at the sides, approximately at the front end of the measured field.

There are two switches on the right side of the cabinet to turn on/off the two illumination systems.

There are no particular measures to prevent intrusion of daylight into the prototype instrument. However, this is not a problem, because the cabinet leaves a gap of only 1 mm above the surface, and because the illumination systems provide illumination measured in thousands of lux.

The r_1 illumination system places by far the most of its light on the road surface at about the measured field and on the white wedge just above the road surface. Some of this light will be reflected onto the black interior surfaces and a bit of this light with be reflected again to add some illumination on the measured field and the white strip. This reflected light has a different directionality than the direct illumination, but can be ignored, being less than 1 % of the direct illumination.

The r_2 illumination system places most of its light in the same way through reflection in the mirror at the front surface. However, some light is placed at the front surface under the mirror and could – to the degree that it is reflected - raise the luminance of the measured field by specular reflection in the road surface. This, however, is avoided by means of black horizontal panel placed under the mirror over the width of the box.

The overall dimensions are a length of 95 cm, a width of 42 cm and a height of the sloping surface from 53 cm to 68 cm. The "tower" reaches op to a height of 140 cm.

All inside parts are painted black with a matt finish. Outside surfaces are painted grey with a matt finish.

The prototype instrument is not heavy, but a bit akward to handle because of its size and shape. It can be carried in balance by means of the handle on the top lid, and it can be moved like a hand truck by means of two wheels mounted low at the back and another handle mounted high.
There is a protective bottom that can be fixed to the instrument by means two buckle brackets at each of the two sides.
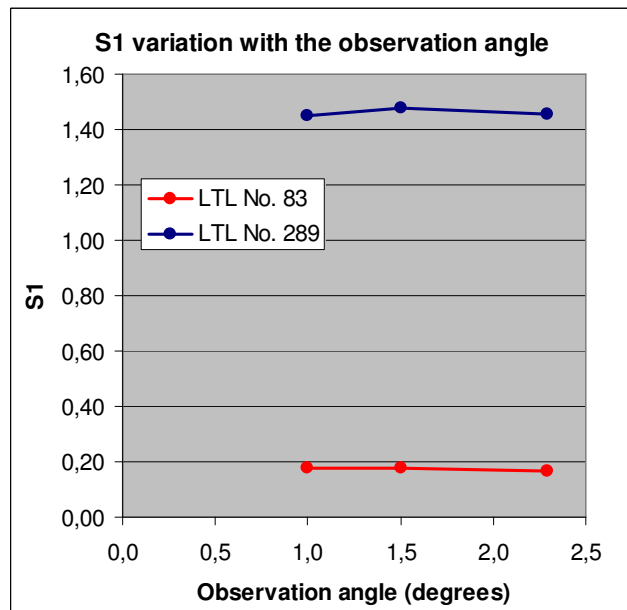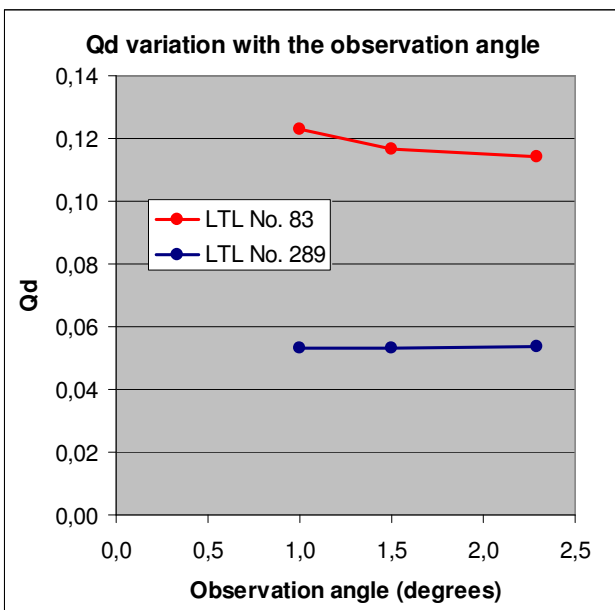
Figure 9 shows the prototype instrument with a camera mount placed on the top of the "tower". The mount can be placed in the locations corresponding to observations angles of 1,0°, 1,5° and 2,29°. The value of 1,0° is the standard value for road surfaces, while 2,29° is the standard value for road markings. The value of 1,5° has been added at an intermediate value.

