Title: Legibility of Text on Traffic Signs as a Function of Luminance and Size

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This study investigates on a quantitative basis two strategies that can be used to increase the legibility distance of retroreflective traffic signs with negative luminance contrast legend or symbols at night. The first strategy involves the increase of the letter, numeral, or symbol size associated with a corresponding increase in the stroke width (representing the visual detail) and with an increase in the traffic sign area. The second strategy involves the increase of the traffic sign background luminance. The study also investigates the increase in the legibility distance when the sign legend/symbol size and the sign background luminance are simultaneously increased together.

Further improvement of traffic sign legibility is needed to meet the needs of drivers with degraded visual capabilities, such as elderly drivers. A computer model has been developed to determine the legibility distance of a negative luminance contrast traffic sign with a dark legend on a bright background at night as a function of letter height (or stroke-width), sign background luminance, driver’s age and other factors.

Looking at the legibility distance results based upon a negative luminance contrast traffic sign with a letter height to stroke-width ratio of 5 and an observer 50 years of age, the legibility distance increases by 13.2% (from 91.04 m to 103.08 m) if the background luminance is doubled (from 50 cd/m² to 100 cd/m²). Doubling the letter height (from 17.78 cm to 35.56 cm) or doubling the associated stroke-width results in an increase of roughly 100% (from 91.04 m to 182.09 m) in the legibility distance. Doubling both simultaneously, the background luminance (from 50 cd/m² to 100 cd/m²) and the letter height (from 17.78 cm to 35.56 cm), yields an increase of 126.5% (from 91.04 m to 206.20 m) in the legibility distance. Doubling the corresponding sign area results in an increase of 41.6% (from 91.04 m to 128.87 m) in the legibility distance. Doubling both simultaneously, the background luminance (from 50 cd/m² to 100 cd/m²) and the corresponding sign area, yields an increase of 60.2% (from 91.04 m to 145.82 m) in the legibility distance.

For a given set of constraints, such as costs for sheeting materials of different retroreflectivity, costs for sign substrates, sign posts and/or supports for different sign sizes, etc, the user may determine with the help of the results of this study which strategy (sign size increase or background luminance increase) or which mix of the two strategies provides the most cost-efficient approach to increase the legibility distance.

Keywords: Sign Legibility, Legibility Distance, Sign Background Luminance, Sign Size, Retroreflectivity
INTRODUCTION
During the last few decades a change in the demography of the United States is ongoing: the fraction of
the elderly people in relation to the fraction of the young people is growing rapidly. As the automobile
remains the primary means of transportation for elderly people, more and more elderly drivers are using the
roads, compared to the overall motoring public. Elderly people commonly experience diminished visual
and cognitive capabilities and therefore have a disadvantage reading traffic signs at night.
As people grow older, visual acuity, depth perception, glare tolerance and light/dark adaptation
decrease steadily, making nighttime driving difficult. Slower reactions, hearing defects and reduced
flexibility for looking from side to side may further impair driving ability. Elderly drivers also often have
trouble processing an overload of information from traffic signs and signals.
The Manual of Uniform Traffic Control Devices for Streets and Highways (MUTCD) [1] describes the
principles and practices for the design and use of signs, signals, and pavement markings for all streets and
highways in the United States. This study suggests that some elements and standards in today’s MUTCD
pertaining to traffic sign legibility may not adequately meet the needs of today and the future.
Realizing the need for further improvement in traffic sign legibility in order to meet the needs of drivers
with degraded visual capabilities, such as elderly drivers, several properties of traffic signs may be
redesigned to provide longer legibility distances.

APPROACH

Objectives
This study investigates on a quantitative basis two strategies that can be used to increase the legibility
distance of retroreflective traffic signs with negative luminance contrast legend or symbols at night. The
first strategy involves the increase of the letter, numeral, or symbol size associated with a corresponding
increase in the stroke width (representing the visual detail) and with an increase in the traffic sign area. The
second strategy involves the increase of the traffic sign background luminance. The study also investigates
the increase in the legibility distance when the sign legend/symbol size and the sign background luminance
are simultaneously increased together.

