Legibility of LED based variable message traffic signs

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Indhold

1. Introduktion

The project described in the following has been organized by the NMF "Nordic Meeting For improved road equipment". Refer to www.nmfv.dk.

This report describes a number of tests of the legibility of variable message traffic signs that were carried out in a period from the spring of 2008 until the autumn of 2009. A variable message traffic sign is called VMS in the following.

Persons involved in the planning and execution of the tests include Lene Herrstedt (Trafitec), Sara Nygårdhs (VTI), Sven-Olof Lundkvist (VTI), Belinda la Cour Lund (Trafitec), Puk Kristine Andersson (Trafitec) and Esben Raahauge Nielsen (DELTA Light and Optics).

All the tests involve presentation of a number of prearranged messages on a VMS, representing variation of some parameters supposedly related to the legibility of the messages, to a group of test persons. In the early tests, the criterion for the legibility was the legibility distance of each of the messages for each of the test persons. In the later tests the criterion was rating of the legibility at predetermined distances.

By legibility distance is meant the largest distance at which the legend can be correctly read by a test person. The maximum legibility distance is obtained when the message is presented with good conditions regarding luminance and contrast, so that the visual acuity of the test person is the limiting factor. It is a general rule of thumb, which is also supported by the tests, that for persons with normal visual acuity the maximum legibility distance expressed in metres can be estimated as 7 times the character height expressed in centimetres.

Some basic information is provided in section 2. The early tests are described in section 3 for the purpose of explaining the background for later tests. These are described in sections 4, 5, 6 and 7 for respectively the luminance of the VMS needed for legibility, the preferred luminance, the quality of character legends and the quality of traffic signs. By quality is meant aspects affecting legibility.

Conclusions are provided in section 8 and also listed below.

Annex A is an operational interpretation of the results of the project. Sections A.2 and A.3 are largely based on the results, while section A.4 represents general procedures as accounted for in the CIE TC-4-40 draft technical report "Performance evaluation of retroreflective traffic signs", draft 2009 or in national road standards such as Danish road standards.

Conclusions regarding regulation of the VMS luminance:

- the apparent luminance of characters with thin strokes depends on the pixel stroke width
- *accordingly, the VMS nominal luminance, as defined in EN 12966-1 "Road vertical signs – Variable message traffic signs – Part 1: Product standard", has to be set in view of the stroke width of the characters*
- the VMS nominal luminance has to be regulated in view of the ambient illumination on the VMS. A suitable regulation curve called "L3 continuous", or just L3, that provides luminance as a function of illuminance is introduced
- a luminance index LI is introduced in order to include both of the above-mentioned aspects of VMS luminance
- an LI value of 0,25 provides almost maximum legibility distances, while an LI value of 0,5 provides the preferred luminance in rating tests
- the ambient illumination on the VMS is best described by a weighted illuminance on the front and the back of the sign with weights of respectively 75 % and 25 %.

Conclusions regarding legibility of legends:

- when the VMS luminance and the presentation of legends is adequate, the legibility distance expressed in metres can be 7 times the character height expressed in centimetres as corresponding to normal visual acuity defined by 6/6 vision
- use of more pixels to form the strokes of characters lead to better ratings of the legibility at short to medium distances, but not at distances close to the maximum legibility distance. The general conclusion is that the pixel spacing S should be sufficiently small compared to the shortest distance D at which the legend is to be read. It is proposed that S is maximum 0,0004×D (or that D is minimum S/0,0004)
- city names can be formed with good legibility with a character pixel height of 8
- city names with a capital letter followed by small letters are more readable than city names with capital letters only
- a less dense packing of letters forming city names leads to higher ratings of the legibility than a dense packing. The general conclusion is probably that the line spacing should be approximately 40 % larger than the letter height, when using capitals only, and approximately 50 % larger than the letter height, when using leading capitals followed by small letters. Additionally, the gap between letters should be approximately 25 % of the letter height
- the three last-mentioned conclusions are assumed to be valid not only for city names, but for all character messages using letters and digits
- the legibility of some often used warning signs with pictograms for "queue", "road work" and "danger" is not really good, when presented on a VMS with 48 times 48 pixels on which pixels can only be on or off. A VMS with more pixels can present the pictograms with more detail and would probably make them more legible. It is probable that the technique of "smoothening" by in-

dividual setting of the luminance of each pixel can lead to improvement of the legibility, but this was not tested.

Annex B provides a worked example for an LED based VMS.

2. Some basic information

2.1 Luminance setting with regard to ambient light

EN 12966-1 defines the luminance of a legend shown on a VMS with luminous elements as the total intensity of the active elements forming the legend divided by an equivalent area extended by the active elements. The equivalent area includes half an element spacing to both sides of the active elements. The luminance defined this way is called the "nominal luminance" in the following.

An example of the equivalent area for elements that are not placed in a matrix is shown in figure 1.

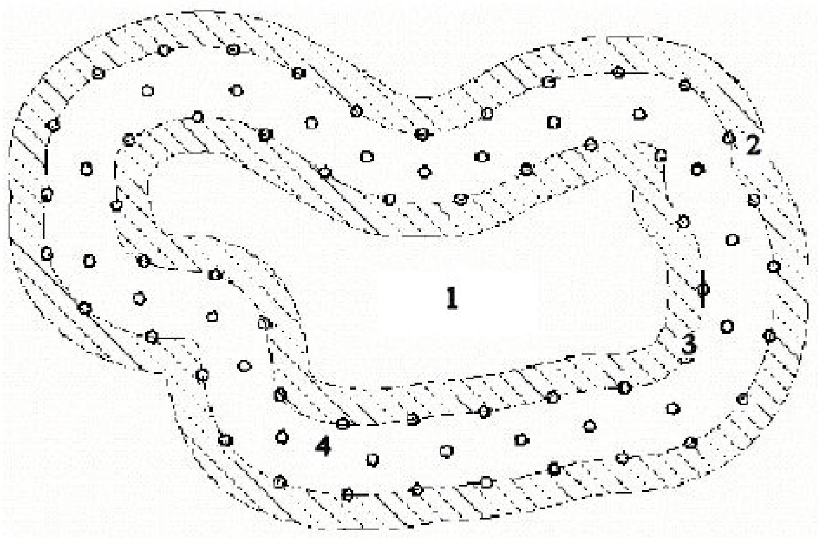
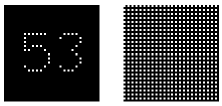


Figure 1: The equivalent area includes the area in between active elements and also the shaded areas of a width of half an element spacing outside of the active elements.

The definition has a simple implication for a VMS with elements in a matrix with a uniform spacing. All legends have the same nominal luminance as long as they are represented by strokes and areas without gaps between the active elements. Further, this particular luminance can be measured by means of a luminance meter after turning on all of the elements.

EXAMPLE 1: These legends all have the same nominal luminance. The luminance is easily measured for the legend with all elements on.

EXAMPLE 2: If turning on only every second pixel in a stroke, the nominal luminance drops to one quarter.



EN 12966-1 does not provide advice on how to regulate the luminance of a VMS with respect to the ambient light level, but does define three classes of luminance L1, L2 and L3 for use during initial type testing.

These definitions include a few pairs of values for the minimum luminance of the VMS and the ambient illuminance on the front of the VMS. The definitions also include values of the maximum luminance of the VMS, but these are not considered here. Additionally, the luminance values are different for different colours, but only the colour white is considered in the following.

For daylight conditions, only two such pairs of values are relevant. These are shown as points in figure 2. Straight lines through the points for class L2 can be used to define a regulation curve, which is also shown in figure 2 with the legend "L2 continuous". Similar lines or curves are shown for "L3 continuous" and for "twice L3 continuous". The luminance values for the curves at a given illuminance form the proportions 1:2:4.

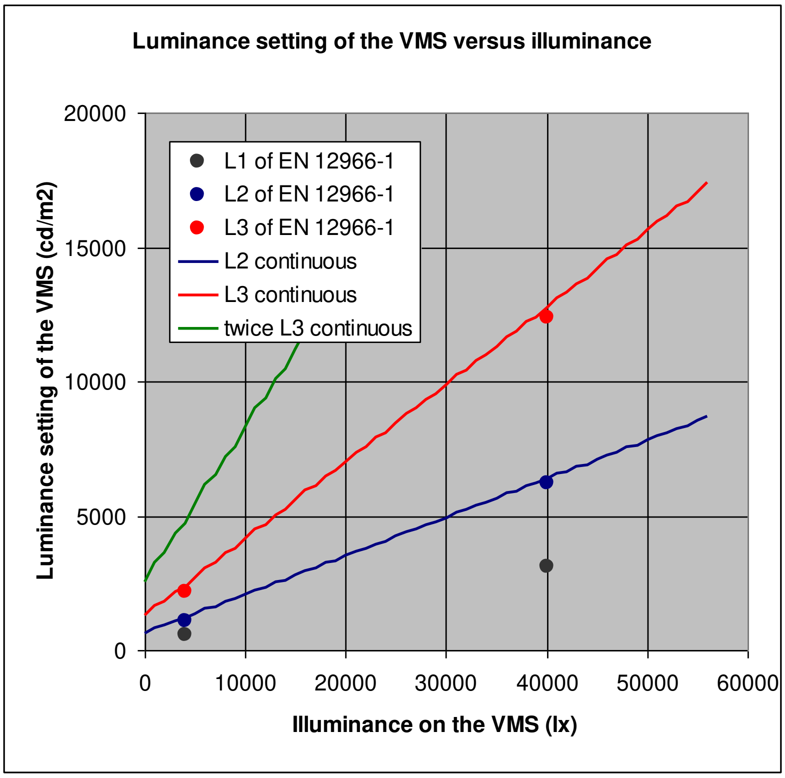


Figure 2: Points for the luminance classes L1, L2 and L3 of EN 12966-1 and some lines based on the points.

During tests in daylight the luminance has been regulated with regard to the ambient light level according to these curves. In practice this was done by an operator at the VMS that monitored the ambient illuminance at intervals and adjusted the VMS luminance accordingly. The operator also changed pre-programmed legends, when requested to do so.

2.2 Location, VMS's used and test methods

Most of the tests were carried out on a blind road, 400 m long, called Nordvej at the Technical University in Lyngby, Denmark. This road has some traffic, but not much, and with a low speed only. The remaining tests were carried out on a big open sports field next to Nordvej, where the direction could be chosen with respect to the direction of the sun.

In legibility distance tests, a VMS was placed at the end of Nordvej and made to display some prearranged legends one by one. Whenever the legend was changed, some test persons started walking towards the VMS from a long distance until they one by one declared that they could read the legend. An operator verified that the legend was read correctly and noted the legibility distance. Figure 3 shows a group of persons walking towards the VMS.

Figure 3: A group of test persons on Nordvej in Lyngby.

In rating tests, the persons were located at a fixed distance from the VMS and evaluated the legibility of the VMS individually. The exception is a single test in which the persons as a group could ask for higher or lower luminance of the VMS until it was deemed optimum.

A VMS on the loan from the Danish Road Directorate was used for the first tests carried out during the spring of 2008, see figure 4. This VMS is a matrix sign with

44 × 45 pixels, a pixel spacing of 20 mm and a front area of approximately 900 × 900 mm.
This VMS could not easily be made available for continued tests as transport required a truck (the VMS has a mass of 90 kg, a heavy support and a heavy battery).

Another VMS was supplied by Nissen GmbH for use for the remaining tests, see figure 5. This VMS has 48 x 48 pixels with a spacing of 15 mm and a sign face of approximately 700 × 700 mm.

Figure 4: Two VMS's on loan from the Danish Road Directorate. Only one was used.

Figure 5: The VMS from Nissen GmbH – back and front.

The Nissen VMS can be set to luminance levels on a scale with steps of 1, 2, 3 … 100. In practice the first 10 steps provide approximately the same luminance, so that the useful steps are 11, 12, 13 … 100. These steps provide luminance values in the range from approximately 800 to 13 000 cd/m^2.

2.3 Maximum legibility distance for normal visual acuity

A person with normal visual acuity defined as 6/6 vison is able to identify a character whose height extends 5 minutes of arc in good conditions. This means that the character can be identified at a distance expressed in metres of approximately 7 times the character height expressed in centimetres. The ratio between the distance and the character height is called the legibility index.

NOTE: Normal visual acuity is sometimes defined by the ability to discriminate a detail of a diameter of one minute of arc. The above-mentioned rule means that a character can be identified, when the character height forms 5 details in height.

The above-mentioned rule of thumb is used to estimate maximum legibility distances provided in some cases in the following. These are expected to be obtained when conditions are good, i.e.: when the VMS displays a legend with a suitable luminance, a high contrast and a good quality in terms of detail and spatiation.

The test persons were generally able to reach the maximum legibility distances, and some were able to reach larger or even much larger distances. The reason is clearly that some of the test persons have better than normal visual acuity.

3. Some early tests

3.1 Sources of variation and handling of results

Figure 6 shows the 10 digits as presented to 3 test persons on the Nissen VMS (refer to section 2.2) in that sequence. The height of the digits is 21 pixels corresponding to 31.5 cm.

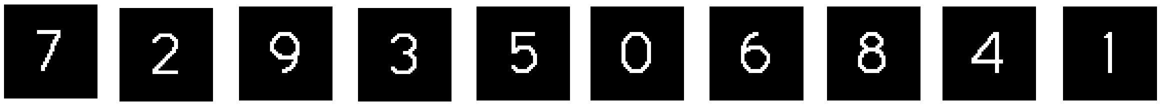


Figure 6: The ten digits shown on the Nissen VMS.

The legibility distances and the average legibility distances for the three persons are indicated in figure 7. It is seen that the 10 average legibility distances are not quite the same for the 10 digits; in particular that the digit 8 has the shortest distance and the digit 1 has the longest.

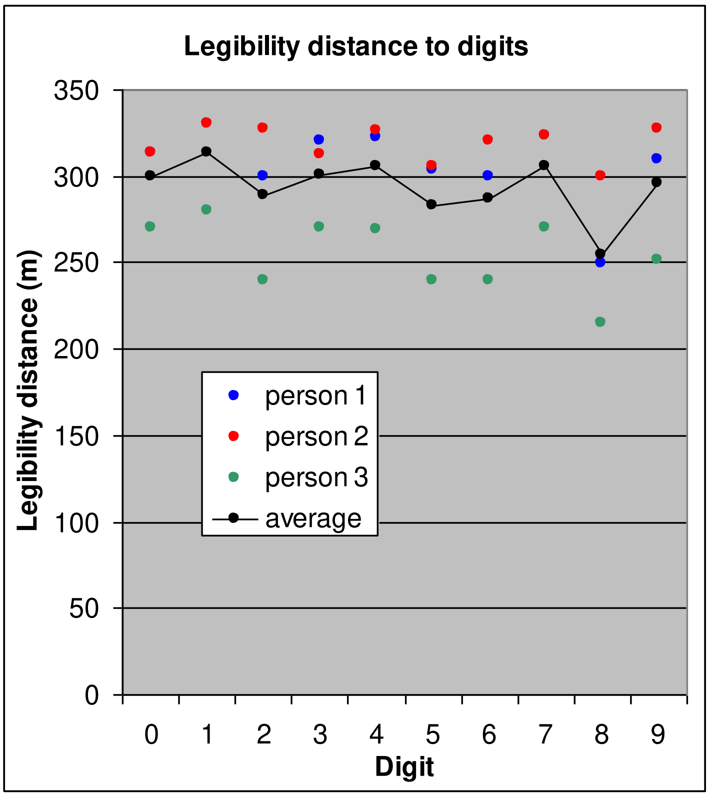
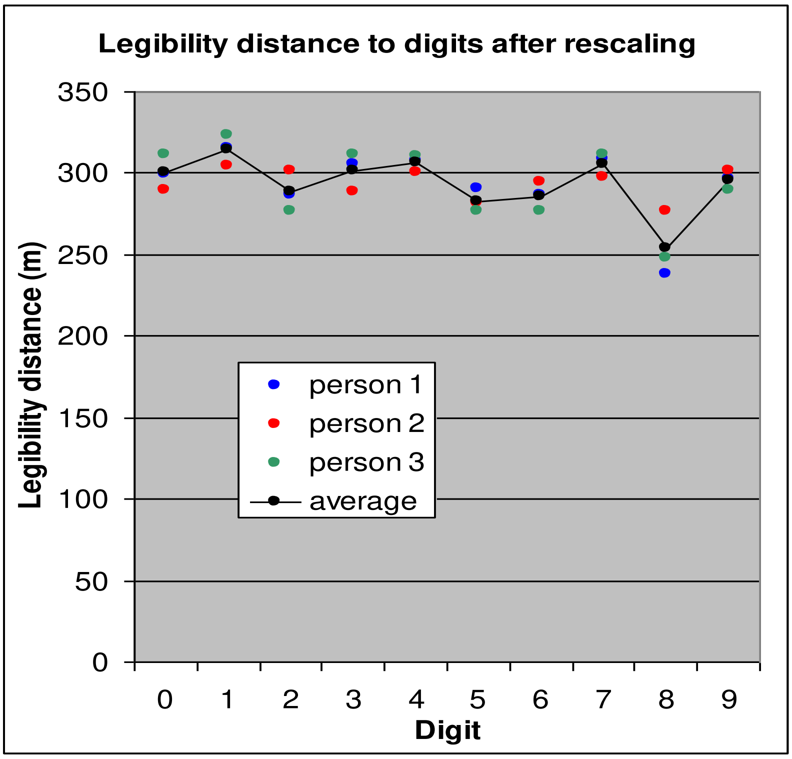


Figure 7: Legibility distances for three test persons for the 10 digits.

