DEVELOPMENT OF A LEGIBILITY MODEL AND PC SOFTWARE TO PREDICT THE LEGIBILITY OF TEXT ON TRAFFIC SIGNS FOR HIGH LUMINANCE AND CONTRAST CONDITIONS

A Thesis Presented to
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the Fritz J. and Dolores H. Russ
College of Engineering and Technology
of
Ohio University

In Partial Fulfillment
Of the Requirements for the Degree
Master of Science

by
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June, 2003
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1 INTRODUCTION

The legibility of road signs at night depends on several factors, such as the size of symbols, the colors of sign legends and backgrounds, the luminance of the legends and backgrounds, the type of material used, any ambient illumination, and the lights from approaching cars [1]. Further, contrast polarity, driver’s age, observation time, observation and entrance angle, and the distance between the vehicle and the traffic sign are other factors that affect legibility.

From a human visual performance point of view, legibility is defined as the ability of an observer to discriminate visual stimulus detail to such a degree that the observer can recognize an object, such as a character, a numeral, or a symbol. The term readability, although defined similarly to legibility by the American Heritage® dictionary, generally refers to the ability of an observer to understand a legible message [2].

There is no device that can measure legibility directly; a human must always be involved in its determination. However, one key factor is contrast, which can be defined as:

\[
Contrast = \frac{L_{\text{max}} - L_{\text{min}}}{L_{\text{max}}} \tag{1 - 1}
\]

where

- \(L_{\text{max}}\) is the maximum luminance (either legend or background luminance),
- \(L_{\text{min}}\) is the minimum luminance (either legend or background luminance).
When legend luminance is higher than background luminance (bright legend on dark background), the contrast is known as **positive luminance contrast**. On the other hand, when the background luminance is higher than legend luminance (dark legend on bright background), the contrast is known as **negative luminance contrast**.

Legibility performance in the context of this thesis is quantified by two factors: multiples of threshold contrast (MOT (Actual Contrast/Contrast Threshold)) and percentage of correct responses.

We are expressing the legibility performance as a **multiple of the threshold contrast** for a selected probability value for correct identification of the character of a given visual angle. Multiples of Threshold Contrast can simply be defined as the ratio of actual contrast to the contrast threshold for a given probability value. In order for a sign to be legible, MOT (Actual Contrast/Contrast Threshold) should be higher than 1. In other words, the actual contrast of the traffic sign should be higher than the contrast threshold for a given probability for the sign to be legible. We use the threshold contrast at this probability value as a baseline and we express the legibility performance (quality of legibility) as a multiple of that baseline value. For instance, it can be stated that an MOT value of 10 can be defined as a very good legibility condition. MOT is one way quality measure of how good the legibility performance of the sign is.

The relationship between probability of correct responses (percentage of correct responses) and multiples of threshold contrast is demonstrated in Figure 1. Figure 1 shows that multiples of threshold contrast (MOT (Actual Contrast/Contrast Threshold)) has a decreasing trend while probability of recognition increases when keeping all the
other values (target luminance, background luminance, observation time, observer’s age, target distance, font height, stroke width, and field factor) constant. When MOT (Actual Contrast/Contrast Threshold) is below 1, the traffic sign is no longer legible. It should be noted that if higher probability of recognition is desired, the traffic sign will become illegible for probabilities higher than 99%. However, the exact same traffic sign is legible for lower probability levels (lower than 99%).

Figure 1: LEGI results for Variable Probability. Target Luminance = 7.8 cd/m^2, Background Luminance = 1.3 cd/m^2, Observation time = 2 sec., Observer's Age = 25, Target Distance = 600 ft (183 m), Font Height = 12", Stroke Width = 3", Field Factor = 4.5.
1.1 Statement of the Problem

Blackwell [4] conducted one of the most important and famous studies in the illumination area during WWII. The paper was published in 1946 and he stated that the probability of recognition continuously increases as the target luminance increases. This study is based on the determination of the contrast threshold of the normal human observer under three different experimental conditions and the stimuli utilized were in circular in form. Those conditions are presented in three different sections throughout the paper that refer to the three different sets of conditions. In the first part, circular stimuli, were brighter than the observation screen (positive contrast) (Table 1). In the second part, the stimulus was darker than the observation screen (negative contrast) (Table 2). The aim of this part is to see whether the contrast values are same or different for negative and positive contrast stimuli. Preliminary experiments indicated that the six-second exposure time used in the experiments of Part I and Part II did not represent sufficient time for minimal thresholds. So, in the third part, a supplementary experiment was conducted to determine the threshold contrasts when an indefinitely long exposure times was used. (Table 3).
Table 1: Arithmetical mean threshold contrast. Stimuli brighter than surround
(Part I) adapted from [4].

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Log B₀: Log Adaptation Brightness (foot-lambert)
Log C: Log Luminal Contrast
Table 2: Arithmetical mean threshold contrast. Stimuli darker than surround (Part II) Adapted from [4].

<p>| Angular subtense of stimulus (minutes of arc). | 114 | 55.5 | 18.9 | 9.55 | 5.01 |</p>
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</table>

Log $B_0$: Log Adaptation Brightness (foot-lambert)
Log $C$: Log Luminal Contrast
Table 3: Arithmetical mean threshold contrast. Stimuli brighter than surround (Part III) for exposures higher than 6 seconds Adapted from [4].

<table>
<thead>
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<td>Log B&lt;sub&gt;0&lt;/sub&gt;</td>
<td>Log C</td>
<td>Log B&lt;sub&gt;0&lt;/sub&gt;</td>
<td>Log C</td>
<td>Log B&lt;sub&gt;0&lt;/sub&gt;</td>
</tr>
<tr>
<td>1.853</td>
<td>-2.462</td>
<td>1.874</td>
<td>-2.063</td>
<td>1.044</td>
</tr>
<tr>
<td>0.070</td>
<td>-2.294</td>
<td>-1.023</td>
<td>-1.672</td>
<td>0.039</td>
</tr>
<tr>
<td>-0.984</td>
<td>-1.971</td>
<td>-1.900</td>
<td>-1.075</td>
<td>-1.887</td>
</tr>
<tr>
<td>-1.871</td>
<td>-1.322</td>
<td>-2.953</td>
<td>-0.157</td>
<td>-2.965</td>
</tr>
<tr>
<td>-2.923</td>
<td>-0.655</td>
<td>-3.932</td>
<td>0.425</td>
<td></td>
</tr>
<tr>
<td>-4.982</td>
<td>0.584</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Log B<sub>0</sub>: Log Adaptation Brightness (foot-lambert)
Log C: Log Luminal Contrast
Further, Guth and McNelis [5], [6] also conducted studies on visual performance. Their study was a comparison in terms of detection of presence and discrimination of detail for the shape of the contrast-luminance relationship. They compared the threshold data for a disc target, parallel bars and a Landolt ring. They reached the same conclusion as Blackwell and stated that legibility increases while luminance increases. The Guth and McNelis studies [5], [6] prove that the results of the Blackwell study, which shows that higher luminance increases the probability of recognition, also applies to legibility.

In recent times there has been an introduction of more retroreflective sheeting materials for traffic sign legends and backgrounds. Zwahlen et al. [3] conducted a study to measure the luminance of yellow warning signs with black legends, at night with no appreciable glare sources within the field of view. Under low beam illumination conditions, the maximum luminance value occurred between 400 and 500 ft for signs on the right side of the roadway and was measured to be about 300 cd/m² (Figure 2). Further, under high beam illumination conditions, the maximum luminance value occurred at 400 ft for signs on the right side of the roadway and was measured to be about 1000 cd/m² (Figure 3).
Figure 2: Luminance values for yellow warning signs with black legend with retroreflective sheeting materials versus distance between car and sign for signs on right side of the roadway under low-beam illumination, including repeat measurements [3].
Figure 3: Luminance values for yellow warning signs with black legend with retroreflective sheeting materials versus distance between car and sign for sign on right side of the roadway under high-beam illumination, including repeat measurements [3].
Further, the results of the study by Zwahlen et al. [7] indicate that increasing target brightness has either no effect or only a small detrimental effect on the correct outside-shape recognition distances for full reflectorization and borders-only reflectorization. Targets with only the borders reflectorized were recognized from farther away than targets that were fully reflectorized. This study showed that higher luminance did not result in longer recognition distances because the higher luminance levels caused radiation (glare).

At this point, questions have arisen as to whether or not this higher brightness may actually has a detrimental effect on legibility performance. Zwahlen and Badurdeen [8] investigated legibility performance and brightness perception as a function of text or background luminance in nighttime surrounds. The variation of the fraction of correct responses in identifying the Landolt ring gap orientation for this study reveals a variation of the legibility performance at different luminance levels. There exists a luminance level at which the legibility performance is highest. Olson and Bernstein [9] and Sivak and Olson [10] discuss of an inverted U-shaped function of percent correct identification at different luminance levels. The authors of this study found an only slightly inverted function for variation of legibility performance observed over the luminance range experimented. The optimal legibility performance at 37.13 cd/m² for a white Landolt ring is found to decline to about 78% of optimal at the highest luminance level 386 cd/m². A similar variation is observed for a black Landolt ring; optimal legibility performance observed at 134.78 cd/m² declines to approximately 78% at the highest luminance level. Olson and Bernstein [9] claim to have observed a more pronounced variation in legibility
performance for a white Landolt ring on a black background. Their findings are summarized in Table 4.

Table 4: Percentages of correct responses for positive contrast from Olson and Bernstein [9].

<table>
<thead>
<tr>
<th>Legend Luminance</th>
<th>Percent Correct Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1 cd/m²</td>
<td>0%</td>
</tr>
<tr>
<td>8-9 cd/m²</td>
<td>96%</td>
</tr>
<tr>
<td>800-900 cd/m²</td>
<td>23%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Legend Luminance</th>
<th>Percent Correct Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1 cd/m²</td>
<td>62%</td>
</tr>
<tr>
<td>0.3-0.4 cd/m²</td>
<td>100%</td>
</tr>
<tr>
<td>300 cd/m²</td>
<td>83%</td>
</tr>
</tbody>
</table>

* More comparable to the experimental conditions in the Zwahlen and Badurdeen [8] study where average legibility index is 6.48 m/cm.

It can be observed from Table 4 that, for a legibility index of 6.0 m/cm with positive contrast, the percentage of correct responses decreases from 100% (legend luminance 0.3-0.4 cd/m²) to 83% (legend luminance 300 cd/m²). The observations for the Olson and Bernstein [9] study with a white Landolt ring on a black background span over greater range of luminance values: 0.1 cd/m² to approximately 1000 cd/m², which is much larger than the range tested in Zwahlen and Badurdeen [8] study. Though Olson and Bernstein study [9] shows a significant variation in legibility performance over the range tested, no such pronounced variation could be observed in Zwhalen and Badurdeen
study [8]. It is also questionable how, for a legibility index of 6.0 m/cm, Olson and Bernstein [9] found the legibility performance to remain at the 100% level over a large range of luminance values which happens to include the luminance values experimented in the present study and within which Zwahlen and Badurdeen [8] were not able to observe any such consistent legibility performance for a white Landolt ring.