This is done by using a computer model developed to investigate the legibility distances of traffic signs
with negative luminance contrast (dark legend or symbol on bright background) under nighttime driving
conditions as a function of the sign background luminance, the sign luminance contrast, the visual detail
size (stroke-width), the probability level at which a driver is capable of discriminating the visual detail size,
the driver’s age and the exposure time. As primary input to the computer model, data obtained by
Blackwell in his Series II experiments [2] is used exhibiting the fundamental relationships between the 50
percent luminance contrast threshold, the background luminance, and the target size.

To account for the difference between traffic sign legibility in the field and contrast threshold of in-
laboratory target detection, contrast multipliers for several relevant factors have been introduced into the
computer model with the assumption of independence and multiplicativity of those factors.

Assumptions for Using the Computer Model

- Atmospheric transmissivity losses are relatively small for a few hundred meters and are
  considered to have little effect upon the illumination returned to the driver’s eyes. Therefore, atmospheric
  transmissivity is set to one.
- The duration of time for sign perception and recognition is not considered here. The computer
  model uses an exposure time that is long enough for the driver to discriminate the legend or symbol on a
  traffic sign, but is not long enough for the driver to finish the legend/symbol recognition in most cases. A
  study [3] indicates that the time required to read a sign message with N words is approximately T [seconds]
  = 1.94 + 0.31N.
- Legibility seems to be somewhat less affected by glare than conspicuity [4], unless the glare angle
  is very small or the glare source is very bright. Therefore, the effects of glare are not considered.
- Visual complexity of the ambient traffic sign background has been found to be a significant factor
  in sign detection but has no significant effect on sign legibility [5]. Thus, the visual complexity of the
  ambient traffic sign background will not be taken into consideration here.
The required luminance contrast threshold for traffic sign legibility is dependent upon many factors besides the legend/symbol size and the sign luminance, such as the driver’s age, the exposure time, etc. All the factors besides legend/symbol size and sign luminance have independent and multiplicative effects [6]. That is, the ratio of the required luminance contrast threshold $C$ for traffic sign legibility and the 50 percent Blackwell luminance contrast threshold $C_{th}$ equals the product of appropriate contrast multipliers.

$$C = C_{th} \cdot M_1 \cdot M_2 \cdot M_3 \cdot M_4 \cdot M_5$$

Equation 1

where $C_{th}$ is the 50 percent Blackwell luminance contrast threshold, $M_1$ the threshold percentage factor, $M_2$ the field factor, $M_3$ the detection-of-presence versus discrimination-of-detail factor, $M_4$ the age factor, and $M_5$ the exposure time factor.

**Threshold Percentage Factor ($M_1$)**

Since Blackwell’s luminance contrast thresholds are based upon 50 percent probability of detection, they must be adjusted for other selected probabilities of detection. The following relationship has been established, based upon the psychometric curve given by Blackwell [2].

$$M_1 = 1 + 0.48 \alpha$$

where $\alpha = \Phi(Z_{th})$ the threshold percentage and $\Phi$ the area under the standard normal distribution curve.

**Field Factor ($M_2$)**

The conditions under which Blackwell obtained the 50 percent contrast threshold data were favorable laboratory conditions. The observers were well trained and highly skilled using a forced-choice method. In order to take into account out-of-laboratory conditions where the subjects are facing a higher visual and mental workload, a field factor has been introduced. Applying the laboratory data to practical problems shows that the field factor ranges between 1.5 and 8, according to Blackwell [7]. In this study, a field factor of $M_2 = 2.4$ is used.

**Detection-of-Presence versus Discrimination-of-Detail Factor ($M_3$)**

Blackwell’s data is based upon the detection of the presence of a circular target. The question now arising is how to apply Blackwell’s data for discriminating visual details of a traffic sign legend or symbol. In order to answer this question Guth and McNelis [8, 9] conducted two studies, using Landolt Rings and parallel bars in the first, and upper-case letters in the second study. An average detection-of-presence versus discrimination-of-detail factor over both studies of $M_3 = 0.518$ is used here.

**Age Factor ($M_4$)**

If a given sign under given conditions can be read by a young driver at a certain luminance contrast threshold, what is the luminance contrast threshold at which the sign can be read by a driver of a certain different age under the same conditions? The data used to develop an analytical relationship for relatively high luminance values ($> 10 \text{ cd/m}^2$) between the contrast multiplier and the observer’s age was taken from [10, 11, 12]. The formula used is $M_4 = 1.5159 - 7.6814 \log_{10} \text{ Age} + 3.8632 \log_{10}^2 \text{ Age} - 7.7746 \log_{10}^3 \text{ Age} + 6.066e^{-7} \log_{10}^4 \text{ Age}^3$.