The diagrams in figure 10 show the Qd and the S1 values at the three observation angles for the samples LTL No. 83 and LTL No. 289.

The Qd value decreases somewhat with increasing observation angle for the sample LTL No. 83. The reason is that this sample has white surface stones that fill more of the view at 1,0° and less at the higher values of the observation angle. For the sample LTL No. 289, the Qd value is constant. Additionally, the S1 values are roughly constant for both samples.

This illustrates that the reflection properties do normally not change much with the observation angle.

Figure 9: The prototype instrument with the camera mount at the top.

Qd variation with the observation angle

LTL No. 83
LTL No. 289

Qd

Observation angle (degrees)

S1 variation with the observation angle

LTL No. 83
LTL No. 289

S1

Observation angle (degrees)

Figure 10: variation of Qd (left) and S1 (right) with the observation angle for two samples.

8. Use of the prototype instrument

The protective bottom should be fixed to the prototype instrument during transport and the camera should be placed in its box. It is most easy to mount/demount the protective bottom, when the instrument is lying on its back surface.

Before use, it should be verified that the optical components are clean:
- the camera lens,
- the two mirrors,
- the wedge next to the measured field.

It is best to place the prototype instrument on a side or the back, when inspecting the two mirrors and the wedge.

The camera lens and the 45 mirror at the bottom are sensitive and should be cleaned with care and suitable agents. The mirror at the front, on the other hand, is an ordinary mirror and durable.

The top surface of the wedge is accessible for cleaning, while the interior is narrow and can be cleaned only by the use of a long and thin brush.

Further, the battery should be charged by using a 12 V battery charger (that comes with the prototype instrument). This may take hours or - if the battery is flat - even longer.

The camera is to be mounted in the holder and to be given the settings that are listed in section 2.

The prototype instrument is to be placed on the road surface to be measured so that the measured field is at the desired location.

As accounted for in section 2, the measured field has the dimensions of 4,4 times 20 cm, when using a field in the camera image of 140 times 11 pixels. Additionally, the centre of the measured field is located as shown in figure 11.
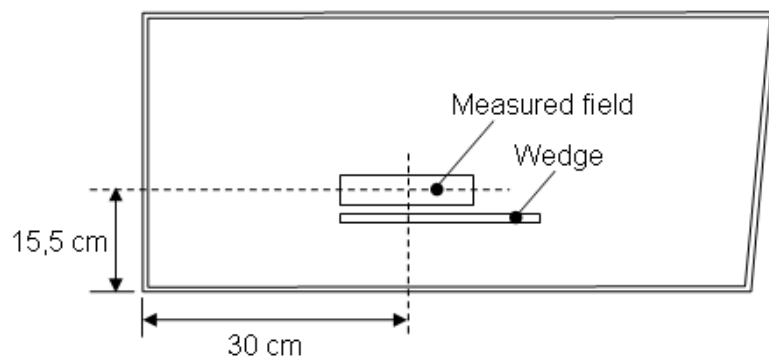
Figure 11: The location of the measured field.

Due to the relatively small area of the measured field, the measured values of r_1 and r_2 may be subject to random variations. This would in particular apply for road surfaces with large stones. Therefore, it should be considered to measure at two or three nearby positions, and let the average values of r_1 and r_2 for these positions represent the road surface.

In case a sample is to be measured, it is practical to mount the sample in a table as shown in figure 12. The table is to be placed on a plane surface, and the sample is to be aligned so that its upper surface lies in the plane of the top surface of the table. Measurements are done with the prototype instrument placed on the table. In case the sample is shorter than 20 cm, the height of the small field in the camera image must be reduced and perhaps moved a bit, so that it fits within the surface of the sample.