It is normal to assume that the digits and numbers formed by the digits are all legible at the same distance. The same assumption is made for letters and text formed by the letters or legends formed by characters in general. This is a practical assumption, and it has been applied throughout the tests described in this report. However, figure 7 shows that the assumption is not quite true for digits.

The assumption is probably not true for numbers, letters and words either, where even larger deviations may probably occur. As an example, the number 14 is probably readable at a longer distance that 80, because the digits in 14 give more room for each other than the digits in 80. Therefore, a random choice of digits and letters and their combinations to numbers and text introduces some uncertainty of the results.

It is seen from figure 7 that the test persons have different levels of legibility distances, but otherwise agree. For instance, the three persons agree that the digit 8 has the shortest legibility distance and the digit 1 the longest. This is typical for other tests as well with some random variation. Therefore, it is reasonable to rescale the legibility distances provided by the persons so that the average legibility distance for each person becomes equal to the common average for all the persons.



The rescaled legibility distances are shown in figure 8, which shows both the agreement between the persons and the deviations. Such rescaling is done for all the test described in this report, both for legibility distances and ratings.

Figure 8: Legibility distances for three test persons for the 10 digits after rescaling.

In some cases the group of test persons changed during a test as some arrived and others had to leave. The rescaling was then done according to averages for those persons that took part in the complete test. For instance, if a test person left after half the test was carried out, his observations were rescaled to match the average for the other test persons during that part of the test.

It may be noted from figure 8 that average legibility distances are approximately 250 m to 310 m, and that these are longer than the maximum legibility distance of 220 m as estimated in accordance with section 2.3. The explanation is that the visual acuity of the three persons is on the average better than 6/6.

Figure 7 illustrates that there are significant variations between the three persons, whose legibility distances as averages for the digits are approximately 310, 320 and 260 m.

It is typical for the daylight tests of legibility distances that all of the test persons have longer legibility distances than corresponding to normal visual acuity, and that some have much longer distances.

3.2 Apparent luminance

An initial test is reported in VTI note 20:2008 “Läsbarhetsförsök av VMS: Resultat från förförsök vid DTU” (in Swedish), but a short account is given below as well. The test was carried out during spring 2008.

This is the only test, where the big VMS with a pixel spacing of 20 mm and a front area of approximately 900 × 900 mm was used; refer to section 2.2.

The legibility distances were determined for the legends formed by the two digit numbers shown in figure 9. The numbers are 27 pixels high, have stroke widths of 1, 2 or 3 pixels and gaps between digits of 1, 2 or 3 pixels. The luminance level is “L2 continuous” or “L3 continuous”, refer to section 2.1.

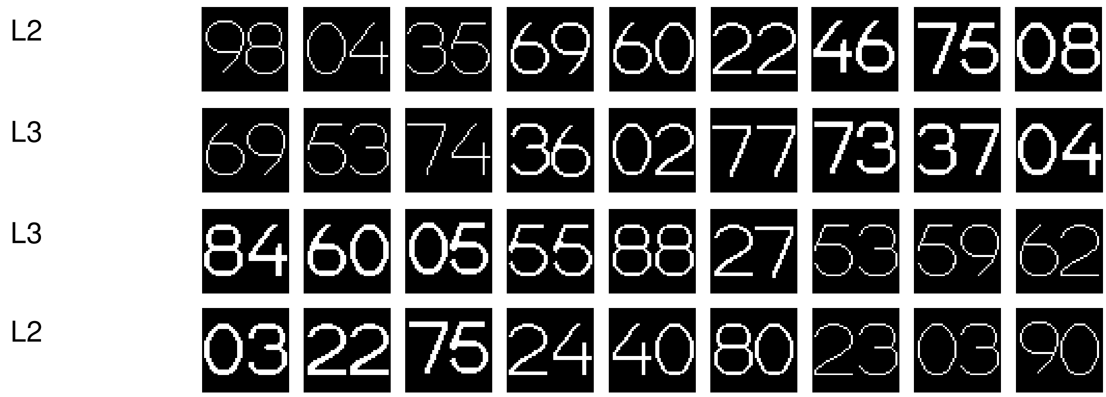


Figure 9: Legends and luminance levels used in the initial test.

The only clear result of the test is shown in figure 10. The legibility, as averaged for the test persons and also for numbers with the same stroke width and luminance level, is shown as a function of a scaled luminance. It is seen that the legibility distance increases with the scaled luminance.

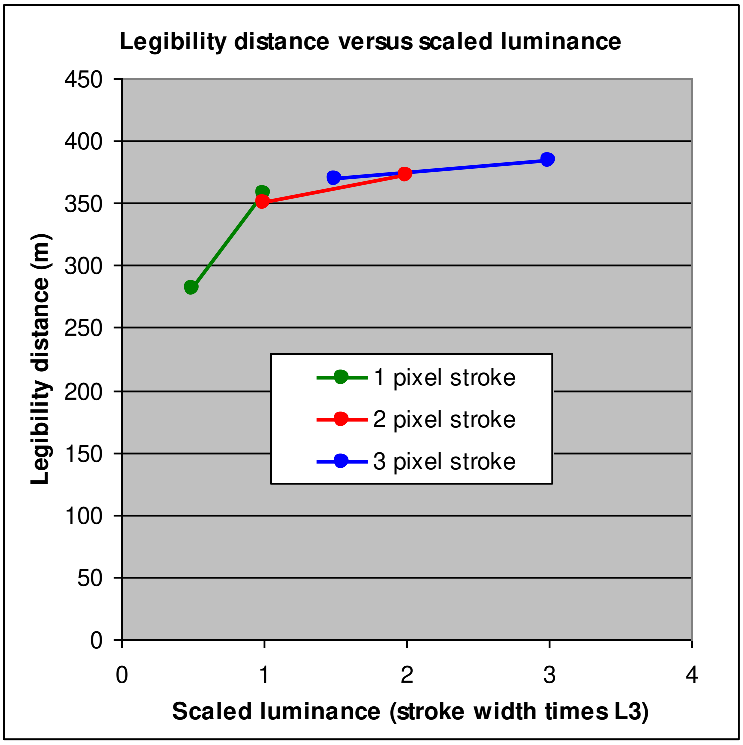


Figure 10: Legibility distance versus scaled luminance.

The scaled luminance is formed as the product of the pixel stroke width and a factor set to ½ or 1 for the luminance levels of respectively “L2 continuous” and “L3 continuous” (the luminance for “L2 continuous” is half the luminance of “L3 continuous”, refer to section 2.1).

It has to be understood that the background on which a legend is seen has a luminance due to reflection of ambient light in the VMS front and to scatter in the human eye. The contrast of the legend to the background can therefore be low.

The idea behind the scaled luminance is that a legend is seen with a blur at long distance, so that it appears to have a wider stroke and thereby a reduced luminance. The actual stroke width of 1, 2 or 3 pixels is not seen, but it affects the apparent luminance and therefore the contrast. Legends are seen with a reduced contrast depending on the stroke width. These matters are illustrated in figure 11.

Some numbers on a black background

The numbers on a realistic background in daylight conditions

The numbers seen with blur at a distance

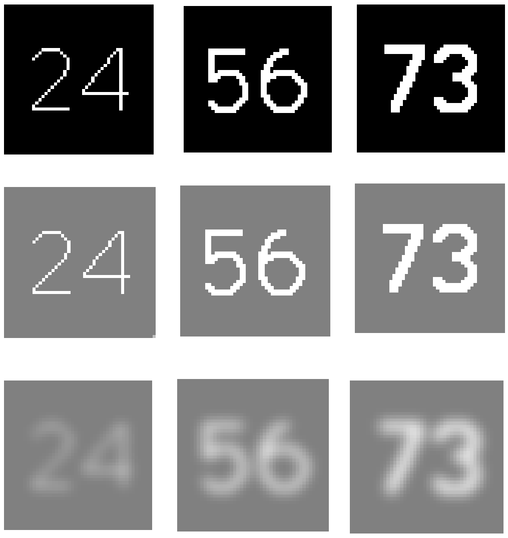


Figure 11: Legends are seen with a reduced contrasts depending on the stroke width.

The limiting aspect in this test is actually the contrast of the numbers. If the contrast had been good, persons with good visual acuity would be able to read the numbers at more than 400 m distance. But the contrast is not good and decreases with distance - because blurring increases.

It is concluded that the nominal luminance as defined in EN 12966-1 is not representative for the apparent luminance with which legends with thin strokes are seen at a distance. Blurring reduces the apparent luminance and the contrast - thereby reducing the legibility distance.

This effect is strong in the initial test as the stroke widths of 1, 2 and 3 pixels are small compared to the height of the number of 27 pixels. The value of the initial test is to bring the matter of the stroke width to attention, so it could be considered in the main tests. Apart from this, there is little useful information from the initial test, among else because the 400 m distance available on the road was not sufficient for all observers.

3.3 Repeatability and reproducibility

The legibility distances to the two digit numbers shown in figure 12 were determined two times by a group of 5 persons. The numbers have a height of 20 pixels equal to 30 cm on the Nissen VMS refer to section 2.2), stroke widths of 1, 2 or 3 pixels, and gaps between the digits of 3, 4 or 5 pixels. The luminance setting was constant at “L2 continuous” (refer to section 2.1).

Figure 12: Legends shown twice to one group of 5 persons.

A similar repetition was done by another group of 5 persons using the two digit numbers shown in figure 13. These reflect the same variation of the stroke width and the gap between the two digits. However, the luminance setting was twice as high at “L3 continuous” (refer to section 2.1).

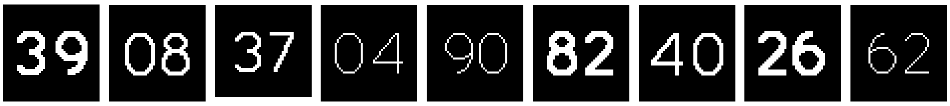


Figure 13: Legends shown twice to another group of 5 persons.

The average legibility distances are shown in figure 14. The repeatability seems to be quite good even if one point is far off; the Pearson coefficient of correlation is 0,86 indicating a fairly good correlation.

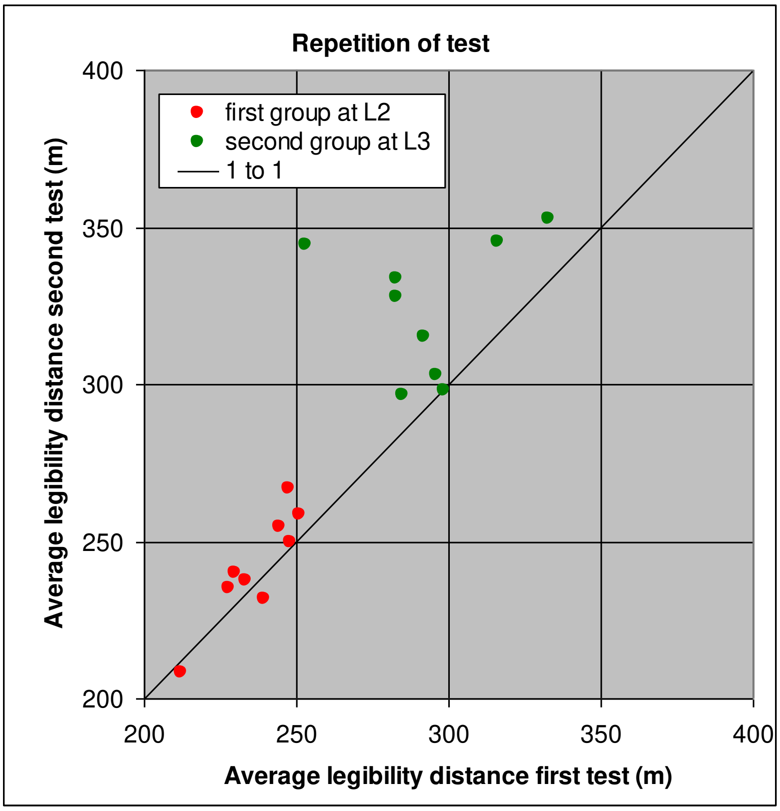


Figure 14: Result of the repetition test.

One can note that the average legibility distances tend to be higher in the second than in the first test. The reason may be that the persons were already familiar with the numbers in the second test.

One can also note that the average legibility distances determined by the second group at “L3 continuous” are much higher than the legibility distances determined for the first group at “L2 continuous”. One of the reasons is that the luminance is twice as high; another reason is that the second group is on the average fairly young, while the first group is on the average fairly old.

Each group also determined the legibility distances to the legends that had been shown to the other group, and with the same luminance setting. The average legibility distances of the two groups are compared in figure 15. For the distances that were determined twice by a group, the averages of the two determinations are used. Additionally, the averages have been rescaled so that the two groups have the same overall average.

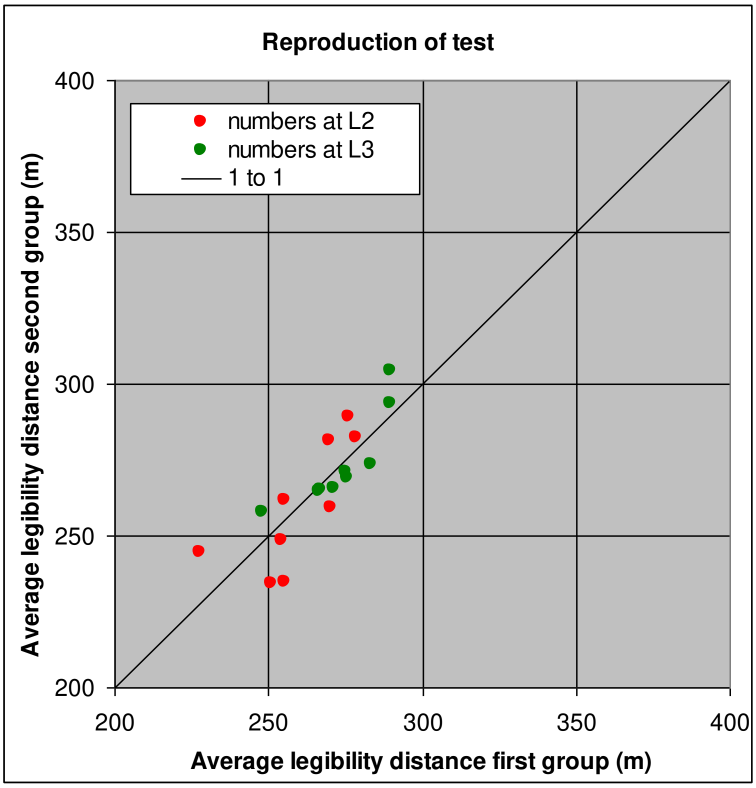


Figure 15: Result of the reproduction test.

Accordingly, figure 15 shows if the two groups react in the same manner to the variables of the stroke width, the gap between digits and the luminance. In this sense the reproducibility seems to be fairly good, the Pearson coefficient of correlation is 0.82.

It can be questioned if the above-mentioned scaling of the average distances for the two groups to provide the same overall averages is reasonable. However, the fairly old group cannot read the legends at the same distances as the fairly young group. It is not interesting to reveal that, but more interesting to see if the two groups react in the same manner to the above-mentioned variables (stroke width, gap between digits and luminance).

One can note that the true influence of twice the luminance is estimated in a realistic manner from figure 14. It is an increase of the legibility distance of 15 to 20 m in the prevailing circumstances.

The data shows an additional influence of the stroke width in an interaction with the luminance of the same kind as discussed in section 3.2.

This supports that the nominal luminance as defined in EN 12966-1 is not representative for the apparent luminance with which legends with thin strokes are seen at a distance.

Apart from this, the data does not reveal any direct influence of the stroke width, and there is no clear influence of the gap between the two digits either.

3.4 Early tests of the quality of the legend

The real aim of the initial test presented in section 3.2 was to reveal a possible influence of the quality of the legend on the legibility distance. The quality was represented by stroke width set to 1, 2 or 3 pixels, and the spacing of digits represented by the gap between two digits set to 1, 2 or 3 pixels. The stroke width proved to have a clear influence on the legibility distance by means of the apparent luminance as reported in section 3.2, but otherwise no clear influence. The spacing had no influence in spite of being down to 1 pixel for numbers with a height of 27 pixels.

A similar study was carried out later using the two digit numbers shown in figure 16. These all have a height of 20 pixels, but a variation of the quality in the sense that the stroke width is 1, 2 or 3 pixels, and the gap between the digits is 3, 4 or 5 pixels. These numbers were shown on the Nissen VMS (refer to section 2.2), where the height of 20 pixels corresponds to 30 cm.

"L2 continuous"

"L3 continuous"

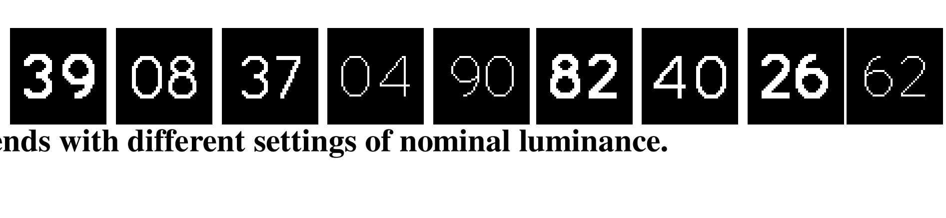


Figure 16: Legends with different settings of nominal luminance.

The conclusion was the same as for the first test, a possible influence of the quality of the legend as such is not revealed. The test was repeated at night with the same conclusion. However, the test confirms the influence of the stroke width on the apparent luminance and thereby the legibility distance. This is discussed in section 4.

