Performance based requirements for retroreflective road signs

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1. Introduction

Performance based requirements for retroreflective road signs are in principle based on driving scenarios, each involving a complete description of the situation, including the geometry of a road, a vehicle, a road sign and the intensity distribution of the headlamps of the vehicle. The ERGO program provided by Avery Dennison gives a good impression of the input needed for a road scenario. A more simple program SIGN is provided by the Danish Road Directorate and DELTA.

Work to set up performance based requirements was carried out in CEN/TC 226 WG3 in a period until 1997 and then continued in a UK/Nordic working group up to 1998. This work has led to inclusion of performance based requirements in Danish road standards (1999, Udbuds- og anlægsforskrifter, afmærkningsmateriel, almindelig arbejdsbeskrivelse) and a draft BSI standard (BS 8408:2003 Road traffic signs, Testing and performance of microprismatic retroreflective sheeting materials - Specification).

The purpose of this report is to describe and compare these approaches called DK and UK in the following. The descriptions of the two approaches are given in sections 2 and 3, while suggestions for a common approach are given in section 4.

The Danish road standards include test method for the retroreflection of as well glass beaded as microprismatic sheeting materials, and the performance based requirements apply for sheeting materials of both technologies.

The BSI draft contains both test methods and performance specifications - both only for microprismatic sheeting materials. The performance specifications are intended to apply only for these sheeting materials, but in the following they are being discussed as if generally applicable (which they are).

A French approach is being developed, and has been made available in a numbe rof spreadsheets. As for the UK approach, the performance specifications are intended to apply only for microprismatic sheeting materials, but are being discussed as if generally applicable.

2. DK approach in the Danish road standards

The DK approach uses the same basis and the same method, as in the report of the UK/Nordic working group, but is formulated in a different way; refer to the following subsections.

2.1 The basis of the DK approach

The basis is a driving scenario with:

- a passenger car of a geometry as given in table 1
- low beam headlamps of an intensity distribution as shown in figure 1
- a road sign located 5 m to the right of the centre of the passenger car and 2,5 m above the road surface

- retroreflectivity of the road sign as provided by linear interpolation in a table of values of the coefficient of retroreflected luminance R_L for values of the observation angle α of 0,20°; 0,33°; 0,50°; 1,00°; 1,50° and 2,00°
- a drive from 200 m distance to the road sign down to a short distance

Table 1: Data for the geometry of vehicles.

geometry of:	h1	h2	s1	s2	s3
motorcycle	0,80 m	1,00 m	-	-	0,50 m
passenger car	0,65 m	1,20 m	1,00 m	0,20 m	2,00 m
bus/lorry	0,80 m	2,20 m	1,80 m	0,20 m	0,95 m

h1: height of headlamp(s) above the road
h2: height of driver's eyes above the road
s1: distance between headlamps
s2: transverse distance of eyes from left headlamp
s3: distance of eyes behind headlamp(s)

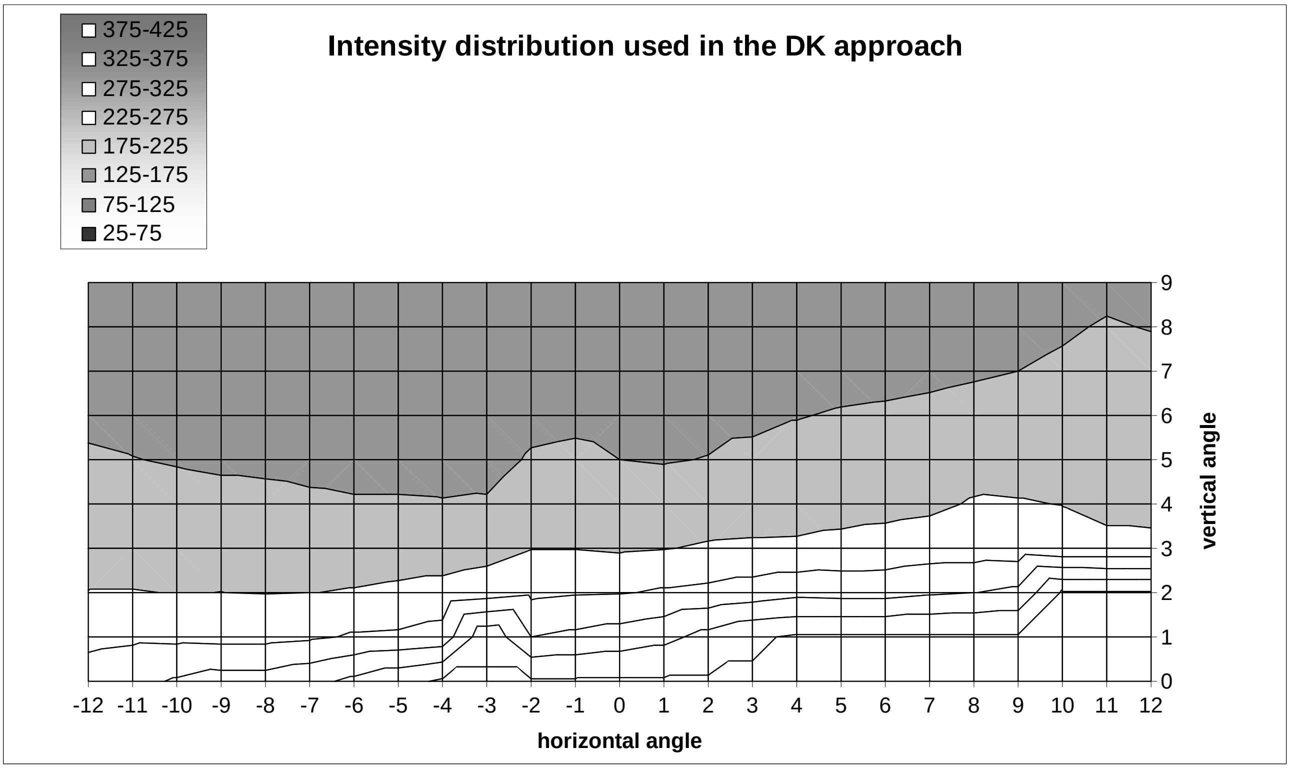


Figure 1: Intensity distribution in candelas used in the DK approach.

2.2 The method of the DK approach

The method was simply to adjust the R_L values in a trial and error procedure, until the road sign luminance is constant at 1 cd/m^2, independent of the distance. These R_L values are 36,0; 14,5; 8,20; 3,11; 1,81 and 1,41 cd·m^{-2}·lx^{-1} for the above-mentioned values of the observation angle α.

Requirements for a particular luminance level are then obtained by multiplying the above-mentioned R_L values with the corresponding factor, for instance by a factor of 5 for a luminance of 5 cd/m^2.

Further, as requirements for retroreflection are conventionally expressed in terms of the coefficient of retroreflection R_A, the R_L values are converted to R_A values by multiplication with cosβ, where β is the entrance angle. Values of β of 5°, 15°, 30° and 40° are considered.

Further, the luminance values are for white parts of sign faces. For other colours, the required R_A values are reduced in proportions according to the colours, refer the colour factors of table 2.

Finally, the luminance values apply for the specific circumstances of the driving scenario and may be said to be nominal. Actual luminance values may be higher or lower than the nominal luminance in a proportion that depends on the actual vehicle and the location of the road sign.

Table 3 shows such proportions between actual/nominal luminance values for the other vehicles included in table 1 (motorcycle and bus/lorry) and for some typical sign locations. Additional variations occur in practice because of a large variability of headlamp intensities.