Figure 11: A table to be used for the measurement of samples.
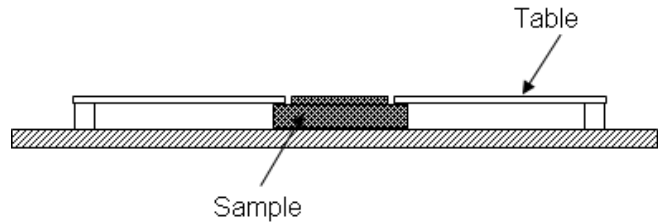
EXAMPLE: A table with the dimensions given in the drawing below was used for the samples AC-O-4, SMA-O-3 and AC-N-1 included in table 1. The prototype instrument was placed with its back edge at the back edge of the table. Most of the width of the sample surfaces was covered by moving the prototype instrument sidewise in steps. Due to the length of the sample surface of 17 cm, the height of the small field in the camera image was reduced.

The sample was later given one more opening and used also for the samples LTL 83 and LTL 289 that are also included in table 1.
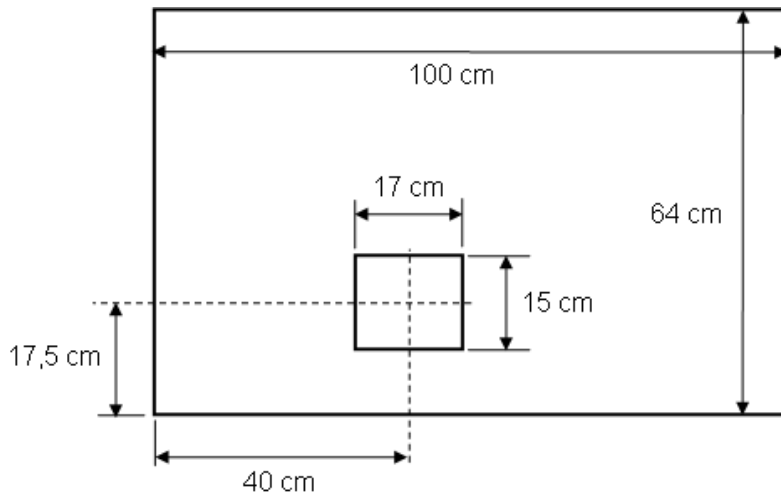
The camera in its holder should not be mounted on the top of the prototype instrument until it is placed at the measuring location, either on a road surface or on top of a table. Check before each exposure that the focus (a bit less than 2 m) and the zoom (maximum zoom of f equal to 50 mm) has not been changed by handling.

The camera is then turned on and the following sequence is carried out:
illumination system 1 is turned on,
an image is exposed,
illumination system 1 is turned off,
illumination system 2 is turned on,
an image is exposed
illumination system 2 is turned off.

The sequence takes only about 15 seconds.

Before or after a series of measurements, the calibration wedge may be measured. The prototype instrument is placed on a plane surface and the calibration wedge is placed next to the in-built wedge, so that it covers the measured field.

After a series of measurements, the images are handled like described in section 6. This is somewhat time consuming as each pair of images for r_1 and r_2 may take about 5 minutes.

The r_1 and r_2 values of the calibration wedge should be close to the values of respectively 2480 and 142 provided in section 5. If not, it may be considered to rescale all measured values accordingly.

Annex A: Some principles for in situ measurement of road surface reflection properties

A.1 Introduction

Road surface reflection properties are introduced in A.2.

Among else, it is stated that a road surface can be characterized by its average reflection and a measure of its degree of specular reflection. The average reflection can be indicated by the average luminance coefficient Q0 or the luminance coefficient in diffuse illumination Qd. The degree of specular reflection, on the other hand, is indicated by the specular factor S1, which is the ratio between two individual reflection values called r_1 and r_2.

In A.3 it is shown that Q0 and Qd can be estimated on the basis of r_1 and r_2. This provides the possibility of basing in situ measurement of road surface reflection properties on the measurement of those two reflection values only.

The principles of a portable instrument for in situ measurement are discussed in A.4. It is shown that it is permissible to use illumination with rather large angular spreads for the measurement of r_1, while the angular spreads of illumination must be small, when measuring r_2.

A.2 Road surface reflection properties

The reflection of a road surface can in principle be described by means of values of the luminance coefficient q, which is given by:

Q = L/E

where   L   is the luminance produced by illumination,
and   E   is the illuminance on the plane of the road surface.

The unit for q is $cd \cdot m^{-2} \cdot lx^{-1}$.

