Readability of variable message traffic sign

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Foreword

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

1. Introduction, summary and conclusions

This report describes a number of tests of the readability of variable message traffic signs that were carried out in a period from the spring of 2008 until the autumn of 2009. An even earlier test is not mentioned. A variable message traffic sign is called VMS in the following.

The authors served as project leaders following each other in the sequence they are listed. Other persons involved in the planning and execution of the tests include Sven-Olof Lundkvist (VTI), Belinda la Cour Lund (Trafitec), Puk Kristine Andersson (Trafitec) and Esben Raahauge Nielsen (DELTA Light and Optics).

The tests are described approximately in the sequence they were carried out. To some degree the sequence describes a “learning by doing” process in which later tests were based on earlier tests.

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

By reading distance is meant the largest distance at which the legend can be read by a test person. The maximum reading 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. For persons with normal visual acuity, the maximum reading distance expressed in metres can be estimated as 8 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 and 6 for respectively the luminance of the VMS, the quality of character legends and the quality of traffic signs. By quality is meant aspects affecting readability.

Conclusions are provided in section 7.

It is a clear conclusion that the apparent luminance of characters with thin strokes depends on the ratio of the stroke width and the character height, and that this affects readability and ratings. 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. The ambient illumination on the VMS, on the other hand, is best described by a weighted illuminance on the front and the back of the sign with weights of respectively 75 % and 25 %.

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 reading distances, while an LI value of 0,25 provides the preferred luminance in rating tests.

The use of more pixels to form the strokes of characters lead to better ratings of the readability at short to medium distances, but not at distances close to the maximum reading distance.

A less dense packing of letters forming city names leads to higher ratings of the readability than a dense packing. The general conclusion is probably that gaps between letters of ¼ of the pixel height is sufficient.

The readability of some often used warning signs for “queue”, “road work” and “danger” is rather poor. An attempt to improve the readability was not successful.

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.

When the VMS has elements in a matrix with a uniform spacing, the luminance of any legend shown on the VMS is the luminance obtained when all the elements in the matrix are turned on.

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

The luminance defined this way is called the “nominal luminance” in the following.

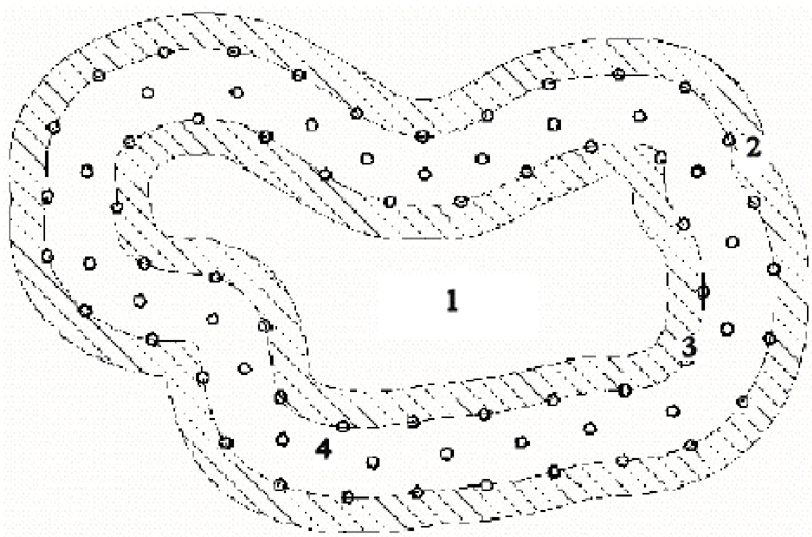


Figure 1: The equivalent area includes the area in between active elements and also the shaded areas of a width of half an element spacing outside of the active elements.

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

During tests in daylight the luminance has been regulated with regard to the ambient light 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.

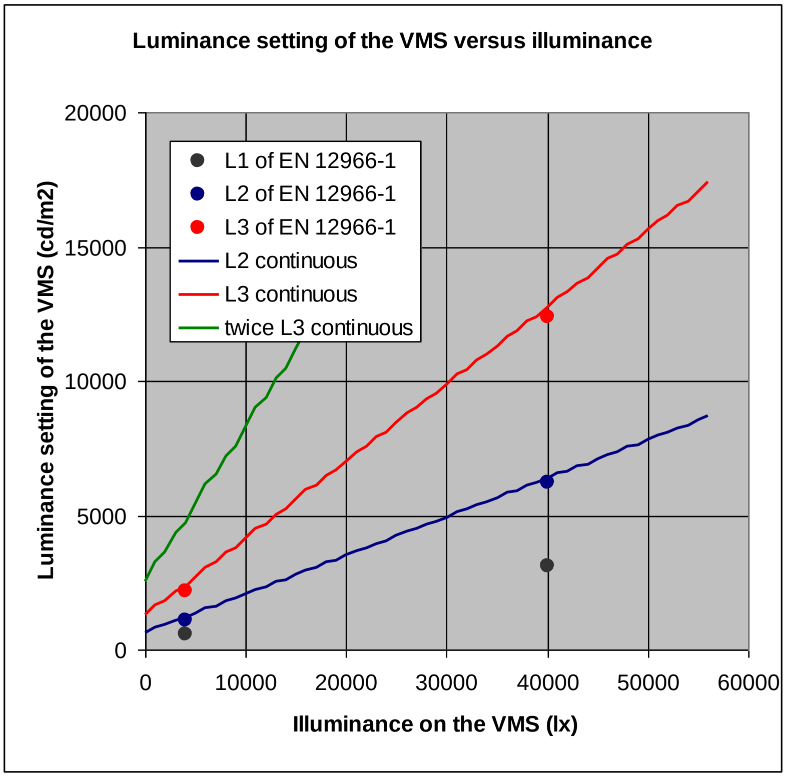


Figure 2: Points for the luminance classes L1, L2 and L3 of EN 12966-1 and some lines based on the points.

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 reading distance test, 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 reading distance. Figure 3 shows a group of persons walking towards the VMS.

In rating tests, the persons were located at a fixed distance from the VMS and evaluated the readability 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.

Figure 3: A group of test persons on Nordvej.

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 has good optical qualities, but 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). Additionally, there were problems in making the VMS work in spite of help from ÅF - Hansen & Henneberg A/S working as consultant for the Danish Road Directorate. This VMS is only mentioned once in the following, in connection with the first test.

Another VMS was supplied by Nissen GmbH for use for the remaining tests, see figure 5. Persons from Nissen were also helpful in providing instructions for how to program and operate the VMS. The VMS was first on loan, but was later bought at a reduced prize. This VMS has 48 x 48 pixels with a spacing of 15 mm, a sign face of approximately 700 × 700 mm, a mass permitting carrying and a reasonable power consumption.

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.

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

Figure 5: The VMS from Nissen GmbH.

3 Some early tests

3.1 Sources of variation and handling of results

Figure 6 shows the 10 digits that as presented to 3 test persons on the Nissen VMS (refer to section 2.2) in that sequence.

The reading distances and the average reading distances for the three persons are indicated in figure 7. It is seen that the 10 average reading 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.

It is normal to assume that the digits and numbers formed by the digits are all readable 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 reading distances, but otherwise agree. For instance, the three persons agree that the digit 8 has the shortest reading 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 reading distances provided by the persons so that each of the average reading distances becomes equal to the common average.

The rescaled reading 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 reading distances and ratings.

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 persons 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.

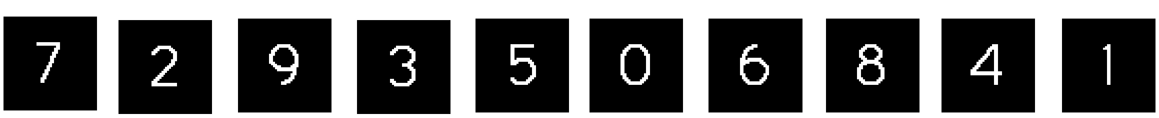


Figure 6: The ten digits shown on the Nissen VMS.