Smyth [11] found optimal legibility at 20 e.f.c. and reported no appreciable increase in legibility distance for a small increase in brightness, whereas a large increase in brightness was reported to have decreased the legibility distance. It should be noted that this study was one of the first studies in this area. Unfortunately, how the units “e.f.c.” are defined is not known and not explained anywhere. Though the exact value of optimal luminance reported by Smyth [11] could not be discerned it could be reasonably assumed that variation observed for Smyth [11] study is similar to what was observed in the Zwahlen and Badurdeen study [8]. Smyth [11] concluded that the maximum legibility distance was practically the same for black on white (negative contrast) or white on black signs (positive contrast) and that negative contrast was found to be more distinctive and attractive by some subjects. However, this conclusion cannot be supported through the findings of the Zwahlen and Badurdeen [8] study. The results of the Zwahlen and Badurdeen [8] study indicate that the subjects were better able to identify the orientation of positive contrast than negative contrast. The higher (compared to positive contrast) values of the standard deviation of the average fraction of correct responses for negative contrast was indicative of the subjects’ difficulty in properly identifying the gap orientations for negative contrast. The results of the exit interview questionnaire of
Zwahlen and Badurdeen [8] study also indicated that some subjects had more difficulty in viewing negative contrast than positive contrast.

Based on the results of Zwahlen and Badurdeen [8] study, an optimal luminance for legibility performance at near threshold size was found, which was different for negative and positive contrast. There was also an influence of luminance on legibility performance. The main conclusion is that, higher luminance values actually decrease the probability of correct responses.

A major difference between the findings of the Zwahlen and Badurdeen [8] study and previous studies with same intent was that the authors found an only slightly inverted function for variation of legibility performance with sign/background luminance which is not as pronounced as an inverted U-shaped function reported by some researchers [9][10]. The findings of Zwahlen and Badurdeen study [8] also indicate that white text used against black background gives higher legibility performance than black text used against a white background. Further, during the experiments, the subjects were asked would they perform better if the brightness would be higher or lower. For instance, at the same luminance level (225 cd/m²); for the negative contrast 80% of the subjects and for the positive contrast 70% of the subjects indicated that they would have performed better if the brightness were lower in the Zwahlen and Baudrdeen study [8]. It should be noted that in case of negative contrast, the whole background is white and the screen is brighter, however, in case of positive contrast only the Landolt ring is white and bright.
1.2 Objective of the Study

The objective of this study is to develop a legibility model and modify an existing PC software program to predict the legibility of text on traffic signs for high luminance and contrast conditions. The legibility model is based on the experimentation conducted at the Human Factors and Ergonomics Laboratory about the nighttime legibility of traffic signs as a function of legend and background luminance. The Human Factors and Ergonomics Laboratory is a part of the Ohio Research Institute for Transportation and Environment in Ohio University, Athens, OH, USA.

LEGI is a program that is used for determination of legibility and recognition and for the determination of simple detection. LEGI had been developed at the Human Factors and Ergonomics Laboratory and based purely on Blackwell’s 1946 data [4]. However, as previously stated, higher luminance values actually decrease the probability of correct responses. Beyond the maximum probability of correct responses, the legend luminance needs to be adjusted in such a way that a modified LEGI would give the probability observed in the experiments for higher luminance values. In order to adjust LEGI, a “correction” function, which applies for beyond the maximum probability of correct responses, is required and this function will adjust the luminance in such a way that corrected probability values will be calculated.

The main objective of this thesis is to find this legend luminance correction function and build that into the existing version of LEGI. Any time such a model is established, the validity of the model should be demonstrated as a part of the scientific
process. In the context of this thesis, the validation is done by experimentation and theory.

1.3 Scope of Work

♦ The first step of this study was an extensive literature review to find out what factors affect legibility.

♦ The second step was to find a model to adjust the high luminance values that when input to a modified LEGI program provide the correct fraction of correct responses (legibility performance). The model consists of two functions, one for positive contrast and one for negative contrast.

♦ The third step of the study was to develop the computer software to incorporate the correction function.

♦ The fourth step was to conduct experiments to demonstrate the validity of the found correction functions. Validation experiments were done for the optimum and higher luminance values where legibility decreases has been observed.
2 LITERATURE REVIEW

2.1 Luminance and Legibility Relationship for Traffic Signs

Blackwell’s (1946) [4] paper is known as the cornerstone study on the contrast threshold of the human eye. His study was based on the determination of the contrast threshold of the normal human observer under three different experimental conditions. The data presented in Blackwell study [4] represents approximately 450,000 responses from trained observers obtained under laboratory conditions. The parameters of interest were stimulus contrast, stimulus area, and adaptation brightness. The study consists of three different parts that refer to the three different sets of conditions and experimental designs. In the first part, the circular stimuli were brighter than the observation screen (positive contrast) (Table 1). In the second part, the stimuli were darker than the observation screen (negative contrast) (Table 2). The aim of this part was to see whether the contrast values are the same or different for negative and positive contrast stimuli. In the third part, the difference from Part I and Part III was the use of indefinitely long exposure times (Table 3). The reason of this third set was that for minimal threshold values the 6 seconds used in Part I and Part II were not sufficiently long.

The conclusion from the first part of Blackwell study was that contrast becomes constant with respect to adaptive brightness especially for large stimuli. The results of the second part, in most instances, gave evidence that negative stimuli and positive stimuli are equivalent for equal area and contrast. However, in the case of large stimuli and low adaptation brightness a consistent discrepancy was found. When the threshold contrasts of the same observers are compared between positive stimuli and negative stimuli,
negative stimuli had 20% lower thresholds. As the result of the third set of experiments, the author states that doubling the exposure did not increase the frequency of correct judgment.

Guth and McNelis (1967) [6] reported on visual performance. Their study was a comparison in terms of detection of presence and discrimination of detail for the shape of the contrast-luminance relationship. They compared the threshold data for a disc target, parallel bars and a Landolt ring. For the four-minute disc target, the results of threshold values obtained in their experiment were comparable with the results of Blackwell [4] and Smyth [11]. The results are parallel. The parallelism is important, since it means that the effect of background luminance on threshold contrast is same for both experiments. These also matched with the standard curve published in IES Lightning Handbook, Fourth Edition [12]. Moreover, when the results of parallel bars were analyzed, it was seen that the threshold contrast curves for parallel bars were a bit steeper than the curves for the disc. This means that a given contrast level would require a lower luminance level for a given degree of threshold visibility. For the Landolt ring, it was stated that the values that were valid for a disc target were not valid for a Landolt ring, however, detail and presence curves for Landolt ring itself are similar.

Blackwell and Blackwell (1971) [13] presented the visual performance data for 156 normal observers of various ages. Their aim was to make the threshold contrast data that are obtained from only young university age students useful for all age groups. They experimented with people between the ages of 20 and 70 and who had a visual acuity of 20/30 or better. This group of people might be considered as people who have the optimal
visual acuity in their age group. As a result, the authors provided a contrast multiplier. This multiplier would be used to convert the laboratory forced-choice threshold data to threshold values corresponding to more ordinary criteria. The authors also presented the contrast multipliers for different portions of the normal population that are reported in a matrix by Guth and McNelis (1969) [5]. In this matrix the multipliers are presented for people of average ages 20 to 65 in steps of 5 and for percentile levels of 50, 60, 70, 80, 90, and 95.

Aktan et al. (2002) [14] reported about a theoretical approach for a derivation of legibility threshold luminance contrast data for road sign applications. This paper was based on a theoretical study and a field experiment that would be employed to validate and adjust the generated data. Authors modeled some real world scenarios with TarVIP to test the applicability of the legibility data generated. It was stated that the model is quite capable of estimating the actual legibility distances observed in the field at night. The authors state that the use of young subjects with a visual acuity of 20/20 or better was a drawback of the results of the experiments since the use of young subjects does not represent the entire population.

Norren (1981) [15] analyzed the visual acuity in a condition of traffic sign viewing in terms of the effects of luminance changes. In this study, visual acuity of eight subjects for Landolt C (Landolt ring) was measured as a function of stimulus luminance. Both negative and positive contrasts are considered. The study aimed to simulate the traffic sign environment, and used a stimulus width of 0.7° with a surround field of 60°. Moreover, the surround luminance is changed from 0.5 to about 5000 cd/m² in steps of
10. It is concluded that when the presentation time is short, the acuity was considerably lower than when the presentation time was longer. Moreover, when the symbols were dark, and the surrounding had a low luminance (5 cd/m²), the visual acuity decreased for high luminance. The authors described this as “the glare effect”. It was stated that when the intensities of Landolt rings were low, the surrounding luminance had a minor influence on acuity. On the other hand, when the stimulus luminance decreased below the surrounding luminance, the acuity also decreased. This situation represented a traffic sign that was viewed against a clear sky. The authors defined the term irradiation as “conditions in which the symbol is so much brighter than the background that its legibility deteriorates”.

2.2 Traffic Sign Text (Legend) and Legibility of Traffic Signs Relationship

Zwahlen and Schnell (1999) [16] reported on the legibility of traffic sign text and symbols. In their study, 11 new reflectorized right-shoulder-mounted traffic signs, all of which have different types of texts were used. The experiment was conducted with 10 young subjects and three replications were made. One of the most important conclusions was that the subjects should be given clear instructions. If the subjects are allowed to guess what they recognize the legibility decreases and recognition distance increases, and the effect is stronger under nighttime conditions. Moreover, the average daytime legibility and recognition distances were about 1.8 times longer than the corresponding nighttime values.

Zwahlen et al. (1995) [17] reported on the review of legibility relationships within the context of textual information presentation. This paper refered to Forbes’s [18] paper,
in which the term legibility is defined as “a subject’s ability to read the characters on a traffic sign”. It was reported that legibility was affected by factors such as height, character width, stroke width, height-width ratio, height-stroke width ratio, intercharacter spacing, interword spacing, and interline spacing and the relations of these factors. Obviously, these were not the only factors that affect the legibility. This paper included a considerable literature review. It was concluded that instead of unrelated characters and numbers, single characters and meaningful words should be used. Moreover, the authors stated that, although the recommended stroke width to height ratios varied among studies, the general result was that characters displayed with a positive contrast require smaller stroke widths than characters displayed with a negative contrast. Irradiation became a serious problem as the display luminance increases.

Zwahlen et al. (1991) [19] reported on the recognition of traffic sign symbols in the field during daytime and nighttime. In this study, 12 retroreflective warning signs were used. It was concluded that daytime average symbol recognition distances are about 2 times longer than the corresponding distances obtained in the laboratory and about 1.2 times longer than the corresponding nighttime distances. 10 subjects were used in both daytime and nighttime experiments. As a result, laboratory studies are open to discussion about their real world validity.