Because of lack of conclusions regarding the possible influence of the quality of the legend, the tests were continued by means of the two digit numbers shown in figure 17. These numbers were presented in a mixed and random order on the Nissen VMS (refer to section 2.2) and the legibility distances were determined by a small group of three persons.

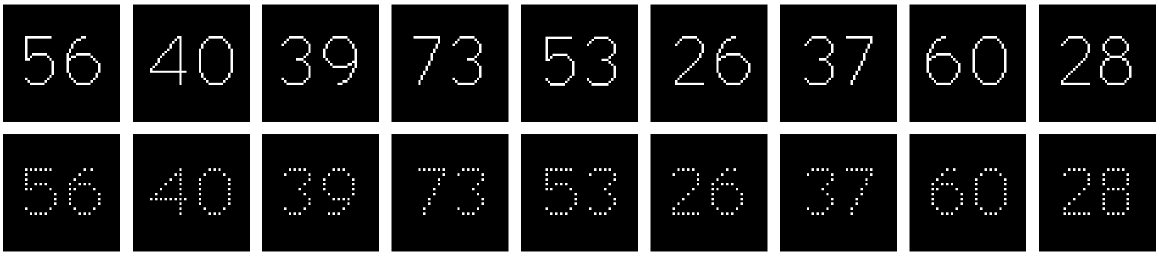


Figure 17: Legends formed with a height of 20 pixels (top row) and 10 pixels (bottom row).

All of the numbers have a height of 20 pixels. However, those in the upper row use all of the available pixels, while those in the lower row use only every second pixel in both directions – this turns out to be approximately half the number of pixels compared to those in the upper row. The numbers in the upper row were shown with a luminance setting of “L2 continuous” (refer to section 2.1), while the numbers in the lower row were shown with twice the intensity from each pixel so as to provide a total output of about the same.

The legibility distances are compared in figure 18. Except for a single point that is far off, the agreement is good. Therefore, there is no loss in legibility distance by presenting numbers with a pixel height of 10 pixels instead of a pixel height of 20 (as long as the actual heights measured in centimetres are the same).

It was tested if the numbers with fewer pixels have disadvantages at shorter distances, like being difficult to interpret, but this did not seem to be the case.

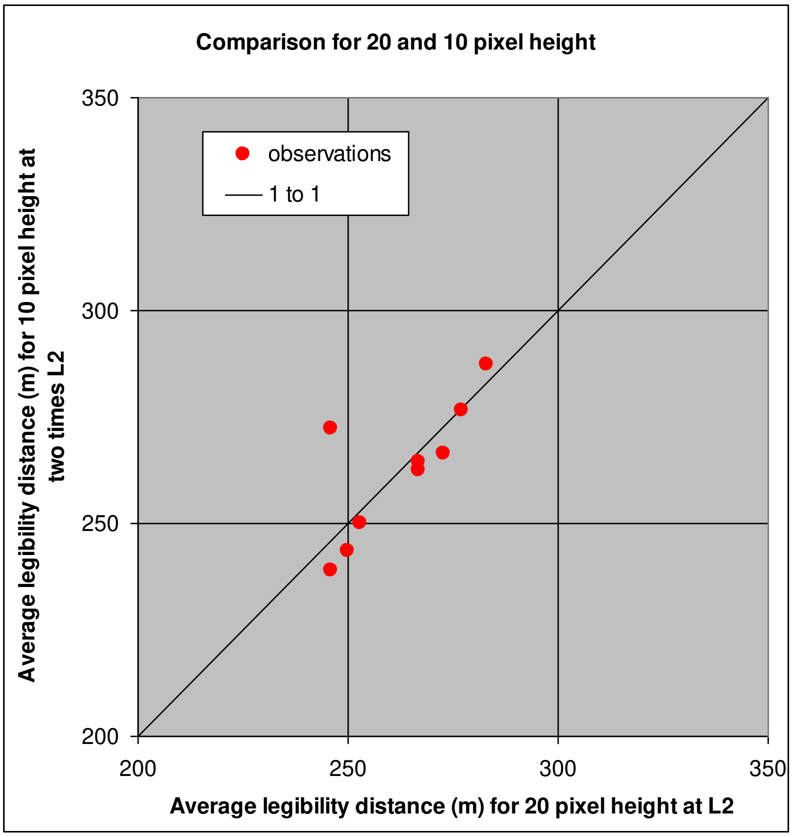
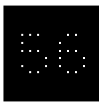


Figure 18: Comparison legibility distances for numbers with heights of 20 and 10 pixels.

According to EN 12966-1, the equivalent area is not doubled, but multiplied by four when every second pixel is deactivated, and therefore the output from each remaining pixel should be raised by a factor of four according to EN 12966-1. This illustrates that something is wrong with the luminance definition of EN 12966-1, but the four times higher output was actually also used. The legibility distances did not change – probably because they are already at the maximum allowed by visual acuity.

NOTE: Sporadic experiments were made with numbers formed with quite few pixels such as shown here but these turned out to be confusing. The exact minimum number of pixels was not determined.



4. Luminance needed for legibility

A test is introduced in section 4.1 and on this basis a luminance index is proposed in section 4.2 and a regulation curve in section 4.3.

4.1 A test and the results of the test

The test is the one that is considered in section 3.4 regarding the quality of the legend, but it is considered here in terms of luminance needed for legibility. The legends used are shown in figure 19, where the luminance settings are also indicated.

65 cd/m^2 at night

130 cd/m^2 at night “L2 continuous” at day

320 cd/m^2 at night “L3 continuous” at day

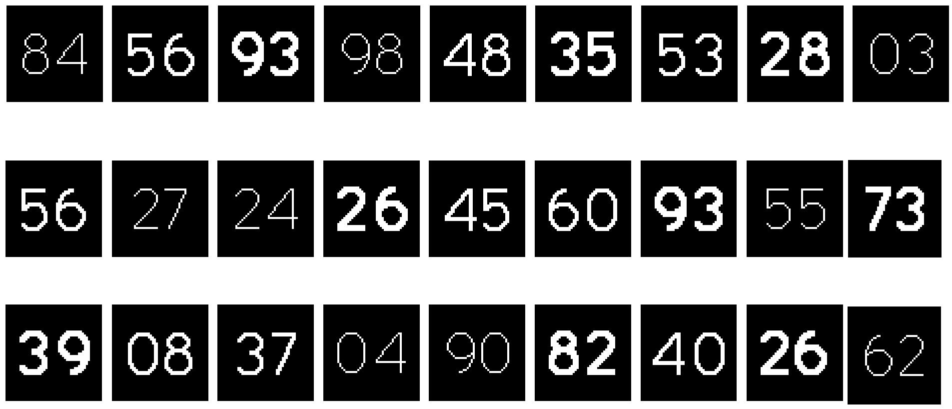


Figure 19: Legends with different settings of nominal luminance.

Only the two lower rows of legends were used in daytime and with the indicated luminance settings of “L2 continuous” and “L3 continuous”. All three rows of legends were used at night with the luminance settings that are indicated.

The legends are two digit numbers with a height of 20 pixels equal to 30 cm on the Nissen VMS and stroke widths of 1, 2 or 3 pixels width. The legends were presented in random order and the maximum legibility distances were determined for each of the persons that took part.

The daytime conditions were cloudy. The conditions at night were as prevailing at the test road at night with a local road lighting providing a low lighting level of less than 4 lx measured on the road surface. Five persons took part at day and six persons at night.

The lowest luminance of 800 cd/m^2 that can be set on the VMS is actually too high for night conditions, and therefore a relatively dark sheeting material with a transmittance of 7,2 % was mounted in front of the VMS. The nominal luminance values span roughly the ranges allowed by EN 12966-1 for luminance classes L2 and L3 at low levels of ambient light (the minimum luminance is 60 and 75 cd/m^2 for respectively L2 and L3, while the maximum luminance is 375 cd/m^2).

The average legibility distances are shown in figures 20 and 21 for respectively day and night conditions as functions of a scaled luminance. The averages are formed not only for the persons that took part, but also for three legends with the same stroke width and luminance.

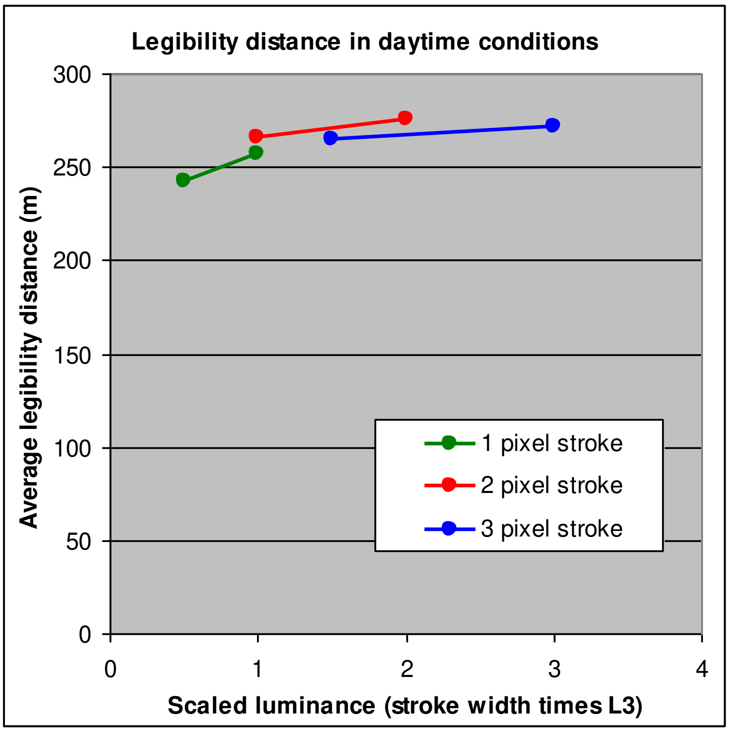


Figure 20: Legibility distance versus scaled luminance in daytime conditions.

In figure 20 for day conditions, the scaled luminance is formed in the following manner. For legends shown with the nominal luminance of “L3 continuous”, the scaled luminance is the pixel stroke width of the legends, either 1, 2 or 3. For the legends presented with the nominal luminance of “L2 continuous”, the scaled luminance is half the pixel stroke width of the legends, either ½, 1 or 1,5. The justification is that the luminance provided by “L2 continuous” is half the luminance provided by “L3 continuous”.

In figure 21 for night conditions, the scaled luminance is the nominal luminance times the stroke width.

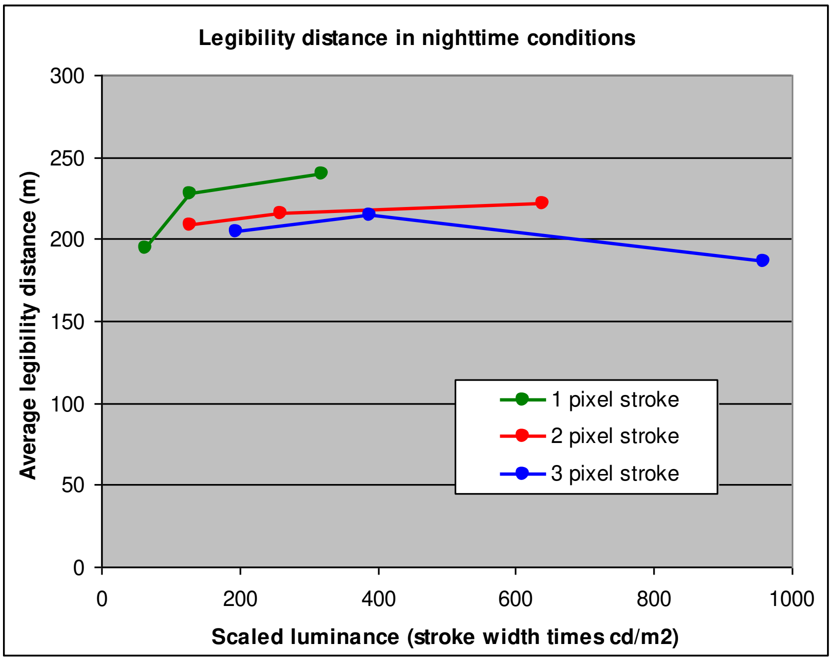


Figure 21: Legibility distance versus scaled luminance in nighttime conditions.

There is not very much variation of the legibility distance with the scaled luminance in daytime conditions, refer to figure 20. The reason is probably that the scaled luminance is varied by a factor of 6 only (from 0,5 to 3 times “L3 continuous”) and that it is sufficient, or close to being sufficient, in all cases.

There is more variation of the legibility distance in night conditions, refer to figure 21. One reason is probably that the scaled luminance is varied by a relatively large factor of close to 15 (from 65 cd/m^2 to 960 cd/m^2), so that the total variation is from slightly insufficient to slightly glaring. Some of the variation seems random and may really be caused by the use of different messages for the different luminance levels.

It is seen that the legibility distances are lower in night conditions than in daytime conditions, compare figures 20 and 21. There is no explanation for that as it is unlikely that night conditions as such cause reduction of legibility distances. It may be that the cause is the above-mentioned sheeting material placed in front of the VMS in night conditions, but it has not been verified what property of the sheeting material might be responsible.

It seems that the scaled luminance can be “L3 continuous” in daytime conditions and approximately 100 cd/m^2 in night conditions without loss of legibility distance.

4.2 Proposal for a regulation curve

According to the previous section, the scaled luminance needs to be approximately the luminance derived from “L3 continuous” for daylight situations and 100 cd/m^2 or a bit less for night conditions.

“L3 continuous” was defined in section 2.1 by means of a linear relationship between the VMS nominal luminance and the VMS illuminance in a range from 4 000 to 40 000 lx. This relationship was used for regulation of the VMS nominal luminance in daylight tests in this range, and even a somewhat larger range.

However, the linear relationship cannot be extended to low lighting levels, where it would predict the need for a scaled luminance of more than 1000 cd/m^2, which is in contradiction with the above-mentioned need for 100 cd/m^2. Therefore, there is a need for redefining “L3 continuous” so that it can cover the full range of VMS illuminance from full daylight to night conditions.

The starting point for such a redefinition can be the minimum nominal luminance values used to define luminance class L3 in EN 12966-1. These are shown in table 1, where it can be noted that the value of 75 cd/m^2 for night conditions at 4 lx or less meets approximately the above-mentioned need for 100 cd/m^2. It is therefore assumed that the intermediate values for 40 lx and 400 lx are also useful although it is not known at what basis they have been set.

VMS illuminance	Nominal luminance
40 000 lx	12 400 cd/m^2
4 000 lx	2 200 cd/m^2
400 lx	600 cd/m^2
40 lx	250 cd/m^2
4 lx and less	75 cd/m^2

Table 1: Minimum nominal luminance used to define L3 in EN 12966-1.

Figure 22 shows a smooth function that has been fitted to meet the points of table 1 to a fairly good accuracy. This function is not provided as there may be other equally good functions, and as a function need not be very accurate. Deviations up to ± 25 % or even more will hardly have much effect on the legibility.

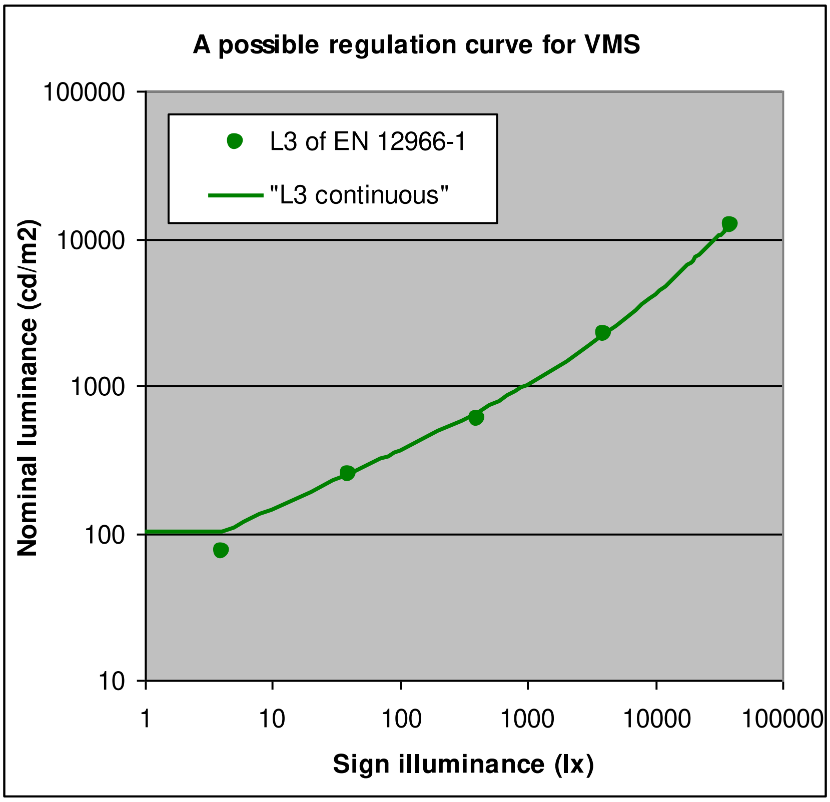


Figure 22: A possible regulation curve for VMS.

It is assumed in the following that “L3 continuous” is defined as a curve that covers the whole range of VMS illuminance in a smooth manner and at least approximately reproduces the points of table 1. Such a curve applies for the colour white. Other colours are to be presented with reduced luminance values in the approximate proportions of EN 12966-1.

4.3 Proposal for a luminance index

The tests discussed in section 4.1 and earlier tests discussed in sections 3.2 and 3.4 demonstrate that the nominal luminance defined in EN 12966-1 is not representative for the apparent luminance with which legends with thin strokes are seen at a distance.