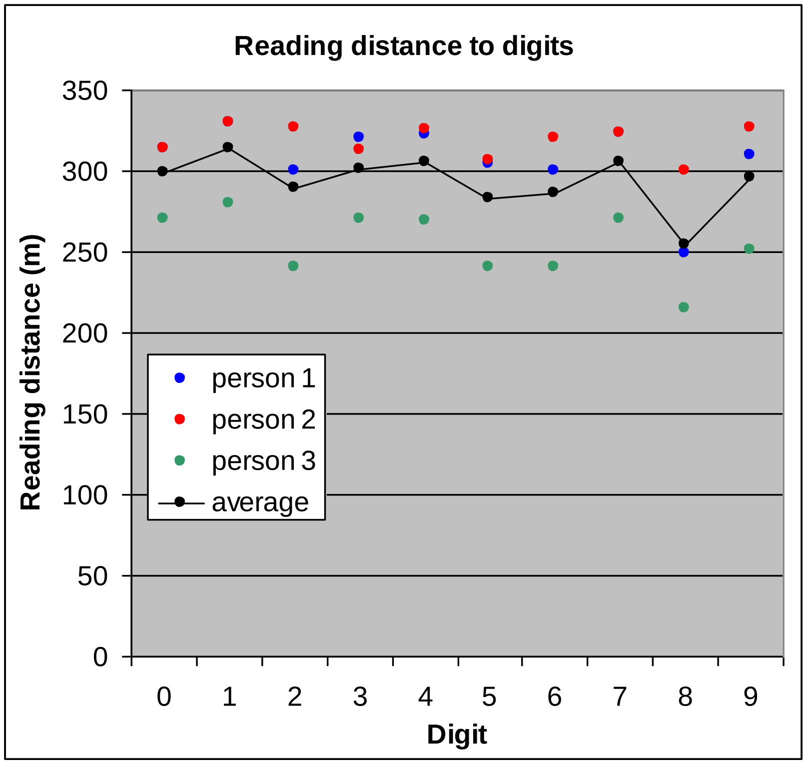


Figure 7: Reading distances for three test persons for the 10 digits.

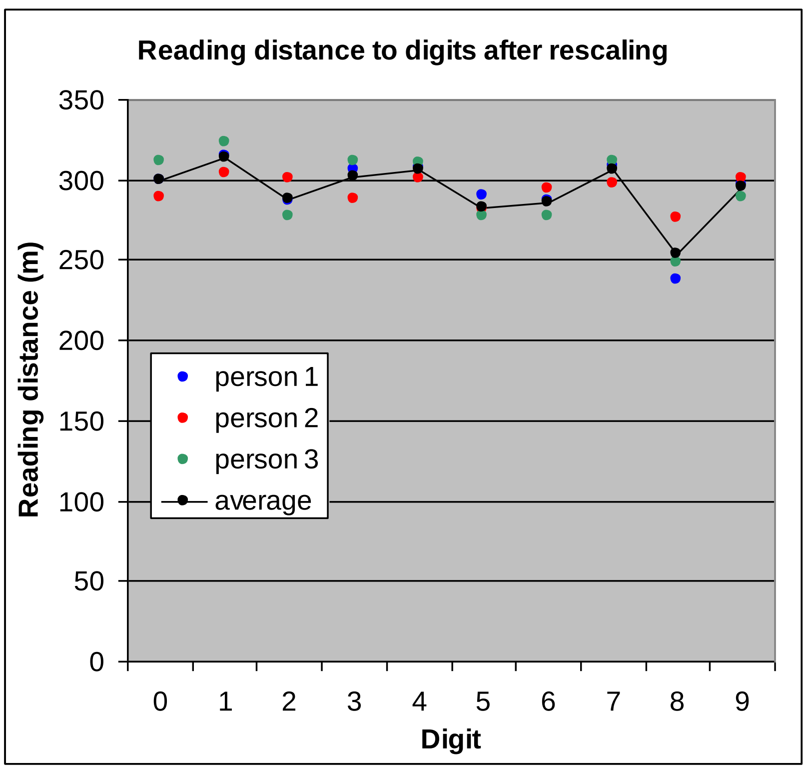


Figure 8: Reading distances for three test persons for the 10 digits after rescaling.

3.2 Apparent luminance

An initial test is reported in VTI note 20:2008 “Läsbarhetsförsök av VMS: Resultat från förförsök vid DTU - Ett samarbetsprojekt inom NMF” (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 reading 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.

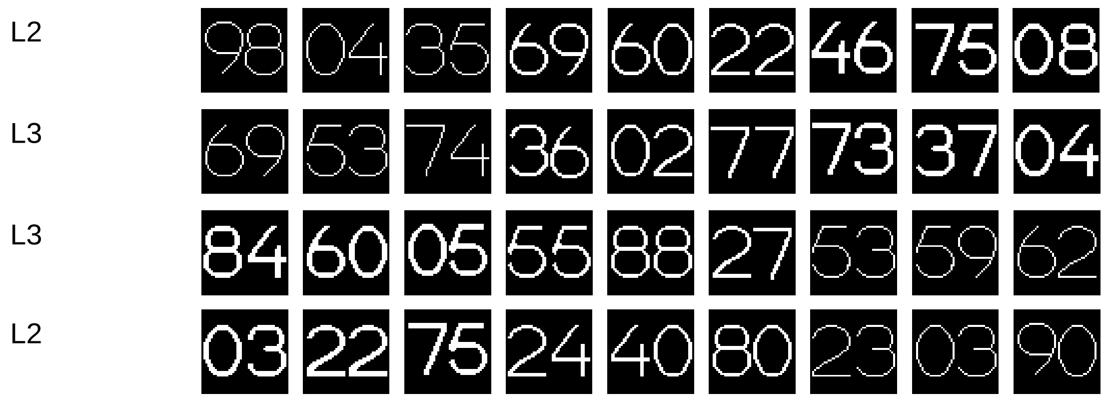


Figure 9: Legends and luminance levels used in the initial test.

The only clear result of the test is shown in figure 10. The reading distance, 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 reading distance increases with the 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.

These matters are illustrated in figure 11.

The limiting aspect in this test is actually the contrast of the numbers. If the contrast had been good, persons with normal 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 reading 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 can it could be considered in the main tests to be discussed. 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.

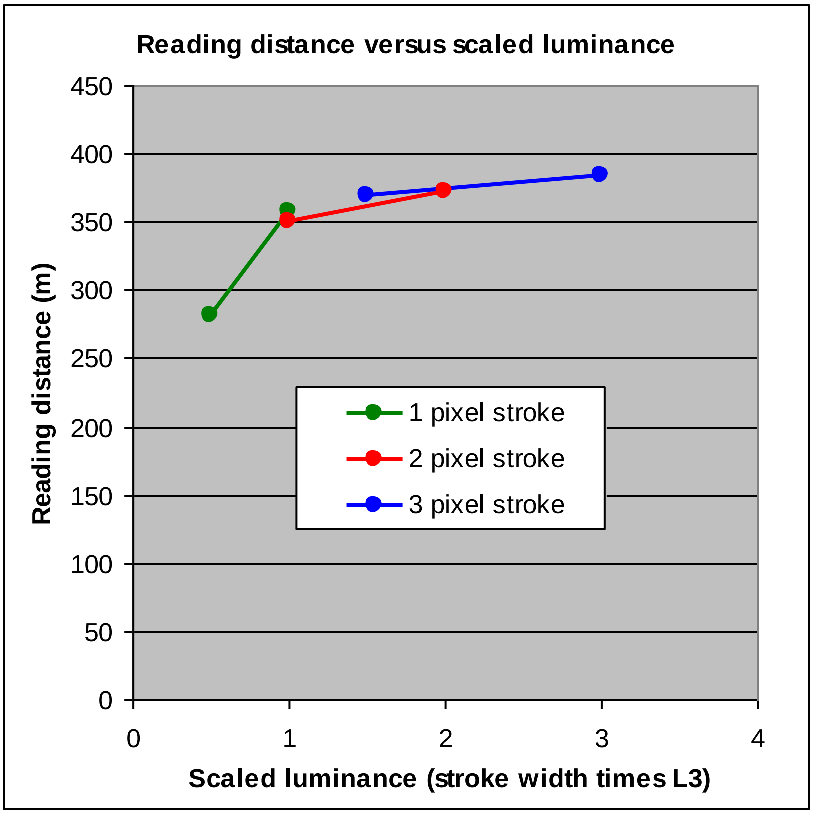


Figure 10: Reading distance versus scaled luminance.