**Exposure Time Factor ($M_5$)**

Exposure time duration of the test stimulus affects the luminance contrast threshold necessary to detect the test stimulus. The shorter the exposure time, the higher the required luminance contrast threshold. In order to establish an analytical relationship, Blackwell’s data [13] has been used and fitted by three functions for $[T] = \text{seconds}$ the exposure time as follows:

$$M_5 = \begin{cases} 1.074 + 0.5678 \cdot \log(T) + 3.8646 \cdot \log(T)^2 + 4.0336 \cdot \log(T)^3 + 2.0728 \cdot \log(T)^4, & -2 \leq \log(T) < -0.5 \\ 1.074 - 0.2778 \cdot \log(T) + 0.4526 \cdot \log(T)^2 - 0.3455 \cdot \log(T)^3 + 0.0972 \cdot \log(T)^4, & -0.5 \leq \log(T) \leq 1 \\ 1, & \log(T) > 1 \end{cases}$$

Zwahlen [14] reports that a driver spends between 0.5 s and 0.6 s looking at a warning sign during one eye fixation. Therefore $T$ and $M_5$ can be assumed to be 0.55 s and 1.1831, respectively.
Algorithm

When all contrast multipliers in Equation 1 are known and either C or C\text{th} is given, the other can be determined by solving Equation 1. The relationship between the 50 percent luminance contrast threshold C\text{th}, the subtended visual angular target size (more often referred to as the visual angle) and the background luminance is exhibited by Blackwell’s contrast threshold data [2]. Given any two of the three variables, the third one can be determined.

Before using the Series II Blackwell contrast threshold data (for negative contrast conditions) in a computer model, the data needs smoothing. This has been done with respect to Weber-Fechner’s law

\[ C = \text{const} \alpha \]

where C is the luminance contrast threshold, and \( \alpha \) the subtended visual angular target size in minutes of arc; and with respect to Ricco’s law

\[ C\alpha^2 = K |\alpha|_\text{arc}\]  \[\Leftrightarrow \log C = \log K - 2 \cdot \log |\alpha|_\text{arc} \]

where K is a constant as a function of the background luminance.

In order to compute an output value for any non-discrete input value an interpolation algorithm has been implemented. A two-dimensional non-linear interpolation has been used with the background luminance ranging from 10\(^{-2}\) to 10\(^{3.5}\) cd/m\(^2\) and the visual angle ranging from 0.2 to 1000 minutes of arc. The interpolation algorithm satisfies the requirement that the relative error should be less than 5 percent over all background luminance levels.

Traffic Sign Legibility Examination Program (TSLEP)

The described algorithm has been implemented into the Traffic Sign Legibility Examination Program. This program lets the user choose a dependent variable (V\text{D}), an independent variable (V\text{I}), and an auxiliary variable (V\text{A}). Possible selections for the dependent variable are “Sign contrast”, “Visual angle”, and “Seeing distance”. Depending on what dependent variable has been chosen, TSLEP offers the following selections for the independent and the auxiliary variable: “Sign contrast”, “Visual angle”, “Driver’s age”, “Threshold percentage”, and “Sign luminance”. For each possible combination of V\text{D}, V\text{I} and V\text{A} (36 combinations in total), a graph and a table V\text{D}(V\text{I}) for up to five different constant values of V\text{A} can be output by TSLEP. The program provides output graphs and tables using the English system of measurement only.

RESULTS

Legibility Indices of the Standard Letter Series for Selected Driver Ages at Night

The average human visual system has a visual acuity of 20/20. Visual acuity is designated as 20/20 if a visual detail of 1 minute of arc in angular size can be resolved; if a visual detail as narrow as 0.5 minute of arc in angular size can be resolved, visual acuity is 20/10. A visual acuity of 20/20 is considered normal although better acuity (20/15 or 20/10) is quite common. Having made these definitions it follows from geometric relations that an observer with a normal visual acuity of 20/20 is able to discriminate a letter with a stroke-width of 2.54 cm (1 in) at a distance of 87.32 m (286.48 ft). Here, the stroke-width corresponds to the visual detail size.