Table 2: Colour factors of the DK approach.

colour	colour factors [1)]
white	(1,00)
yellow	0,70
orange	0,40
red	0,20
blue	0,06
green	0,14
dark green	0,08
brown	0,01
grey	0,50

[1)] For all printed colours except white, the proportions are reduced by 30%

Table 3: Approximate proportion of the actual road sign luminance relative to the nominal luminance.

sign position:	relative to vehicle 5 m left	above	5 m right
	passenger car:		
5,0 m above road surface	0,5	0,5	0,5
2,5 m above road surface	0,8	0,8	**1,0**
1,0 m above road surface	1,1	1,7	10 to 15*
	motorcycle:		
5,0 m above road surface	1,5	1,5	1,5
2,5 m above road surface	2,0	2,5	3,5
1,0 m above road surface	4,0	6,0	appr. 50*
	bus/lorry:		
5,0 m above road surface	0,2	0,2	0,2
2,5 m above road surface	0,3	0,3	0,35
1,0 m above road surface	0,4	0,6	appr. 6*

* road signs in this position are close to the elevated part of the low beam leading to high luminance depending on distance and curvature of the road

2.3 The formulation of the DK approach

The final step by the UK/Nordic working group was to define

- subclasses of distance in terms of ranges of the above-mentioned values of α
- subclasses of luminance
- subclasses of entrnace angularity in terms of ranges of the above-mentioned values of β.

These subclasses were supposed to be used independently of each other resulting in a fairly large number of combinations.

The final step in the DK approach implies a simplification, in which the subclasses are linked together to provide only three classes. These are named types 3, 4 and 5, as types 1 and 2 are occupied by other types of sign faces (respectively translucent materials for transilluminated signs and materials of ordinary reflection).

Type 3 aims at:

- short distances defined by values of α of 0,50°; 1,00°; 1,50° and 2,00° (α of 0,33° is actually added in order to establish a connection to the geometry used by portable instruments in Europe of α = 0,33° and β = 5°)
- a luminance of 3 cd/m^2
- a wide entrance angularity defined by values of β of 5°, 15°, 30° and 40° (40° only as an option at α = 2,0°)

Type 4 aims at:

- medium distances defined by values of α of 0,33°; 0,50°; 1,00°and 1,50°
- a luminance of 5 cd/m^2
- a medium entrance angularity defined by values of β of 5°, 15° and 30°

Type 5 aims at:

- long distances defined by values of α of 0,20°; 0,33°; 0,50°and 1,00°
- a luminance of 10 cd/m^2
- a low entrance angularity defined by values of β of 5°and 15°

The distances corresponding to the values of α of 0,20°; 0,33°; 0,50°; 1,00°; 1,50° and 2,00° are assumed to be respectively 200 m, 120 m, 90 m, 50 m, 40 m and 30 m. Accordingly, short distances are in the range of 90 m down to 30 m; medium distances are in the range from 120 m down to 40 m and long distances in the range from 200 m down to 50 m.

The requirements are expressed as minimum R_A values. According to this, a retroreflective sheeting material that meets the requirements for a particular type will secure at least the corresponding luminance - within the corresponding ranges of distance and entrance angularity. The R_A minimum values are illustrated for white materials for the case of β = 5° in figure 2.

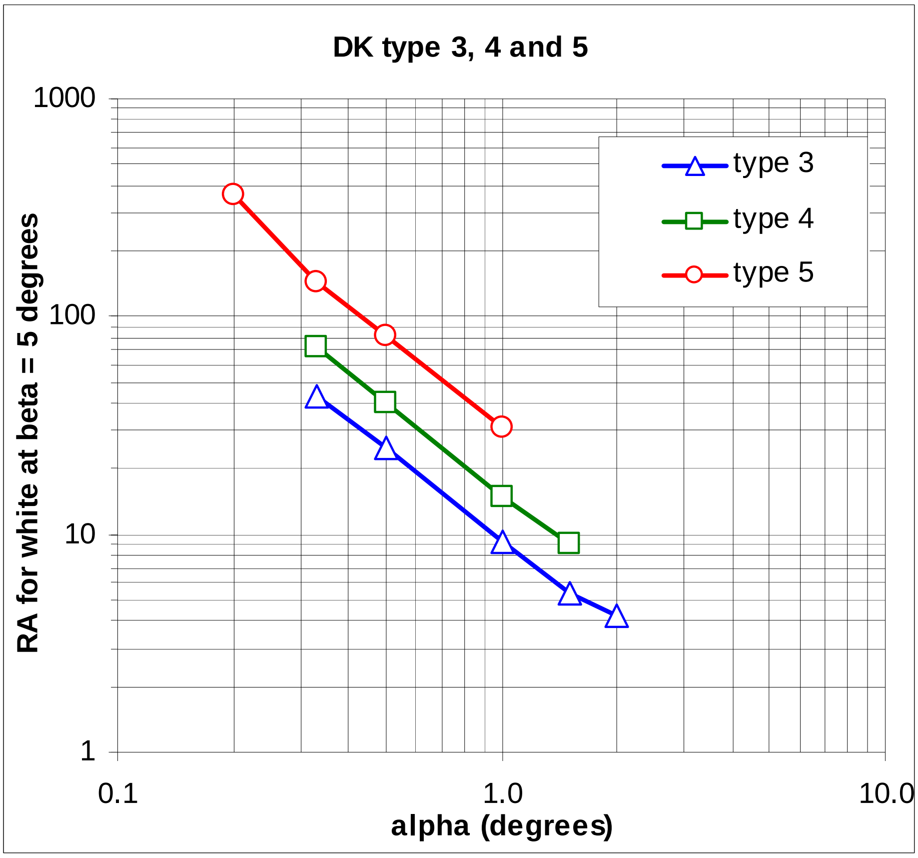


Figure 2: Minimum R_A values for types 3, 4 and 5 of the DK approach.

2.4 Comments to the DK approach

The DK approach may be said to be 'constant luminance', but with different nominal luminance levels linked to the distance ranges - higher the longer the distance. This is meant as a compensation for the fact that road signs are mostly placed higher, when they are to be read at longer distances, so that the actual luminance is lower than the nominal luminance, refer to table 3.

Another rationale behind the link between luminance level and distance is that it is in some ways (probably not all) easier to provide a high luminance at a long distance than at a short - because it takes less retroreflected light, and retroreflected light is a limited resource.

Finally, the types 3, 4 and 5 have some overlap of application, so that the variation of the nominal luminance introduces the option of promoting some signs with respect to other signs, or to create luminance balance between signs in different positions, refer to table 3. This is actually used systematically in the Danish road standards.

3. UK approach in the BSI draft

The UK approach has some elements from the report of the UK/Nordic working group, but with significant modifications and additions; refer to the following subsections.

3.1 The basis of the UK approach

The basis used for the UK approach does assume the same passenger car and the same sign location as in the DK approach - after transformation from right hand driving to left hand driving. The headlamp intensity distribution as well is transformed for left hand driving.

The transformations for left hand driving are themselves without significance, but some additional modifications are as follows:

- the intensity distribution for the low beam headlamps is not the one described in figure 1, but another as described in figure 3
- the driving scenario is simplified in the sense that the two headlamps are attributed the same value of the observation angle α, determined as the mean value of the two actual values of the observation angle α_1 and α_2 for the two headlamps
- the values of the observation angle α used for the passenger car have been changed to 0,25°; 0,30°; 0,40°; 0,5°; 0,65°; 0,90°; 1,20°; 1,50° and 2,00°.