Some numbers on a black background

The numbers on a realistic background in daylight conditions

The numbers seen with blur at a distance

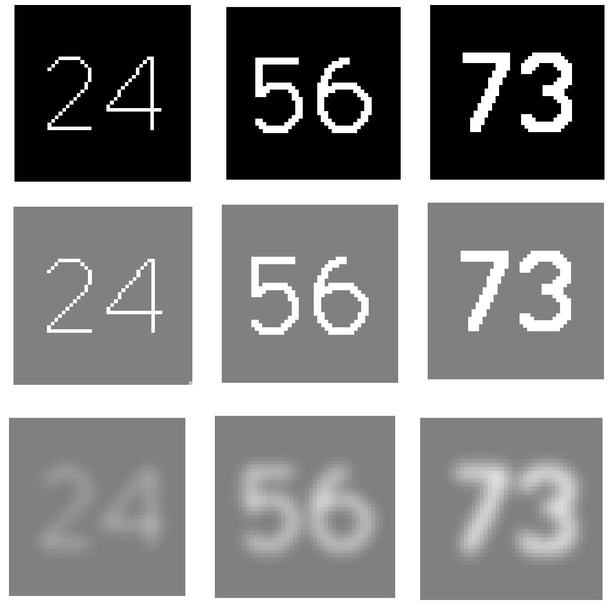


Figure 11: Legends are seen with a reduced contrasts depending on the stroke width.

3.3 Repeatability and reproducibility

The reading 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 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).

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).

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

One can note that the average reading 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 reading distances determined by the second group at L3 continuous are much higher than then reading 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 groups also determined the reading distances to the legends that had been shown to the other group, and with the same luminance setting. The average reading 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.

Accordingly, figure 15 shows if the two groups reproduce approximately the same influence of stroke with, gap between digit and luminance. In this sense the reproducibility seems to be fairly good, the Pearson coefficient 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.

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 reading 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. The intention was actually to describe the quality of a legend by means of those two parameters, but the tests failed to provide any such conclusions. These test are therefore not mentioned further.

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

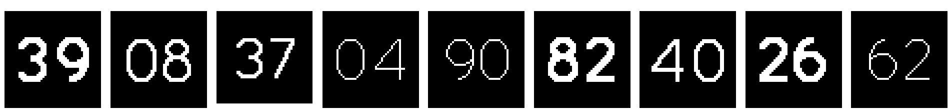


Figure 13: Legends shown twice to another group of persons.

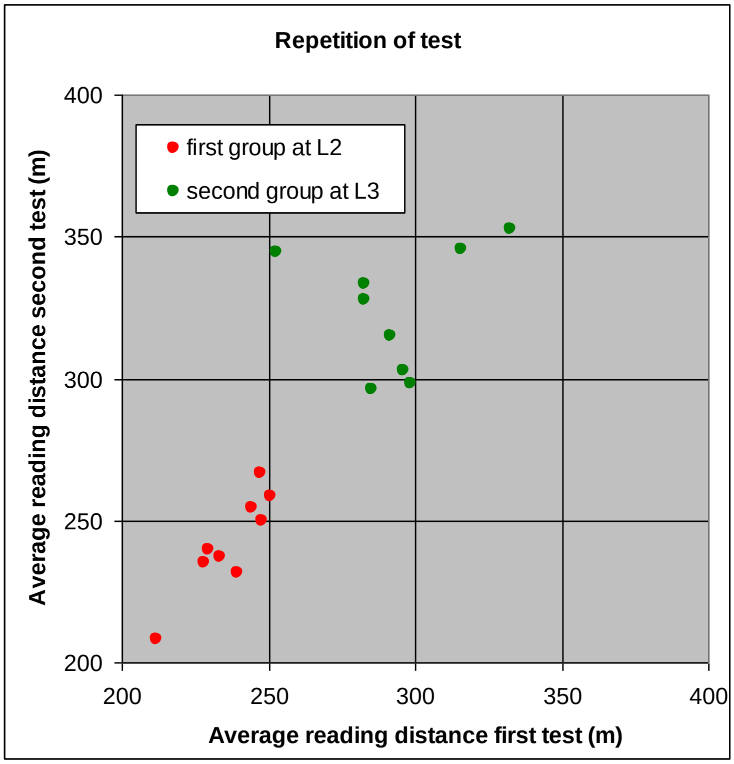


Figure 14: Result of the repetition test.

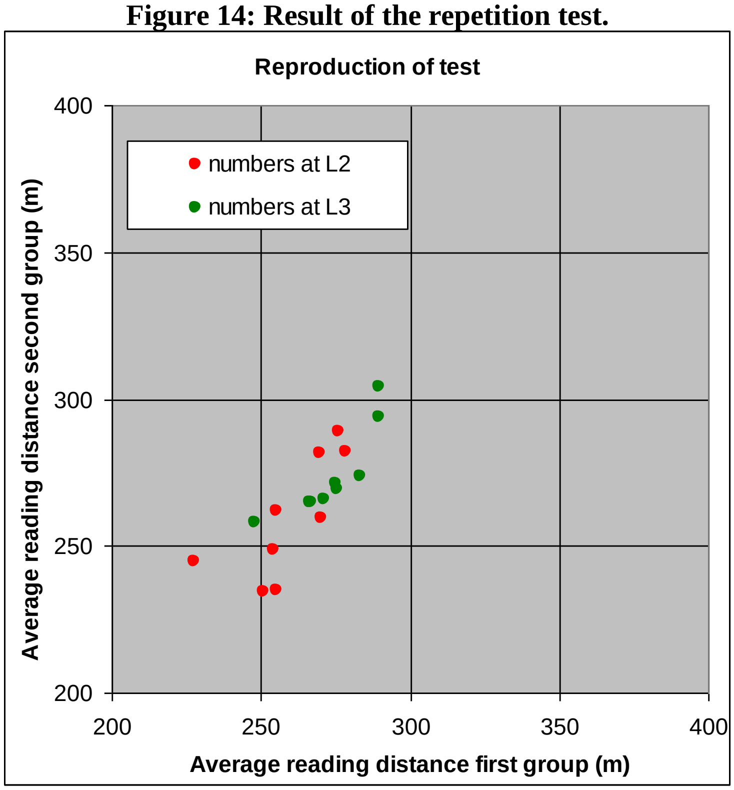


Figure 15: Result of the reproduction test.

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 reading 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 reading 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 27 pixels high numbers.

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.

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 reading distance. This is discussed in section 4.

Figure 16: Legends with different settings of nominal luminance.

Because of lack of conclusion 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 reading distances were determined by a small group of three persons.

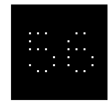
All of the numbers have a height of 20 pixels. However, those in the upper row use all of the available pixels, while those in the lower row use only every second pixel in both directions – this turns out to be approximately half the number of pixels compared to those in the upper row. The numbers in 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 reading 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 reading distance by presenting numbers with a height of 10 pixels instead of 20 pixels.

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.

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 reading 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 turn to be confusing. The exact minimum number of pixels was not determined.



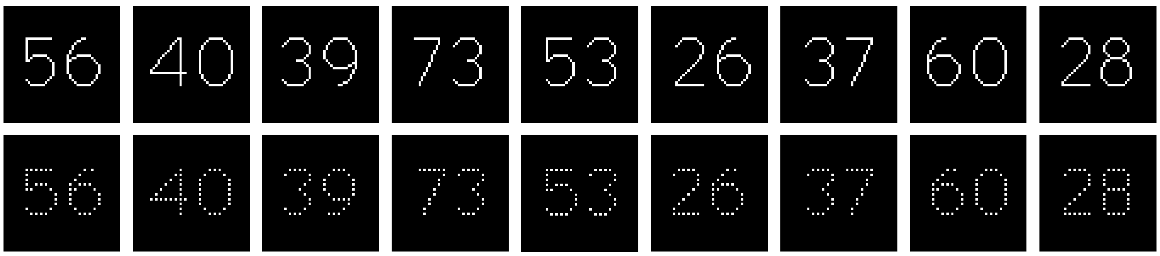


Figure 17: Legends formed with a height of 20 pixels (top row) and 10 pixels (bottom row).