A value of q depends on the geometry of measurement and illumination, which is defined by the angles shown in figure A.1:
- α is the angle of measurement/observation measured between the plane of the road surface and the direction of measurement observation,
- β is the side or azimuth angle measured between two half planes, both perpendicular to the plane of the road surface, and containing respectively the direction for measurement/observation and the direction of measurement,
- γ is the entrance angle measured between the normal to the plane of the road and the direction of illumination.

It is a tradition not to supply values of the luminance coefficient q directly, but to represent them by values of the reduced luminance coefficient r given by $r = 10.000 \times q \times \cos^3(\gamma)$ instead. This leads to convenient numerical values and some practical advantages for the calculation of road surface luminance in road lighting.

Figure A.1: The angles α, β and γ.
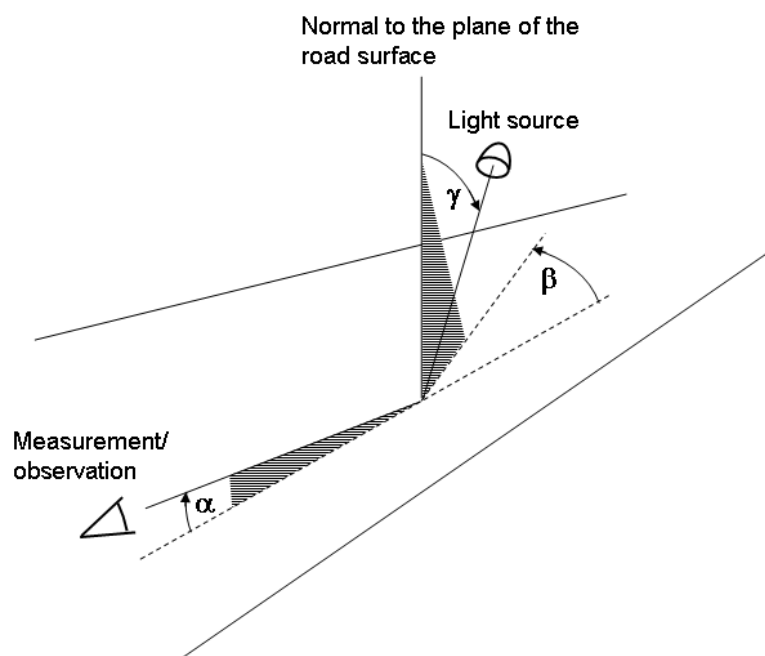
The value of the angle of measurement/observation is traditionally 1° corresponding to distances of 60 to 90 m for a driver of a passenger car. Because of this, it is sufficient to supply a table of r values with β and γ as parameters to describe the reflection properties of a road surface. Such a table is called an r-table.

An r-table is presented in a standard format as shown in table A.1.

The standard format has values of β from 0° to 180° only, as a symmetry about the plane 0°/180° is assumed. The standard format does not use γ directly as a parameter, but tan(γ).

Table A.1: Example of an r-table in a standard format.

Tan(γ)	β (degrees)																	
	0	2	5	10	15	20	25	30	35	40	45	60	75	90	105	120	165	180
0,00	*354*	354	354	354	354	354	354	354	354	354	354	354	354	354	354	354	354	354
0,25	391	391	390	389	388	385	381	378	373	369	365	351	338	328	319	313	304	304
0,50	406	404	403	397	390	379	366	355	343	330	318	291	268	256	247	242	240	240
0,75	405	403	399	384	365	342	319	298	278	260	244	213	192	182	176	175	177	177
1,00	396	392	384	357	322	287	254	228	207	189	175	147	133	126	124	123	129	130
1,25	383	374	360	317	269	227	193	168	149	134	123	103	93	89	87	89	95	96
1,50	360	351	328	270	215	172	141	119	105	94	86	72	66	63	63	64	71	72
1,75	335	325	294	224	165	127	102	86	75	67	61	52	47	46	47	48	54	55
2,00	*312*	298	259	182	126	94	75	63	56	50	45	38	35	35	35	37	42	43
2,50	270	250	199	120	76	53	43	35	32	28	26	23	22	21	22	23	28	28
3,00	233	206	148	78	46	31	26	21	19	18	17	15	14	14	15	16	19	20
3,50	202	171	109	51	29	20	17	14	13	12	11	10	10	10	11	11	14	15
4,00	177	142	82	35	20	13	11	10	9	8	8	7	7	7	8	8	11	11
4,50	155	118	61	24	14	10	8	7	7	6	6	5	5	6	6	6	8	9
5,00	137	100	47	18	10	7	6	6	5	5	5	4	4	5	5	5	7	7
5,50	121	84	37	13	8	6	5	5	4	3								
6,00	108	72	29	11	6	5	4	4	4									
6,50	97	62	24	8	5	4	4	3										
7,00	89	55	20	7	4	3	3	3										
7,50	81	49	17	6	4	3	3											
8,00	74	43	15	5	3	2	2											
8,50	68	38	12	4	3	2	2											
9,00	63	34	11	4	2	2												
9,50	58	31	9	3	2	2												
10,00	54	28	8	3	2	2												
10,50	51	26	7	3	2	2												
11,00	48	24	6	2	2	2												
11,50	45	22	6	2	1													
12,00	43	21	5	2	1													