An example of how the apparent luminance varies with distance is shown in figure 23. The example is based on legends with a pixel height of 20 pixels corresponding to 30 cm and stroke widths of 1 or 3 pixels. The legend with the stroke width of 1 pixel is assumed to be set to a nominal luminance of “L3 continuous”, while the legend with the stroke width of 3 pixels is set to a nominal luminance of 1/3 of “L3 continuous”. Accordingly, both legends are set to a scaled luminance of “L3 continuous”.

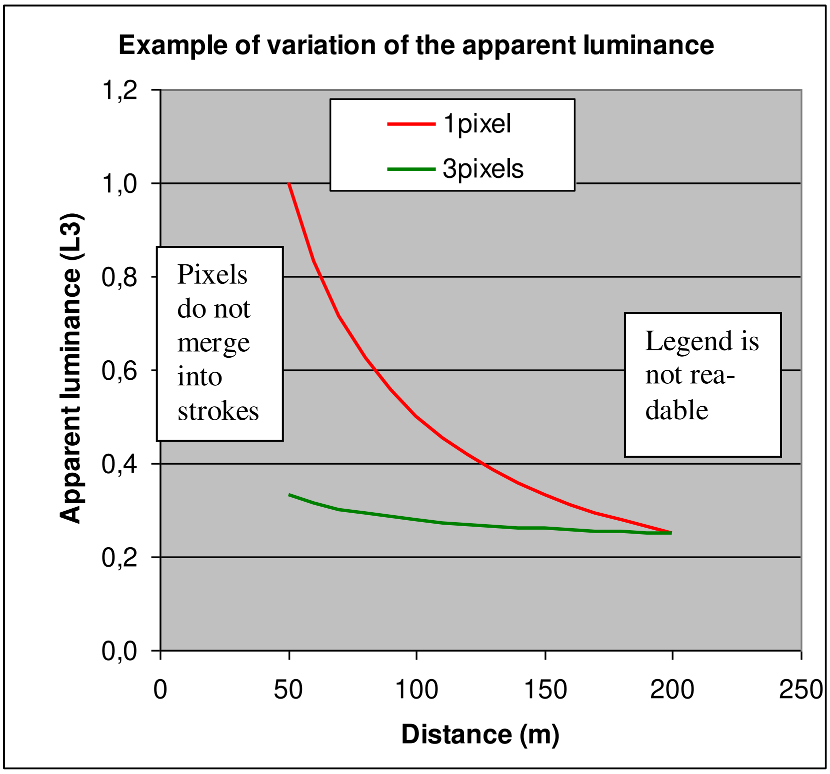


Figure 23: Example of variation of the apparent luminance of with the distance of observation. The two curves are for legends with stroke widths of 1 and 3 pixels.

At short distances, below 50 m in the example, the pixels can be distinguished individually and do in principle not merge into strokes. Therefore, an apparent luminance has not been assigned to the legends for short distances (the individual pixels are seen with a high luminance).

At a particular distance, indicated as 50 m in the example, the pixels do merge into strokes. At this distance the apparent luminance equals the nominal luminance. With increasing distance the stroke widths seem to increase and the apparent luminance decreases in inverse proportion. At a certain distance, indicated as 200 m in the example, the legends become unreadable because details get too blurred or the contrast too low. The curves for the two legends meet at this distance at an apparent luminance of one quarter of “L3 continuous”.

The example illustrates that:
- the apparent luminance varies with distance
- the legend with the thin stroke width shows the larger variation.

If the scaled luminance is set to 12 400 cd/m^2 corresponding to a sign illuminance of 40 000 lx, the apparent luminance at 200 m distance is only 3 100 cd/m^2. This would be the typical luminance of the surroundings to the VMS. For instance a wall with a reflectance of 0,25 illuminated with 40 000 lx obtains a luminance of 3 180 cd/m^2. The sky close to the horizon has a similar luminance level. Accordingly, the apparent luminance of a legend needed for maximum legibility distance seems to be roughly the luminance of the surroundings.

The test discussed in the previous section is based on 30 cm high legends formed by 20 pixels in the height and pixel stroke widths of 1, 2 or 3. It is proposed that for general use a luminance index LI is computed by this equation:

$LI = F_{legend} \times F_{luminance}$

The factor F_{legend} is given by:
$F_{legend} = 5 \times S/H$

Where S is the pixel stroke width of the legend and H is the pixel height of the legend.

The assumption behind F_{legend} is that a legend at a long distance close to the maximum legibility distance is seen with a broadened stroke because of blur and that the broadened stroke is 1/5 of the legend height. In case the actual stroke width is less than 1/5 of the height, the blur causes a reduction of the apparent luminance to a fraction F_{legend} of the nominal luminance set on the VMS.

Accordingly, the factor F_{legend} is intended to account for loss of apparent luminance of legends with thin strokes caused by blur at long distance.

In case the legend does not have a thin stroke, i.e. when the actual stroke width is 1/5 of the height or more, F_{legend} turns out to have a value of 1 or more. This is not realistic, as blur will always lower the apparent luminance, not raise it, and therefore it is best to set a maximum value of unity for F_{legend}.

The factor $F_{luminance}$ is given by:
$F_{luminance} = L_{nominal}/L3$
Where $L_{nominal}$ is the actual nominal luminance set on the VMS and L3 is the luminance corresponding to “L3 continuous” at the actual VMS illuminance.

The LI value is the apparent luminance seen at a distance close to the maximum legibility distance measured in the unit of “L3 continuous”. The need for scaled luminance according to section 4.1 corresponds to an LI value of 0,25, which means that the apparent luminance is one quarter of “L3 continuous”.

The following inverse equation is useful, as the practical problem is to calculate the value of $L_{nominal}$ that must be set in order to provide a desired value of LI:

$L_{nominal} = LI \times L3/F_{legend} = LI \times L3 \times H/(5 \times S)$

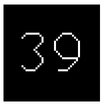
This equation agrees with the experience that the nominal luminance must be raised in inverse proportion to the stroke width.

In the initial test reported in section 3.2, the legends had a pixel height of 27. Accordingly, the LI values were lower than in those later tests, where the legends had a pixel height of 20. That is probably the reason why there is more variation of the legibility distances in the initial test, where the LI was probably critically low in some cases.

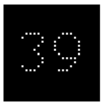
In some tests, the legends were 30 cm high, but formed by a smaller number of active pixels, for instance every second. In these cases the nominal luminance was set higher in inverse proportion to the pixel height so that the total luminous intensity of the legend is constant. This provided the same legibility distance and undoubtedly the same apparent luminance.

The equation does agree with this observation, but in a less obvious manner. If for instance the legend height is 10 pixels instead of 20 pixels, the equations says that the nominal luminance can be reduced to half the previous value. However, the pixel spacing has been doubled so that the nominal luminance has to be based on a four times higher equivalent area. The total consequence is that each pixel has to provide double intensity. Refer to the illustration in figure 24.

a. 20 pixels and 30 cm high, output per pixel of 1



b. 10 pixels and 30 cm high, output per pixel of 2



c. 10 pixels and 15 cm high, output per pixel of ½

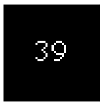


Figure 24: Proportions of outputs per pixel needed to provide the same luminance index.

If the VMS is used to show smaller legends, for instance with a height of 10 pixels without change of pixel spacing, then the prediction of the equation that the nominal luminance can be reduced is simple and correct. Refer again to figure 24.

5. Preferred luminance

The tests accounted for in the previous sections were mostly carried out in cloudy conditions and the road used in the test has shading trees about the end of the road, where the VMS was placed.

Therefore, there was a need to do test in sunny conditions in an open area. The neighbouring football field was used for this purpose by placing the Nissen VMS at suitable locations in the periphery of the field so that it could be observed in selected directions relative to the sun.

As the previous tests involving legibility distance are rather time consuming, appraisals of the sign luminance combined with a recording of the illuminance on both sides of the VMS were used instead.

A model for how the two luminance values influences the preferred luminance was derived in an initial test as described in section 5.1. This model was verified in a larger test that allows frequent appraisal as described in section 5.2. Some observations and conclusions are provided in section 5.3.

5.1 A model derived in an initial test

An initial test involved the three legends shown in figure 25. The legends are two-digit number with a height of 20 pixels corresponding to 30 cm and stroke widths of 1, 2 and 3 pixels.

Figure 25: Legends with a height of 20 pixels height and stroke widths of 1, 2 or 3 pixels.

A group of a 2-3 persons observed the VMS from a distance of 200 m and had the luminance set to a preferred value for each of the numbers. The setting was done by an operator at the VMS who also measured the illuminance on both the front and the back of the VMS by means of a luxmeter as shown in figure 26.

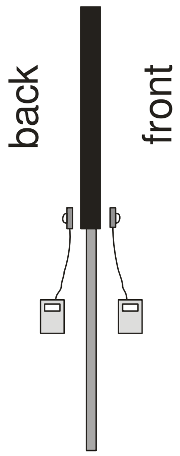
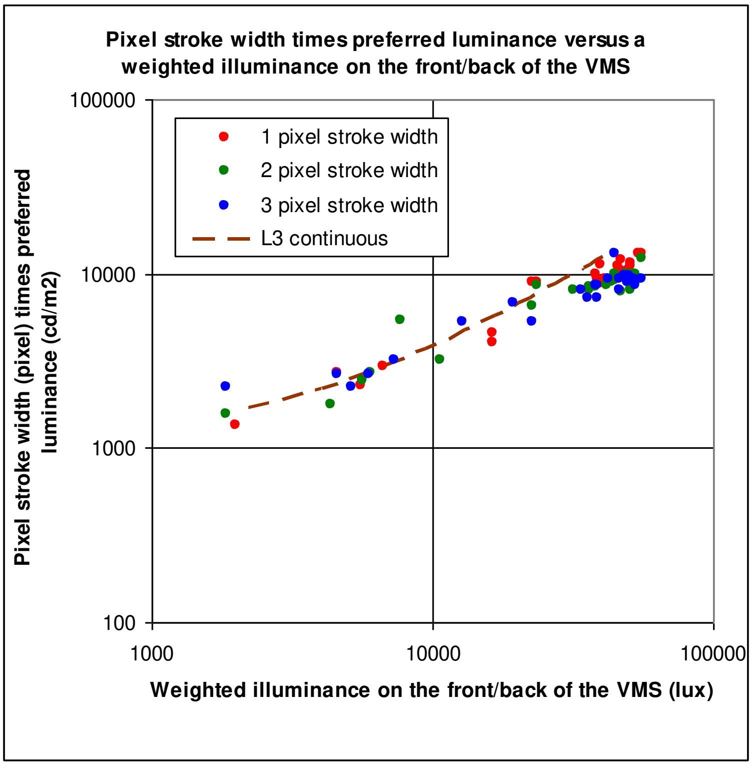


Figure 26: Measurement of the illuminance on both the front and the back of the VMS.

The presentations were repeated at intervals, while the daylight changed. The presentations included overcast conditions and conditions with the sun both in front and to the back of the VMS at varying angles.



The product of the pixel stroke width and the preferred luminance is shown as a function of a weighted illuminance on the front/back of the VMS in figure 27. The weight is 75 % to the illuminance on the front of the VMS and 25 % to the illuminance on the back of the VMS.

Figure 27: Correlation between the product of the pixel stroke width and the preferred luminance to the weighted illuminance on the front/back of the VMS.

Figure 27 illustrates that the preferred luminance is explained well by the stroke width and the two illuminance values. The Pearson coefficient of correlation is as high as 0.96.

The points for the three stroke widths actually mix nicely with each other. This indicates that the group prefers a luminance in the inverse proportion to the stroke width, so that the scaled weighted luminance is approximately the same for the three legends. This is as expected on the basis of the tests reported in previous sections.

The preferred luminance increases with increasing ambient light represented by the two illuminance values. The best correlation is obtained by means of a weighted illuminance using the above-mentioned weights. The preferred luminance times the pixel stroke width roughly follows the curve for “L3 continuous” (refer to section 2.1).

5.2 Confirmation of the model in a larger test

The method of the initial test reported in the previous section is time consuming because the luminance has to be adjusted until a group of persons arrives at agreement about the preferred luminance. Because of this, and because of bad luck with weather, the initial test included only 60 observations for the three numbers in 20 daylight conditions.

Therefore, it was decided to test the model in a larger test that was arranged to allow for more test persons and more quick observations.

The same three legends were used, but with addition of a fourth legend showing a number with the same height but using only every second pixel in the two directions. The four legends are shown in figure 28, where the number “39” is the additional legend. This number can be thought of as having a stroke width of ½ pixels, so the stroke widths form the sequence ½, 1, 2 and 3 pixels. The purpose of the addition is to obtain a stronger test of the effect of the stroke width.

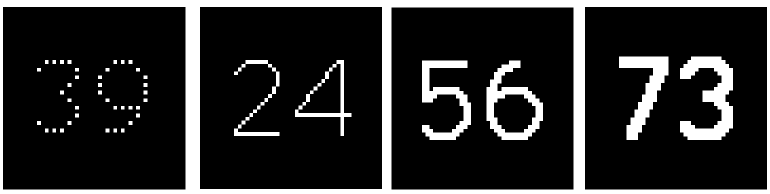


Figure 28: Numbers with 20 pixels height and ½, 1, 2 or 3 pixels stroke width.

The numbers were shown one by one and this was repeated for three settings of the nominal luminance to “L2 continuous”, “L3 continuous” and “twice L3 continuous”. Refer to section 2.1 regarding the luminance settings, which form the proportions 1 : 2 : 4. The settings were with respect to the weighted illuminance on the front/back of the VMS as described in section 5.1.

An operator at the VMS measured the two illuminance values, calculated the weighted illuminance, adjusted to the first luminance level and started an automatic sequence of the VMS in which the four numbers were shown one by one three times, each time with a pause in between. During the two pauses, the operator adjusted the VMS to the next luminance setting.

The automatic sequence was preceded by the VMS showing a word meaning "ready" (in Danish) and terminated by the VMS showing a word meaning "the end" (in Danish). During the pauses, the VMS showed "pause". The order in which the numbers were presented was different for the three luminance levels in order to make the repetitions less obvious to the persons.

The sequence involved a total of 12 cases (four numbers times three luminance settings) and was started at intervals.

The test persons were placed 200 m in front of the VMS and rated the luminance on a scale from 1 to 5 meaning "much too low", "too low", "optimum", "too high" and "much too high" for legibility. When looking against the sun, the persons were equipped with a hat in order to shade the sun.

The observations include a total of approximately 75 daylight situations with cloudy conditions or sunshine with the sun at various positions behind or in front of the VMS. The daylight situations represent large variations in the two illuminance values forming the combined illuminance. A total of 11 persons took part, but they were not all present at all observations.

A supervisor directed the observations by instructing the persons, requesting start of a sequence from the operator and noting circumstances regarding the daylight conditions and possible mistakes made by the operator.

Figure 29 shows the average ratings for each of the daylight situations as a function of the weighted illuminance. The average rating for a daylight situation is for the persons and also the twelve cases, and represents the level of the rating at the daylight situation.

The average rating does not vary much, and this is taken as support of the model of the previous section regarding the influence of the ambient light. The support is considered to be strong in view of the large variation of daylight situations.

NOTE: In some daylight situations, the setting "twice L3" required a higher luminance than can be set with the VMS and accordingly the ratings were not included. This would affect some the averages of the diagram as "twice L3" consistently leads to higher ratings than the other settings. The bit of cheating is that in those cases an average rating for "twice L3" was entered into the empty places. These cases are relatively few.

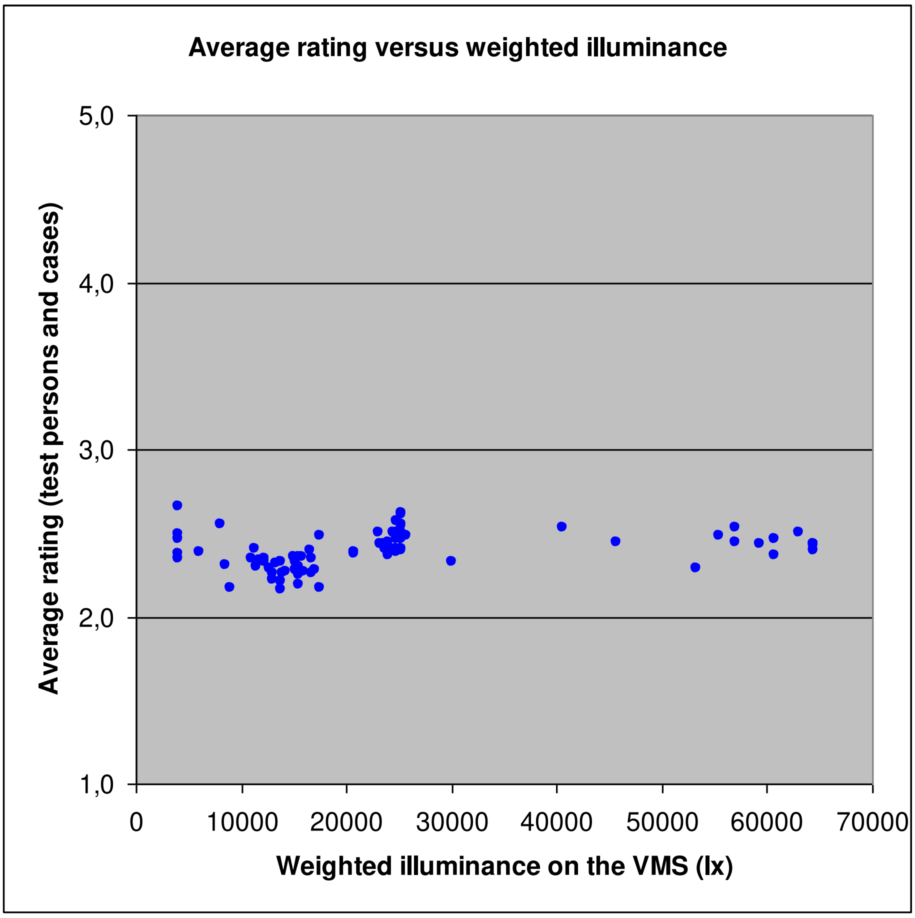


Figure 29: Average rating versus weighted illuminance on the front/back of the VMS.