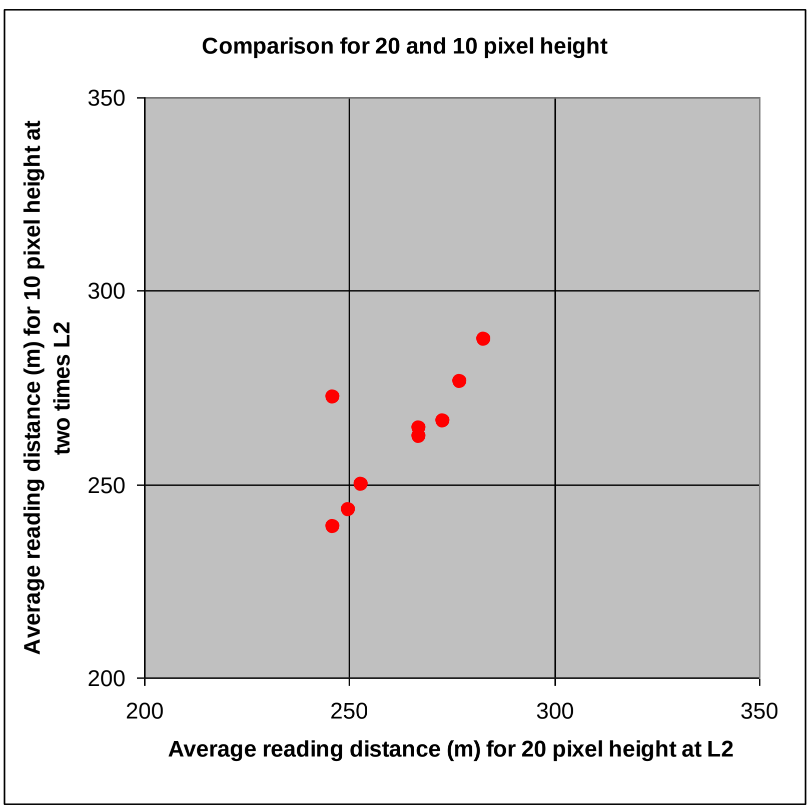


Figure 18: Comparison reading distances for numbers with heights of 20 and 10 pixels.

4 Luminance needed for readability

4.1 Introduction

A test is introduced in section 4.2 and on this basis a luminance index is proposed in section 4.3 and a regulation curve in section 4.4.

4.2 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 readability. The legends used are shown in figure 19, where the luminance settings are also indicated.

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 reading 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).

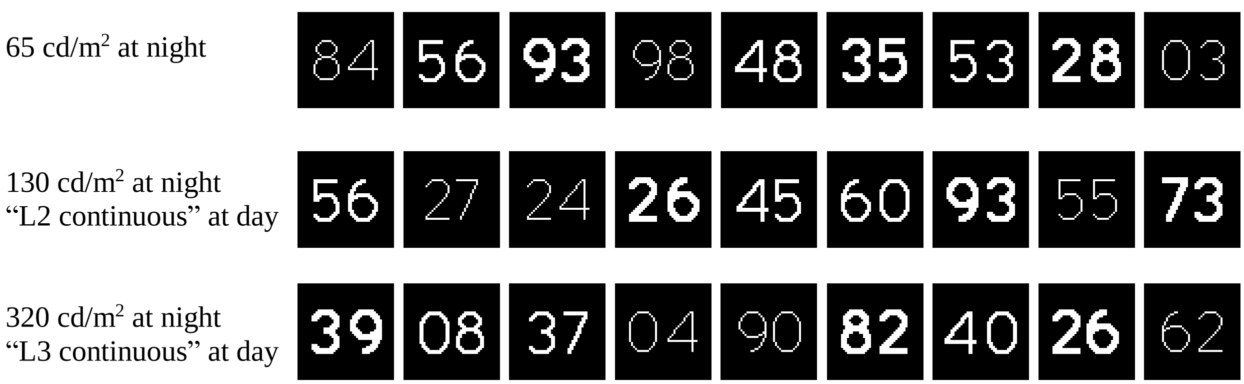


Figure 19: Legends with different settings of nominal luminance.

The average reading 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, and also for three legends with the same stroke width and luminance.

In figure 20, the scaled luminance for legends shown with the nominal luminance of “L3 continuous” is the pixel stroke width of the legends, either 1, 2 or 3. For the legends presented with the nominal luminance of “L2 continuous”, which is half the luminance of “L3 continuous”, the scaled luminance is half the pixel stroke width of the legends, either ½, 1 or 1,5.

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

It is seen that the reading distances are lower in night than in day conditions, compare figures 20 and 21. It is assumed that this is caused by the optical properties of the sheeting material mounted in front of the VMS in night conditions, as it is unlikely that night conditions as such cause reduction of reading distances.

There is not very much variation of the reading distance with the scaled luminance. The reason is probably that the luminance is sufficient, or close to being sufficient, in all cases. Some of the variation seems random and may really be caused by the use of different messages for the different luminance levels. For instance, the two numbers with the lowest reading distances both include the digit “8”, which is shown in section 3.1 to have the lowest reading distance of the 10 digits.

In view of this, there is no strong basis for firm conclusions. It seems that the scaled luminance can be “L3 continuous” in daytime conditions without loss of reading distance. The scaled luminance can probably be 100 cd/m^2 or even lower in night conditions without loss of reading distance.

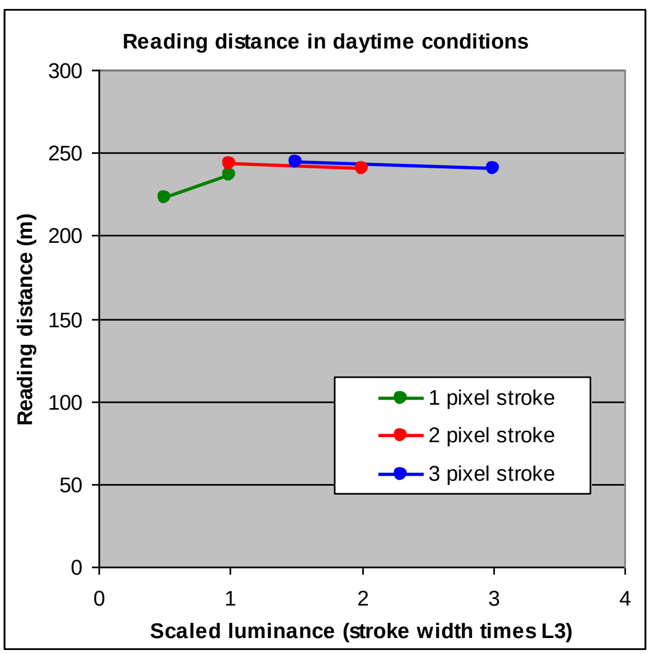


Figure 20: Reading distance versus scaled luminance in daytime conditions.

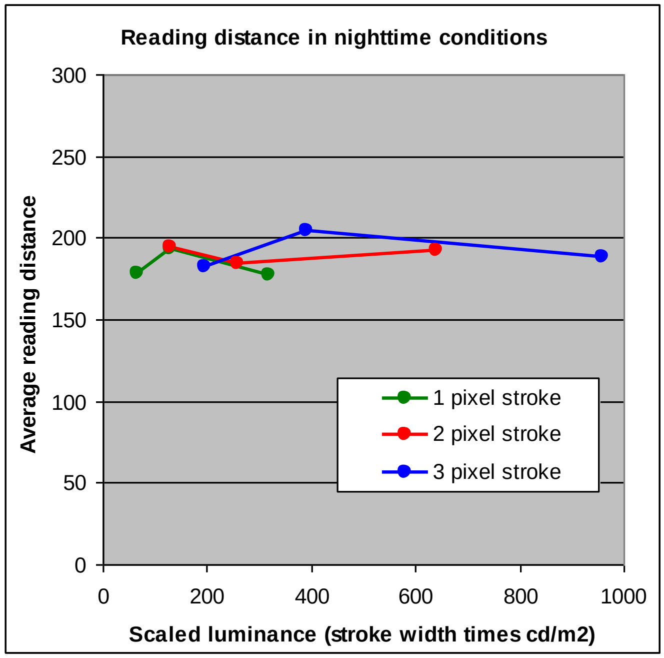


Figure 21: Reading distance versus scaled luminance in night conditions.