Alphabet styles used on standard traffic signs are specified in the Standard Alphabets for Highway Signs and Pavement Markings [15] and are denoted as letter series B through F, including an additional letter series E(m), E modified. Letter series B is narrowest and letter series E(m) is widest. All standard letter series are proportionally spaced.

In order to describe the relative legibility of different letter styles a legibility index is commonly used. The legibility index is the ratio of the legibility distance based upon a visual acuity of 20/20, and the letter height. It indicates the number of meters (feet) of legibility per cm (in) of letter height for a certain letter series with a certain letter height to stroke-width ratio. Assuming a stroke-width of 2.54 cm (1 in) as in the example before and a letter height to stroke-width ratio of 5, the legibility index of such a letter (for an observer with a visual acuity of 20/20) is 6.88 m/cm (57.3 ft/in), since 87.32 m / (5 \cdot 2.54 cm) = 6.88 m/cm.

It has been found using TSLEP that the traffic sign background luminance must be 87 cd/m\(^2\) for a traffic sign with a negative legend-to-background luminance contrast of close to one (absolute value) to provide young drivers at night with a legibility index of 6.88 m/cm (57.3 ft/in), given a letter height to stroke-width ratio of H/SW = 5, a threshold percentage of P = 95 % and an exposure time of ET = 0.55 s. Using a
threshold percentage of P = 95% means that 95% of the population can in fact visually resolve the stroke-width. The legibility indices as calculated with TSLEP for the different letter series and for selected observer ages are shown in Table 1.

This table indicates that, under the same viewing conditions, the legibility indices for drivers of 70 years of age are almost half of those for young drivers and that the legibility indices for drivers of 80 years of age are almost one-third of those for young drivers. Historically in the past, a legibility index of 6 m/cm (50 ft/in) has become a well-established, though arbitrary, requirement. Table 1 suggests that only letter series E, F and E(m) are satisfactory (legibility index > 6 m/cm or 50 ft/in respectively) for young drivers under nighttime driving conditions when a legibility index of 6 m/cm (50 ft/in) is required. It can further be concluded that no letter series can provide a legibility index of 6 m/cm (50 ft/in) for older drivers (> 50 years of age) at night.

**Legibility Improvement by Increasing the Traffic Sign Luminance Level**

Realizing that none of the standard alphabet styles can provide older drivers (> 50 years of age) with the needed legibility index of 6 m/cm (50 ft/in) under the given conditions at night, one strategy to improve the legibility index and to increase the legibility distance is to increase the traffic sign background luminance. Figure 1 is an example of graphical TSLEP output, showing the legibility indices for the letter series E(m) in ft/in for selected driver ages at night as a function of the sign background luminance. The dependent variable “D(ft)” directly represents the legibility index in ft/in since the letter height has been set to 2.54 cm (1 in). Since letter series E(m) with a letter height to stroke-width ratio of H/SW = 5 has been used the visual detail size (or stroke-width) is 0.508 cm (0.2 in), denoted as “T.D.Size” by TSLEP. The threshold percentage and the exposure time are set to 95% and 0.55 s respectively, and the negative legend-to-background luminance contrast is assumed to be close to one (absolute value).

Figure 1 indicates that the legibility distance increases for all selected driver ages as the sign luminance increases. For sign luminance values above 10 cd/m² the legibility distances for the selected driver ages are almost linear with the sign luminance. If the sign luminance level is about 40 cd/m², a 20 year old driver achieves a legibility index of 6 m/cm (50 ft/in) for the letter series E(m). When the sign luminance level increases to about 120 cd/m², a 50 year old driver achieves the same legibility distance of 6 m/cm (50 ft/in); a 60 year old driver can do so when the luminance level increases to about 370 cd/m². However, it seems impossible for very old drivers (of age 70 and older) to achieve a legibility index of 6 m/cm (50 ft/in) for any reasonable sign luminance, when the legibility is not improved by any other means (e. g. by increasing the sign size). Furthermore, increasing the sign luminance to a very high level, e. g. by using microprismatic sheeting materials, increases the danger of “halation” or “irradiation” that have a detrimental effect on the legibility distance and are not well understood yet.

**Legibility Improvement by Increasing the Traffic Sign Legend/Symbol Size and the Traffic Sign Luminance Level**

Since increasing only the sign background luminance has turned out not to be satisfactory with regard to the desired legibility index of 6 m/cm (50 ft/in) for all driver ages, a second strategy to improve the sign legibility involves increasing the sign size. Combining the two strategies, i. e. increasing the sign luminance and the sign size simultaneously together, yields a third strategy. However, one needs to find out which of the three strategies is the most effective one to improve the legibility of traffic signs.