The luminance coefficient q does not vary strongly at values of β of 5° or higher, corresponding to reflection of an approximately diffuse character produced by reflection in the surface material. However, because of the above-mentioned factor of $\cos^3(\gamma)$, the r-values decrease with tan(γ).

At small values of β, the r-values decreases more slowly with tan(γ) and reach in fact often a maximum before decreasing again. This corresponds to a steady increase of the luminance coefficient q with tan(γ) to high values. This feature is explained by specular reflections in the facets of the road surface.

In this way, an r-table can be understood as showing reflection of a diffuse nature overlaid with specular reflection. This is useful, but somewhat simplified as both types of reflection are distorted in the texture of the road surface.

An r-table is characterized by a measure for the average reflection and a degree of specular reflection expressing the balance between diffuse and specular reflection.

The average reflection can be indicated by the average luminance coefficient Q0 or the luminance coefficient in diffuse illumination Qd. Both have the unit of $cd \cdot m^{-2} \cdot lx^{-1}$.

Q0 and Qd can both be determined by means of weighted summation of the r-values of an r-table. The weights are so that the summation of Q0 is with more emphasis on specular reflection than the summation of Qd. For this reason, the value of Q0 is larger than the value of Qd.

The specular degree is indicated by the specular factor S1, which is the ratio between the r-values at $(\tan\gamma=2; \beta=0°)$ and $(\tan\gamma=0; \beta=0°)$. Those two values are promoted by fat types in table A.1 by and are designated r_1 and r_2 for the r-values at respectively $(\tan\gamma=0; \beta=0°)$ and $(\tan\gamma=2; \beta=0°)$ in the following.

An r-table can result from measurement on a road surface, or it can be a standard r-table. The following standard r-tables are in use:
- an N-series including N1, N2, N3 and N4,
- a C-series including C1 and C2,
- an R-series including R1, R2, R3 and R4.

These standard r-tables apply for dry road surfaces. For wet road surfaces, there is a W-series including W1, W2, W3 and W4 in use.

The values of Q0, Qd and S1 for the above-mentioned standard r-tables are shown in table A.2

Table A.2: Q0, Qd and S1 for standard r-tables.

Serie	Tabel	Q0	Qd	S1
N1-N4	N1	0,100	0,092	0,18
	N2	0,070	0,061	0,41
	N3	0,070	0,054	0,88
	N4	0,080	0,054	1,61
R1-R4	R1	0,100	0,087	0,25
	R2	0,070	0,057	0,58
	R3	0,070	0,050	1,11
	R4	0,080	0,052	1,55
C1-C2	C1	0,100	0,090	0,24
	C2	0,070	0,054	0,91

One intention behind the characterization with Q0/Qd and S1 is to make it sufficient to measure either Q0 or Qd and S1 for a given road surface, and then represent the road surface by one of the standard r-tables. This standard r-table is selected on the basis of the value of S1, and then rescaled to match the measured values of Q0 or Qd.