The passenger car is called vehicle type V1. To the scenario for the passenger car is added a scenario for a large vehicle called vehicle type V2 with:

- the same geometry as the bus/lorry of table 1 - transformed for left hand traffic
- the same intensity distribution of the headlamps as for the passenger car, refer to figure 3
- the driving scenario is simplified in the same way as mentioned above for the passenger car, but the values of the observation angle α are changed to 0,5°; 0,65°; 0,90°; 1,20°; 1,50°; 2,00°; 2,50°; 3,00° and 4,00°.

The headlamp intensities of figure 3 are not used directly, but after correction for measurement at 12,8 volts to the typical operating voltage for a vehicle on the road, taken as 13,5 volts. The correction factor is 1,19.

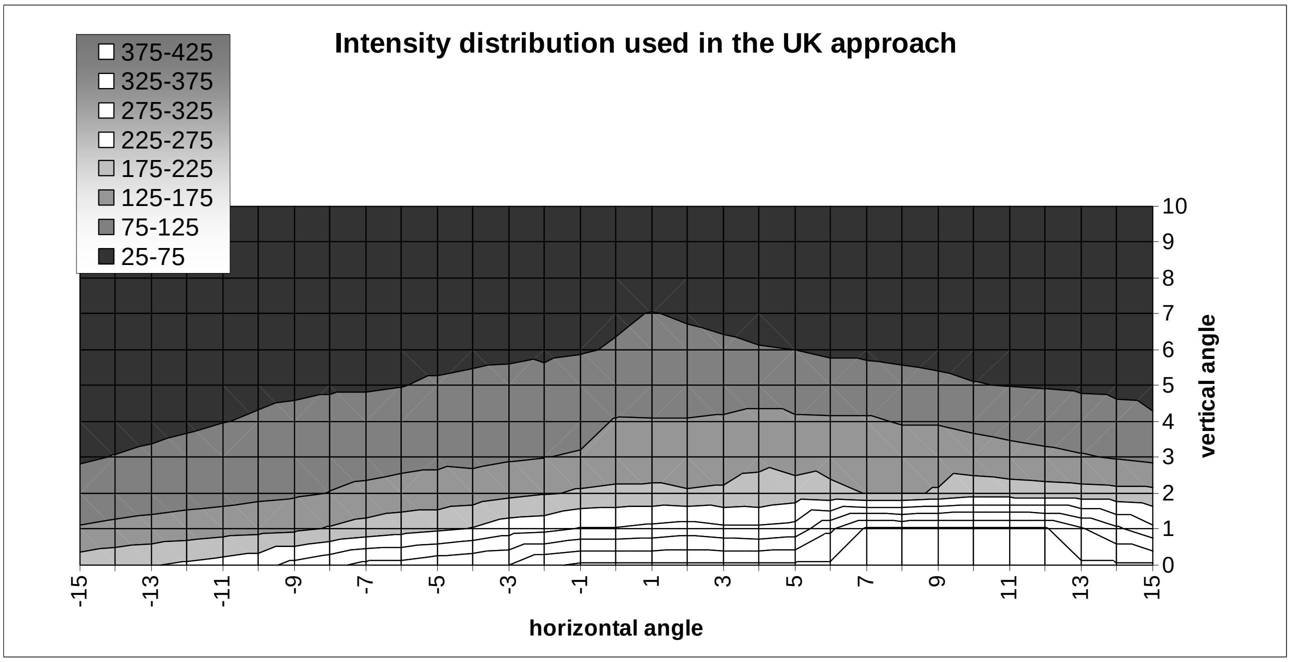


Figure 3: Intensity distribution in candelas used in the UK approach (before transformation for left hand driving).

3.2 The method of the UK approach

The method is described as a step by step calculation of the road sign luminance, followed by an evaluation of the resulting luminance values in terms of a luminance index. However, as all the steps are fixed, the method can be interpreted in the same way as in the DK approach, in terms of the R_L values needed to provide a constant luminance of 1 cd/m^2 independent of the distance.

For the passenger car, the R_L values are 36,8; 26,8; 17,1; 12,7; 9,36; 5,70; 3,83; 2,75 and 2,91 cd·m^{-2}·lx^{-1} for the above-mentioned values of the observation angle α of respectively 0,25°; 0,30°; 0,40°; 0,5°; 0,65°; 0,90°; 1,20°; 1,50° and 2,00°. For the large vehicle, the R_L values are 45,1; 28,4; 16,3; 11,2; 8,48; 5,51; 3,94; 3,04 and 2,49 cd·m^{-2}·lx^{-1} for the above-mentioned values of the observation angle α of respectively 0,5°; 0,65°; 0,90°; 1,20°; 1,50°; 2,00°; 2,50°; 3,00° and 4,00°.

The UK method could therefore lead to tables of desired R_A values in the same way as in the DK approach, by a conversion of the R_L values to the actual luminance level and then to R_A values.

Such tables are not provided in the drfat BSI standard, but some elements remain from the Nordic/UK working group report. One of these is the use of colour factors, refer to table 4. Note that this table has some additions and some differences compared to table 2.

Another such element is a table with the same purpose at table 3, but modified to suit other elements of the UK approach, refer to table 5.

Table 4: Colour factors of the UK approach.

colour	proportion
white	(1,00)
yellow-green (fluorescent)	0,80
yellow	0,70
yellow (fluorescent)	0,60
orange	0,40
orange (fluorescent)	0,30
red	0,20
blue	0,05
light green	0,10
dark green	0,05
brown	0,015
grey	0,50

Table 5: Sign position correction factors of the UK approach.

Position category		Distance class							
		D1		D2		D3		D4	
		V1	V2	V1	V2	V1	V2	V1	V2
		Car	Large vehicle	Car	Large vehicle	Car	Large vehicle	Car	Large vehicle
P1	Left verge	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
P2	Right verge	0.73	0.72	0.73	0.71	0.64	0.64	0.50	0.49
P3	Overhead	0.46	0.45	0.51	0.47	0.39	0.39	0.36	0.39
P4	Low left	2.75	3.19	7.98	9.04	9.92	13.79	9.38	11.62

3.3 The formulation of the UK approach

The UK approach operates with independent subclasses for distance and for entrance angularity as in the Nordic/UK working group report. The number distance subclasses has been increased to four after addition of a class D4 for 'short'. The three entrance angularity subclasses of the above-mentioned report remains. Additional independent subclasses are two for performance and two for the two vehicles. Therefore, the total number of combinations is 48.

The distance subclasses D1, D2, D3 and D4 for respectively 'long', 'medium', 'short' and 'close' are defined by selections of the observation angle α within the totals listed above. The selections include always four values; for instance D1 has the selection of 0,25°; 0,30°; 0,40° and 0,65° for the passenger car and 0,5°; 0,65°; 0,90° and 1,50° for the large vehicle.

The entrance angularity subclasses A1, A2 and A3 for 'narrow', 'medium' and 'wide' are defined by selections of the entrance angle β:

- A1: 5°and 15°
- A2: 5°, 15° and 30°
- A3: 5°, 15°, 30°and 40°.

The two subclasses of performance are called 'luminance index A' and 'luminance index B'. They apply for respectively directional signs, on one hand, and warning and regulatory signs, on the other hand. Luminance index B is easiest to explain as it aims at a constant luminance of 3 cd/m^2 at all four distances, corresponding to the four values of the observation angle α within a distance subclass. Luminance index A aims at 10 cd/m^2 at the longest distance, 4 cd/m^2 at the next shorter distance and 3 cd/m^2 at the two shortest distances.