Table 2 shows how the legibility distances as calculated by TSLEP of a negative contrast traffic sign (letter series E(m) literals of an initial letter height of 17.78 cm (7 in) and an initial stroke-width of 3.56 cm (1.4 in)) for a 50 year old driver increase, when several selected strategies are applied. For example, it is found that the legibility distance increases by 13.2% (from 91.04 m to 103.08 m) if the background luminance is doubled (from 50 cd/m² to 100 cd/m²) and the letter height is doubled (from 17.78 cm to 35.56 cm), yields an increase of 126.5% (from 91.04 m to 206.20 m) in the legibility distance. Doubling the corresponding sign area results in an increase of roughly 100% (from 91.04 m to 182.09 m) in the legibility distance. Doubling both simultaneously, the background luminance (from 50 cd/m² to 100 cd/m²) and the letter height (from 17.78 cm to 35.56 cm), yields an increase of 126.5% (from 91.04 m to 206.20 m) in the legibility distance. Doubling the corresponding sign area results in an increase of 41.6% (from 91.04 m to 128.87 m) in the legibility distance. Doubling both simultaneously, the background luminance (from 50 cd/m² to 100 cd/m²) and the corresponding sign area, yields an increase of 60.2% (from 91.04 m to 145.82 m) in the legibility distance. Note that doubling the letter height means a four-fold increase in the traffic sign area. In this example, the sign luminance contrast is assumed to be close to one (absolute value), the threshold percentage and the exposure time are set to 95% and 0.55 s,
respectively. The data provided in Table 2 is displayed in Figure 2. If the legibility of a traffic sign needs to be improved, increasing the letter height of the sign legend (or increasing the corresponding sign area) appears to be more effective than increasing the sign luminance. However, it is imperative to bear in mind the costs and to consider any physical limitations of either strategy when making a judgement on the effectiveness.

Impact of the Threshold Percentage Parameter on the Legibility Index

Figure 3 shows the legibility indices in ft/in for the letter series E(m) and a 20 year old observer for selected sign background luminance levels at night as a function of the threshold percentage. It illustrates how the threshold percentage parameter, otherwise set to 95% throughout all examples in this study, influences the legibility distance. Note that the higher the threshold percentage the more sign luminance is required to provide the driver with the same legibility distance. For instance, a 20 year old driver achieves the same legibility distance of about 17.4 m (57 ft): at the 50% threshold for a sign luminance of 18.9 cd/m², at the 85% threshold for a sign luminance of 51 cd/m², at the 95% threshold for a sign luminance of 87 cd/m², at the 98% threshold for a sign luminance of 121 cd/m², and at the 99% threshold for a sign luminance of 150 cd/m².

Legibility of the R-33 “DO NOT PASS” Regulatory Traffic Sign

A 76.20 cm x 91.44 cm (30” x 36”) “DO NOT PASS” regulatory traffic sign, depicted in Figure 4, has been examined by using TSLEP. The sign has a black legend on a white background using letter series D standard alphabet styles with a letter height to stroke-width ratio of 6.25, a letter height of 17.78 cm (7 in), and a corresponding stroke-width of 2.84 cm (1.12 in). Figure 5 shows the legibility distances in ft for the above described R-33 “DO NOT PASS” regulatory traffic sign for selected background luminance values at night as a function of the driver’s age. Four of the five sign luminance values used in Figure 5 originate from a review of several nighttime traffic sign legibility studies by Sivak and Olson [16]. They recommend an optimal sign luminance for negative luminance contrast traffic signs of 75 cd/m² and sign replacement luminance values of 2.4 cd/m², 7.2 cd/m² and 16.8 cd/m² for the 50th, 75th and 85th percentile, respectively. The fifth sign luminance value of 87 cd/m² has been found to be an “ideal” sign luminance value by TSLEP earlier in this study. The sign luminance contrast is assumed to be close to one (absolute value), the threshold percentage and the exposure time are set to 95% and 0.55 s, respectively.