2.3 Legibility of Fluorescent Color Retroreflective Targets

Zwahlen and Badurdeen (2001) [20] analyzed daytime legibility as a function of non-fluorescent and fluorescent traffic sign colors. In this paper, results of two experiments were reported. Six young subjects were used in both experiments and the
sign surface facing sun and sign surface in shade conditions were analyzed. It was reported that the legibility index for the white Landolt ring and the green sheeting material was higher than the legibility indices for a white Landolt ring on the other sheeting materials in the shade. On the other hand, a black Landolt ring on green material reduced the legibility index 85% compared with the white Landolt ring value in the shade and 77.5% in the sun. The overall conclusion is that, fluorescent yellow or yellow green materials might be substituted for the regular yellow traffic sign color (mainly for conspicuity enhancement), however this only increased the legibility index by 7.6%.

Zwahlen and Schnell (1996) [21] analyzed the conspicuity advantage of fluorescent color targets in the field during daytime. In this paper, daytime conspicuity of fluorescent and non-fluorescent color targets were investigated against a green background in terms of visual detection and color recognition. The colors used were: white, blue, green, red, fluorescent red, fluorescent yellow-green, yellow, fluorescent yellow, orange, and fluorescent orange. The experiment was conducted with two groups of subjects and with two different target sizes. Three different peripheral viewing angles were used for the two groups. After the field experiments, the authors concluded that to maximize the peripheral daytime conspicuity, both highly conspicuous fluorescent colors along with a fairly large target size should be selected.

Burns and Johnson (1995) [22] reported on the correlation of measured spectral radiance of fluorescent and non-fluorescent materials to perceived conspicuity under Natural Lighting. They concluded that a correlation exists between the perceived brightness of fluorescent colors and their photometric properties under natural daylight
illuminance. Moreover, the luminance contrast of fluorescent colored materials was significantly greater than their matching ordinary colors under daytime conditions.

Burns and Pavelka (1995) [23] investigated the visibility of durable fluorescent materials for signing applications. They concluded that fluorescent colored retroreflective materials were detected with higher frequency and were recognized with greater accuracy at farther distances than the corresponding standard highway colors. Moreover, fluorescent colors were more conspicuous during daylight than the standard highway colors. They have stated that daytime visibility was a very important issue on which research should be conducted.

Jenssen (1995) [24] presented a report on the visibility of fluorescent retroreflective traffic control devices. In this report 36 color combinations were tested, as they were potential applications in traffic signing. Color contrast, legibility, and the effect of surrounding camouflage for fluorescent and non-fluorescent colors were evaluated. They concluded that under daytime conditions relative color contrast was better for fluorescent colors compared to non-fluorescent colors. However, legibility of both type of colors was similar based on error rate. As an overall result, the fluorescent yellow-green plate with black legend came out as the best among all combinations both for the color contrast and for the legibility.

Burns et al. (1995) [25] analyzed colorimetry of durable fluorescent retroreflective materials. As a result of their analysis, they concluded that the availability of commercial 2-monochromotor spectrophotometers should be increased in order to deal
with the results that were inadequate for precise quality control of fluorescent retroreflective materials.

Zwahlen and Vel (1992) [26] presented conspicuity in terms of peripheral visual detection and recognition of fluorescent color targets vs. non-fluorescent color targets against different backgrounds during daytime. In this study, ten color targets were used. Six of them were non-fluorescent and four of them were fluorescent. They were tested against different non-uniform multi-color backgrounds. It is concluded that when the background is either a city background, a fall foliage background or spring background, fluorescent yellow was the best color to be used for the target that provides the highest peripheral detection performance. On the other hand, for the same background types, the fluorescent orange target provided the highest peripheral correct recognition performance. Nevertheless, it should be noted in this study that all the subjects were healthy college students.

2.4 Effect of font design on legibility

Poynter [27] stated that threshold luminance contrast for letter recognition was dependent upon the amount of color contrast present, the background luminance, letter size, the age of observer, and the level of glare. A size function (the height of letters measured in degrees of visual angle), a contrast multiplier for background luminance, a contrast multiplier for observer age, a contrast multiplier for color, and a contrast multiplier for veiling luminance were presented in the paper. The model was validated by applying it to English letters. However, it was also discussed that only a small number of independent variables were used for validation and more experimentation was necessary.
Poynter also mentioned that the extent to which letter style might affect the predictive accuracy of his model was largely unknown. One style factor that will certainly affect model accuracy is the ratio of letter height (the index of size used in this thesis) and average critical detail for the font. In his paper, critical detail was defined to be the smallest unit of distance that must be resolved to distinguish between letters. For instance, critical detail in a discrimination between the letters “C” and “O” would be the gap in the letter “C”. The author states that letters in his experiments had an average letter height / critical detail ratio (HCDR) of 5.5 and in case of large deviations from this ratio the letter height used in the size function could be calibrated by $\frac{5.5}{HCDR}$.

Garvey, Pietrucha and Meeker [29] conducted a study with the objective of improving highway guide sign legibility by replacing the 40-year-old series (E) modified guide sign font with a new font called Clearview. The Clearview font was developed by Meeker & Associates, Inc. There were two parts of the study. Daytime and nighttime experiments were conducted for both parts of this study. In the first part, the dependent variable was the threshold distance for word recognition, where the threshold was defined to be the furthest distance at which a subject could correctly identify the target word’s location on the sign: top, middle or bottom. In the second part the dependent variable was threshold distance for word legibility, where the threshold was defined to be the furthest distance at which a subject was able to read the word correctly. The main innovation in the Clearview alphabet is that the openness of letters is increased when compared to the Series E (modified) and so the Clearview’s intercharacter spacing is shorter than that of the Standard Highway Alphabet (Figure 4).
Clearview spacing results in words that take up 12 percent less sign space than do the Standard Highway fonts. A 12 percent increase in Clearview character height produces words equal in sign space to those shown in the Standard Highway fonts. Both studies included Clearview fonts matched in letter height with Standard Highway and Clearview fonts matched in overall sign size with Standard Highway. The resulting fonts are called *Clearview* (or *Clearview condensed*) at 100 percent (of Standard highway letter height) and *Clearview* (or *Clearview condensed*) at 112 percent (of Standard Highway letter height), respectively. It should be noted that the only standard alphabet that uses both upper and lower case letters is Series E (modified). Specifically, the fonts tested were:

- Clearview condensed at 100 percent (mixed case),
  - Capital letter height 12.7 cm (5 in.)

**Figure 4: Sign area as a function of font [29].**
Mixed case fonts have both upper case and lower case letters. The first letter of a word is in upper case and the rest of the word is in lower case letters. An example of only upper case and mixed case words is presented in Figure 6.

It is concluded that, in the legibility task (second study), in which individual letter reading is required, the larger letters used with all-uppercase Series D font resulted in greater legibility distances (daytime 5.3 m/cm, nighttime 5.1 m/cm) than did the smaller mixed-case Clearview Condensed font (daytime 4.8 m/cm, nighttime 3.9 m/cm); however, when the mixed-case font was increased in size to take up the same sign area as
the Series D font, performance between the mixed-case and all-uppercase words was the same (Clearview 112% daytime 5.4 m/cm, nighttime 5.7 m/cm and Series E (M) daytime 5.3 m/cm, nighttime 5.2 m/cm).

In the recognition task (first study), the two mixed-case fonts (Series E (M) daytime 10.9 m/cm, nighttime 8.1 m/cm and Clearview daytime 10.2 m/cm, nighttime 8.2 m/cm) that matched Series D in the sign area performed significantly better than all uppercase font (Series D daytime 8.7 m/cm, nighttime 6.9 m/cm). Even the version of Clearview Condensed (daytime 9 m/cm, nighttime 6.8 m/cm) that took up much less sign space performed as well as the Series D all-uppercase font (daytime 8.9 m/cm, nighttime 7 m/cm). Garvey, Pietrucha and Meeker [29] stated that there are two likely reasons for the mixed case superiority in the recognition task. First, when viewed from far away, all-uppercase characters look like fuzzy rectangles whereas words in the mixed case, with ascenders and descenders (Figure 5), have a distinct shape or footprint (Figure 6). Second, mental images of place names (indeed, of all proper nouns) are likely to be in mixed case, making it an easier cognitive task to make a match with mixed-case sign copy than with words written entirely in uppercase letters.
Figure 5: Ascenders and Descenders (from [28]).

Figure 6: Both signs have the same "footprint", but the one on the right (mixed case first letter capital other letters lower case) is easier to read than the one on the left (all uppercase). (From [28]).

It was concluded that guide signs probably are read by using both legibility and recognition criteria, depending on the specific needs of traveler. This study indicated that if the size of mixed-case words is matched to the size of words depicted in all-uppercase letters (a cost effectiveness measure), the mixed-case provides equivalent reading distance in a legibility task and a superior reading distance (20-25%) in a recognition task. Therefore, Garvey, Pietrucha and Meeker [29] concluded that mixed-case words
should be recommended for use not just on highway guide signs but on all guide signs, including conventional road and street name signs for both daytime and nighttime driving conditions.

Moreover, under daytime conditions, there was no difference in either word legibility or recognition distance between the Series E (M) (legibility index 5.5 m/cm, recognition index 10.9 m/cm) and either of the two comparably sized Clearview fonts (Clearview legibility index 5.3 m/cm, recognition index 10.1 m/cm; Clearview at 112% legibility index 5.6 m/cm, recognition index 11.1 m/cm). At night, however, with bright sign materials, the Clearview font produced substantially longer reading distances (Clearview at 112% 5.7 m/cm) than Series E (M) (5 m/cm). In both the legibility and the recognition tasks, the Clearview fonts (Clearview at 112% 5.7 m/cm) that took up the same amount of sign space as did the Series E (M) (5 m/cm) resulted in significantly longer nighttime reading distances, and the version of Clearview (5 m/cm) that took up less sign space than did Series E (M) performed as well as the Series E (M) (5 m/cm).

Results of the Garvey, Pietrucha and Meeker [29] study indicated that the nighttime legibility distances achieved by older drivers increased by an average of 17 m when Clearview letters were used to replace Series E letters (101 versus 118 m(16%)). As an overall conclusion, the Clearview font’s wider open spaces allowed some irradiation without decreasing the distance at which the alphabet is legible and the Clearview font, which was specifically designed for high-brightness highway signs at night, allowed nighttime recognition distances 16 % greater than those allowed by the Standard Highway Series (E) M font, without increasing overall sign dimensions. Unlike
the initial work of Mace, et al. [47], no decline in daytime legibility distance was observed for the Clearview font.

Forbes et al. [30] and [31] conducted one of the oldest and most important studies comparing lower case and upper case letters. The study also analyzed the effects of font design on legibility. Letters from 5 in. to 18 in. in height were mounted on a bridge 17 ft. above the ground and a total of 75 observers, ages ranging from 18 to 75, made 3939 individual observations under daylight and evening conditions with artificial illumination. White on black, series E uppercase letters and lower case letters of approximately the same average width-height ratio were used. These letters represented the development of this form of letter for freeway signs by the California Division of Highways. The stroke width of the series “E” capital was widened slightly, also to correspond to the letters used by the California Division of Highways (Table 5 and Table 6). Loop height is presented in Figure 7 and stem height is presented in Figure 8.

![Loop height](image)

**Figure 7:** Lowercase letter "loop" height.

![Stem height](image)

**Figure 8:** The main vertical or near vertical portion of a letterform adapted from [32].
### Table 5: Width and Spacing of Uppercase Letters adapted from [32].