The two vehicles are the passenger car V1 and the large vehicle V2.

For any of the 48 combinations of subclasses, a luminance index value can be calculated according to a procedure that is described in detail.

As stated above, tables of R_A values could have been derived for the different combinations of subclasses. The R_A values are illustrated for white materials for the case of β = 5° in figures 4.

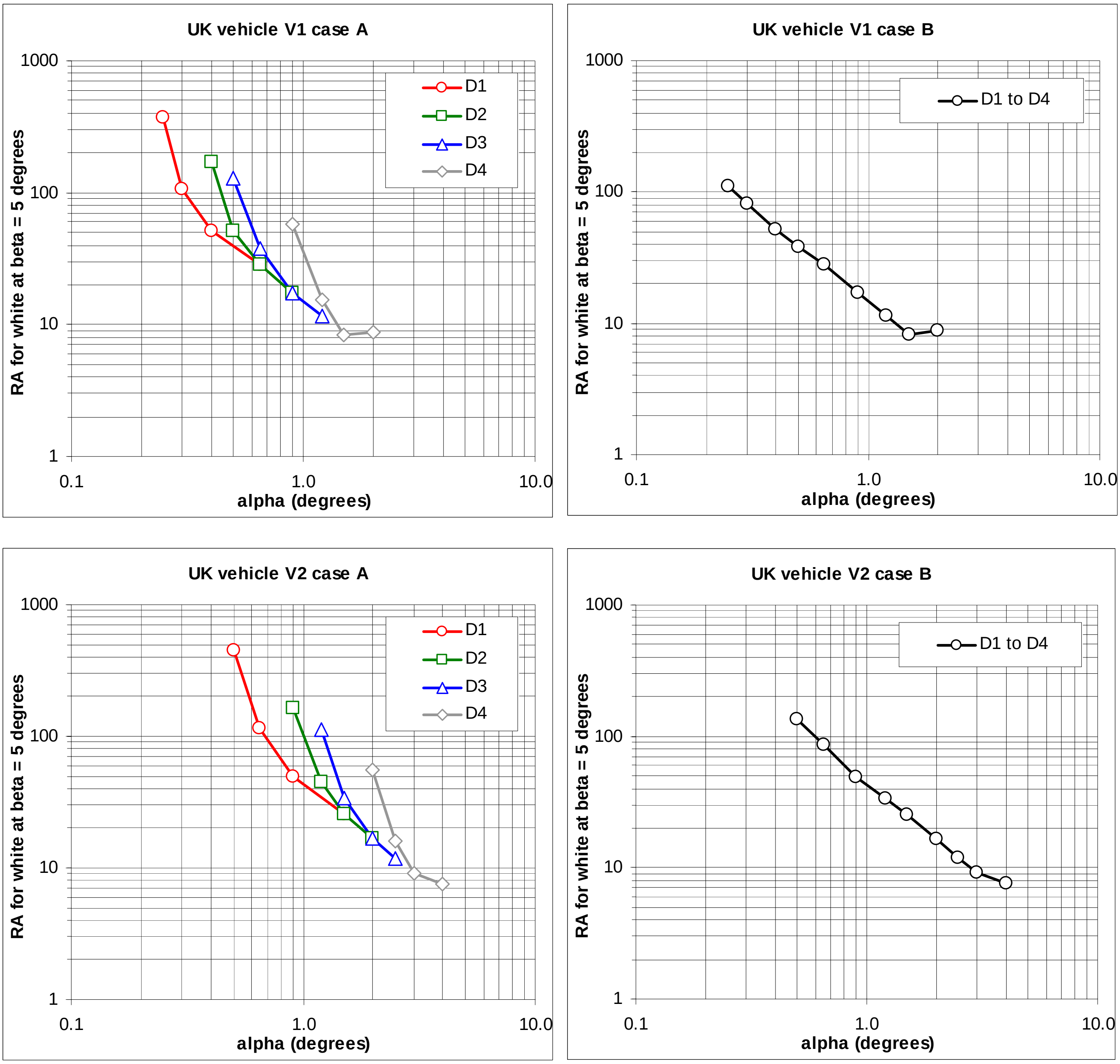


Figure 4: R_A values for vehicles V1 and V2, and case A and B, of the UK approach.

Tables of R_A values could in fact also be used to derive the luminance index value for a particular sheeting material.

An example of a table of desired R_A values is given in table 6, while the R_A values of table 7 represent a sheeting material, for which the luminance index is to be derived. The luminance index is derived in four steps as shown in table 8.

Table 6: Desired R_A values for vehicle V1, luminance index B, distance subclass D1 and entrance angularity class A1.

observation angle α	0,25°	0,30°	0,40°	0,5°	0,65°
entrance angle β					
5°	111	80,8	51,5	-	28,2
15°	107	78,3	50,0	-	27,3

Table 7: R_A values provided by a sheeting material.

observation angle α	0,25°	0,30°	0,40°	0,5°	0,65°
entrance angle β					
5°	404	429	412	-	233
15°	336	378	356	-	206

Table 8: Example of luminance index calculation.

observation angle α	0,25°	0,30°	0,40°	0,5°	0,65°
	Step 1: form the ratios of desired/provided R_A values				
entrance angle β					
5°	0,275	0,188	0,124	-	0,121
15°	0,318	0,207	0,140	-	0,133
largest ratios	Step 2: select the largest ratios				
	0,318	0,207	0,140	-	0,133
average of largest ratios	Step 3: form the average of the largest ratios				
	0,200				
luminance index	Step 4: determine the luminance index as the reciprocal of the average of the largest ratios				
	5,00				

The luminance index will become unity, if the R_A values provided by sheeting material match the desired R_A values. If the R_A values provided by the sheeting material are generally higher or lower, the luminance index will become correspondingly higher or lower.

The luminance index could still become unity, if R_A values provided by the sheeting material are smaller than the desired R_A values at one or more values of α, if R_A values are larger at other values of α. However, the nature of calculation is such that if one of the R_A values provided by the sheeting material falls much below the desired R_A value, the other R_A values provided by the sheeting material must be very much higher.

In this way, a table of desired R_A values does not prescribe what R_A values must minimum be provided in order to result in a luminance index of unity. There is some leeway, but not excessive, for lower values.

3.4 Comments to the UK approach

It is a bit awkward that the UK approach uses non-conventional values of the observation angle α.

It seems a complexity that the UK approach is described in terms of a driving scenario, when it could as well have resulted in tables of desired R_A values, refer to the previous section. The driving scenario description is bulky, and probably less comprehensible than it would have been in terms of tables. An advantage of the driving scenario description may be that all details and assumptions are accounted for in a clear manner, but these could have been referred to an informal annex or a background report.

It is probably because of the driving scenario description that the vehicles have been simplified to have in essence two headlamps in the same position. This simplification is in principle not necessary as illustrated by the driving scenario behind the DK approach.

As compared to the DK approach offering a total of 3 classes or types in combinations of luminance, distance and entrance angularity, the UK approach offers 48 combinations of subclasses - without including luminance levels in the combinations.

This illustrates that the UK approach does not provide direct on/off criteria for the selection of sheeting materials for particular applications - such as the DK approach, but rather a general evaluation scheme for sheeting materials.