If one assumes a minimum required time to process a traffic sign of the kind described above of 3 s (recommended by the CIE Joint Technical Report No. 73 [17]) and adds 0.65 s corresponding to an 85th percentile last eye fixation time, the minimum required legibility distance for a driver approaching the traffic sign at a speed of 88.5 km/h (55 mph) is 89.7 m (294 ft). Comparing the minimum required legibility distance of 89.7 m (294 ft) to the legibility distances in Figure 5, one may conclude that no driver over 50 years of age can achieve the minimum required legibility distance under the given conditions even for an “ideal” sign luminance of about 75 – 90 cd/m².

SUMMARY, DISCUSSION OF RESULTS, AND CONCLUSIONS

This study investigated on a quantitative basis how the legibility distance of a traffic sign with a negative luminance contrast at night increases when increasing either the sign legend letter height (or the corresponding sign area) or the sign background luminance, or when increasing both simultaneously together, the sign legend letter height (or the corresponding sign area) and the sign background luminance. A computer model has been developed to determine the legibility distance of a negative luminance contrast traffic sign at night as a function of the letter height (or stroke-width), the sign background luminance, the driver’s age and other factors. Blackwell’s widely established and very comprehensive Series II contrast threshold data have been used to find these fundamental relationships. The contrast threshold is adjusted by several contrast multipliers to account for different driver ages, different threshold percentages, out-of-laboratory conditions, etc, with the assumption that all factors independently and multiplicatively contribute to the final contrast threshold. The assumptions made for the single contrast multipliers seem to be reasonable since they are based upon well-established studies and produce realistic results. For example, the legibility distance at night as calculated by TSLEP of a 60.96 cm (24 in) x 76.2 cm (30 in) “DO NOT PASS” regulatory traffic sign with a stroke-width of 2.44 cm (0.96 in) for a 22.5 year old observer, a sign background luminance of 50 cd/m², a negative luminance contrast of close to one (absolute value) and a threshold percentage of 95%, is 75.2 m (246.8 ft) The average legibility distance of the same traffic sign under low-beam automobile headlamps illumination as found in an earlier field study
[18] using ten subject with an average age of 22.5 was 71.0 m (232.9 ft) – a very comparable value to the TSLEP result. Therefore, TSLEP seems to be a very useful tool to study the effects of chosen traffic sign design parameters.

Using TSLEP, it has been found that elderly drivers are at a high disadvantage reading traffic signs at night and can not be provided with a required legibility index of 6 m/cm (50 ft/in). In order to increase the legibility distance of a traffic sign at night, increasing the sign legend letter height or increasing the sign area seems to be much more effective than increasing the sign background luminance. Increasing the sign background luminance to very high values increases the danger of “halation” or “irradiation” having a detrimental effect on the legibility distance. However, increasing only the sign size may be limited by physical limitations such as allowable stress on sign substrates, posts and/or supports. Given the costs and retroreflection properties of different sheeting materials, bearing in mind any physical limitations of increasing the sign size and being aware of the effects of halation/irradiation, one may find out based upon the results of this study and a cost-benefit analysis what strategy (increasing the sign background luminance vs. increasing the sign size vs. a mix of the two) is the most cost-efficient one to achieve an agreed increase in the legibility distance.
REFERENCES

## TABLES AND FIGURES

Table 1 Legibility indices for selected driver ages at night calculated using TSLEP

<table>
<thead>
<tr>
<th>Letter Series</th>
<th>H/SW</th>
<th>Legibility Index m/cm (ft/in)</th>
<th>Adjusted Legibility Index for a Selected Driver Age (years) m/cm (ft/in)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>20</td>
<td>50</td>
</tr>
<tr>
<td>B 8/1</td>
<td>4.296(35.8)</td>
<td>4.296(35.8)</td>
<td>3.528(29.4)</td>
</tr>
<tr>
<td>C 7/1</td>
<td>4.908(40.9)</td>
<td>4.908(40.9)</td>
<td>4.044(33.7)</td>
</tr>
<tr>
<td>D 6.25/1</td>
<td>5.496(45.8)</td>
<td>5.496(45.8)</td>
<td>4.524(37.7)</td>
</tr>
<tr>
<td>E 5.75/1</td>
<td>5.976(49.8)</td>
<td>5.976(49.8)</td>
<td>4.920(41.0)</td>
</tr>
<tr>
<td>F 5.25/1</td>
<td>6.552(54.6)</td>
<td>6.552(54.6)</td>
<td>5.388(44.9)</td>
</tr>
<tr>
<td>E(m) 5/1</td>
<td>6.876(57.3)</td>
<td>6.876(57.3)</td>
<td>5.652(47.1)</td>
</tr>
</tbody>
</table>