4.3 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 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 or less. Therefore, there is a need for redefining "LS 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 nicely the above-mentioned need for 100 cd/m^2 or less. 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.

Figure 22 shows a smooth function that has been fitted to meet all 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 readability.

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.

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

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

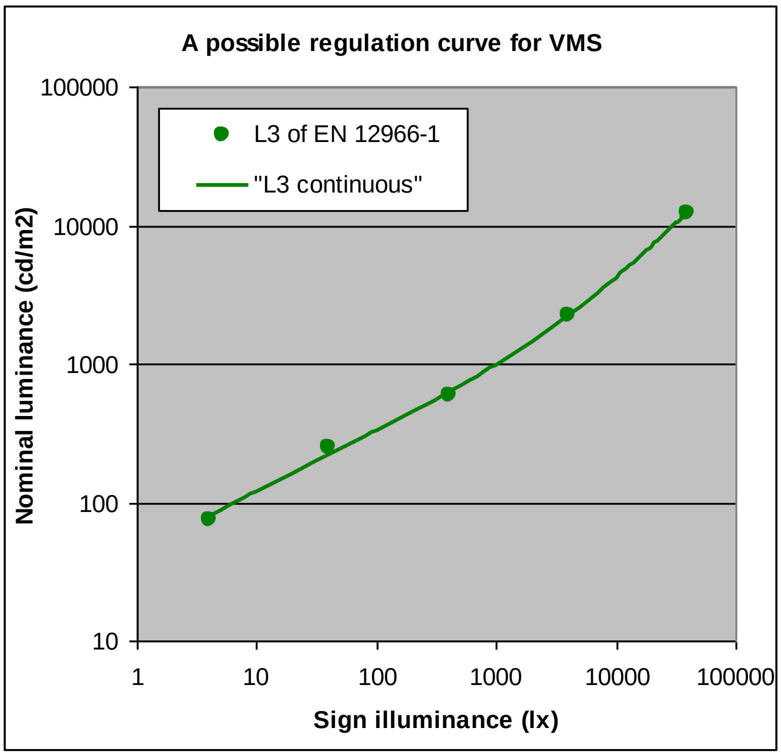


Figure 24: Possible regulation curves for VMS.

4.4 Proposal for a luminance index

The tests discussed in section 4.2 are not strongly convincing, but some earlier tests 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. However, the apparent luminance can be explained by means of a scaled luminance, which is the product of the nominal luminance and the pixel stroke width.

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”.

At a short distance the pixels do not merge into strokes, so that in principle each pixel is seen with a high luminance. This does not necessarily prevent that the legend can be read as the human brain might be able to see the pattern.

At a particular distance, indicated as 50 m in the figure, the pixels 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 figure, the legend becomes unreadable because details become too blurred or the contrast too low.

In the example, the curves for the two legends meet at a maximum reading distance of 200 m distance. The apparent luminance is 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
- the apparent luminance can be the same at the maximum distance where the legends should be readable when presented with the same scaled luminance.

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 the horizon has a similar luminance level. Accordingly, the apparent luminance of a legend needed for maximum reading distance seems to be roughly the luminance of the surroundings.

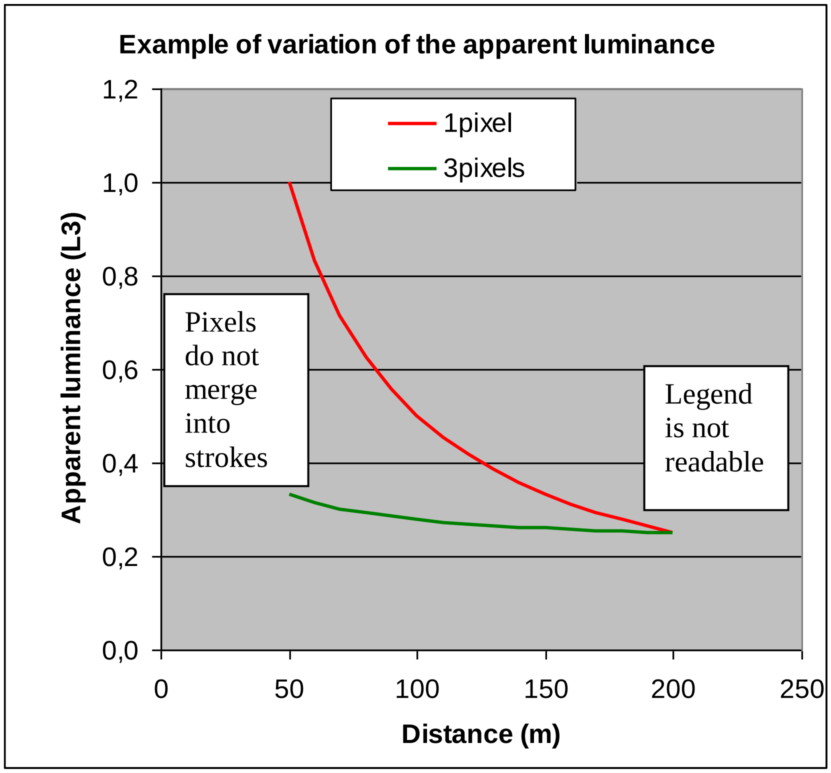


Figure 23: Example of variation of the apparent luminance of with the distance of observation. The two curves are for legends with stroke widths of 1 and 3 pixels.

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 reading 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 need for scaled luminance according to section 4.2 corresponds to an LI value of 0,25.

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 reading 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 reading 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.

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.

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

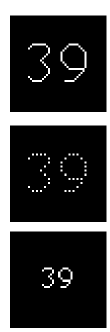


Figure 24: Proportions of outputs per pixel needed to provide the same luminance index.

5 Preferred luminance

5.1 Introduction

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 maximum visibility 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 has been derived in an initial test as described in section 5.2. This model was verified in a larger test that allows frequent appraisal as described in section 5.3. Some comments and conclusions are provided in section 5.3.

5.2 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.

A group of a few 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.

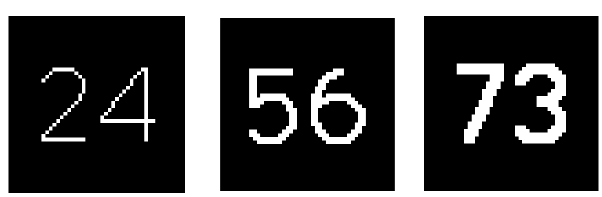
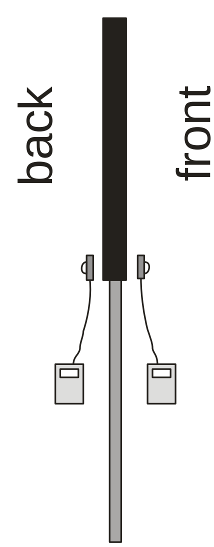


Figure 25: Legends with a height of 20 pixels height and stroke widths of 1, 2 or 3 pixels.

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 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).