The large number of combinations are due to:

- independence of distance and entrance angularity subclasses
- evaluation for both 'constant luminance' (for warning and regulatory signs) and 'varying luminance' (for directional signs)
- evaluation for both a passenger car and a large vehicle

It should be possible to combine the distance and angularity classes, as in the DK approach. After all, it is unlikely that signs that are intended to be read at large distance cannot be aimed towards the traffic.

The UK approach includes the 'varying luminance' with higher luminance at the longer distances within the range, in addition to the 'constant luminance'. The rationale behind varying luminance is that the signs can be made a bit smaller, and that it is in some ways (probably not all) easier to provide a high luminance at a long distance than at a short.

The large vehicle in addition to passenger car is a clear way to introduce an evaluation for large vehicles, and it may be the best way.

The essence of the matter is that drivers of large vehicles need to have retroreflection at larger values of the observation angle α than drivers of passenger cars; and that the two ranges of α only partly overlap. Where the two ranges overlap, the driver of the large vehicle will experience some of the road sign luminance experienced by the driver of the passenger car (about 40%), but at the largest values of α (shortest distances), he is not secured of any road sign luminance at all, unless particular requirements are made.

Another way to secure some road sign luminance for drivers of large vehicles could then have been to extend the distance classes to larger values of α (shorter distances) for passenger cars.

Regardless on how drivers of large vehicles are considered, the consequence would be larger emphasis on retroreflection at large angles of α. This again would work against microprismatic sheeting materials - at least those existing on the market - and for glass beaded sheeting materials.

Each combination may lead to a luminance index for a particular sheeting material. The use of luminance indices is an improvement compared to the use of minimum criteria in the DK approach, as it does introduce a reasonable leeway for deviations that could for instance be caused by measuring uncertainty.

The BSI draft gives recommendations for suitable values of the luminance indices, which could serve for adding on/off criteria in tender specifications or elsewhere.

However, it is not possible to pick a high luminance index for all combinations - as retroreflection is a limited resource- and therefore the different considerations have to be weighed against each other.

As a fairly complex example, the use of varying luminance for directional signs places some emphasis on retroreflection at the smaller values of the observation angle α in a distance class. These values of the observation angle α are larger for the large vehicle than for the passenger car, so that emphasis on both vehicles leads to emphasis on retroreflection over a larger range of the observation angle α. This effectively leads to a high and roughly constant luminance for the passenger car (and a lower varying luminance for the large vehicle). This is perhaps the reason that varying luminance has not been applied for warning and regulatory signs - to secure that emphasis can be placed on both vehicles.

4. French approach in spreadsheets

The French approach is based on driving scenarios like the UK approach, and share some of the basis with the other approaches, but differs in the method, the fomulation and some of the details. The French approach is being drafted and is at present described in some spreadsheets made available by Vincent Ledoux.

Additionally, the French approach is described in a report with the title 'Methodology Description', which was forwarded to CIE TC 4-40 in March 2004. This report introduces some modifications with respect to the spreadsheets, among else a reduction in the required R_A values, elimination of some of the families of driving scenarios and elimination of the short distance for the large vehicle.

The account given in the following takes these modifications into account.

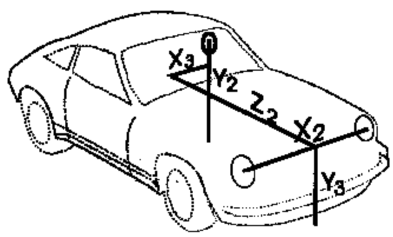
The aim of the French approach is to provide test regimes and requirements for use in France in connection with the CUAP for microprismatic sheeting materials. As these are considered to be applicable in particular for road signs for use on major roads like motorways and trunk roads, emphasis is placed on such roads and fairly large viewing distances. Some of the simplifications are said (by Vincent Ledoux) not to be applicable for road signs at city roads with shorter viewing distances.

4.1 The basis of the French approach

The basis used for the French approach assumes a passenger car and a large vehicle. The geometrical measures of the passenger car are the same as in the other approaches, while the geometrical measures of the large vehicle differ somewhat from those of the other approaches. The measures are given in table 9; which can be compared to table 1 for the other approaches.

Table 9: Data for the geometry of vehicles in the French approach.

Geometrical measures		passenger car (m)	large vehicle (m)
distance between headlamps	X2	1.0	1.92
height of headlamps above the road	Y3	0.65	0.9
height of driver's eyes above the road	Y2	1.2	2.5
distance of eyes behind headlamps	Z2	2.0	1.52
transverse distance of the eyes from the centre of the vehicle	X3	0.3	0.69



The intensity distribution used for the low beam headlamps is the same as the one used in the UK approach, refer to figure 3. For the UK approach, the intensities were corrected for typical operating voltages, but this is not the case for the French approach.

4.2 The method of the French approach

The method is based on 7 families of road scenarios, each with some variation from the others, but otherwise defined by a type of road, a location and orientation of a road sign relative to the road, and a radius of horizontal curve for some of the families. These 7 families are all used in connection with the passenger car, while only 2 are used in connection with the large vehicle.

For each of the families, the situations are analyzed at 2 or 3 distances, selected among 50, 100 and 170 m, and described by means of:

- the average value of the observation angle α for each headlamp
- the standard value of the observation angle, either 0,20°; 0,333°; 0,50°; 0,666°; 0,75°; 1,00°; 1,50°; 2,00° or 2,50°, which is closest to the above-mentioned average value
- the illuminance E at the road sign on a plane perpendicular to the illumination direction for each headlamp
- $\cos\upsilon$, where υ is the viewing angle measured from the viewing axis to the axis of the road sign
- the sum R of the two individual R_A values for the headlamps needed to provide a particular road sign luminance L by means of $R = L \times \cos\upsilon/(E_1+E_2)$, where E_1 and E_2 are the illuminance values for the two headlamps

The required road sign luminance L is introduced as a linear function of the distance, defined by 3 cd/m^2 at 50 m distance and 7 cd/m^2 at 200 m distance. At the above-mentioned distances of 50, 100 and 170 m, the luminance values are respectively 3; 4,33 and 6,2 cd/m^2.

4.3 The formulation of the French approach

The idea of the French approach seems to be that the families of road scenarios define some of the need for road signs, and that each family leads to R_A requirements for retroreflective sheeting materials to be applied for road signs for situations reflected by that family.

The requirements are expressed as a minimum for the sum of the two R_A values - one for each headlamp - at 2 or 3 of the distances of 50, 100 and 170 m. Refer to the previous section.

The angles to be used for the testing of the R_A values are also defined. It is already mentioned in the previous section that the value of the observation angle α is defined as one among a set of standard values.

The values of the other angles, the two components of the entrance angle β and the rotation angle ε, are defined as well. The simplification is made that these angles are constant for the 2 or 3 distances used for a family of road scenarios (this is the simplification that might not be applicable for shorter distances).

As mentioned above, the French approach is intended for road signs on major roads only. It is rpobably for this reason that this approach shows no recognition of the need to introduce distance classes as in the other two approaches.

The families already consider entrance angles without any particular need for the introduction of angularity classes in the way it is done in the UK approach.

The requirements aim at the above-mentioned particular variation of luminance with distance, and seem to be formulated as minimum requirements. It would of course be possible to introduce a luminance index method.

The requirements are assumed to apply for white parts of road signs, although this is not clearly stated. The intention is probably to introduce relaxed requirements for other colours, perhaps by means of colour factors as in the other approaches.

The requirements are expressed by means of the sum of R_A values for the two headlamps, and these are mostly to be measured at different standard values of the observation angle α. If it is assumed that R_A values vary with α as a power function of α, then these requirements can be converted to requirements for individual R_A values. The results are shown in figures 5 and 6 for respectively the passenger car and the large vehicle.