Figure 30 shows the average rating versus a scaled luminance setting. By the average rating is meant the average for all daylight situations and all observers, so that the twelve cases are isolated in the remaining values.

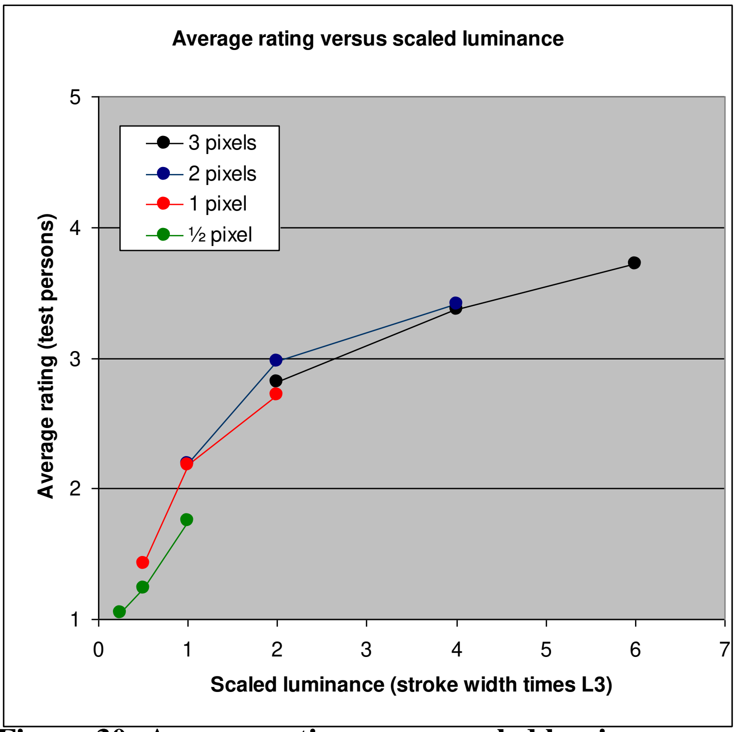


Figure 30: Average rating versus scaled luminance.

The scaled luminance are those provided in table 2. The stroke widths of ½, 1, 2 and 3 pixels are given factors of respectively 1/2, 1, 2 and 3; while luminance settings of "L2 continuous", "L3 continuous" and "twice L3 continuous" are given factors of respectively ½, 1 and 2. The scaled luminance values are the products of these factors for the twelve cases.

Figure 30 uses the stroke width as a parameter, but it is seen that the points for the twelve cases lie with some approximation on a single curve. This is a confirmation that – at least for numbers with thin stroke widths – the apparent luminance is in proportion to the stroke width times the luminance. Additionally, it seems justified that the number formed by using only every second pixel in the two directions can be assigned a stroke width of ½ pixel.

Stroke width	Luminance setting		
	L2	L3	Twice L3
½ pixel	0,25	0,50	1,00
1 pixel	0,50	1,00	2,00
2 pixels	1,00	2,00	4,00
3 pixels	1,00	3,00	6,00

Table 2: Scaled luminance values.

5.3 Observations and conclusions

5.3.1 Regulation of the VMS luminance in response to ambient light

The stability of average ratings against strong variations of daylight situations, as reported in the previous section, leads to two conclusions:

- the usefulness of the regulation curve for luminance in response to illumination on the VMS, as proposed in section 4.2, is confirmed
- the illumination on the VMS is best represented by a combined illuminance for the front and the back of the VMS with weights of respectively 75 % and 25 %.

The illuminance on the front of the VMS has the larger weight of the two. This illuminance monitors probably the background luminance of the VMS caused by reflection of the incident light. Regulation of the luminance of the VMS with regard to this illuminance serves to maintain a suitable contrast of the legend.

The illuminance on the back of the sign monitors the luminance level of the background to the sign, in particular of the sky. Regulation of the luminance of the VMS with regard to this illuminance serves probably as a counter measure against glare from the surroundings. This illuminance is the more important when the sun is located somewhere behind the sign.

The exact weights of the two illuminance values depend probably on the properties of the sign with regard to reflection from the front of the sign. These properties may be reflected by the actual luminance ratio class defined in EN 12966-1. However, there is not sufficient data to reveal these matters in any detail.

The use of two illuminance values implies the use of a photo detector on the back of the VMS as well as on the front of the VMS. The two photo detectors need not, of course, be located on the VMS but can be located somewhere in the vicinity and be used to monitor a group of VMS's with the same orientation.

5.3.2 The preferred VMS luminance

The twelve cases included in the test reported in the previous section span a fairly large total range of scaled luminance values, from 0,25 to 6, and provokes a fairly large range of average ratings from close to 1 (much too low) up close to 4 (too high).

The average rating of 3 "optimum" occurs at a scaled luminance of approximately 2. For comparison, the scaled luminance at which almost the maximum legibility distance is obtained according to section 3 is approximately 1. The preferred luminance seems therefore to be twice the luminance needed for legibility.

A scaled luminance of 2 results in an LI value of 0.5, refer to section 4.3. At this LI value, the apparent luminance as seen from a distance close to the maximum legibility distance is approximately 0,5 times the luminance provided by “L3 continuous”.

EXAMPLE 1: For an LI value of 0,5 the apparent luminance is approximately 50 cd/m² in darkness at a sign illuminance of 4 lx, and increasing gradually in daylight situations with increasing sign illuminance to become approximately 6 200 cd/m² at a sign illuminance of 40 000 lx.

The actual nominal luminance $L_{nominal}$ to be set on the sign depends on the legend height H and stroke width S, both measured in pixels, in accordance with: $L_{nominal} = LI \times L3/F_{legend} = LI \times L3 \times H/(5 \times S)$. The nominal luminance need not be set very accurately as the eye is tolerant to significant changes of luminance. Judging from figure 30, the tolerance can be ± 25 % or more.

EXAMPLE 2: For H = 20 pixels and S = 1 pixel, $L_{nominal}$ becomes 4×LI×L3. For LI = 0,5 $L_{nominal}$ equals 2×L3, so that the nominal luminance to be set on the VMS is four times the apparent luminance mentioned in example 1.

6. Quality of legends

In section 3.4 it is reported that some initial tests of the quality of legends did not provide real information. It may have been that the quality of the legends was acceptable in all cases, or that change of the legend itself simultaneously with change of the quality may have masked a possible influence of the quality. It may also have been that simplicity of the legends combined with ample time and attention for the observations may have masked an influence of the quality that would have appeared in real driving, where conditions are less good.

Therefore, additional tests have been carried out with more complex legends and with restrictions regarding the time for observation.

Further, these tests were based on ratings of legibility instead of determination of the maximum legibility distance. It is understood that ratings may not always be completely objective, but they are more easy to carry out and may also be more sensitive in revealing influence of the parameters.

The five persons taking part were instructed to rate the legibility of the legends and to use the following scale by always choosing one of the options:

- 1: very poor
- 2: poor
- 3: medium
- 4: good
- 5: very good.

The results are presented as ratings averaged for the test persons and in some cases also for a number of legends. These averages are used with decimals.

The rating is performed at a long distance and one or two shorter distances. For the three digit numbers discussed in section 6.1 the rating is performed at each of the distances of 150 m, 100 m and 70 m, while for the city names discussed in section 6.2 the rating is performed at the distances of 100 m and 70 m. In both cases the longest distance is intended to be approximately the maximum legibility distance. Refer to section 2.3.

The ratings took place during daytime, in which the pre-arranged legends were presented with a luminance that in view of the character height and the stroke width, both measured in pixels, lead to the preferable luminance according to section 4.3; i.e. so that the luminance index LI is 0,5. The illuminance on the VMS was measured at intervals and the nominal luminance adjusted accordingly.

Some tests with three digit number are considered in section 6.1, while tests with sets of city names are reported in section 6.2.

6.1 Three digit numbers

Each of the legends shown in figure 31 were presented during 2,5 seconds followed by a pause of 5 seconds before presentation of the next legend. Those in the top row were presented first, and they were then altogether given a single rating by each person. Then those in the bottom row were presented next and given a single rating by each person. This happened at distances of 150 m, 100 m and 70 m.

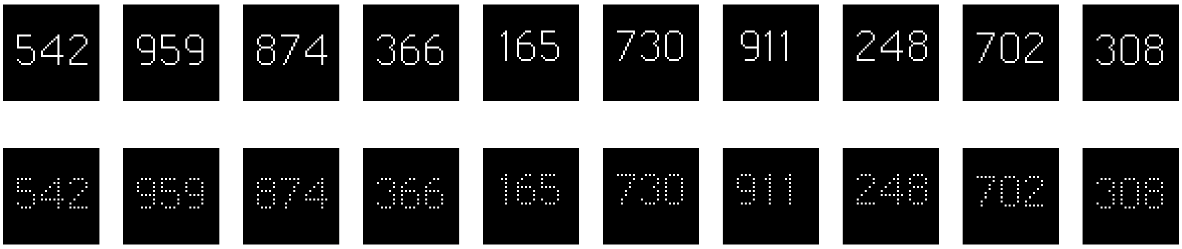


Figure 31: Three digit numbers 15 (top row) and 8 (bottom row) pixels in the height.

The time for presentation of 2.5 seconds is suitable for legibility of a single message according to Danish road standards.

The character height of the legends in the top row is 15 pixels corresponding to 22,5 cm. The character height of the legends in the bottom row is also 22.5 cm, but the legends are formed using only every second pixel in both directions. Accordingly the legends in the bottom row were presented with twice the nominal luminance compared to those of the top row in order that legends in both rows have the same luminance index. Refer to section 4.3.

The average ratings are shown in figure 32.

The ratings are approximately at 3 “medium legibility” for the two sets of legends at the long distance of 150 m. The two sets of legends actually look much the same at this distance because of broadening by blur and they may even be difficult to distinguish. The fairly low rating indicates that the distance of 150 m is close to the maximum legibility distancefor normal visual acuity, which is estimated to approximately 160 m. Refer to section 2.3.

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the maximum legibility distancefor normal visual acuity, which is estimated to approximately 160 m. Refer to section 2.3.

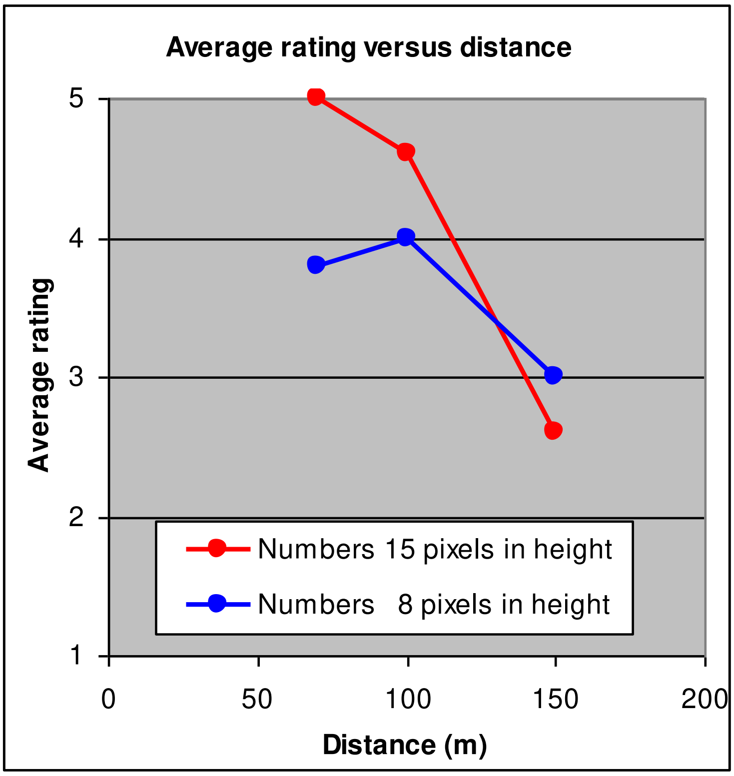


Figure 32: Average ratings of three digit numbers.

The legends in the upper row with 15 pixels in the height receive very good ratings at the shorter distances of 100 m and 70 m. The ratings tend of course to increase with decreasing distance, but an additional cause is that the stroke appears to be well defined and with high luminance and contrast.

The legends in the lower row with 8 pixels in the height receive less good ratings at the shorter distances. The reason is probably that the blur does not make the pixels merge clearly into strokes, so that the legends become confusing.

It is concluded that use of more pixels to form the strokes lead to better ratings of the legibility at short to medium distances. The general conclusion is that the pixel spacing S should be sufficiently small compared to the shortest distance D at which the legend is to be read. It is proposed that S is maximum 0.0004×D. This proposal is based on the general experience that a pixel spacing of 20 mm is generally accepted for VMS that are to be read at distances down to 50 m.

NOTE: A person with normal visual acuity is just able to discriminate a detail of 1 minute of arc. Assuming that the crucial detail is the pixel spacing S, then S should be maximum tan(1/60 degrees) ×D = 0,00029×D.

6.2 City names

The city names are shown in figure 33 as arranged systematically into four sets of city names with four versions A, B, C and D each. The cities are all well known to the persons that took part.

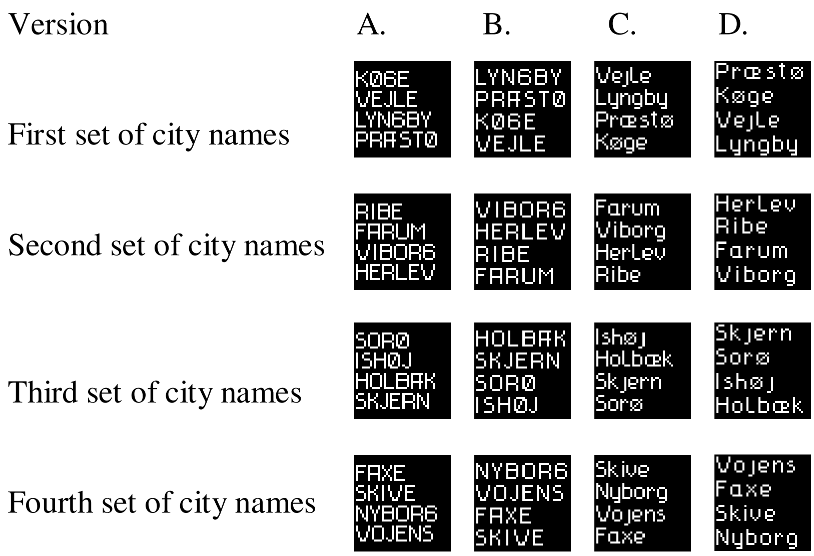


Figure 33: Four sets of city names in four versions.

Capital letters are with a height of 8 pixels. The small letters a, e, u, m, n, r, o, s, x, ø and æ have a height of 6 pixels, while the letters b, h, i, k, l and t have a height of 8 pixels. The letters g, j and y also have height of 8 pixels, but two of these pixels extend below the line.

Other measures of the versions A, B, C and D are accounted for in Table 3.

Version	Letters	Line spacing	Character spacing *)	Area per character **)
A	Capital letters	10 pixels	6,5 pixels	65 pixels^2
B		11 pixels	7,5 pixels	83 pixels^2
C	Initial capital letter followed by small letters	11 pixels	5,9 pixels	65 pixels^2
D		12 pixels	6,9 pixels	83 pixels^2
*) Average width of the letters as they occur in the 16 city names plus gaps between letters **) The product of the line spacing and the average character spacing				

Table 3: Some measures of the different versions of city names.

Version A is with capital letters in a dense packing with a gap of one pixel spacing between the letters and a line spacing of 10 pixels.

Version B is with capital letters in a less dense packing with a gap of two pixel spacings between the letters and a line spacing of 11 pixels.

Versions C and D are comparable to versions A and B respectively, except that they are with initial capital letters followed by small letters and that the line spacing is one pixel larger in view of the extension below the line by some of the small letters. However, the average character spacing is smaller for the small letters than for the capital letters so that the areas measured in pixels is actually the same for versions A and C, and the same for versions B and D.

It is to be noted that the sequence of the city names has been changed in the different versions. Additionally, the sets of city names was shown in the mixed sequence illustrated in figure 34. In this way it has been obtained that each city name occurs four times each, without this being obvious to the persons taking part.

Figure 34: Order of presentation of sets of city names.

Each set of city names was presented during 3.5 seconds, which is suitable for legibility of four messages according to Danish road standards, followed by a pause of 10 seconds before showing the next set. The persons noted the ratings during the pauses.

The average ratings are shown in figures 35 and 36 for respectively 100 and 70 m distance. The averages are formed both for the persons and for the four sets of city names, leaving four values for the different versions.