<table>
<thead>
<tr>
<th>Capital Letter</th>
<th>Width in Inches per Inch of Letter Height</th>
<th>Right plus Left Margin</th>
<th>Added Constant</th>
<th>Total of Width plus Spacing</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1.02</td>
<td>0.08</td>
<td>0.15</td>
<td>1.25</td>
</tr>
<tr>
<td>B</td>
<td>0.81</td>
<td>0.22</td>
<td>0.15</td>
<td>1.18</td>
</tr>
<tr>
<td>C</td>
<td>0.80</td>
<td>0.11</td>
<td>0.15</td>
<td>1.06</td>
</tr>
<tr>
<td>D</td>
<td>0.81</td>
<td>0.20</td>
<td>0.15</td>
<td>1.16</td>
</tr>
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</tr>
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<td>0.30</td>
<td>0.15</td>
<td>1.27</td>
</tr>
<tr>
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<td>0.30</td>
<td>0.15</td>
<td>0.65</td>
</tr>
<tr>
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<td>0.15</td>
<td>1.15</td>
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</tr>
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<td>0.15</td>
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<td>0.15</td>
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<tr>
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<td>0.10</td>
<td>0.15</td>
<td>1.09</td>
</tr>
<tr>
<td>R</td>
<td>0.82</td>
<td>0.20</td>
<td>0.15</td>
<td>1.17</td>
</tr>
<tr>
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<td>0.15</td>
<td>1.05</td>
</tr>
<tr>
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<td>0.15</td>
<td>0.94</td>
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<td>0.08</td>
<td>0.15</td>
<td>1.31</td>
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<td>0.08</td>
<td>0.15</td>
<td>1.24</td>
</tr>
<tr>
<td>Y</td>
<td>1.01</td>
<td>0.08</td>
<td>0.15</td>
<td>1.22</td>
</tr>
<tr>
<td>Z</td>
<td>0.82</td>
<td>0.26</td>
<td>0.15</td>
<td>1.23</td>
</tr>
</tbody>
</table>

Average width weighted for occurrence in California place names:

- Neat letters = 0.81
- Letter plus spacing = 1.13
Table 6: Width and Spacing of Lower Case Letters adapted from [32].

<table>
<thead>
<tr>
<th>Neat Letter</th>
<th>Right plus Left Margin</th>
<th>Added Constant</th>
<th>Total of Width plus Spacing</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>0.85</td>
<td>0.23</td>
<td>0.17</td>
</tr>
<tr>
<td>b</td>
<td>0.86</td>
<td>0.23</td>
<td>0.17</td>
</tr>
<tr>
<td>c</td>
<td>0.85</td>
<td>0.14</td>
<td>0.17</td>
</tr>
<tr>
<td>d</td>
<td>0.84</td>
<td>0.23</td>
<td>0.17</td>
</tr>
<tr>
<td>e</td>
<td>0.85</td>
<td>0.14</td>
<td>0.17</td>
</tr>
<tr>
<td>f</td>
<td>0.55</td>
<td>0.10</td>
<td>0.17</td>
</tr>
<tr>
<td>g</td>
<td>0.85</td>
<td>0.23</td>
<td>0.17</td>
</tr>
<tr>
<td>h</td>
<td>0.84</td>
<td>0.34</td>
<td>0.17</td>
</tr>
<tr>
<td>i</td>
<td>0.25</td>
<td>0.34</td>
<td>0.17</td>
</tr>
<tr>
<td>j</td>
<td>0.47</td>
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</tr>
<tr>
<td>k</td>
<td>0.83</td>
<td>0.23</td>
<td>0.17</td>
</tr>
<tr>
<td>l</td>
<td>0.25</td>
<td>0.34</td>
<td>0.17</td>
</tr>
<tr>
<td>m</td>
<td>1.42</td>
<td>0.34</td>
<td>0.17</td>
</tr>
<tr>
<td>n</td>
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<td>0.17</td>
</tr>
<tr>
<td>o</td>
<td>0.88</td>
<td>0.12</td>
<td>0.17</td>
</tr>
<tr>
<td>p</td>
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<td>0.17</td>
</tr>
<tr>
<td>q</td>
<td>0.86</td>
<td>0.23</td>
<td>0.17</td>
</tr>
<tr>
<td>r</td>
<td>0.65</td>
<td>0.20</td>
<td>0.17</td>
</tr>
<tr>
<td>s</td>
<td>0.83</td>
<td>0.09</td>
<td>0.17</td>
</tr>
<tr>
<td>t</td>
<td>0.67</td>
<td>0.10</td>
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<tr>
<td>u</td>
<td>0.85</td>
<td>0.34</td>
<td>0.17</td>
</tr>
<tr>
<td>v</td>
<td>1.01</td>
<td>0.06</td>
<td>0.17</td>
</tr>
<tr>
<td>w</td>
<td>1.32</td>
<td>0.08</td>
<td>0.17</td>
</tr>
<tr>
<td>x</td>
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<td>y</td>
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</tr>
<tr>
<td>z</td>
<td>0.87</td>
<td>0.14</td>
<td>0.17</td>
</tr>
</tbody>
</table>

Average width weighted for occurrence in California place names:
Neat letters = 0.77
Letter plus spacing = 1.15
By means of a prearranged series of positions, each size and form of letter was presented an equal number of times at right, left, top and bottom of the sign background to balance out errors due to position on the sign bridge (Figure 9) (Forbes [30], [31]).

![Image of sign background with text]

**Figure 9:** Each size and form of letter was presented an equal number of times at right, left, top and bottom of the sign background to balance out errors due to position on the sign bridge [30].

In order to approximate the effects of word pattern (as opposed to letter legibility) and word familiarity, three sets of measurements were made: (1) using scrambled letters; (2) using California place names being viewed for the first time; and (3) using California place names being viewed for the second time. The “scrambled” groups controlled for guessing and equalized familiarity between observers. The familiar place names, unknown to the observers ahead of time, were designed to use pattern recognition similar to that by drivers somewhat familiar with the territory. The familiar names known ahead
of time to the observers might correspond to the reading of signs by drivers who drive the same highway everyday – for example, commuters on freeways. The simultaneous use of both scrambled and familiar test signs allowed better control of psychological factors.

As was expected, for both kinds of the alphabet the median and 85th percentile distance increased with the size of letters and with the degree of familiarity. The increase due to increasing familiarity was greater for lower case letters than for capitals. Median legibility distance from the scrambled material proved to be roughly three-fourths as great as the recognition distances determined with familiar names when observed “without knowledge” of the names to be used. This relationship was also approximately the same for night observations.

Letter height has been used rather generally as a basic index of capital letter size since it is constant for all letters of the alphabet. For lower case letters, however, stem height (Figure 8) was found to be variable and therefore “loop” height was the only constant dimension. The “loop” height is presented in Figure 7. The comparison of lower case and capital letters can be stated in several ways. If recognition distance (and legibility distance) is expressed in terms of letter height using the total height of the “risers” (risers are ascenders, and presented in Figure 5) of the lower case letters, these letters appeared at some disadvantage, presumably because they were narrower. When distance “seen” was plotted against loop height, comparison of median distances showed an increasing advantage for lower case letters over capital letters as familiarity of test signs increased. However, when stem height (Figure 8) was used the advantage was reversed. On the basis of width, the lower case words could be seen farther than the
capital words, presumably because they were higher and larger. Thus where length of the sign is the controlling factor, which is often the case, these lower case letters would have an advantage.

On the basis of the sign area, the advantage of one type of alphabet over the other depends upon the vertical spacing or margins. Due to the open area between the stems (Figure 8) of lower case letters in a word, it would be expected that the margins or space between lines could be less than for capital letters without loss of legibility. Consequently, approximately 85th percentile distances (representing 20/20 vision) for scrambled capitals and place names “without knowledge” were 55 and 75 ft. per inch of letter height. For lower case letters of equal “loop” height, these distances were about 10 percent greater. Further, the author stated that more observations and experiments were necessary.

Garvey, Pietrucha and Meeker [33] stated that it was possible to improve the legibility of legends on conventional guide signs in two ways. The first way was that the use of properly sized mixed-case letters (lowercase with an initial capital) improved the ability of guide sign readers to more accurately recognize destination names [30]. The second way was the irradiation (halation, glare) that was caused by the current 40-year old highway guide sign font’s thick stroke or bold design coupled with the latest high-brightness reflective signing materials (such as 3M’s diamond grade LDP and VIP retroreflective sheeting) can be avoided with a suitable font. This article described process of creating and evaluating the Clearview font. The authors analyzed how selecting a word-legibility versus word-recognition task can have a dramatic impact on
sign-reading distance, how all uppercase words are read differently from mixed words, and how the Clearview font can improve guide sign readability over the current mixed-case Standard Highway Series E (M) font. They concluded that since Clearview was specifically designed to improve sign readability at night with high brightness materials, the Clearview font significantly outperformed the current highway fonts while using the same amount of space. A 16% increase in recognition distance was found with the Clearview font. On the other hand, Texas Transportation Institute studies [34] and [35] do not show this much of an increase. With highway signs on 88 kph (55 mph) roadways, the increase in legibility distance could translate into an additional 49 m (160 ft) (additional 2 seconds at 88 kph).

At one vendor’s web site [36], what constitutes a good type font to use for U.S. signs has been also discussed. They have mentioned that many U.S. signs, tags and labels use a new font, SmartSigns Clearview®, that has been specifically developed and tested for warnings. It is exclusively offered by Electromark. Since Electromark is one of the vendors, they state that Clearview is very important. For a quick illustration of why this font is important, they have presented the letters e, a, and s in the following illustrations Figure 10 and Figure 11.

![Figure 10: Ariel, Universe and Clearview Letters from [36].](image-url)
The letters made from SmartSign Clearview® (in gray) remain readable. This is especially true when seen with degraded vision.

Figure 11: Clearview and Univers alphabets for 20/40 and 20/70 visual acuity from [36].

Most signs are approached from an angle and often with less than perfect vision and lighting. As a driver ages, his/her visual acuity and night-time vision decrease dramatically. With common sign and label fonts important letters (see the e, a and S) tend to close up and fill in: see circled areas in Figure 11.

At his web site [37] Richard C. Moeur provided examples for standard sign typefaces. The standard typefaces used for highway signs in the US are defined in the "Standard Alphabets for Highway Signs", published by the Federal Highway Administration (Figure 12, Figure 13, Figure 14, Figure 15, Figure 16, Figure 17, and Figure 18).
Figure 12: Series A Discontinued in early 1970s from [37].

Figure 13: Series B from [37].

Figure 14: Series C from [37].

Figure 15: Series D from [37].

Figure 16: Series E from [37].

Figure 17: Series E modified from [37].

Figure 18: Series F from [37].
The Series B, C, D, E and F typefaces have only capital letters. The only standard alphabet that uses both upper and lower case letters is Series E modified. Although most sign font vendors include lower case letters in their versions of the FHWA Series B, C, D, E and F fonts, the lower case letters in these fonts are not approved by FHWA.