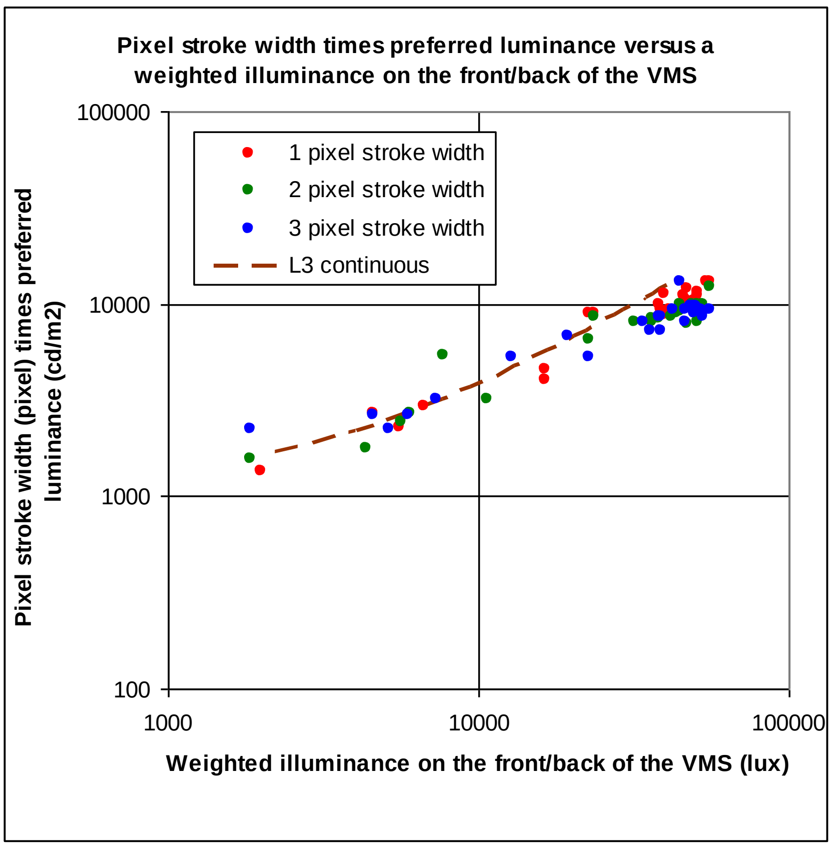


Figure 27: Correlation between the product of the pixel stroke width and the preferred luminance to the weighted illuminance on the front/back of the VMS.

5.3 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 set 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 including 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.

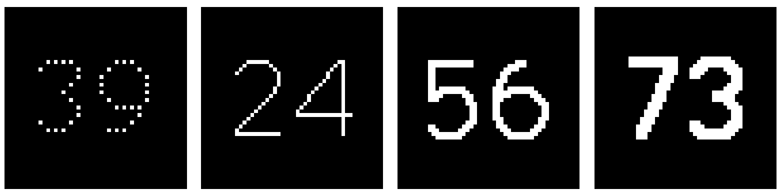


Figure 28: Numbers with 20 pixels height and ½, 1, 2 or 3 pixels stroke width.

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 described in section 5.2.

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 readability. 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.

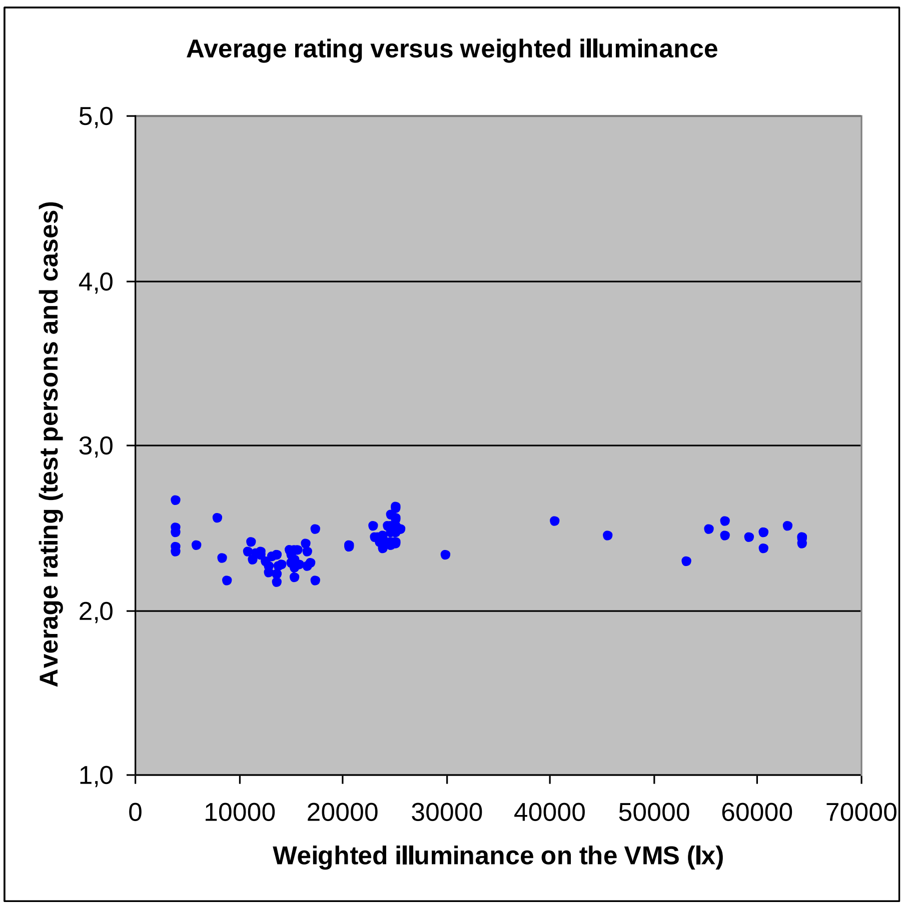


Figure 29: Average rating versus weighted illuminance on the front/back of the VMS.

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 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.

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.

Table 2: Scaled luminance values.

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

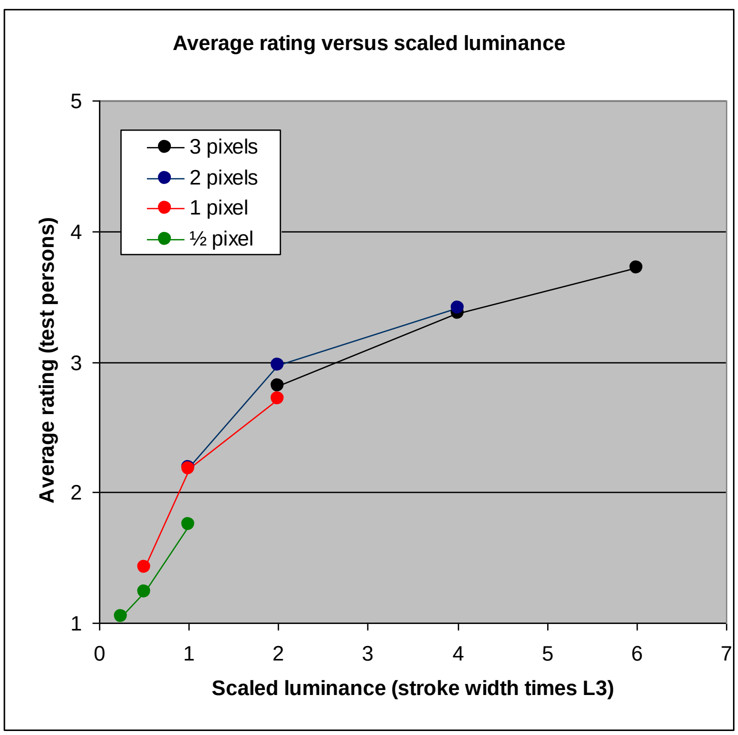


Figure 30: Average rating versus scaled luminance.

5.4 Observations and conclusions

These twelve cases included resulting from the test reported in the previous section span a fairly large total range of scaled luminance values, from 0,25 to 6. This provokes a fairly large range of average ratings from very 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 reading distance is obtained according to section 3 is approximately 1. The preferred luminance seems therefore to be twice the luminance needed for readability.

A scaled luminance of 2 results in an LI value of 0,5, refer to section 4.4. The apparent luminance as seen from a distance close to the maximum reading distance is approximately LI×L3 = 0,5×L3.