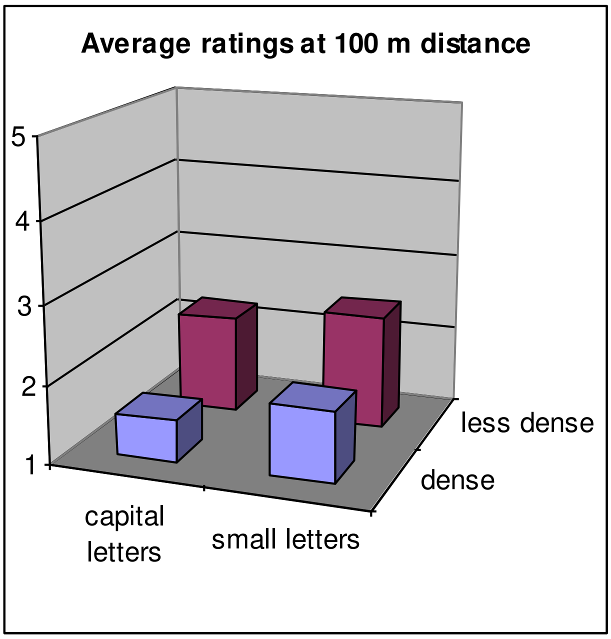


Figure 35: Average ratings of sets of city names at 100 m distance.

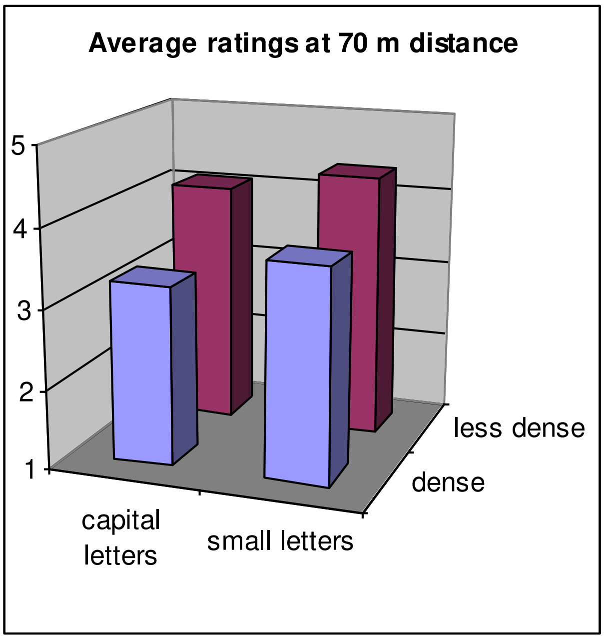


Figure 36: Average ratings of sets of city names at 70 m distance.

It is seen that the average ratings are fairly low at 100 m distance. This is undoubtedly explained by the matter that the distance is at the maximum for legibility, which is estimated to 84 m in accordance with section 2.3. At 70 m distance the ratings are much higher, which is natural.

At 70 m, the ratings of the legibility are at least “medium” for all four versions, and even above “good” for version D. **This shows that characters can be formed with good legibility with a pixel height of 8.**

At both distances, the average ratings for the versions with small letters are higher than for the comparable versions with capital letters.

The difference in ratings is not caused by a difference in the space used for the city names, as the comparable versions with small and capital letters actually take up the same area, refer to table 3. When using small letters, the line spacing measured in pixels needs to be larger, but each line may contain more letters, and in this sense it is possible to pack the same amount of information onto a VMS as when using capital letters only.

In the above-mentioned sense, it is concluded that a city name with a capital letter followed by small letters is more readable than a city name with capital letters only. The actual lay-out of the VMS may of course prevent the use of small letters; for instance if lines are prearranged with a pixel height suitable for capital letters only. But when this is not the case, the use of small letters results in the best legibility. This conclusion is assumed to be valid not only for city names, but for all character messages.

Additionally, at both distances, the average ratings for versions with less dense packing of letters are higher than for the versions with dense packing.

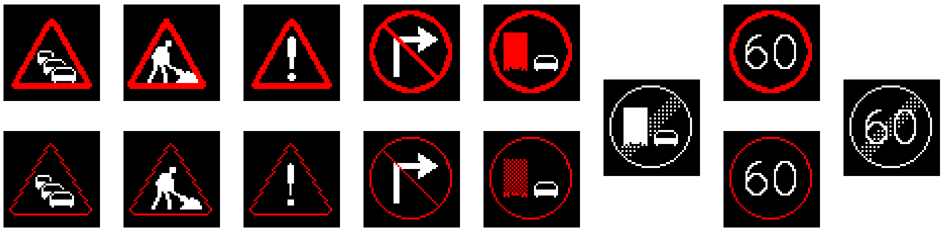
It is concluded that a less dense packing of the letters leads to better legibility than a dense packing. The general conclusion is probably that the line spacing should be approximately 40 % larger than the letter height, when using capitals only, and approximately 50 % larger than the letter height, when using leading capitals followed by small letters. Additionally, the gap between letters should be approximately 25 % of the letter height.

7. Quality of traffic signs

The traffic signs shown in figure 37 were used to test the ability of the Nissen VMS to present the signs and make their pictograms readable. The signs are labelled with the codes used in Danish road standards. The dimensions are those that apply for the standard size of 70 cm according to Danish road standards. This size is used for traffic signs on normal traffic roads.

Thick red border

Thin red border



A20 A39 A99 C11-1 C52 C54
C55 C56

Figure 37: Traffic signs.

The signs are placed in two groups with a thick red border and a thin red border. Two of the signs, C54 and C56, have a white border and are the same for the two groups.

The reasons for testing two versions of the signs is that the Nissen VMS presents the colour red with approximately the same luminance as the colour white, while according to EN 12966-1 it would be more suitable to present the colour red with only a quarter of the luminance of the colour white.

Therefore, it was felt that the thick red border would be glaring and make the legibility of the pictogram difficult.

As the luminance values of the two colours cannot be adjusted independently of each other on the Nissen VMS, the red border was made thinner in order that the apparent luminance as seen at a distance is reduced by blurring. The widths of the borders are respectively 3 and 1 pixels for the two groups.

For the sign C52 with thin red border an additional precaution was taken by activating only every second pixel in the red surface representing a truck. This makes the red surface appear with only a quarter of the luminance as seen at a distance, and makes it less likely that the truck hides the passenger car by overglow. For the same reason, the two vehicles were moved a bit away from each other in the C52 and also the sign C54.

The signs were presented with the luminance of 1,2 times L3. This would provide the preferable luminance index LI value of 0,5 for a character of 1 pixel stroke width and 12 pixel height. Refer to section 4.3.

Only the signs C55 and C56 have characters. These are 17 pixels high, have a stroke width of 1 pixel and correspond to an LI value smaller than 0,5. The arrow in C11-1 is 20 pixels high, has a stroke width of 3 pixels and corresponds to an LI value larger than 0,5. The other pictograms are not easily attributed an LI value as this depends on which details must be seen in order to distinguish the pictogram.

The signs were rated in the same way as explained in section 6. These tests were actually carried out on the same day, and the same five persons took part. The rating regarded legibility of the signs and their pictograms and was indicated by the choice of one of these options:

1: very poor
2: poor
3: medium
4: good
5: very good.

The results are presented as ratings averaged for the test persons.

Each sign was presented during 2 seconds, which is suitable for legibility of a single message according to Danish road standards, followed by a pause of 10 seconds before presentation of the next sign. The presentation was in a mixed and random order. The persons noted the ratings during the pauses.

The average ratings are shown in figures 38 and 39.

The ratings differ clearly for the different signs. It is understandable that the signs A20 and A39 with much detail of the pictograms receive low ratings, and that the signs C11-1 and C55 with simple pictograms receive higher ratings. It is perhaps less understandable that A99 with the simple exclamation mark receives low ratings.

Apart from this, the ratings are higher for the 70 m distance than the 100 m distance for the simple reason that reading is more easy when closer up.

However, the ratings are not really very good for the signs A20, A39 and A99 considering the moderate distances. Further, the attempt to improve the legibility by introducing the thin red border does not seem to work.

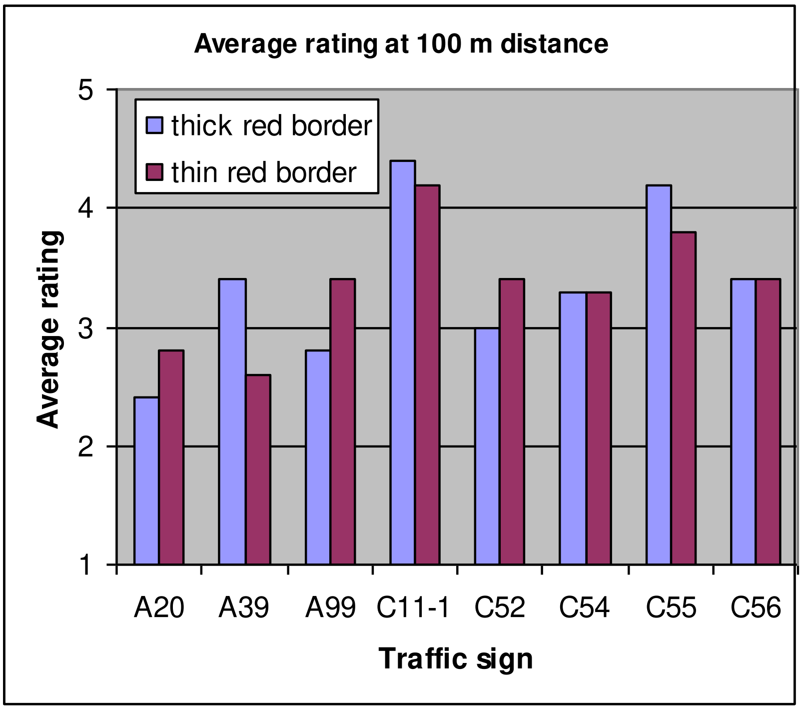


Figure 38: Average ratings of traffic signs at 100 m distance.

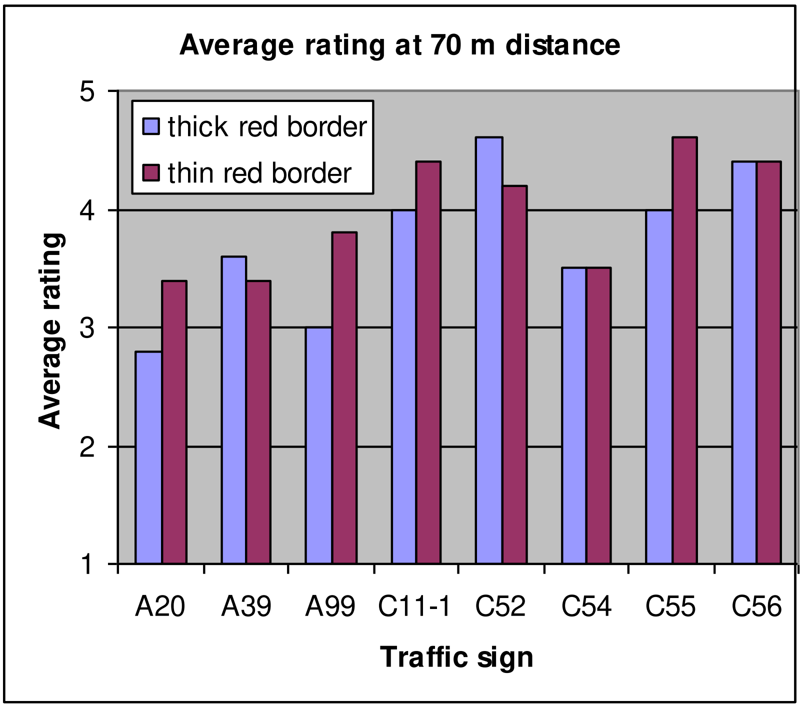


Figure 39: Average ratings of traffic signs at 70 m distance.

This conclusion applies for the signs as presented on a VMS with 48 times 48 pixels, on which pixels can only be on or off. A VMS with more pixels can present the pictograms with more detail and would probably make them more legible.

It would have been desirable to test signs on a VMS with "smoothening", which requires that pixel can be set individually on a scale up to 100 %, where 100 % corresponds to the overall luminance level. Several VMS's on the market have this property. It is likely that "smoothening" gives a better representation of the pictogram and thereby makes them more legible. Refer to figures 40, in which the sign A99 is shown with and without "smoothening".

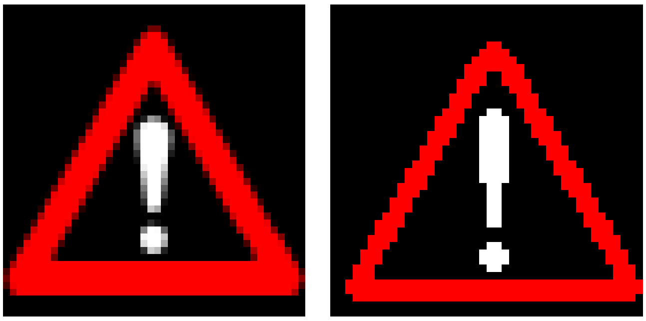
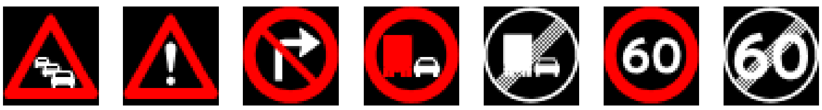


Figure 40: A sign shown with and without "smoothening" (respectively left and right).

NOTE: These signs based on "smoothening" were inspected at one time and seemed promising. They were shown on the VMS that was on loan from the Road Directorate in a short period.



8. Conclusions

The various tests provide strong evidence that character legends with a thin stroke are seen at long distances with a more thick stroke due to blurring in the human eye and that the apparent luminance is reduced accordingly as compared to the nominal luminance defined in EN 12966-1.

It is proposed that this reduction is accounted for by a factor F_{legend} given by $F_{legend} = 5 \times S/H$ where S is the pixel stroke width and H is the pixel height of the characters.

The assumption behind F_{legend} is that a legend at a long distance close to the maximum legibility distance is seen with a broadened stroke of 1/5 of the legend height. The maximum value of the factor should be 1, even for large stroke widths.

There is evidence in tests involving the legibility distance that a particular luminance, depending on the ambient illumination, provides close to the longest possible legibility distance. This evidence is supported by tests involving rating of the legibility.

It is proposed that this particular luminance is described by a luminance index LI obtained as $LI = F_{legend} \times F_{luminance}$ where $F_{luminance}$ is given by $F_{luminance} = L_{nominal}/L3$. $L_{nominal}$ is the actual nominal luminance set on the VMS in accordance with the definition of luminance of EN 12966-1 while L3 is the luminance corresponding to a luminance regulation curve “L3 continuous”.

This luminance regulation curve is hinted at in EN 12966-1 (but not really defined) by means of a number of minimum nominal luminance values for a luminance class L3. Each value is associated with a value of the illuminance on the VMS from ambient light of respectively 4, 40, 400, 4 000 and 40 000 lx. The curve “L3 continuous” is introduced in this report by fitting a curve to these pairs of values.

It is concluded that the LI value needed to provide almost the longest legibility distance is approximately 0,25, while the LI value that provides the luminance preferred in ratings is approximately 0,5.

The usefulness of the curve “L3 continuous” is verified in fairly comprehensive daylight tests.

Further, it is concluded that the sign illuminance is best described by a weighted illuminance on the front and the back of the sign with weights of respectively 75 % and 25 %.

The exact weights of the two illuminance values may depend on the properties of the sign with regard to reflection from the front of the sign. These properties may be characterized by the actual luminance ratio class defined in EN 12966-1. However, there is not sufficient data to reveal these matters in any detail.

The use of two illuminance values implies the use of a photo detector on the back of the VMS as well as on the front of the VMS. The two photo detectors need not, of course, to be located on the VMS but can be located somewhere in the vicinity and be used to monitor a group of VMS's with the same orientation.

The VMS luminance need not be set very accurately as the eye is tolerant to significant changes of luminance. It is estimated that the tolerance can be ± 25 % or even larger without significant adverse effects.

There is direct and indirect evidence that - when the VMS luminance and the presentation of legends is adequate - the legibility distance expressed in metres can be 7 times the character height expressed in centimetres corresponding to normal visual acuity.

A test for night conditions indicates a somewhat shorter maximum legibility distance than at daylight conditions. This may be due to actual circumstances of the test (use of a sheeting material to reduce the VMS luminance sufficiently for night conditions) and not be true in general, as there is no reason to believe that legibility distances should be reduced at night.

Some initial tests on the quality of legends with respect to pixel height, pixel stroke width and spatiation did not provide real information for reasons that are explained or at least hinted at in the report. Therefore, additional tests were carried out with more complex legends and with restrictions regarding the time for observation.

It is concluded that use of more pixels to form the strokes of characters lead to better ratings of the legibility at short to medium distances, but not at distances close to the maximum legibility distance. The general conclusion is that the pixel spacing S should be sufficiently small compared to the shortest distance D at which the legend is to be read. It is proposed that S is maximum $0{,}0004 \times D$ (or that D is minimum $S/0{,}0004$).

It is concluded that city names can be formed with good legibility with a character height of 8 pixels.

It is also concluded that a city name with a capital letter followed by small letters is more readable than a city name with capital letters only. The actual lay-out of the VMS may of course prevent the use of small letters; for instance if lines are prearranged with a pixel height suitable for capital letters only. But when this is not the case, it is best to use small letters.

It is further concluded that a less dense packing of letter forming city names leads to higher ratings of the legibility than a dense packing. The general conclusion is probably that the line spacing should be approximately 40 % larger than the letter height, when using capitals only, and approximately 50 % larger than the letter height, when using leading capitals followed by small letters. Additionally, the gap between letters should be approximately 25 % of the letter height.