The representation of R_A as a power function of α makes the the figures 5 and 6 show straight lines for each of the geometries. This requires some approximation, as the actual requirements for the sum of two R_A values cannot strictly be represented this way. However, the approximation is slight, and it is mostly due to the use of standard α values instead of actual α values.

In principle, R_A can be represented by other functions of α than power functions - there is no unique way to choose the representation. However, the representation by power functions is natural and simple, and is intended only for illustration and comparison to the R_A requirements derived in the other approaches.

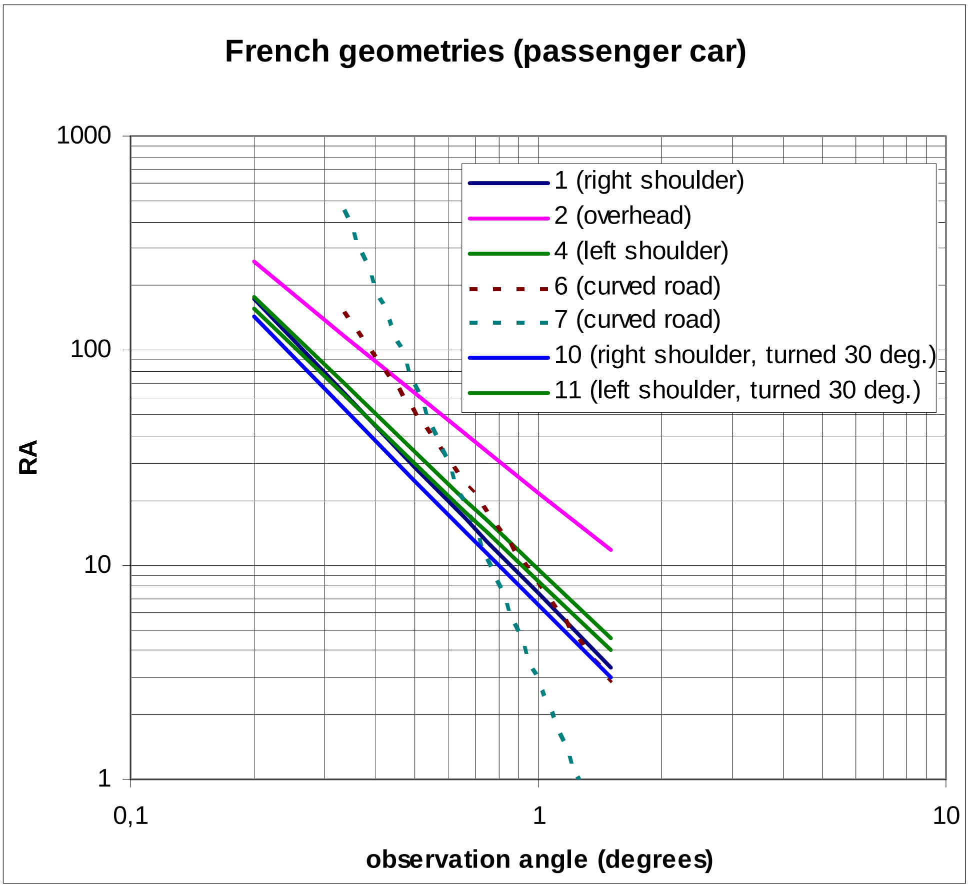


Figure 5: R_A values for the French families of road scenarios (passenger car).

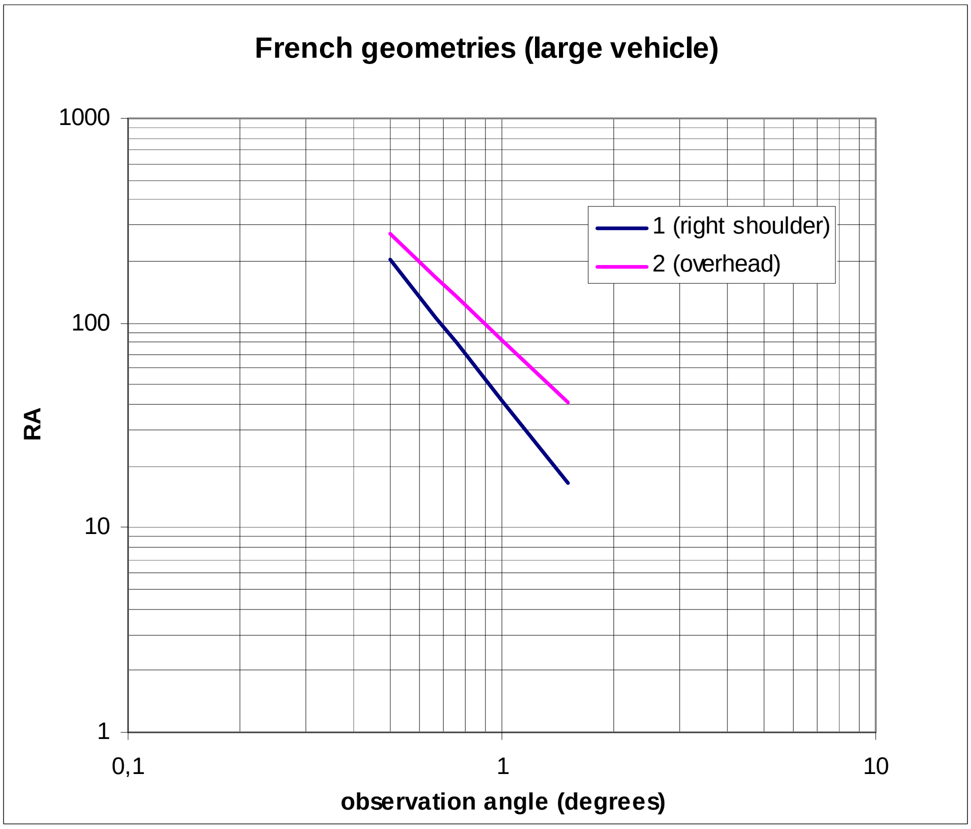


Figure 6: R_A values for the French families of road scenarios (large vehicle).

4.4 Comments to the French approach

The French approach introduces a classification of road sign applications in terms of the families of road scenarios. This classification can be used to decide which applications are possible, or desirable, for particular sheeting materials.

In a way, this is a direct approach, and could be made easy to handle in practice.

But all approaches have disadvantages. It does take as much as 7 classes to cover some of the road sign applications in France. For Europe as a whole, it could require a higher number of classes, if such could be defined in practice.

The testing seems also to become complex, with individual test regimes for each of the 7 classes.

The French approach avoids the simplification of the UK approach to have in essence two headlamps in the same position, but at the expense of expressing the requirements by means of the sums of two R_A values.

The concept of linear increase of luminance with distance adds to the complexity of the discussion already given in connection with the UK approach, refer to section 3.4.

Like in the UK approach, two vehicles are introduced - the passenger car and the large vehicle. This actually introduces two different sets of requirements, and a need to resolve when to apply one set or the other. Refer again to section 3.4.

5. Ideas concerning a common approach

5.1 A basis

The basis could be a driving scenario for a passenger car, with perhaps the addition of a driving scenario for a large vehicle.

The approaches considered in this report use the same geometry for the passenger car, refer to table 1, while there is some difference for the large vehicle, refer to table 3.