EXAMPLE 1: For an LI value of 0,5 the apparent luminance is approximately 37 cd/m^2 in darkness at a sign illuminance of 4 lx, and increasing gradually in daylight situations with increasing sign illuminance to approximately 6 200 cd/m^2 at a sign illuminance of 40 000 lx.

The actual nominal luminance to be set on the sign depends on the legend height H and stroke width S, both measured in pixels, in accordance with: $L_{nominal} = LI×L3/F_{legend} = LI×L3×H/(5×S)$. 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.

The illumination on the VMS is best represented by a combined illuminance for the front and the back of the VMS.

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, 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.

6 Quality of legends

6.1 Introduction

In section 3.4 it is reported that some initial tests on the quality of legends did not provide real information. It may have been that the quality of the legends were 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 readability instead of determination of the maximum reading distance. It is understood that ratings may not always be completely objective, but they are more easy to carry out and may be also be more sensitive in revealing influence of the parameters.

The five persons taking part were instructed to rate the readability 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. The long distance is intended to represent approximately the maximum reading distance, while the shorter distances are included as such are relevant for reading VMS's during driving.

The maximum reading distance is estimated by the commonly used rule of thumb that it is 8 times the character height expressed in metres when the letter height is expressed in centimetres. The rule of thumb applies for normal visual acuity and conditions of sufficient luminance and contrast and is in fair agreement with the maximum reading distances reported in section 4 (that 30 cm legends should be readable at a distance of 240 m).

NOTE: The maximum reading distance is shorter for the low luminance shown by retroreflective road sign illuminated by low beam headlamps at night.

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 4.4; 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 6.2, while tests with sets of city names are reported in section 6.3.

6.2 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.

The time for presentation of 2,5 seconds is suitable for readability 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 4.4.

The average ratings are shown in figure 32.

The ratings are approximately at 3 “medium readability” 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 reading distance, which is estimated to 180 m.

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 readability at short to medium distances.

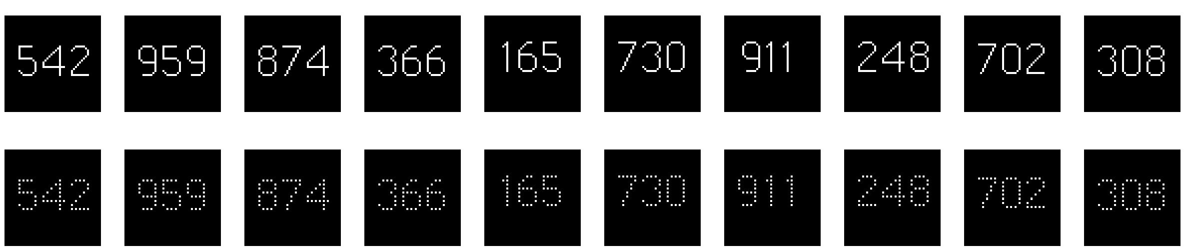


Figure 31: Three digit numbers 15 (top row) and 8 (bottom row) pixels in the height.

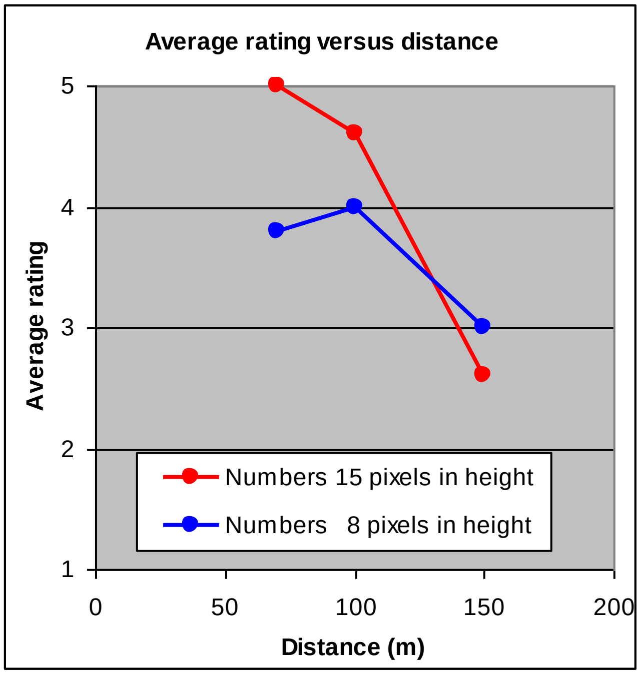


Figure 32: Average ratings of three digit numbers.

6.3 City names

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

Versions A and B are both with capital letters of a height of 8 pixels, but with a dense packing of the letters in version A and less dense in version B. In the dense packing there is a gap of one pixel spacing between the letters in both directions, while in the less dense packing the gap is twice as larger.

Versions C and D are both with initial capital letters following by small letters.

The capital letter have a height of 8 pixels as in presentations A and B. 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.

Versions C and D have respectively a dense and a less dense packing as described for versions A and B. However, because of the letters extending below the line, the line separation is actually one pixel larger in versions C and D than in versions A and B respectively.

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 the same city names occur four times each, without this being obvious to the persons taking part.

Each set of city names was presented during 3,5 seconds, which is suitable for readability 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.

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 readability, which is estimated to 96 m. At 70 m distance the ratings are much higher, which is natural.

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

The obvious conclusions are that it is better to use small letters than capital letters, and better to use a less dense packing of letters.

However, as pointed out above, the small letters are associated with a larger line separation than the capital letters, because they actually take up more pixels in the height direction. Therefore, it may be that it is the larger line separation that causes the ratings to be higher for small letters (and not the small letters themselves).

The only certain conclusion is therefore that less dense packing of the letters lead to higher ratings and probably better readability.

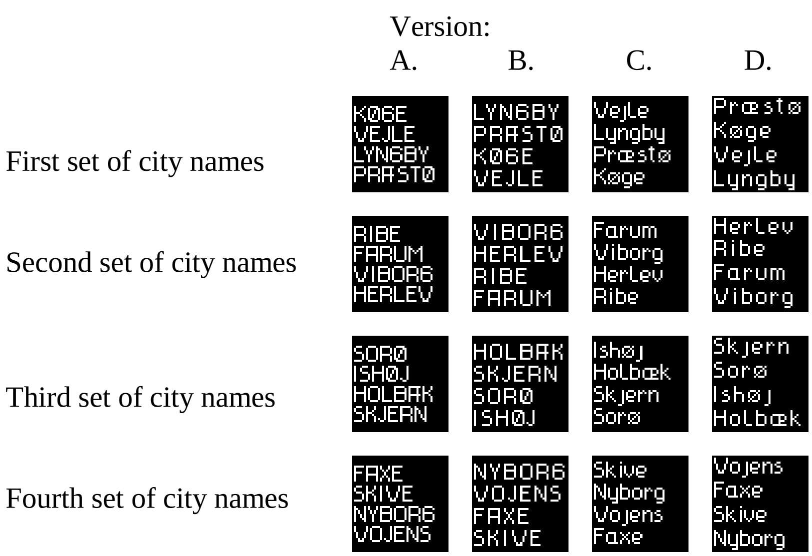


Figure 33: Four sets of city names in four versions.

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

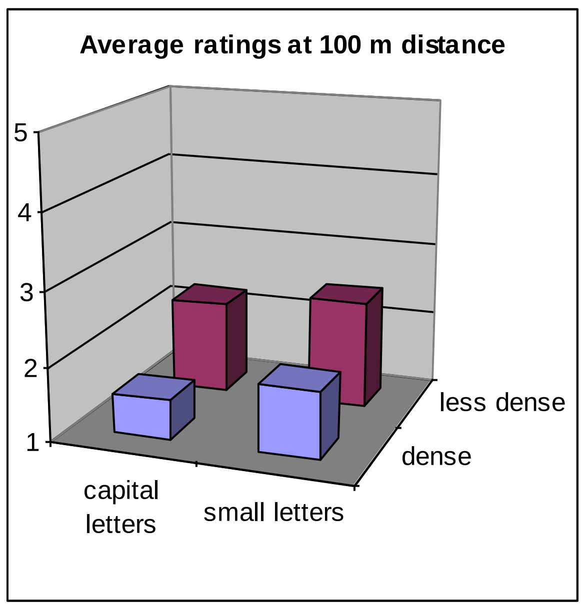


Figure 34: Average ratings of sets of city names at 100 m distance.