Capital letters on large guide signs (e.g. 1 MILE) are usually in Series E, whereas destination legends typically use Series E modified upper and lower case lettering.

The reason Series E Modified is called 'modified' is because the letter stroke (width of lines making up letter) is modified to be 20% of the letter height. For comparison, standard B thru F letters have a stroke width approximately 13-18% of the height.

The average widths, heights and spacings specifications are presented in the FHWA Manual on Uniform Traffic Control Devices Design Guidelines for Standard Alphabets [38].

The lower case loop height for Series E modified is 75% of the upper case height. The loop height for lower case letters is presented in Figure 7. For example, a lower case 's' is 75% of the height of an upper case 'S'.

Figure 19: Button copy lettering from [37].

Button copy lettering (Figure 19) has been in use for decades across the country for large expressway and freeway guide signs. "Button copy" is a generic term for highway sign characters which are made out of enameled metal, with small white circular reflectors (the 'buttons') inlaid in the surface to provide retroreflectivity at night. Button copy is no longer manufactured in the United States, as it could no longer compete cost-wise with newer computer-cut reflective sign letters. Arizona was the last state to specify button copy sign lettering, but stopped ordering new button copy signs in late 2000. Button copy typefaces closely resemble standard FHWA Series D, E, and Series E modified typefaces, except for minor differences to accommodate the inlaid reflectors.
The National Park Service uses a font known as Clarendon for sign legends (Figure 20). This typeface is very similar to the standard font known as Clarendon. This font is distinctive (for a highway sign font, that is) for using serifs. Serifs are little finishing strokes on the ends of the lines that form a character. Serifs are presented in Figure 21.

These letters have serifs on them. $T_{\text{serifs}}$

Figure 21: Serifs from [39].
Chrysler, Carlson, and Hawkins [40] analyzed nighttime legibility of traffic signs as a function of font, color, and retroreflective sheeting. In their abstract, they stated that they conducted this study on a closed course at nighttime and measured the legibility distance for 6-inch (150 mm) letters. The fonts tested were Highway Series D and two experimental fonts which were Clearview Condensed Road and D-Modified font. The Clearview font has a thinner stroke width than Series D and was used for white on green signs. The D-Modified font has a thicker stroke than Series D and was used for black letters on white, yellow, and orange backgrounds. The three types of retroreflective sheeting that were tested are ASTM Type I11 (beaded), Type VIII, and Type IX. The material type of the reflective copy matched the background materials in all cases. Forty-eight signs were used; all sign blanks were 12-inch x 30-inch (300 x 760 mm) with a border. Twenty-four participants, aged 55-75, drove a passenger sedan (1989 Ford Crown Victoria LTD) around a closed course at 30 mph while attempting to read the ground mounted signs. The authors stated that results showed no difference between drivers aged 55-65 and those aged 65-75. Overall treatment means ranged from 143 ft to 206 ft (43-63 m) producing legibility indexes in the range of 24-34 ft of legibility per inch of letter height (2.9-4.1 m/cm). Color was found to be a significant factor affecting legibility with yellow and white backgrounds producing the longest legibility distances followed by green and then orange. Across all background colors, retroreflective sheeting type was a significant factor with specific differences among sheetings dependent on color. Last but not least, the authors reported that the font design was surprising in that Highway Series D was better or equivalent to both alternatives (Clearview Condensed Road and D-
Modified font) tested. These results do not match with the Garvey et al. results [29] which found 16% increase for Clearview at nighttime.

Smiley et al. [41] conducted an on-road study to determine the required letter height for street name signs in downtown and suburban portions of the City of Toronto. They stated that to be effective, a street name sign must meet two important criteria. First, it must be conspicuous, and therefore easily detected especially in visually cluttered urban backgrounds. Second, it must have sufficient letter height to allow drivers the time and distance needed to read the sign, make a lane change and reduce speed prior to making turns. The authors mention that until this on-road study was conducted there were no studies that had been carried out on city streets to determine what letter height is required to allow drivers sufficient time and distance to comfortably make turns. Their on-road study examines this issue for current street name signs as well as for new test signs. In downtown core, they looked at 3 letter heights, 10, 15 and 20 cm (4, 6 and 8 inches) on new signs. These signs had white letters on a blue background and used Clearview font and 3M Diamond grade VIP. In the suburban portion of the study, two letter heights, 13 and 20 cm, (5 and 8 inches) were examined with blue and green background, respectively. Based on their results, the authors made recommendations with respect to letter height, reflectorization, placement and use of advance signs. For downtown areas 20 cm letter height signs were recommended, since at 38 km/h these signs provide the equivalent of 7 seconds at the approach speed for drivers to change lanes and they had high driver ratings. Moreover, while 15 cm signs were rated as providing “enough time” there are faster approach speeds on some downtown arterials
than in the test area. For suburban areas, with mean approach speeds of 65 km/h or less, 20 cm letter height advance signs were recommended over the 13 cm signs since with the 13 cm advance signs, subjects had avg. 10 seconds which they rated as just under “enough time” average and subjects were driving slower than surrounding traffic in order to read signs. It was also discussed that no conclusions could be drawn about the relative legibility of Clearview and series E (modified) from this study since the aim of this study was to investigate the required letter height for street name signs in downtown and suburban areas. For all areas reflectorized signs were recommended. The authors stated that in the downtown area the diamond grade reflective material worked very well, however, high-grade engineering background used on the suburban signs did not perform as well at night as during the day because of lower levels of reflectivity and less ambient light.

Yager, Aquilante and Plass [42] analyzed high and low luminance letters, acuity reserve, and font effects on reading speed. They compared reading speed with two fonts, Dutch (serif) and Swiss (sans serif). Text was displayed on a computer monitor, white letters on black with the rapid serial visual presentation (RSVP) method. Luminance of letters was either 146.0 or 0.146 cd / m². Lower case x-height of the fonts (see Figure 22) was approximately 5.5 times as large as letter acuity. At the high luminance, there was no difference between reading rates. There was a significant advantage for Swiss font at low luminance. The acuity reserve (print size relative to acuity threshold) for the Swiss font was higher than for the Dutch font at the low luminance, which may account for the difference in reading speeds.
Figure 22: Traditionally, x-height is the height of the lowercase letter x. As a general rule, x-height is the height of the body of lowercase letters of a typeface, excluding the ascenders and descenders [39].

Garvey, Zineddin and Pietrucha [43] reported on letter legibility for signs and other large format applications. The authors stated that numerous studies evaluated the legibility of various fonts displayed in small print. There also had been a great deal of research into the legibility and recognition of standard highway sign alphabets. There had, however been no attempt to empirically determine large format distance legibility for the growing number of fonts currently available to non-transportation sign manufacturers. This study systematically evaluated the letter legibility of a set of fonts that are consistent with commercial (e.g. storefront), industrial, transit, and highway signage. The fonts were evaluated in a laboratory setting. Individual test charts were designed for each of the fonts based on the standard Snellen distance visual acuity chart. Recognition activity thresholds for each font yielded the minimum visual angle of letter height necessary for their resolution. The relative legibility of each font is discussed, as is the effect of font choice on sign size, and theoretical issues related to critical detail for letter recognition acuity. It is concluded that both Bank Gothic Light and Dutch Regular are found to be the most legible fonts followed by Dutch Bold. Commercial strips proved to be the most difficult to read. The Swiss Outline performed poorly. Moreover, the
findings reported in this paper indicate that stroke-width resolution alone did not determine letter acuity, even with simple letterforms.

Carlson [34], [35] conducted one of the most extensive studies on the evaluation of Clearview on freeway guide signs with microprismatic sheeting. The Clearview legibility results were compared to the legibility of freeway guide signs constructed with the series E (modified) alphabet. A total of 60 subjects divided into three age groups participated in this nighttime study. The findings indicated that the Clearview alphabet provides statistically longer legibility distances than the Series E (modified) alphabet. The largest differences were 74 ft (12%) for shoulder-mounted signs and 70 ft (11.9%) for overhead signs. Depending on speed, these improvements can provide a driver up to 0.7 extra seconds (on a 70 mph highway) to read freeway guide signs. In terms of subject age, the largest benefits of Clearview were associated with the older driver.

Zwahlen et al. [44] presented an extensive review of legibility relationships within the context of textual information presentation. They grouped the normalized data from several previous studies into sets, relating the visual angle (minutes of arc) to the width to the height (W/H) ratio, the intercharacter spacing to height ratio (S/H), and the stroke width to height ratio (SW/H), for both negative and positive contrasts. Second order polynomial least squares fits were established to obtain a proposed and tentative functional relationship between the visual angle and W/H, S/H, and SW/H. Overall, it was found that single characters / numerals or meaningful words (such as is typically found on traffic signs) were more legible than unrelated groups of characters / numerals.
(typically found on license plates). Further, the data indicated that positive contrast characters generally required smaller stroke width than negative contrast characters and that more widely spaced characters showed an increased legibility over closely spaced characters.
3 ANALYSIS OF THE CURRENT OHIO UNIVERSITY LEGIBILITY AND DETECTION ANALYSIS PROGRAM (LEGI)

The Ohio University Detection and Legibility Analysis Program LEGI is based on Blackwell’s 1946 study [4]. Only the legibility analysis algorithm is discussed here. Blackwell’s contrast threshold data are the most reliable available in legibility studies and consist of about 435,000 observations. Blackwell conducted his experiments using circular stimuli of various sizes ranging from 0.6 to 360 minutes in angular diameter. Since Blackwell’s data is based on the detection of the presence of the circular targets, Guth and McNelis in the late 1960s [5][6] conducted two consecutive studies in which the objective was to compare threshold data for circular targets with similar data for a variety of different objects. Based on their work, the stroke width is used instead of the target dimension to obtain the legibility threshold of a symbol or a letter based on Blackwell 1946 study [4].

LEGI does not consider the glare effect that may be caused by high luminance values (greater than 100 cd/m²).

For an alphanumerical legibility analysis, LEGI requires as input a subset of the observation conditions shown in Figure 23, which include background luminance (cd/m²), target luminance (cd/m²), target distance (m), observation time (s), observer age (years), Z score (for probability of correct responses), letter height (m), stroke width (m), stroke width to height ratio (SW/H), and a field factor to account for the change from ideal laboratory and observer conditions to real world conditions. Before the
alphanumerical legibility data input screen shown in Figure 23, there is an option to select the detection input screen or the legibility input screen.

![AlphaNumeral Legibility Data Input](image)

**Figure 23:** LEGI alphanumerical legibility analysis input window. This window is one of the two options of LEGI. The other option is the detection input window.

The LEGI output, shown in Figure 24, includes a summary of the input conditions, including those not specified but calculated based on the data given on input screen, plus visual angle (min), actual contrast, actual contrast ratio, actual modulation contrast, SW/H (included in the result section rather than the input section), field factor
(again included in the result section rather than in the input section), contrast threshold, and multiples of threshold contrast (MOT = Actual Contrast/Contrast Threshold). Finally, LEGI determines whether the target analyzed for the selected probability of correct recognition is legible or illegible (“Conclusion”). An MOT (Actual Contrast/Contrast Threshold) value of 1.00 represents the borderline between legible and illegible; a higher MOT (Actual Contrast/Contrast Threshold) value ($\geq 1.0$) would indicate a legible target. MOT (Actual Contrast/Contrast Threshold) values greater than 10 indicate that the legend is highly legible and all visual details are highly distinct. LEGI creates an output file, which can either be saved as data file (.dat) extension or a text file (.tx) extension.