For the N series of r-tables, N1 is selected when S1≤0,50; N2 when 0,50<S1≤1,00; N3 when 1,00<S1≤1,50 and N4 when 1,50<S1. There are similar criteria for the C and R series of r-tables.

If, as an example, the measured Qd value is 0,08 and the standard r-table N2 with a Qd value of 0,07 has been selected, this table is to be rescaled with a factor of 0,08/0,07 = 1,143. However, it is more practical to use N2 as it is without rescaling, and instead rescale the luminance values resulting from calculations of road lighting.

**A.3 Estimation of Q0 or Qd on the basis of r_1 and r_2**

LTL report No. 10, "Road surface reflection data", the Danish lighting laboratory 1975 presents among else *r*-tables for 285 road surfaces and their values of Q0 and S1. These data are considered to be of a good quality and have been used for several purposes over the years – including the construction of the N- and C-series of standard r-tables. The R-series of standard r-tables, on the other hand, are based on a smaller number of measured r-tables of an even older date and probably of a less good quality.

An additional use of these data has been to form the basis for a portable instrument - called the LTL 200 – for in situ measurement of road surface reflection properties. This instrument was produced in a few copies and worked well without being perfect.

However, the basis show that it is possible to construct an r-table from a few characteristic r-values, of which r_1 and r_2 are the most important. The ratio between these two r-values gives directly the value of S1 and, if Q0 and/or Qd can also be determined on the basis of the two r-values, they can lead to a complete characterization of the reflection properties of a road surface.

Linear regression in the above-mentioned data in LTL report No. 10 shows that the best possible linear representation of Q0 is given by $(0,957 \times r_1 + 0,746 \times r_2 + 104)/10.000$. As an example, the r-table shown in table A.1 has a calculated value of Q0 of 0,068, while the correct value id 0,070.

For the total of the 285 r-tables, the correlation shown in figure A.2 is established. The correlation is very good with, however, a standard deviation of 7,4 %. This means that the deviation can be 14,5 % or higher in 5 % of the cases.
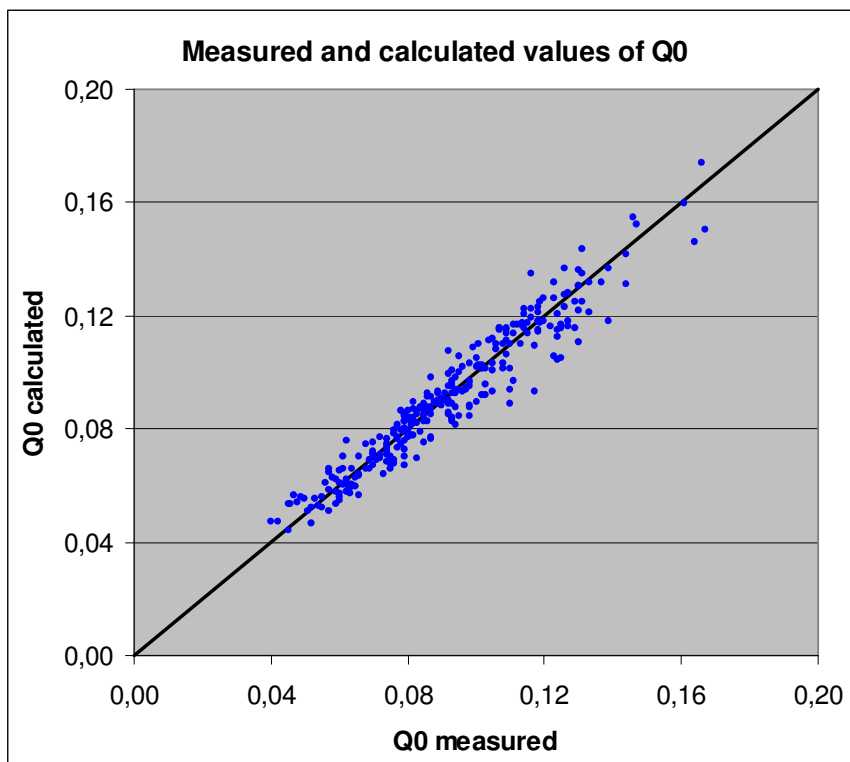
Figure A. 2: Measured and calculated values of Q0 for r-tables in LTL report No. 10.