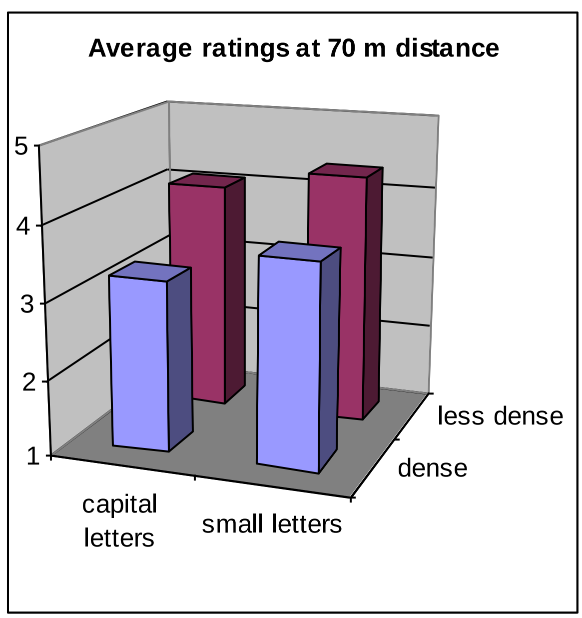


Figure 35: Average ratings of sets of city names at 70 m distance.

7 Quality of traffic signs

The traffic signs shown in figure 36 was used to test the ability of the Nissen VMS to present the signs and make their symbols 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.

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 reading of the symbol difficult.

As the luminance values of the two colours cannot be adjusted independently of each other, 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 4.4.

Only the sign C55 has characters and these are 17 pixels high and have accordingly an LI value smaller than 0,5. The arrow in C11-1 is 20 pixels high, but has a stroke width of 3 pixels, and corresponds to an LI value larger than 0,5. The other symbols are not easily attributed an LI value as this depends on which details must be seen in order to distinguish the symbol.

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 readability of the signs and their symbols 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 readability 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 37 and 38.

The ratings differ clearly for the different signs. It is understandable that the signs A20 and A99 with much detail of the symbol receive low ratings, and that the signs C11-1 and C55 with simple symbols 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 readability by introducing the thin red border does not seem to work.

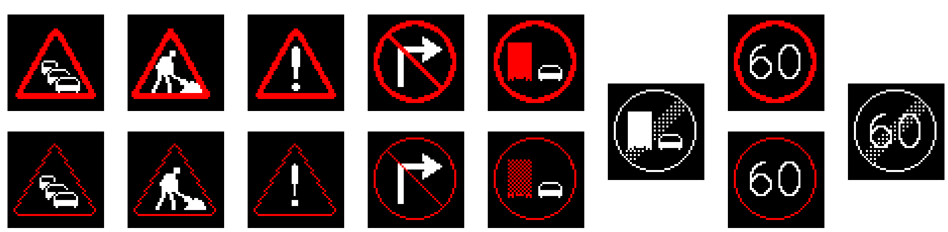
There were some further sporadic attempts to improve the readability, but these were not conclusive.

It would have been desirable to test signs on a VMS with "smoothening" meaning that each pixel can be set individually as on a TV set.

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.

Thick red border

Thin red border



A20 A39 A99 C11-1 C52 C54 C55 C56

Figure 36: Traffic signs.

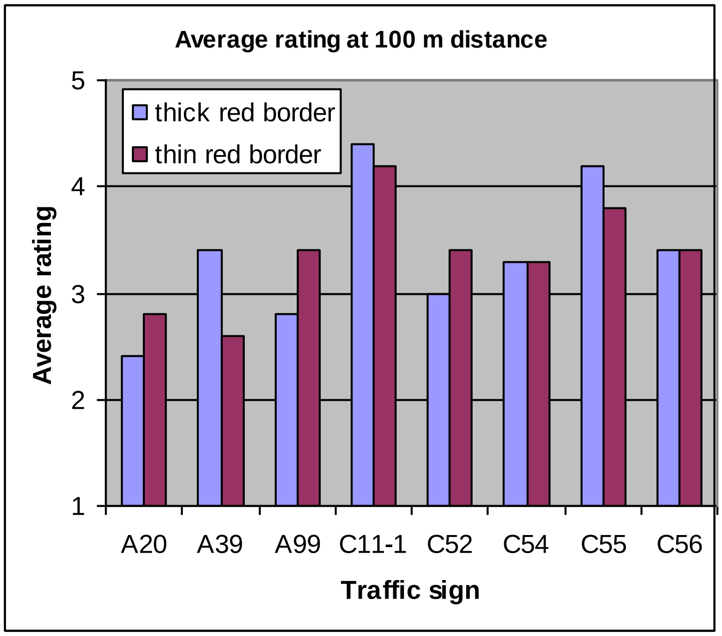


Figure 37: Average ratings of traffic signs at 100 m distance.

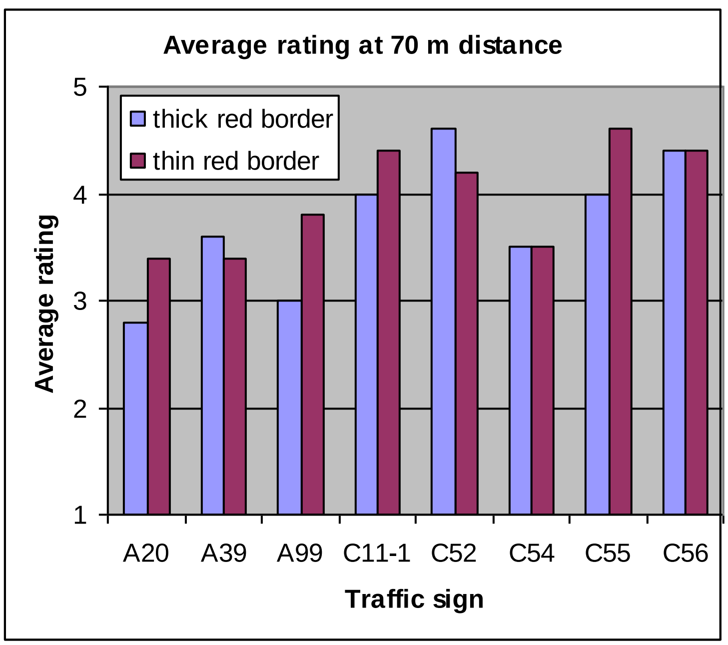


Figure 38: Average ratings of traffic signs at 70 m distance.

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 reading 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 reading distance that a particular luminance, depending on the ambient illumination from the surroundings and the above-mentioned factor, will provide close to maximum reading distance. This evidence it in itself rather weak, but is supported by tests involving rating of the readability.

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 maximum reading 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 major adverse effects.

There is direct and indirect evidence that the maximum reading distance expressed in metres can be estimated as 8 times the character height expressed in centimetres.

This evidence is obtained for daylight conditions. A single test for night conditions indicates a somewhat shorter maximum reading distance. 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 true in general, as there is no reason to believe that reading 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 readability at short to medium distances, but not at distances close to the maximum reading distance. The conclusion is based on characters with pixels heights of 15 and 8.

It is also concluded that a less dense packing of letter forming city names leads to higher ratings of the readability than a dense packing. This is based on a dense packing with only one pixel gap in both directions compared to a less dense packing with a two pixel gap. The letter height was 8 pixels. The general conclusion is probably that a gap of minimum ¼ of the pixel height is sufficient.

It may be that city names written with an initial capital letter followed by small letters are more readable that city names formed by capital letters only. However, this conclusion is not proved with certainty and may be caused by the simple fact that the use small letters leads to a slightly larger line separation.

Test of traffic signs resulted in rather poor ratings of the readability of some often used warning signs for “queue”, “road work” and “danger”. A rather obvious attempt to improve the readability was not successful. It is probable that the technique of “smoothening” by individual setting of the luminance of each pixel can lead to improvement of the readability, but this was not tested.