<table>
<thead>
<tr>
<th>LEGI OUTPUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observation Condition:</td>
</tr>
<tr>
<td>Target Luminance : 3.840 [cd/m²]</td>
</tr>
<tr>
<td>Background Luminance : 1.100 [cd/m²]</td>
</tr>
<tr>
<td>Age : 25 [years]</td>
</tr>
<tr>
<td>Exposure time : 2.000 [sec]</td>
</tr>
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<td>ZScore : 1.645</td>
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<tr>
<td>Polarity : Positive</td>
</tr>
<tr>
<td>Target Distance (m) : 183.000 [m]</td>
</tr>
<tr>
<td>Font Height (m) : 0.304800 [m]</td>
</tr>
<tr>
<td>Stroke Width (m) : 0.076200 [m]</td>
</tr>
<tr>
<td>Result:</td>
</tr>
<tr>
<td>Visual Angle : 1.431455 [min]</td>
</tr>
<tr>
<td>Actual Contrast : 2.490909</td>
</tr>
<tr>
<td>Actual Contrast Ratio : 3.490909</td>
</tr>
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<td>Actual Modulation Contrast : 0.554656</td>
</tr>
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<td>Ratio of SW and H (SW/H) : 0.250000</td>
</tr>
<tr>
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</tr>
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<tr>
<td>Contrast Threshold : 4.608391</td>
</tr>
<tr>
<td>MOT (Contrast) : 0.540516</td>
</tr>
<tr>
<td>Conclusion : Illegible!</td>
</tr>
</tbody>
</table>

Figure 24: Sample LEGI Output for Illegible Condition.
3.1 An Example MOT Calculation by LEGI

Data in this example is adapted from a previous study conducted at nighttime by Zwahlen et al. [44]. Microprismatic Type III legend on Microprismatic Type III background sheeting materials are used to calculate MOT (Actual Contrast/Contrast Threshold) step by step to demonstrate how LEGI is used. The user inputs 10 variables to LEGI. Those variables and their values for this particular example are shown in Table 7.

<table>
<thead>
<tr>
<th>LEGI INPUT</th>
<th>VALUE FOR THE EXAMPLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Legend Luminance</td>
<td>3.84 cd/m²</td>
</tr>
<tr>
<td>Background Luminance</td>
<td>1.10 cd/m²</td>
</tr>
<tr>
<td>Target Distance</td>
<td>600 ft (183 m)</td>
</tr>
<tr>
<td>Observation Time</td>
<td>2 seconds</td>
</tr>
<tr>
<td>Observer’s age</td>
<td>25</td>
</tr>
<tr>
<td>ZScore = 1.645 (95%)</td>
<td>1.645 (95%)</td>
</tr>
<tr>
<td>Letter Height</td>
<td>12” (0.3048 m)</td>
</tr>
<tr>
<td>Stroke Width</td>
<td>3” (0.0762)</td>
</tr>
<tr>
<td>SW/H</td>
<td>0.25</td>
</tr>
<tr>
<td>Field Factor</td>
<td>4.5</td>
</tr>
</tbody>
</table>

The key formulas to understand LEGI output are:

\[
\text{Actual Contrast} = \frac{\text{Target Luminance} - \text{Background Luminance}}{\text{Background Luminance}}
\]

(3-1)

\[
\text{MOT (Contrast)} = \frac{\text{Actual Contrast}}{\text{Contrast Threshold}}
\]

(3-2)
3.2 Contrast Threshold Step by Step Calculation

Luminance contrast for traffic sign recognition is dependent upon many factors besides legend or symbol size and background luminance, including driver’s age, exposure time, duration, the fraction of correct responses and some other factors [49]. Poynter stated that “All the factors besides legend or symbol size and background luminance have independent and multiplicative effects” [27]. That is, the ratio of required luminance contrast “C” for traffic sign recognition and luminance contrast threshold “Cth” is equal to the product of appropriate contrast multiplier terms [49], or equivalently:

\[ C = C_{th} \cdot M_1 \cdot M_2 \ldots M_n \]  \hspace{1cm} (3-3)

There are five factors that are considered in LEGI. Equation (3-3) can be written as:

\[ C = C_{th} \cdot M_1 \cdot M_2 \cdot M_3 \cdot M_4 \cdot M_5 \]  \hspace{1cm} (3-4)

where, \( C \) = required luminance contrast

\( C_{th} = \) 50 percent threshold contrast;

\( M_1 = \) threshold percentage factor;

\( M_2 = \) field factor;

\( M_3 = \) presence versus discrimination factor;

\( M_4 = \) age factor;

\( M_5 = \) exposure time factor.
3.2.1 Visual Angle

The relationship among contrast threshold $C_{th}$, subtended visual angular target size (often referred as the visual angle) and background luminance is exhibited by Blackwell’s contrast threshold data. Given any two of the three variables, the third one can be determined by using Blackwell’s contrast threshold data [49]. In order to calculate visual angle (Figure 25) stroke width of the letter and the target distance is used. Letter height does not have any effect on visual angle calculations in LEGI.

![Figure 25: Visual angle (minutes) of stroke width.](image)

*Figure 25: Visual angle (minutes) of stroke width.*
Sanders and McCormick [1] presents a formula for computing the visual angle for angles less than about 10 degrees:

\[ VA \text{ (minutes)} = \frac{3438xH}{D} \]  \hspace{1cm} (3 - 5)

Where \( H \) is the height of a stimulus or detail (stroke width), and \( D \) is the distance from the eye to the target. It should be noted that \( H \) and \( D \) must be the same units, such as inches, feet, meters, millimeters, etc. The visual angle used in the legibility calculations using LEGI are usually in minutes.

For this particular example the stroke width is 0.0762 m and the distance from the eye is 183 m, visual angle is calculated to be 1.431 minutes.

### 3.2.2 Actual Contrast

Actual Contrast = \( \frac{\text{Target Luminance} - \text{Background Luminance}}{\text{Background Luminance}} \)  \hspace{1cm} (3 - 1)

For this particular example, the target luminance is 3.84 cd/m² and the background luminance is 1.10 cd/m² and the actual contrast is calculated to be:

Actual Contrast = \( \frac{(3.84 - 1.10)}{1.10} = 2.49 \)

### 3.2.3 Actual Contrast Ratio

\[ \text{MOT (Contrast)} = \frac{\text{Actual Contrast}}{\text{Contrast Threshold}} \]  \hspace{1cm} (3 - 2)

For this particular example, using the same values as above:

Actual Contrast Ratio = \( 3.84 / 1.10 = 3.49 \)
3.2.4 \( C_{th} \) (Luminance Contrast Threshold)
The study of the contrast threshold data from the middle of the last century. Gustav Theodor Fechner (1801-1887), who may be called the father of psychophysics, believed that the contrast threshold is constant except for very small or very large values of background luminance. Later work has shown that this is true only for stimuli of large angular subtense (>1°) and values of background luminance greater than about 10 cd/m\(^2\).

As stated before, the most extensive and elaborately organized research on contrast thresholds was conducted by Blackwell [4] and his associates spanning over a number of years. In Blackwell study [4], Contrast Thresholds were presented for stimuli brighter and darker than their background, and for two values of stimulus exposure. In each case, Blackwell [4] studied the effects of parameters such as stimulus contrast, stimulus area, and adaptation brightness for the determination of the contrast threshold of the normal human observer.

For this particular example;

Legend Luminance = 3.84 cd/m\(^2\)

Background Luminance = 1.10 cd/m\(^2\)

Since the legend luminance is higher than the background luminance, this is a positive contrast condition and Blackwell Part I data, which is presented in Table 1 should be used.
3.2.5 \( M_i = \text{threshold percentage factor (percentage of threshold / probability of correct responses for minimum size threshold conditions)} \)

The probability of detection of the test stimuli is represented with a curve referred as “average probability curve” by Blackwell [4]. Blackwell [4] found that a normal distribution describes this average probability curve fairly well. The average probability function can be used in determining the constant which will convert the contrast thresholds presented in Blackwell study [4] to “thresholds” corresponding to other levels of probability. Blackwell [13] changed this name to “accuracy curve”, in order to represent accuracy of seeing in a latter study. Within the context of the Xiaong study [49], this curve was referred as the percentage of threshold. Since Blackwell’s contrast threshold values, presented in Tables 1, 2, and 3 (reproduced from Blackwell study [4]), are based upon 50 percent of detection, they must be adjusted to represent different percentages of detection or threshold. The percentage of threshold curve illustrates, on a relative basis, how Blackwell’s contrast threshold data must be increased in order to obtain thresholds up to 100 percent. From Blackwell’s study [4] and Xiaong’s thesis [49], the percentage conversion factor is defined to be

\[
PF = 1 + 0.48 \times Z
\]  

(3-6)

where \( Z \) is the conversion factor. \( Z \) is referred as Zscore throughout this thesis.

In order to obtain detailed derivations of the conversion factor, one is referred to both the Blackwell study [4] and the Xiaong Ohio University Non-Thesis study [49].

In this particular case the \( Z \) score is assumed to be 1.645 (95%).

For \( Z \) being 1.645, \( PF \) is calculated to be 1.7896.

\[
PF = 1 + 0.48 \times Z = 1 + 0.48 \times 1.645 = 1.7896
\]
3.2.6 \( M_2 = \text{Field Factor} \)

The field factor was introduced and utilized by Blackwell in 1959 [13] to interpret the laboratory data for practical problems since the laboratory data were not directly applicable to field measurements. Under laboratory conditions, the observers were highly trained and motivated, knew where to look, when to look, which normally would lead to extraordinarily fine visual performance. No other mental load like in driving was required.

The Field Factor is assumed to be 4.5 in this particular example based on experimental field data. In order to find an appropriate field factor, a trial and error method might be utilized. Details about the calculation of this field factor in a particular case are presented in the Zwahlen, Russ and Vatan study [44].

3.2.7 \( M_3 = \text{Presence versus discrimination factor} \)

As stated before, Blackwell’s data [4] are for the detection of the presence of circular targets. Guth and Mc Nelis [5], [6] compared threshold data of circular target with similar data for a variety of different objects such as a Landolt Ring, a disc and parallel bars. The details of the calculation of the presence versus discrimination factor is discussed in [49]. It is assumed to be 0.518 in Xiaong’s thesis [49] and this value is built into LEGI and is not adjusted by the user.

This is the factor to differentiate between detection of the presence of a circular target and discrimination of a symbol or a letter on a traffic sign.
3.2.8 \( M_4 = \text{Age factor} \)

Driver age is another important factor in the legibility calculations. The observers in Blackwell’s experiment were drawn exclusively from a population so-called “normal young adult observers” in their twenties without any known ocular abnormality or visual impairment. Many studies had shown that age is a very important factor in legibility and it is the visual performance that is decreasing as the observer group average age increases. Based on Blackwell [13] data Zwahlen and Schnell [48] constructed a combined age-background luminance function to adjust the human contrast threshold more accurately in visibility and legibility calculations.