The DK and UK approaches are based on a driving scenario with the same location of the road sign (5 m to the right of the centre of the passenger car and 2,5 m above the road surface) - except for transformation between right hand and left hand driving - and they result in requirements for single R_A values. Other sign locations are considered by means of sign position correction factors.

There is some technical difference between those two approaches in the way the basic values of the coefficient of retroreflected luminance R_L are constructed. The DK approach involves a trial and error procedure with linear interpolation in the basic values, while the UK approach involves a simplification of the vehicle.

The French approach differs from this by using a larger number of generalized driving scenarios, covering several positions of road signs. Each of these leads to requirements for the sum of two R_A values, one for each of the headlamps of the vehicle.

The DK and UK approaches lead to requirements for single R_A values. The requirements derived in the French approach can be interpreted in terms of requirements for single R_A values - if a further assumption regarding the variation of the R_A value with the observation angle α is introduced.

However, one important difference remains. The requirements of the DK and UK approaches can be expressed by tables of R_A values using the entrance angle β as a free variable; i.e. the matter of entrance angularity is considered separately and independent of the basic driving scenario. The R_A requirements of the French approach applies for actual values of the entrance angle β; i.e. the entrance angularity is considered inherently in the driving scenarios.

This difference can be expressed in another way. The DK and UK approaches rely on an initial testing regime for the R_A values of retroreflective sheetings and then set requirements for generalized situations. The French approach incorporates the testing regime within the requirements and sets requirements for specific situations.

The DK and UK approaches seem preferable, as they allow in principle different test regimes for different types of retroreflective sheetings - or changes in testing regimes without the need for change of requirements; and vice versa.

A further technical difference is that the DK approach uses a set of conventional values for the observation angle α of 0,20°; 0,33°; 0,50°; 1,00°; 1,50° and 2,00°, while the UK approach uses a modified set of 0,25°; 0,30°; 0,40°; 0,5°; 0,65°; 0,90°; 1,20°; 1,50° and 2,00°. The French approach uses the set of conventional values, but with additional values inserted between 0,50° and 1,00°, namely 0,20°; 0,333°; 0,50°; 0,666°; 0,75°; 1,00°; 1,50° and 2,00°. The French set of values seems the more satisfactory.

A major difference between the two approaches is the addition of a scenario for a large vehicle in the UK approach and also the French approach. It needs careful consideration of how to include large vehicles in a common approach. At least, this might require extension of the set of α values beyond 2,00°.

Another major difference between the approaches is the use of widely different intensity distributions for the low beams of the headlamps, refer to figures 1 and 3.

The intensity distribution behind the UK and French approaches is less liberal concerning intensities in directions above the cut-of than the intensity distribution behind the DK approach. This is the reason that the UK approach promises less luminance than the DK approach for the same R_A values. Refer to figure 5, which compares R_A values for the UK case B with those of DK types 3, 4 and 5. UK case B is seen to very nearly coincide with DK type 4, in spite of the difference in luminance of respectively 3 and 5 $cd \cdot m^{-2}$.

The assumption concerning headlamp intensity therefore creates a significant difference in luminance level. This may sound serious, but is in fact not serious as argued below.

The intensities of headlamps differ significantly from vehicle to vehicle, and change with age and accumulation of dirt, refer to a note 'European low beam headlamps in view of retroreflective road signs', draft report by Kai Sørensen and Bent Rasmussen, DELTA, August 2003.

The intensity distribution of figure 1 has been constructed around intensities measured at some characteristic directions on a German motorway, and may be assumed to represent headlamps in use. The intensity distribution of figure 3, on the other hand, represent new and clean headlamps. It is the median distribution (50th percentile) reported in UMTRI Report 2000-36. 'A market-weighted description of low-beam headlight patterns in Europe'.

Headlamps on vehicles on the road do easily span the variation between the two distributions, and certainly an even larger variation. Because of this, drivers will experience more or less road sign luminance depending on their headlamps. Therefore, a road sign luminance evaluated in a driving scenario can only be a nominal luminance, and the variation among vehicles and drivers should be kept in mind.

It is sobering that the actual R_A values of the UK and DK approaches are much the same in spite of the technical differences and the difference of the intensity distributions. This is because requirement will always be set with a view to what is being supplied on the market. The aim of performance requirements is not necessarily to assure that the supply meets the drivers demands, but rather to provide a performance related basis for comparing sheeting materials and for evaluating the best use of individual sheeting materials.

It is also sobering that the curves in figure 7 show approximately the same slope in spite of a considerable difference in variation of intensity across the distributions (the variation of intensity is less in figure 1 than in figure 3). The passenger car and the large vehicle also results in approximately the same slope, refer to figure 8.

The reason for this is that the slope is primarily determined by the distance law of illumination and secondly by the geometry of the vehicle and thirdly by the variation of intensity (unless the variation is large like for a road sign just about the cut-off of the low beam).

Assuming that the slope is given, the establishment of the basis for performance requirements involves essentially the choice of the scale beween R_A and nominal luminance. The intensity distribution of figure 3 is preferable for this purpose, being supported by more measurements, and representing a more safe assumption than the intensity distribution of figure 1.

A final matter relates to how the luminance is assumed to vary with distance, compare cases A and B of the UK approach in figure 4. Case A is for luminance increasing with distance in the proportion 3-3-4-10, and accordingly the curve changes slope, while case B is for constant luminance, and the slope of the curve is constant.

The French approach is intermediate in this respect, as it assumes a smaller, gradual increase of luminance with distance. Accordingly, the slope is constant, but higher than in the UK case B, refer to figures 5 and 6.

The slope is roughly the same for the different French scenarios with shoulder mounted signs on straight roads. It is a bit less for the scenario with an overhead sign, this being caused by the fairly large variation of the luminous intensity in the assumed intensity distribution. The road scenarios for curved roads show much larger slopes, probably because the signs get out of the width covered by the intensity distribution of the headlamps at the longest distance.

This raises the question of what road scenarios to incorporate, either directly as in the French approach, or indirectly by means of sign position correction factors as in the other approaches. The latter seems the more flexible, but the real question is if scenarios should include roads with curve - horizontal and/or vertical.

The important question is how the luminance should vary with distance. The question relates to the question raised in the above, of how to incorporate large vehicles. The matter is considered in section 5.3.

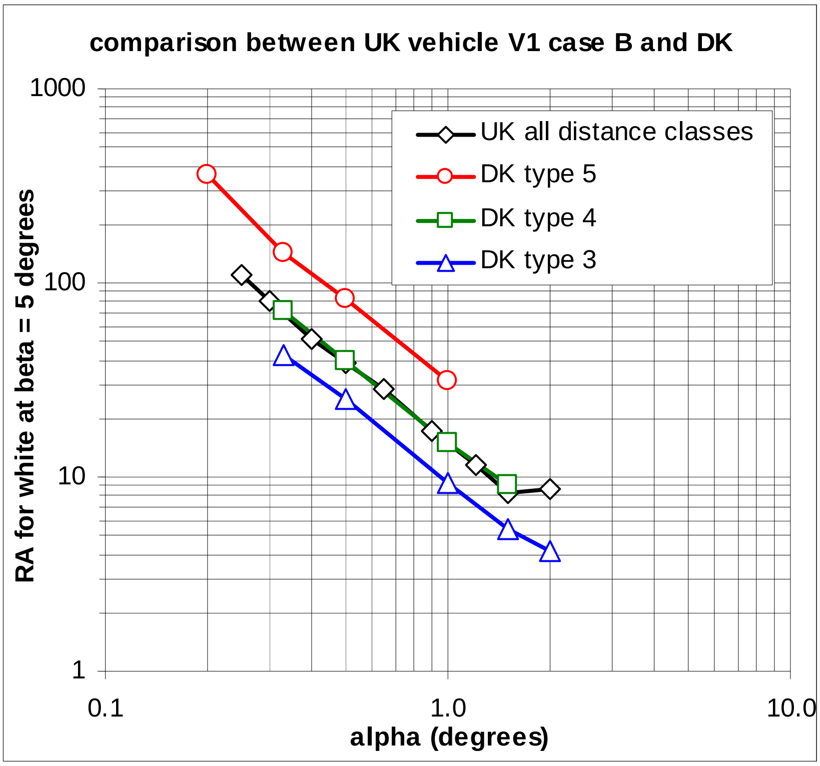


Figure 7: R_A values for the UK vehicle V1 case B and for DK types 3, 4 and 5.