In order to obtain a correlation for Qd it has been necessary to digitize the r-tables of LTL report No. 10 and calculate the Qd values. The correlation is shown in figure A.3.

The best possible linear representation of Q0 is given by $(0,981 \times r_1 + 0,323 \times r_2 + 86,1)/10.000$. The correlation is shown in figure A.3 and is seen to better than for Q0. The standard deviation is 5,0 %, which means that the deviation can be 9,8 % or higher in 5 % of the cases.

Figure A.3: Measured and calculated values of Qd for r-tables in LTL report No. 10.
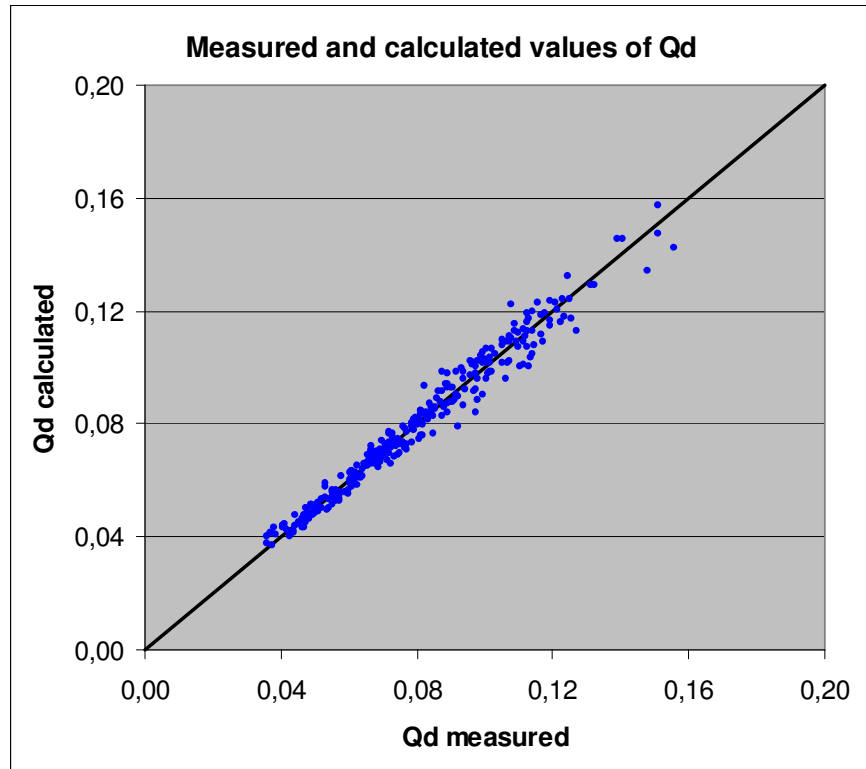

The reason why Qd can be reproduced with a better accuracy than Q0 is that Qd has the least weight o specular reflection – which is the type of reflection that is the most difficult to reproduce.

Because of this, it is an advantage to use Qd in stead of Q0 as a measures for the average reflection of a road surface..

However, this raises as old discussion of whether Qd or Q0 provides the best directional distribution of the illumination of a road surface in road lighting – and of road lighting traditions in different countries. The author thinks that Qd is also best in this connection and that LED lighting pushes in this direction.