The combined age-luminance function is presented to be:

\[
F_{age} = 1 + 0.15 \times 10^{(-3.633 + 2.556 \times \log(\text{Age}) - 0.122 \times \log(L_b))} \quad (3-7)
\]

\[0.0034 \text{ cd/m}^2 \leq L_b \leq 1713 \text{ cd/m}^2\]

\[20 \text{ years} < \text{Age} < 65 \text{ years}\]

Where \( \text{Age} = \) years

\( L_b = \) Background Luminance in \( \text{cd/m}^2 \)

The observer age was assumed to be 25 years for the LEGI calculations in this particular example.
3.2.9 \( M_5 = \text{Exposure Time} \)

Exposure time is another factor that affects the contrast threshold. For shorter viewing or exposure time of the target, a higher threshold contrast is required.

The exposure time factor is calculated as follows [49].

\[-2 \text{ sec.} \leq \log(T) < -0.5 \text{ sec.}\]
\[F_{ET} = 1.074 + 1.5678 \log(T) + 3.8646 \log(T)^2 + 4.0336 \log(T)^3 + 2.0728 \log(T)^4\]

\[-0.5 \text{ sec.} \leq \log(T) < 1 \text{ sec.}\]
\[F_{ET} = 1.074 - 0.2778 \log(T) + 0.4526 \log(T)^2 - 0.3455 \log(T)^3 + 0.0972 \log(T)^4\]

\[\log(T) > 1 \text{ sec.}\]
\[F_{ET} = 1\]

where \( F_{ET} = \text{Exposure Time Factor} \)

\( T = \text{Observation Time (seconds)} \)

For the detailed derivation of the aforementioned exposure time factor, one should consult the Xiaong [49] study.

In this particular case, the exposure time (observation time) is assumed to be 2 seconds.

\[\text{Observation time} = 2 \text{ seconds, } \log(2) = 0.301.\]

When \(-0.5 \leq \log(T) < 1\)
\[F_{ET} = 1.074 - 0.2778 \log(2) + 0.4526 \log(2)^2 - 0.3455 \log(2)^3 + 0.0972 \log(2)^4\]
\[F_{ET} = 1.0227\]
4 METHODOLOGY

4.1 Analysis of Zwahlen and Badurdeen [8] research results

In the Zwahlen and Badurdeen [8] study, an optimal luminance for legibility performance at near minimum size threshold conditions, which is different for negative and positive contrast, was found. The fraction of correct responses and the optimal luminance values presented in this study is only valid for minimum size threshold conditions. If the legend size (landolt ring size) is increased, it will no longer be a problem to read the legend (tell the orientation of the gap of the presented landolt ring).

The fraction of correct responses for a white landolt ring on a black background (positive contrast) and a black landolt ring on a white background (negative contrast) are presented in Figure 26. Figure 26 is analyzed in considerable detail since most of the changes in the LEGI program are based on these results.
Figure 26: Average fraction of correct responses as a function of luminance levels for white and black landolt rings at near minimum size threshold conditions.

An analysis of the results obtained and shown in Figure 26 for the average fraction of correct responses at near minimum size threshold conditions reveals an initial increase in legibility performance as the luminance level is increased. The highest average fraction of correct responses for a white Landolt ring is observed at a luminance of 37.13 cd/m². Thereafter, the legibility performance gradually decreases as the luminance level is increased. The legibility performance with a black Landolt ring increases up to 134.78 cd/m² and than decreases at higher luminance levels. However, the legibility performance with a white Landolt ring is found to be higher than that of with a
black Landolt ring at all luminance levels (Figure 26). There is also much higher variation in the ability of subjects’ to identify a black Landolt ring than a white Landolt ring. The findings of the Zwahlen and Badurdeen [8] study also indicate that white text used against black background gives a higher legibility performance than black text used against a white background. The averages and standard deviations for each luminance level for positive and negative contrast are shown in Figure 26. The reason is that in case of negative contrast, the whole background is white and the screen is brighter, however, in case of positive contrast only the Landolt ring is white and bright. The De Boer Scale ratings show that at the same luminance level the subjects find negative contrast more disturbing than the positive contrast.

4.2 Correction Functions

According to curves shown in Figure 26, the optimum luminance level for positive contrast is 37.13 \text{ cd/m}^2, and the optimum level for negative contrast is 134.78 \text{ cd/m}^2.

When the current LEGI program is used with the given luminance levels (higher than 37.13 \text{ cd/m}^2 for positive contrast and higher than 134.78 \text{ cd/m}^2 for negative contrast), LEGI gives higher multiples of threshold values (MOT (Actual Contrast/Contrast Threshold)) for higher luminance levels. However, it has been proven by Zwahlen and Badurdeen [8] that after an optimal luminance value the fraction of correct responses decreases when the luminance increases.

Actual luminance values are plotted against adjusted (calculated) luminance values that when input to LEGI provide the fraction of correct responses and MOT
(Actual Contrast/Contrast Threshold) value at the given probability (Figure 27 is for positive contrast and Figure 28 is for negative contrast). The curve on each graph represents a quadratic fit to the data.

While constructing the function, the aim was to build a function so that the LEGI output will represent the actual fraction of correct responses for the given luminances. When the fraction of correct responses decreases, MOT (Actual Contrast/Contrast Threshold) values should also decrease to show that the legibility is decreasing.

Positive contrast and negative contrast are analyzed separately since they each have a different sets of fractions of correct responses In order to achieve the desired fraction of correct responses for four luminance values for positive contrast (37 cd/m$^2$ to 385 cd/m$^2$) and for three luminance values for negative contrast (134 cd/m$^2$ to 385 cd/m$^2$), the required luminance values are calculated by extensive experimentation with LEGI and LEGI_TS (Figure 27 for positive contrast and Figure 28 for negative contrast). In Figure 27 and Figure 28, required luminance values are referred as calculated luminance values.
4.2.1 Positive Contrast

![Graph showing positive contrast]

Figure 27: Main function for positive contrast to convert the actual legend luminance (data from Zwahlen and Badurdeen study [8] results), entered as a user input to LEGL, to the legend luminance that would, when entered to LEGL, calculate the correct MOT (Actual Contrast/Contrast Threshold) value for the given probability.
4.2.2 Negative Contrast

Figure 28: Main function for negative contrast to convert the actual background luminance (data from Zwahlen and Badurdeen study [8] results), entered as a user input to LEGI, to the background luminance that would, when entered to LEGI, calculate the correct MOT (Actual Contrast/Contrast Threshold) value for the given probability.
4.3 Validation of model

The LEGI software is modified according to the aforementioned model (Section 4.2) which is constructed based on the data from Zwahlen and Badurdeen [8] study results. In order to follow the scientific methodology, this model should be validated. One possible way to validate such a model is repeating the experiment conducted by Zwahlen and Badurdeen [8]. The experimental design and experimental procedure are repeated and the same experimental apparatus was used. All of the experimental conditions were kept exactly the same.

There are three main differences between the study conducted for validation and the original Zwahlen and Badurdeen study [8]. The first difference was in the subjects. The number of subjects was not changed; however, different people were used as subjects and the second difference is that the subjects were not paid for their participation in the validation experiments. The third difference was in the luminance levels. Three luminance levels were selected for both positive and negative contrast instead of six. Only luminance levels equal to or higher than the optimum luminance levels for both positive and negative contrasts were tested. The reason is that the LEGI software has only been modified for luminance values higher than the optimum luminance determined by the Zwahlen and Badurdeen [8] study.
4.4 Experimental Method

The laboratory experiments were conducted at the Human Factors and Ergonomics Laboratory in Room No 017 at the RTEC building at Ohio University. Institutional Review Board (IRB) approval is presented in Appendix A. A Joyce Display Monitor was placed on a table adjacent to a wall. A computer using windows based application software was used to drive the Joyce Monitor. The computer monitor was turned away from the subject. The subject was seated directly in front of and 11.88 m away from the Joyce Display. The settings and the site were the same as the Zwahlen and Badurdeen study [8].

4.4.1 Subjects

Ten subjects who were students at Ohio University were selected for the experiment. Five of the subjects were males (average age 25.2 years, standard deviation 1.94 years) and six were females (average age 26.6 years, standard deviation 2.07 years). All subjects had good visual acuity, with an average visual acuity of 20/21 vision (corrected or uncorrected, Table 10) and were healthy and under no medication. Subjects were not paid in the validation experimnents, however, they have been paid in Zwahlen and Badurdeen study.

The average age for Zwahlen and Badurdeen [8] study was 21.5 years and the average visual acuity was 20/21. Zwahlen and Badurdeen [8] study was conducted with five male and five female subjects.
4.4.2 Experimental Apparatus:

Experimental apparatus utilized in this study is the exact same set of apparatus that was used during Zwahlen and Badurdeen study [8].

A white (or black) Landolt ring on a black (or white) background presented on a Joyce Display Model (DM4) monitor was used as the target for determining legibility performance in this experiment. A Visual Stimulus Generator (VSG) software program from Cambridge Research Systems was used to drive the Joyce Display. The Landolt ring is shown in Figure 29 below. A stroke-width to diameter ratio \( \frac{a}{d_{\text{out}}} \) of 1:5 for the Landolt ring was maintained throughout the experiment. The gap was equal to the stroke width. A Windows application software program was developed to produce Landolt rings of specified dimensions and different gap orientations (opening up, down, left or right). The software was able to control the luminance of each pixel with an 8-bit resolution, providing 256 steps for the luminance level with zero being the minimum luminance of approximately 0 cd/m² and 255 being the maximum luminance of 385.58 cd/m².

Six luminance levels, ranging from \( L_{\text{min}} \) (5.56 cd/m²) to \( L_{\text{max}} \) (385.58 cd/m²) for both positive and negative contrasts were used in Zwahlen and Badurdeen [8] experiments. Since, the only concern of this thesis is the luminance values equal to or higher than the optimum luminance values, found in the previous study, only three luminance levels ranging from 25 cd/m² to 352 cd/m² for positive contrast and 120 cd/m² to 352 cd/m² for negative contrast, including the optimum luminance level for positive and negative contrast were selected.
4.4.3 Experimental Procedure

The experimental procedure explained in this section is the exact same procedure followed by the Zwahlen and Badurdeen [8] study.

Once the subject had completed the subject consent form and agreed to participate in the experiment, he/she was given the subject instruction form and the contents were explained in detail by the experimenter. At this stage, the visual acuity of the subject was tested using a Bausch and Lomb Vision Tester.
During the experiment the subject was seated so that the eyes were 11.88 m away from the achromatic screen of the display. The visual angle $\delta$ of the Landolt ring is defined by

$$ VA \text{ (minutes)} = \frac{3438xH}{D} \quad (4 - 1) $$

where $H$ is the height of a stimulus or detail (the outer diameter of the Landolt ring), and $D$ is the distance from the Joyce display screen and the eyes of the subject ($D = 11.88$ m).