The three last-mentioned conclusions are assumed to be valid not only for city names, but for all character messages involving letters and digits.

Test of traffic signs resulted in rather poor ratings of the legibility of some often used warning signs for “queue”, “road work” and “danger”. A rather obvious attempt to improve the legibility was not successful. This conclusion applies for the signs as presented on a VMS with 48 times 48 pixels, on which pixels can only be on or off. A VMS with more pixels can present the pictograms of the signs with more detail and would probably make them more legible. It is probable that the technique of “smoothening” by individual setting of the luminance of each pixel can lead to improvement of the legibility, but this was not tested.

Annex A: Operational instructions for using LED based VMS

A.1 Introduction

This annex is an operational interpretation of the results of the project described in the report “Legibility of LED based variable message traffic sign” to which this annex is attached.

Sections A.2 and A.3 are largely based on the project results, while section A.4 represents general procedures as accounted for in the CIE TC-4-40 draft technical report “Performance evaluation of retroreflective traffic signs”, draft 2009 or in national road standards such as Danish road standards.

The VMS luminance needs to be regulated with regard to the ambient light. A precise way of doing that is proposed in section A.2. In section A.2.1 it is explained how to take account of the legend stroke width by means of a luminance index LI. A regulation curve for the VMS luminance versus the sign illuminance from ambient light is proposed in section A.2.2 and finally, it is proposed how to measure the sign illuminance in section A.2.3.

The legibility of legends is considered in section A.3. Legibility at long distances is considered in section A.3.1 and at short distances in section A.3.2.

Finally, the minimum legend size, as dependent on the driving speed, the number of standard informations displayed on the VMS, and the distance where reading must be completed, is considered in section A.4.

A.2 Regulation of the VMS luminance with regard to ambient light

A.2.1 Account of the legend stroke width by means of a luminance index LI

The luminance index LI is computed by:
$LI = F_{legend} \times F_{luminance}$

The factor F_{legend} is given by:
$F_{legend} = 5 \times S/H$ if $S<H/5$ else 1
where S is the pixel stroke width of the legend
and H is the pixel height of the legend.

The factor $F_{luminance}$ is given by:
$F_{luminance} = L_{nominal}/L3$
where $L_{nominal}$ is the actual nominal luminance set on the VMS

and L3 is the luminance corresponding to “L3 continuous” at the actual VMS illuminance.

The factor F_{legend} is intended to account for loss of apparent luminance of legends with thin strokes caused by blur at long distance. The factor can be calculated easily for legends consisting of characters and digits. For other legends, such as pictograms on warning signs, it can be attempted to define a critical detail and calculate F_{legend} for that detail. The maximum value of F_{legend} is 1.

The factor $F_{luminance}$ is the actual nominal luminance set on the VMS in proportion to “L3 continuous”. The nominal luminance is the luminance defined in EN 12966-1. “L3 continuous” is introduced in section A.2.2.

It is recommended that $L_{nominal}$ is set to provide an LI value of 0,5; as this value leads to the preferred luminance for legibility. An LI value of 0,25 is sufficient to provide legibility distances at or close to the maximum set by the visual acuity of test persons.

At an LI value of 0,5 the factor $F_{luminance}$ has the value $0{,}5/F_{legend}$. This value should be calculated and $L_{nominal}$ should be set in accordance with $L_{nominal} = F_{luminance} \times L3$.

EXAMPLE 1: A legend with a height H of 10 pixels and a stroke width S of 1 pixel has a value of F_{legend} of $5 \times S/H = 5 \times 1/10 = 0{,}5$. Accordingly, the value of the factor $F_{luminance}$ becomes $0{,}5/F_{legend} = 0{,}5/0{,}5 = 1$. This means that $L_{nominal}$ should be set to the value of L3 provided directly by “L3 continuous”.

It is a consequence that the legend should be taken into account when selecting the proportion of “L3 continuous” to set on the VMS. The VMS must be able to provide a nominal luminance in that proportion. If the VMS must is unable to provide a nominal luminance in the proportion of “L3 continuous” that is needed for a particular legend, it may be considered to redesign the legend.

EXAMPLE 2: A legend with a height 20 pixels and a stroke width of 1 pixel requires that $L_{nominal}$ should be set to twice the value of L3 as provided by “L3 continuous”.

EXAMPLE 3: A legend with a height 20 pixels and a stroke width of 3 pixels needs that $L_{nominal}$ can be set to only one third of the nominal luminance of example 2 (two thirds of L3).

If the VMS is to change between legends of different values of F_{legend}, then the VMS nominal luminance should in principle change as well. This might prove unpractical, so that it is best to design the legends so as to have approximately the same value of F_{legend}.

A.2.2 The regulation curve "L3 continuous"

Figure A.1 shows a smooth function that has been fitted to meet approximately the minimum luminance requirements for the colour white of luminance class L3 of EN 12966-1.

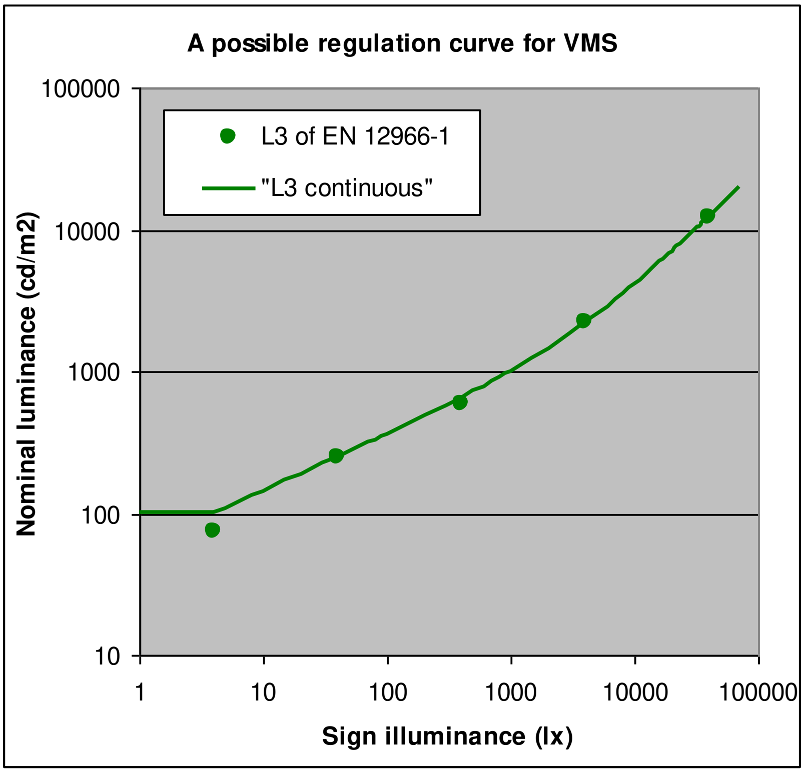


Figure A.1: A possible regulation curve for VMS.

This smooth function is called "L3 continuous" in the following. It shows the nominal luminance L3 of white legends on the VMS as a function of the sign illuminance. The actual nominal luminance to be set on the VMS is given by $L_{nominal} = F_{luminance} \times L3$; refer to section A.2.1.

The luminance of legends of other colours should be in approximately those proportions of the luminance of white that are indicated in table A.1.

Colour	Approximate luminance proportion of white
Yellow	0,60
Green	0,30
Red	0,25
Blue	0,10

Table A.1: Approximate luminance proportion of white for other colours.

NOTE: These proportions are derived from the luminance requirements provided in EN 12966-1.

Table A.1 implies that a VMS message shown in a colour that is different from white should not have a nominal luminance of $L_{nominal}$, but a nominal luminance in the proportion of $L_{nominal}$ provided in table B.1. For instance the colour red should have a luminance that is 25 % of $L_{nominal}$.

Table A.1 also implies that a VMS message that includes fields with the colour white and fields with one or more additional colours should present the luminance of the additional colours in those proportions to white that are indicated in the table. Accordingly, a VMS that has only one overall regulation for all colours simultaneously must in itself provide the correct luminance balance between the colours.

Table A.1 implies proportions of the luminance of fields of the colours white, green, red and blue of 1: 0,6 : 0,3 : 0,25 : 0,1. The actual proportions should not be higher than those proportions by more than 50 %, and not lower by more than 33 %.

Some values of "L3 continuous" are provided in table A.2. The actual luminance should not deviate from those values by more than +50 % and -33%.

Table A.2 introduces a total of 27 steps from the highest possible sign illuminance of probably 70 000 lx down to 4 lx or less. This seems to be a very large number of steps, but the luminance does decrease by approximately 20 % on the average in each step. The number of steps may be higher or lower than 27, but cannot be very much lower if deviations are to be kept within acceptable limits as indicated above.

Step	Sign illuminance	"L3 continuous"	Class L3 of EN 12966-1
1	70 000 lx	19 800 cd/m^2	
2	50 000 lx	14 930 cd/m^2	
	40 000 lx	12 400 cd/m^2	minimum 12 400cd/m^2
3	30 000 lx	9 789 cd/m^2	
4	20 000 lx	7 063 cd/m^2	
5	15 000 lx	5 637 cd/m^2	
6	10 000 lx	4 147 cd/m^2	
7	7 000 lx	3 206 cd/m^2	
8	5 000 lx	2 546 cd/m^2	
	4 000 lx	2 200 cd/m^2	minimum 2 200 cd/m^2
9	3 000 lx	1 839 cd/m^2	
10	2 000 lx	1 452 cd/m^2	
11	1 500 lx	1 241 cd/m^2	
12	1 000 lx	1 008 cd/m^2	
13	700 lx	848 cd/m^2	
14	500 lx	726 cd/m^2	
	400 lx	657 cd/m^2	minimum 600 cd/m^2
15	300 lx	579 cd/m^2	
16	200 lx	487 cd/m^2	
17	150 lx	432 cd/m^2	
18	100 lx	365 cd/m^2	
19	70 lx	316 cd/m^2	
20	50 lx	274 cd/m^2	
	40 lx	250 cd/m^2	minimum 250 cd/m^2
21	30 lx	223 cd/m^2	
22	20 lx	190 cd/m^2	
23	15 lx	170 cd/m^2	
24	10 lx	144 cd/m^2	
25	7 lx	125 cd/m^2	
26	5 lx	110 cd/m^2	
27	4 lx or less	100 cd/m^2	minimum 75 cd/m^2

Table A.2: Values for the regulation curve "L3 continuous".

A.2.3 Measurement of the sign illuminance

The sign illuminance is formed as a combined illuminance with a weight of 75 % to the illuminance on the front of the VMS and 25 % to the illuminance on the back of the VMS.

The illuminance on the front of the VMS has the larger weight of the two. This illuminance monitors the background luminance of the VMS caused by reflection of the incident light. Regulation of the luminance of the VMS with regard to this illuminance serves to maintain a suitable contrast of the legend.

The illuminance on the back of the sign monitors the luminance level of the background to the sign, in particular of the sky. Regulation of the luminance of the VMS with regard to this illuminance serves as a counter measure against glare from the surroundings. This illuminance is the more important when the sun is located somewhere behind the sign.

The exact weights of the two illuminance values may depend on the properties of the sign with regard to reflection from the front of the sign which, on the other hand, may be reflected by the actual luminance ratio class as defined in EN 12966-1. However, when the exact weights are not known, the above-mentioned weights can be used.

The use of two illuminance values implies the use of a photo detector on the back of the VMS as well as on the front of the VMS as shown in figure A.2. The two photo detectors need not, of course, to be located on the VMS but can be located somewhere in the vicinity and be used to monitor a group of VMS’s with the same orientation.

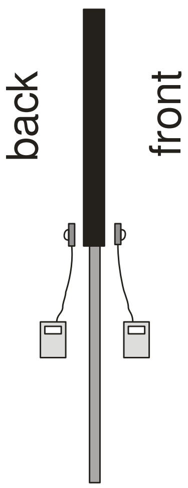


Figure A.2: Measurement of the illuminance on both the front and the back of the VMS.

A photo detector should not have a narrow view to the surroundings as this would cause strong reactions to variation within a small part of the surroundings. On the contrary, the view should be wide meaning that the photo detector should a reasonably good approximation to “cosine correction”.

NOTE 1: Cosine correction means that the directional sensitivity is correct for providing the illuminance on a plane.

Additionally, the photo detector should not have a strong sensitivity to neither the reddish light from a low sun nor the bluish light from the open sky. In fact, the spectral sensitivity should be a reasonably good approximation to “V(λ) correction”.

NOTE 2: V(λ) correction means that the spectral sensitivity is correct for photopic vision.

The two above-mentioned matters facilitate calibration of the photo detectors, as the exact directionality and spectral properties of the light source used for calibration become less critical.

The directional sensitivity may be acceptable when:
$0{,}75 \times \cos(v) \leq S(v)/S(v=0°) \leq 1{,}25 \times \cos(v)$ for $0° \leq v \leq 80°$
$S(v)/S(v=0°) \leq 0{,}22$ for $80° < v \leq 90°$
where S(v) is the signal from the photo detector
and v is the angle of light incidence.

Concerning spectral sensitivity, the signal obtained by illumination with CIE standard illuminant A must not deviate more than 20 % from the signal obtained by illumination with CIE standard illuminant D65 to the same illuminance. Additionally, the photo detector must not show significant sensitivity to neither IR (infrared) nor UV (ultraviolet) radiation.

NOTE 3: CIE standard illuminants A and D65 and A correspond to illumination from respectively incandescent lamps and normal daylight. The spectral distributions are provided in CIE publication 15.2, Colorimetry (1986).

A.3 Legibility of legends

A.3.1 Legibility at long distances

A.3.1.1 General requirements

Legibility at the long distances requires that the legends of the VMS are sufficiently large.

A person with normal visual acuity defined as 6/6 vision is able to identify a character whose height extends 5 minutes of arc in good conditions. This means that the character can be identified at a distance expressed in metres of approximately 7 times the character height expressed in centimetres. The ratio between the legibility distance and the character height is called the legibility index.

NOTE: Normal visual acuity is sometimes defined by the ability to discriminate a detail of a diameter of one minute of arc. The above-mentioned rule means that a character can be identified, when the character height forms 5 details in height.

It may be considered if the driver population as such can be assumed to have 6/6 vision, or if lower vision such as 6/7,5 or 6/9 should be considered in view of drivers with less than normal vision. These may in particular be elderly drivers. Normal vision is not a requirement for having a driving license. In Denmark for instance, the requirement for a non-professional driver is minimum 6/12 on the best eye.

On the other hand, road traffic signs cannot possibly be arranged to provide long legibility distances for persons with much less than normal vision, as the traffic signs would need to have much larger dimensions than normally used.

It may even be assumed that most drivers have normal vision. This is a quote from a CIE TC-4-40 draft technical report "Performance evaluation of retroreflective traffic signs", draft 2009:

> *For legibility calculations, the major variable considered is driver visual acuity. Traditionally, visual acuity has been indirectly associated with age. .... However, visual acuity by age can be misleading because contrast sensitivity reductions are often confused with acuity measures. Most persons with healthy eyes are capable of normal vision (6/6 [20/20]) if they are fully corrected In North America, cataracts used to be a major source of reduced acuity among the aged, but advances in surgical technique and the availability of public health care has largely eliminated cataracts as a major factor. Reductions in acuity are usually due to a retinal disease.*

Additionally, drivers with less than normal vision may compensate by driving at a reduced speed and at routes they know. However, it is proposed that a legibility index of 6 m per cm is used instead of the above-mentioned value of 7 m per cm for normal vision. This serves to take slightly less than normal vision into account and serves to provide for the large majority of drivers according to the above-mentioned CIE TC-4-40 draft technical report. This legibility index value is the basis for VMS in Danish road standards.

EXAMPLE: A VMS on a motorway needs to be readable from a distance of 200 m. If conditions are good, character legends can have a height of 33 cm (33 cm times 6 m/cm is 198 m).

Good conditions mean that the VMS must have a suitable luminance, that the contrast of the legend is good and that the legend is presented with a good quality. It is explained in section A.2 how to set a suitable luminance with regard to ambient light and the legend itself.

A good contrast is obtained when the VMS has a sufficient luminance ratio class, either R1, R2 or R3 as defined in EN 12966-1. R3 is the more strict requirement. It is recommended that the VMS is of class R2 or R3.

A.3.1.2 Character legends

Character legends can be presented with a good quality when using a pixel height of only 8, provided that there are sufficient gaps between lines and characters. The line spacing should be approximately 40 % larger than the letter height, when using capitals only, and approximately 50 % larger than the letter height, when using leading capitals followed by small letters. Additionally, the gap between letters should be approximately 25 % of the letter height.

City names with a capital letter followed by small letters are more readable than city names with capital letters only.

Figure A.3 shows city names presented according to the above-mentioned rules in both versions (capitals only and leading capitals followed by small letters).

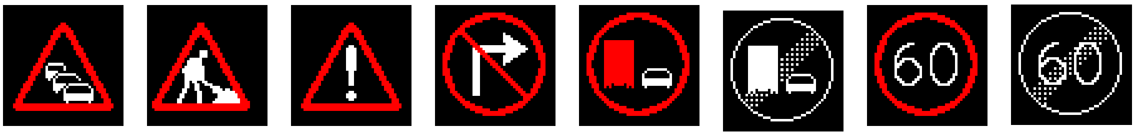
Capitals only

Leading capitals followed by small letters

Figure A.3: Presentation of city names on a 48 times 48 pixel VMS.

A.3.1.3 Pictograms

Regarding standard shape traffic signs, such as exemplified in figure A.4, the surrounding triangle or circle can be identified at a long distance; longer than at the distances where the pictograms are legible. The distances, at which the pictograms are legible, depend on the pictograms themselves and their representations on a VMS.