A.4 Principles for the measurement of r_1 and r_2 with a portable instrument

Figure 4 shows the principle for a portable instrument for the measurements of r_1 and r_2.
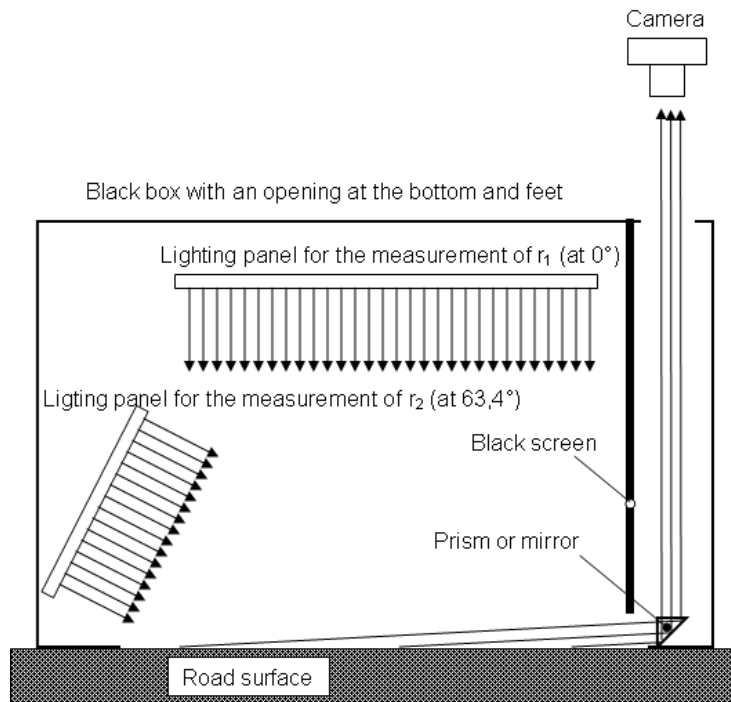
Figure 4: Principle for a portable instrument for the measurement of r_1 and r_2.

The lighting panels will in practice emit light within a certain angular range, whereby the measured value becomes an average of the luminance coefficient within that angular range. Any deviation between this average and the value measured with a small angular spread is a source error.

This deviation can be calculated for a given r-table by assuming lighting within a cone with a given cone angle.

Such deviations are shown in figure 5 for r_1 and the standard tables N1, N2, N3 and N4. The deviations are small up to even $\pm 10°$.

Figure 5: Deviations in measured values of r_1 for lighting in cones.
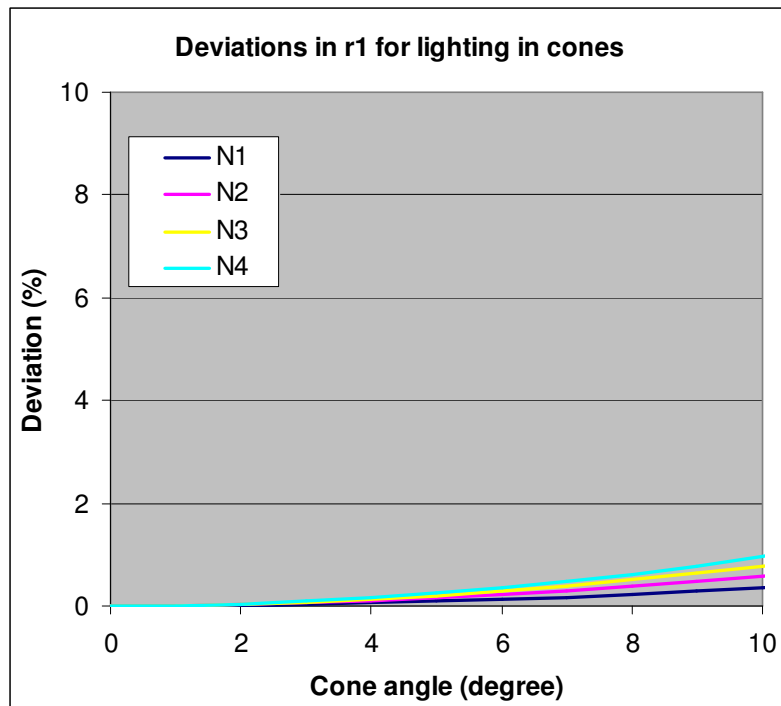
The deviations are shown in figure 6 for r_2 and the standard tables N1, N2, N3 and N4. These deviations can become large unless the cone angle is at most $\pm 2°$. However, a closer study shows that the spread of illumination in the longitudinal direction can be larger, as long as it does not exceed $\pm 2°$ in the transverse direction.

The reason why there is little tolerance for spread in the illumination for r2 is that is that the q value is large at $\beta = 0°$ due to specular reflection, bur decreases rapidly with increasing value of β. This also explains why the deviation grows in the sequence N1, N2, N3 and N4, which corresponds to an increasing degree of specular reflection.

It is to be noted that spread in the measuring direction has the same effect and needs to be kept low.

Figure 6: Deviations in measured values of r_2 for lighting in cones.