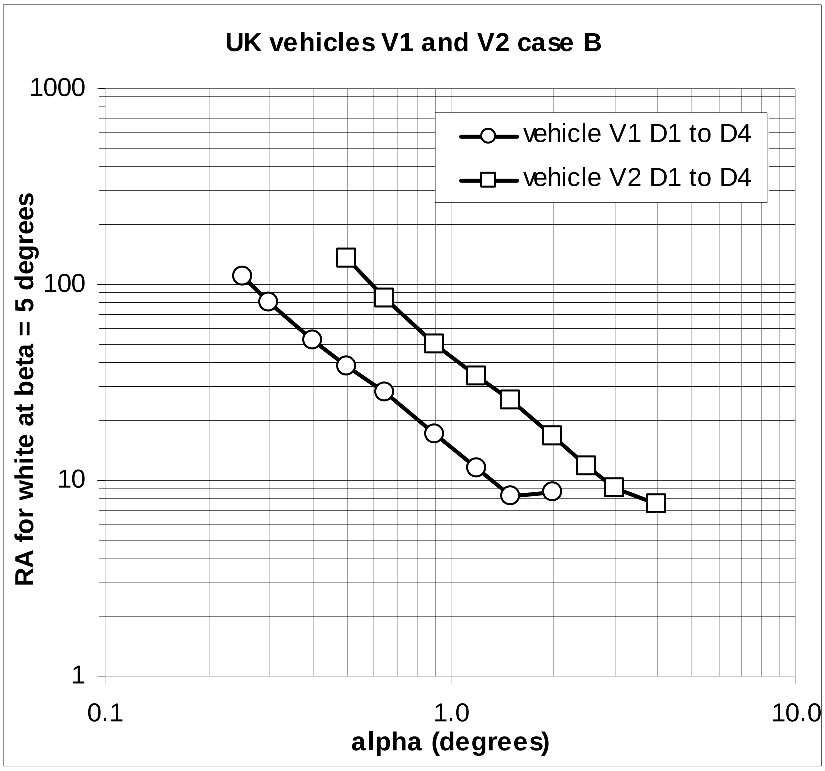


Figure 8: R_A values for the UK vehicles V1 and V2 case B.

5.2 The method

It is probably best to have a clear distinction between testing regimes and requirements as in the DK and UK approaches. If so, it is probably best to establish tables of desired/minimum R_A values, as in the DK approach, as this is conventional and requires less detail of description that the road scenario calculation of luminance used in the UK approach. The two methods are equivalent.

Both the DK and the UK approaches use colour factor tables to obtain R_A values (or luminance) for other colours than white, and sign position correction factor tables to indicate what luminance is obtained in other circumstances than in the driving scenario(s). There are some technical differences in those tables. The tables of the UK approach are probably the more satisfactory.

5.3 The formulation

The luminance index introduced in the UK approach is advantageous to the simple minimum requirements of the DK approach.

Apart from this, the formulation of a common approach requires careful deliberation concerning:
a. combining distance and entrance angularity subclasses, and perhaps luminance subclasses
b. use of 'constant luminance' and 'varying luminance'
c. how to assure sign luminance for drivers of large vehicles (and perhaps motorcycles)

Regarding a, it is perhaps best in a common approach to let subclasses be independent, but simultaneously to recommend certain combinations.

Items b and c are interrelated as the use of 'varying luminance' works against the interests of drivers of large vehicles.

The amount of retroreflected light is limited; if it is used to create large R_A values at small values of the observation angle α in a 'varying luminance' concept, it cannot also be used at large values of the observation angle α to assist drivers of large vehicles.

On the other hand, it does take much more retroreflected light to make conditions good for drivers of large vehicles than for drivers of passenger cars. Drivers of both vehicles need R_A values at the same level, but drivers of large vehicles need them at larger values of the observation angle α than drivers of passenger cars. This takes more light - because the luminous flux needed increases with the square of the width of the retroreflected beam.

> EXAMPLE1: Assume that a driver of a passenger car needs a certain R_A value in the range of α from 0,5° to 1°, then the driver of a large vehicle needs the same R_A value in the range of α from approximately 1° to 2°. The luminous flux needed by the driver is in proportion to 1^2-$0,5^2$ = 0,75. The luminous flux needed by the driver of the large vehicle is approximately in proportion to 2^2-1^2 = 3; or 4 times higher than for the driver of the passenger car.

Therefore, it is not possible to make conditions as good for drivers of large vehicles as for drivers of passenger cars. This may lead to the idea of sacrificing the interests of the drivers of large vehicles and concentrate on the drivers of passenger cars. On the other hand, this is probably not a good idea, because this might also mean sacrificing the interests of drivers of medium size vehicles. Vehicles seem to become gradually bigger on the average.

An alternative might be, as in the UK and the French approaches, to define the tools for evaluating conditions for drivers of both passenger cars and large vehicles, and leave the issue for local decisions.

This is a doubtful alternative, as local people may not have the knowledge to decide. Among else, they may not know that conditions will always be less good for drivers of large vehicles.

The constant luminance concept may be a compromise - if extended to larger values of the observation angle α. The larger the value, the larger the vehicle can be, but the drivers will see lower sign luminances.

A concept of luminance decreasing with distance may also be considered; an extreme formulation would be that the R_A value is independent of the observation angle α. This would put drivers at equal terms, but at low sign luminance levels at the larger distances (probably too low). Another disadvantage of such a concept is that there is no sheeting material on the market to match the concept.

Even the constant luminance concept seems a bit unnatural in view of the sheeting materials on the market. All sheeting materials do of course provide a constant luminance within some distance range, but generally in a fairly small range, and placed at larger distances than adequate for drivers of large vehicles. This did cause some comments, when the DK specifications were published.

Another alternative might be to evaluate conditions for drivers of a medium sized vehicle like a van, instead of including both a passenger car and a large vehicle. This is simple, it avoids discussions regarding emphasis on two types of vehicles and can be defended by the observation that vans are plenty on all roads. Drivers of passenger cars are taken care of this way, as they will always see a road sign luminance that is higher than evaluated for the van. Drivers of large vehicles are partly taken care of, they will see less luminance, but not mcuh less.

One should be aware that the choice between different concepts means a choice between different products on the market.

If a constant luminance concept - with extended range of the observation angle α - is introduced, then glass beaded sheeting materials will be favoured over microprismatic materials. High Intensity sheetings may become the best on motorways, and Engineering Grade sheetings may become the best in cities. There would be opposition to such a conclusion.

The introduction of a van, instead of the passenger car and the large vehicle, would fit somewhat better into a conventional understanding of what types of sheeting materials are suited for different purposes.