Sign background luminance L_b = 87 cd/m², Sign luminance contrast C = 1 (ideal), Threshold percentage P = 95%, Exposure time ET = 0.55 s
Table 2 Example using TSLEP that illustrates five selected strategies to improve the legibility distance of a traffic sign

<table>
<thead>
<tr>
<th>Increase factor</th>
<th>Legibility distance [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Both, background luminance (starting at ( L_b = 50 \text{ cd/m}^2 )) and letter-height (starting at ( L_H = 17.78 \text{ cm} )) increase</td>
</tr>
<tr>
<td>1.0</td>
<td>91.04</td>
</tr>
<tr>
<td>1.1</td>
<td>102.02</td>
</tr>
<tr>
<td>1.2</td>
<td>112.84</td>
</tr>
<tr>
<td>1.3</td>
<td>123.93</td>
</tr>
<tr>
<td>1.4</td>
<td>135.33</td>
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<td>1.5</td>
<td>147.01</td>
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<td>1.6</td>
<td>158.62</td>
</tr>
<tr>
<td>1.7</td>
<td>170.47</td>
</tr>
<tr>
<td>1.8</td>
<td>182.18</td>
</tr>
<tr>
<td>1.9</td>
<td>194.10</td>
</tr>
<tr>
<td>2.0</td>
<td>206.20</td>
</tr>
</tbody>
</table>

Assuming an initial letter-height \( L_H = 17.78 \text{ cm} \) and the use of the letter series E(m) with a letter-height to stroke-width ratio of \( H/SW = 5 \), the initial stroke-width (visual detail size) is \( SW = 3.56 \text{ cm} \). Therefore, increasing the letter-height is associated with a corresponding proportional increase of the stroke-width. Sign luminance contrast \( C = 1 \) (ideal), Exposure time \( ET = 0.55 \text{ s} \), Observer age = 50 years, Threshold percentage \( P = 95\% \).
Figure 1 An example of graphical TSLEP output, showing the legibility indices for the letter series E(m) in ft/in for selected driver ages at night as a function of the sign background luminance.
Both, background luminance (starting at $L_b = 50 \text{ cd/m}^2$) and letter-height (starting at $L_H = 17.78 \text{ cm}$) increase

Letter-height increase only, starting at $L_H = 17.78 \text{ cm}$ ($L_b = 50 \text{ cd/m}^2 = \text{const}$)

Both, background luminance (starting at $L_b = 50 \text{ cd/m}^2$) and sign area (starting at an area for an initial letter-height of $L_H = 17.78 \text{ cm}$) increase

Sign area increase only, starting at an area for an initial letter-height of $L_H = 17.78 \text{ cm}$ ($L_b = 50 \text{ cd/m}^2 = \text{const}$)

Background luminance increase only, starting at $L_b = 50 \text{ cd/m}^2$ ($L_H = 17.78 \text{ cm} = \text{const}$)

Assuming an initial letter-height $L_H = 17.78 \text{ cm}$ and the use of the letter series $E(m)$ with a letter-height to stroke-width ratio of $H/\text{SW} = 5$, the initial stroke-width (visual detail size) is $\text{SW} = 3.56 \text{ cm}$.

Sign luminance contrast $C = 1$ (ideal), Exposure time $ET = 0.55$ s, Observer age = 50 years, Threshold percentage $P = 95\%$

Figure 2 Example using TSLEP that illustrates five selected strategies to improve the legibility distance of a traffic sign.
Figure 3 An example of graphical TSLEP output, showing the legibility indices for the letter series E(m) in ft/in for selected sign background luminance values at night as a function of the threshold percentage.

Figure 4 A 76.20 cm x 91.44 cm (30" x 36") “DO NOT PASS” regulatory traffic sign.
Figure 5. An example of graphical TSLEP output, showing the legibility distances in ft for a 76.20 cm x 91.44 cm (30" x 36") "DO NOT PASS" regulatory traffic sign with a letter-height of LH = 17.78 cm (7 in) and a stroke-width of SW = 2.84 cm (1.12 in), H/SW = 6.25, for selected sign background luminance values at night as a function of the driver’s age.