A20 A39 A99 C11-1 C52 C54 C55 C56

Figure A.4: Traffic signs.

The traffic signs shown in figure A.4 are displayed on a VMS with 48 times 48 pixels, a pixel spacing of 1,5 cm and thus total dimensions of approximately 70 cm times 70 cm. The particular VMS can set a pixel to one of three states: white, red or off.

The signs labelled C55 and C56 have 25,5 cm high numbers for speed limitation and should be readable at distances up to approximately 150 m. The sign labelled C11.1 has a large arrow, and should also be readable at a long distance.

The warning sign for “queue” labelled A20, on the other hand, has much detail and should have a much shorter legibility distance. This is confirmed by a rating of the legibility of poor to medium at 100 m distance. The legibility distance is perhaps a bit longer than 100 m.

The remaining signs have legibility distances in between the two above-mentioned extremes. For some of these traffic signs it would be useful with a better presentation.

A VMS with more pixels can present the pictograms of the signs with more detail and would make them more readable.

It is probable that the technique of “smoothening” by individual setting of the luminance of each pixel can lead to improvement of the legibility. Refer to figure A.5.

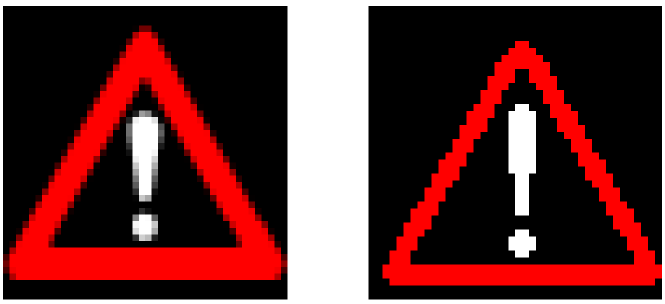


Figure A.5: A sign shown with and without “smoothening” (respectively left and right).

A.3.2 Legibility at short distances

When the legends of the VMS are sufficiently large to be legible at long distances, the size is ample at short distances.

However, the VMS must still have a suitable luminance, the contrast of the legend must be sufficient and the legend must be presented with a sufficient quality.

Concerning luminance, the particular concern at short distances is that a VMS has a limited beam width as reflected by the beam width classes of EN 12966-1. The angular ranges of these classes are shown in table A.3.

Class	Angular range	
	Horizontal	Vertical
B1	±5°	0° to -5°
B2	±7°	0° to -5°
B3	±10°	0° to -5°
B4		0° to -10°
B5	±15°	0° to -5°
B6		0° to -10°
B7	±30°	0° to -20°

Table A.3: Angular ranges of beam width classes.

The luminance of a VMS is defined for a reference direction that is perpendicular to the VMS sign face in the general case. The angular ranges are defined relative to that direction and so that the luminance in any direction inside the angular range is minimum 50 % of the luminance in the reference direction. For directions outside of the angular range there is no guarantee for luminance; it can decrease gradually or drop off abruptly.

The angular ranges shown in table A.3 are fairly small, which means a VMS can loose its luminance at a distance that is not very short.

For an overhead mounted sign, this distance is:
D = h/tan(-V)
where h is the height from the drivers eyes to the upper edge of the VMS
and V is the vertical angle of the relevant beam width class (either -5°, -10° or -20°).

EXAMPLE 1: A VMS is mounted in a gantry with the upper edge of the sign face at a height of 7 m. A driver with his eyes at a height of 1,2 m (h is 5,8 m) may loose luminance at a distance of 66 m, 33 m or 16 m for values of V of respectively -5°, -10° or -20°.

For a side mounted sign, the distance is:
D = s/tan(-H)
where s is the lateral distance from the drivers eyes to the outer edge of the VMS
and H is the horizontal angle of the relevant beam width class (either 5°, 7°, 10°, 15° or 30°).

EXAMPLE 2: A VMS is mounted at the edge of a motorway with the outer edge of the sign face 3 m outside of the edge line. A driver in the fast lane with his eyes 5,75 m inside the edge line (s is 8,75 m) may loose luminance at a distance of 100 m, 71 m, 50 m, 33 m or 15 m for values of H of respectively 5°, 7°, 10°, 15° or 30°.

The VMS should be of a beam width class that allows luminance at the desired shortest distance, to which reading can continue. Alternatively, the distance dictated by the beam width class of the VMS can be accepted if it allows sufficient time for reading; refer to section A.4.

At the edge of the beam, the contrast may be less good than at the reference direction. This may be taken into consideration when requesting the luminance ratio class of the VMS, either R1, R2 or R3.

At short distances, the driver may be able to see the individual pixels so that these do not naturally form strokes of characters or details of pictograms and thereby disturb the reading. To avoid that, the pixel spacing S should be maximum 0,0004×D, where D is the shortest distance at which the VMS legend is to be read. Vice versa, when the VMS has a particular pixel spacing, the distance D should be minimum S/0,0004.

EXAMPLE 3: Commonly used pixel spacings of 20 mm, 15 mm and 10 mm correspond to minimum distances D of respectively 50 m, 37,5 m and 25 m.

A.4 Minimum legend sizes

Figure A.6 shows a vehicle approaching a VMS reaching first a distance D_1 and then a distance D_2.

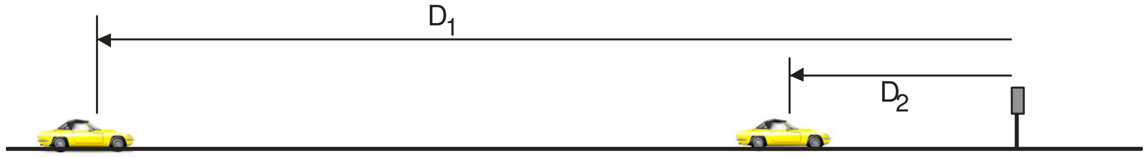


Figure A.6: A vehicle moving between two distances D_1 and D_2 towards a VMS.

D_1 is the legibility distance, meaning the distance where the driver is just close enough to turn the messages on the VMS legible. D_2 is the distance where reading has to be completed.

Driving the range from D_1 to D_2 takes a time interval of $t = (D_1 – D_2)/V$, where D_1 and D_2 are measured in metres and V is the driving speed in metres per second. V can be obtained from the driving speed in km per hour by division with 3,6 (one kilometer per hour is 1000 m/km divided by 3600 seconds per hour equal to 1/3,6 m per second).

This time interval is available for reading. On the other hand, the driver needs a minimum time for the reading depending on the message(s) shown on the VMS. This minimum time may be estimated as $t = 2+N/3$ in accordance with Danish road standards, where N is the number of information units displayed on the VMS. An information unit may be a city name or a pictogram.

This sets a minimum requirement to the legibility distance D_1 depending on the driving speed, the message shown on the VMS and the distance D_2.

For character legends, assuming that conditions are good as described in section A.2, the distance D_1 is obtained in metres as 6 times the height of capitals h measured in centimetres. For pictograms, the legibility distance must be estimated in other ways. Refer to section A.3.2.

Accordingly, a minimum requirement to D_1 implies a minimum requirement to the height of capitals of character legends and to the size and quality of pictograms.

The minimum distance D_2 may be dictated by:

a. the beam width in combination with the geometrical situation, or by the pixel spacing
b. the viewing direction to the VMS
c. the need to start a maneuver implied by the message.

Concerning a. refer to section A.3.3.

Concerning b., it is normally assumed that reading stops if the horizontal angle between the normal line of sight along the road and the viewing direction to the VMS exceeds 15°. The reason for this limitation is that the driver feels unsafe to change the line of sight at a large angle away from the traffic situation in front. Besides, when having come close to the VMS during driving, it gets inconvenient to track it visually.

Additionally, it is normally assumed that reading stops, if the vertical angle exceeds 10°. This is partly because of the angular distance to the normal line of sight, and partly because the car roof in some passenger cars prevents viewing directions higher than 10°.

When comparing these angles to those of the beam width classes accounted for in section A.3, it is seen that the beam width of the VMS is the more limiting in most cases, i.e.: the VMS may loose luminance while still within a useful viewing direction.

Concerning c. the maneuver may be reduction of speed according to a warning displayed on the VMS, or it may be some other maneuvers, like lane changing, according to other messages.

For the particular case when D_2 is 50 m or 25 m, the minimum character heights can be as indicated in tables A.4 or A.5 respectively. A value of D_2 of 50 m is applicable in many cases for overhead VMS on motorways, while a value of 25 m is applicable in many cases for side mounted VMS.

number of information units	Driving speed									
	40 km/h	50 km/h	60 Km/h	70 km/h	80 km/h	90 km/h	100 km/h	110 km/h	120 km/h	130 Km/h
1	12,7	13,7	14,8	15,9	17,0	18,1	19,1	20,2	21,3	22,4
2	13,3	14,5	15,7	17,0	18,2	19,4	20,7	21,9	23,1	24,4
3	13,9	15,3	16,7	18,1	19,4	20,8	22,2	23,6	25,0	26,4
4	14,5	16,0	17,6	19,1	20,7	22,2	23,8	25,3	26,9	28,4

Table A.4: Minimum heights of capitals (cm) assuming a legibility index of 6 m/cm and a distance D_2 where reading must be completed of 50 m.

number of information units	Driving speed									
	40 km/h	50 km/h	60 km/h	70 km/h	80 km/h	90 km/h	100 km/h	110 km/h	120 km/h	130 Km/h
1	8,5	9,6	10,6	11,7	12,8	13,9	15,0	16,0	17,1	18,2
2	9,1	10,3	11,6	12,8	14,0	15,3	16,5	17,7	19,0	20,2
3	9,7	11,1	12,5	13,9	15,3	16,7	18,1	19,4	20,8	22,2
4	10,3	11,9	13,4	15,0	16,5	18,1	19,6	21,1	22,7	24,2

Table A.5: Minimum heights of capitals (cm) assuming a legibility index of 6 m/cm and a distance D_2 where reading must be completed of 25 m.

For pictograms on traffic signs, the standard sizes used in Denmark in accordance with Danish road standards are sufficient. These are 90 cm for traffic signs on motorways and 70 cm on other traffic roads. It is necessary to pay attention to the quality with which the pictograms of some warning signs is displayed.

Annex B: A worked example for an LED based VMS

B.1 A variable message sign

A road administration wishes to use LED based variable message signs with three text lines as illustrated in figure B.1. The font used in the illustration has to be approximated. The signs are to be mounted in gantries on a motorway with a speed limit of 110 km/h.

Figure B.1: Illustration of a VMS with three text lines.

NOTE: The text on the illustration is in Danish, “ulykke” means accident and “Risiko for kø” means risk of queue. It is a requirement that the signs are regulated to provide the optimum luminance with regard to ambient light corresponding to a luminance index value of 0,5; refer to A.2.1.

It is a further requirement that the letter height, as measured by the height of capitals, is sufficient to provide the time that the drivers on the motorway need to read three simple messages, each of them to be considered as an information unit. The time that is needed is given as 3 seconds in accordance with t = 2+N/3 seconds, where N is the number of information units. A supplier offers the LED based variable message sign shown in figure B.2.

Figure B.2: A VMS offered by a producer.

Each of the three text lines is provided by a matrix of LED’s with 14 pixels in height and a sufficient number of pixels in width in view of the messages to be presented. The pixel spacing is 20 mm. The characters are to be drawn with the full height of 14 pixels for capitals and a single pixel stroke width. The nominal luminance, as defined in EN 12966-1 can be regulated to comply width the regulation curve “L3 continuous” or to exceed it by a factor of up to 1,5. Refer to A.2.2.

In the following two sections it is verified that the VMS complies with the above-mentioned requirements.

B.2 Optimum luminance

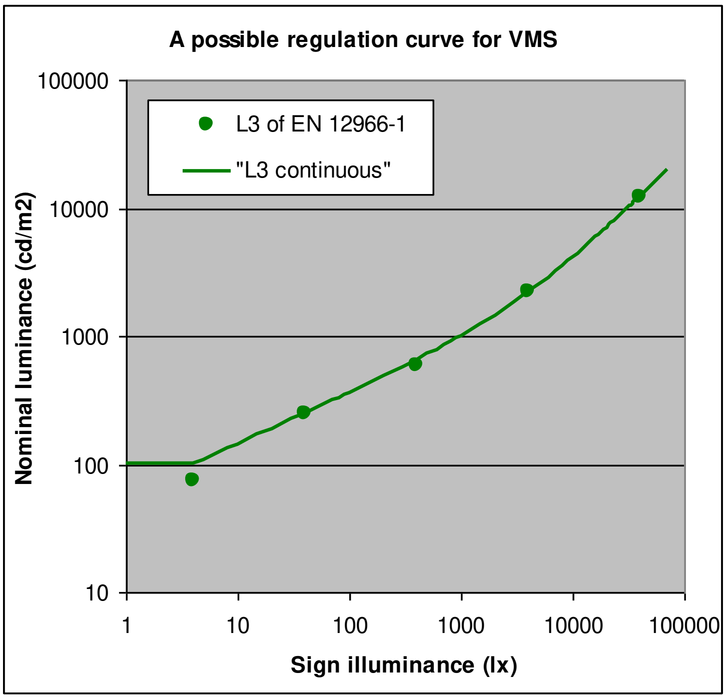
In accordance with A.2.1, the luminance index is given as the product of two factors: $LI = F_{legend} \times F_{luminance}$.

The first factor is: $F_{legend} = 5 \times S/H$
where S is the pixel stroke width
and H is the pixel height of capitals.

The value is $F_{legend} = 5 \times S/H = 5 \times 1/14 = 0{,}37$.

The second factor is: $F_{luminance} = L_{nominal}/L3$
where $L_{nominal}$ is the actual nominal luminance as defined in EN 12966-1
and L3 is the luminance corresponding to the luminance regulation curve “L3 continuous” introduced in A.2.2.

As a luminance index value of 0,5 is requested, the value of $F_{luminance}$ is found by means of $0{,}5 = 0{,}37 \times F_{luminance}$ to $F_{luminance} = 0{,}5/0{,}37 = 1{,}4$.



This means that the nominal luminance has to be set to 1,4 times L3. This is actually possible in view of the ability of the VMS. The regulation curve “L3 continuous” is illustrated in figure B.3.

Figure B.3: The regulation curve “L3 continuous”.

B.3 The reading time provided by the VMS

The reading time provided by the VMS is the time it takes to drive from a distance D_1 in front of the VMS to a distance D_2. See figure B.4.

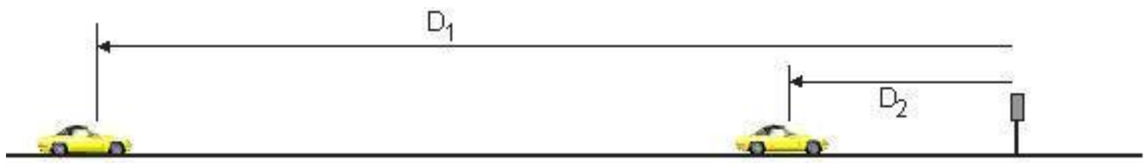


Figure B.4: Two distances defining a range in which reading can proceed.

D_1 is the legibility distance, where the messages on the VMS are just legible so that reading can start. D_2 is the distance where reading has to be completed.

With a character height of capitals of 14×20 mm = 280 mm = 28 cm, the legibility distance D_1 is obtained as 6 m/cm × 28 cm = 168 m. Refer to A.3.1.

On a motorway, is it normally assumed that D_2 is 50 m, refer to A.3.2.

Accordingly, the range in which reading can proceed is 168 m – 50 m = 118 m. If driving at the speed limit of 110 km/h, which equals 110/3,6 = 30,6 m/second, the time provided for reading is 118 m/30,6 m/second = 3,9 seconds. In view of a need of 3 seconds, this is deemed satisfactory.

The same conclusion could have been reached in a simpler way by referring to table B.1, which shows the minimum height of capitals. In this case the actual height of 28 cm exceeds the minimum of 23,6 cm as read from the table.

number of information units	Driving speed									
	40 km/h	50 km/h	60 Km/h	70 km/h	80 km/h	90 km/h	100 km/h	110 km/h	120 km/h	130 Km/h
1	12,7	13,7	14,8	15,9	17,0	18,1	19,1	20,2	21,3	22,4
2	13,3	14,5	15,7	17,0	18,2	19,4	20,7	21,9	23,1	24,4
3	13,9	15,3	16,7	18,1	19,4	20,8	22,2	**23,6**	25,0	26,4
4	14,5	16,0	17,6	19,1	20,7	22,2	23,8	25,3	26,9	28,4

Table B.1: Minimum heights of capitals (cm) assuming a legibility index of 6 m/cm and a distance D_2 where reading must be completed of 50 m.

The reserve in the height of capitals allows more time for reading and thereby time for other tasks and probably also comfort. The reserve also allows the addition of an additional information unit, such as a warning sign. This is illustrated in figures B.5 and B.6.

Figure B.5: Illustration of a VMS with three text lines and a warning sign.

Figure B.6: A VMS offered by a producer.

Annex C: Literature

EN 12966-1 + A1:2010 “Road vertical signs - Variable message traffic signs - Part 1: Product standard”

Lundkvist, Sven-Olof, Nygårdhs, Sara, VTI note 20:2008 “Läsbarhetsförsök av VMS: Resultat från förförsök vid DTU” (in Swedish).

CIE publication 15.2, Colorimetry (1986).

CIE TC-4-40 draft technical report “Performance evaluation of retroreflective traffic signs”, draft 2009.