It should be noted that $H$ and $D$ must be the same units, such as inches, feet, meters, millimeters, etc. The visual angle used in the legibility calculations are usually in minutes.

The visual angles of the screen (vertical and horizontal) are shown in Figure 30. All subjects were initially seated and allowed to adapt to the relatively dark illumination conditions in the laboratory for about 5 - 7 minutes.

Based on some initial presentations of Landolt rings at different visual angles, a value close to the threshold condition visual angle at the second lowest luminance level of 120.29 cd/m$^2$ was found for each subject. This was done by starting with a small Landolt ring size and increasing the size until the subject could properly identify the gap orientations at least 18 out of the 20 times. The diameter of the ring in pixels was set with the software. The number of pixels in the diameter was always set to be in multiples of 5, in order to ensure the 1:5 SW/H ratio. Once this threshold Landolt ring size was found for a subject, that size remained constant for all luminance levels for both positive and negative contrasts.
Figure 30: Horizontal and Vertical Visual Angles of the Joyce Display. Figure from Zwahlen and Badurdeen study [8] where \( \alpha_h \) = the horizontal visual angle and \( \alpha_v \) = the vertical visual angle.

In the Zwahlen and Badurdeen study [8], starting with a monitor setting of 67 (equal to 5.56 cd/m\(^2\)) and at the ring size corresponding to the visual angle found for each subject, the luminance was changed in 6 steps ranging from the minimum level (5.56 cd/m\(^2\)) to the maximum level (385.58 cd/m\(^2\)). These settings were tested under positive contrast and negative contrast. However, In the validation experiments only three luminance levels ranging from 25 cd/m\(^2\) to 352 cd/m\(^2\) for positive contrast and 120 cd/m\(^2\) to 352 cd/m\(^2\) for negative contrast, including the optimum luminance level for positive and negative contrast were selected. The different luminance levels and corresponding monitor settings are measured at the given points in Figure 31 and the measured
luminance values are shown in Table 8. The average luminance values for Zwahlen and Badurdeen study [8] and the validation experiment are summarized in Table 9.

**Table 8: Luminance measurements at different points on the Joyce monitor screen in cd/m² with 400 pixel landolt ring for validation experiment.**

<table>
<thead>
<tr>
<th>Luminance Level</th>
<th>Monitor Setting</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1 (positive)</td>
<td>100</td>
<td>25.52</td>
<td>32.81</td>
<td>25.52</td>
<td>21.87</td>
<td>18.23</td>
<td>24.79</td>
</tr>
<tr>
<td>L1 (negative)</td>
<td>145</td>
<td>120.29</td>
<td>127.58</td>
<td>123.94</td>
<td>116.65</td>
<td>113.00</td>
<td>120.29</td>
</tr>
<tr>
<td>L2 (positive and negative)</td>
<td>174</td>
<td>196.84</td>
<td>218.72</td>
<td>200.49</td>
<td>196.84</td>
<td>189.55</td>
<td>200.49</td>
</tr>
<tr>
<td>L3 (positive and negative)</td>
<td>255</td>
<td>349.95</td>
<td>379.11</td>
<td>353.59</td>
<td>342.65</td>
<td>335.36</td>
<td>352.13</td>
</tr>
</tbody>
</table>

Using photopic filter. Please note that using the scotopic filter the same values would have to be multiplied by approximately 3.426.

![Figure 31: Luminance measurements points for Table 8.](image)
Table 9: Monitor Settings for Luminance Levels.

a. Zwahlen and Badurdeen Study [8]

<table>
<thead>
<tr>
<th>Designator</th>
<th>Positive Contrast</th>
<th>Negative Contrast</th>
<th>Monitor Setting</th>
<th>Luminance Level* (cd/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>L₁</td>
<td>√</td>
<td>√</td>
<td>67</td>
<td>5.56</td>
</tr>
<tr>
<td>L₂</td>
<td>√</td>
<td>√</td>
<td>100</td>
<td>37.13</td>
</tr>
<tr>
<td>L₃</td>
<td>√</td>
<td>√</td>
<td>145</td>
<td>134.78</td>
</tr>
<tr>
<td>L₄</td>
<td>√</td>
<td>√</td>
<td>174</td>
<td>225.82</td>
</tr>
<tr>
<td>L₅</td>
<td>√</td>
<td>√</td>
<td>200</td>
<td>301.55</td>
</tr>
<tr>
<td>L₆</td>
<td>√</td>
<td>√</td>
<td>255</td>
<td>385.58</td>
</tr>
</tbody>
</table>

*b. Present study (Thesis)*

<table>
<thead>
<tr>
<th>Designator</th>
<th>Positive Contrast</th>
<th>Negative Contrast</th>
<th>Monitor Setting</th>
<th>Luminance Level* (cd/m²)**</th>
<th>Zwahlen and Badurdeen [8] study measurements</th>
</tr>
</thead>
<tbody>
<tr>
<td>L₁</td>
<td>√</td>
<td></td>
<td>100</td>
<td>24.79</td>
<td>37.13</td>
</tr>
<tr>
<td>L₂</td>
<td>√</td>
<td></td>
<td>174</td>
<td>200.49</td>
<td>225.82</td>
</tr>
<tr>
<td>L₃</td>
<td>√</td>
<td></td>
<td>255</td>
<td>352.13</td>
<td>385.58</td>
</tr>
<tr>
<td>L₁</td>
<td></td>
<td>√</td>
<td>145</td>
<td>120.29</td>
<td>134.78</td>
</tr>
<tr>
<td>L₂</td>
<td></td>
<td>√</td>
<td>174</td>
<td>200.49</td>
<td>225.82</td>
</tr>
<tr>
<td>L₃</td>
<td></td>
<td>√</td>
<td>255</td>
<td>352.13</td>
<td>385.58</td>
</tr>
</tbody>
</table>

* Measured using photopic filter. Please note that using the scotopic filter the same values would have to be multiplied by approximately 3.426.

** For calibration of validation experiments.
Therefore, in the Zwahlen and Badurdeen [8] study a total of twelve luminance level and contrast combinations and in the current study (validation experiments) six luminance level and contrast combinations were tested.

For both studies, the landolt rings were presented in a completely random manner. At each luminance level and contrast combination the Landolt ring gap orientations were presented in 20 trials. The gap orientations in these 20 trials were presented in a completely randomized manner. A black and white striped parallel bar was presented in between the Landolt ring displays while the experimenter made changes to the ring orientations. The Landolt ring was presented for approximately 3-5 seconds and the subject was asked to verbally identify the orientation of the ring gap. At each luminance level the experimenter recorded the number of true and false answers. After every five presentations of the Landolt ring the subject was asked to rate the perceived brightness of the Landolt ring/screen using a De Boer scale [52] ranging from 1 to 9 and also comment on whether they would have performed better if the brightness of the Landolt ring were higher or lower. A red LED light was used to help the subject read and answer these questions within the dark environment that was maintained in the laboratory.

After the completion of the experimental runs, the subject was requested to complete an exit questionnaire to find out how the subjects perceived the experiment and to record any discomfort, other problems or comments.
4.4.4 **Experimental Design**

*Independent variables:*

The independent variables used in this experiment are subjects (random factor with qualitative levels), luminance level (fixed factor with 3 quantitative levels), and type of contrast (fixed factor with two qualitative levels). The results of the pilot studies conducted in the Zwahlen and Badurdeen study [8] revealed no statistically significant difference between different replications. Therefore only one replication of the experimental runs was conducted both in the Zwahlen and Badurdeen study [8] and current study.

*Dependent variable:*

Legibility performance measured as the fractions of correct recognition of the orientation of the Landolt ring gap.

4.4.5 **Luminance measurement on Joyce Monitor**

After the experiments the luminance at different points on the Joyce Display monitor was measured at the points indicated in Figure 31, for each monitor setting given in Table 9. The measurements were made using a Spectra Pritchard Photometer (Model 1980A, Serial No: D2154) with an aperture size of 6 minutes of arc and using the photopic filter. Measurements were made at several points on the Landolt ring in the case of positive contrast.
4.4.6 **ANOVA Model & EMS Determination**

The ANOVA model that was tested in the experiment is as follows.

\[ Y_{ijklm} = \mu + S_i + L_j + SL_{ij} + C_k + SC_{ik} + LC_{jk} + SLC_{ijk} + E_{ijklm} \]

where,

- **S** – subjects
- **L** – luminance level
- **C** – contrast type

The hypotheses to be tested with this ANOVA model are,

\[ H_{01}: L_1 = L_2 = L_3 \quad \text{(mean legibility performance at different luminance levels not significantly different)} \]

\[ H_{11}: L_1 \neq L_2 \neq L_3 \quad \text{(mean legibility performance at different luminance levels are significantly different)} \]

\[ H_{02}: C_1 = C_2 \quad \text{(mean legibility performance under contrast types not significantly different)} \]

\[ H_{22}: C_1 \neq C_2 \quad \text{(mean legibility performance under contrast types are significantly different)} \]

In addition to these main effects any interaction effect between the different independent variables were tested.
4.4.7 **Experimental Results**

The experimental procedure described above was followed in conducting both the Zwahlen and Badurdeen [8] and the current set of the experiments using ten subjects, with a completely randomized design. For each of the subjects the threshold Landolt ring size was determined separately and this size was maintained throughout the experiment thereafter for that subject. The Landolt ring sizes used for each of the ten subjects and the summary of the fraction of correct responses obtained from the experiment is shown in Table 10.

The results on perceived brightness of the Landolt ring using the De Boer scale, and the subjects’ subjective judgment of whether they would have performed better if the brightness of the Landolt ring or white immediate background were higher or lower are summarized in Table 11 and Table 12, for positive and negative contrast, respectively. The De Boer scale used to assess the perceived brightness is shown in Table 13 and the results of the De Bore Scale assessments are presented in Table 14 (positive contrast) and Table 15 (negative contrast).

The average fraction of correct responses and standard deviation of correct responses as a function of the luminance levels for the white and the black Landolt ring are shown in Table 10. For the optimal luminance, Zwahlen and Badurdeen study [8] found the contrast as 73 and the validation experiments find the contrast to be 49 for positive contrast. For negative contrast, Zwahlen and Badurdeen study [8] found the contrast as 269 and validation experiments found the contrast to be 239.
Table 10: Fraction of correct responses at different luminance levels for positive contrast and negative contrast.

<table>
<thead>
<tr>
<th>Subject No</th>
<th>Age</th>
<th>Gender</th>
<th>Visual Acuity Far Vision</th>
<th>Landolt Ring Size</th>
<th>Legibility Index</th>
<th>Luminance Level (cd/m²)</th>
<th>Positive Contrast</th>
<th>Negative Contrast</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Pixels</td>
<td>mm</td>
<td>m/cm</td>
<td>ft/in</td>
<td>L1</td>
</tr>
<tr>
<td>1</td>
<td>30</td>
<td>F</td>
<td>20/17</td>
<td>40</td>
<td>16</td>
<td>7.425</td>
<td>61.87</td>
<td>0.95</td>
</tr>
<tr>
<td>2</td>
<td>26</td>
<td>F</td>
<td>20/25</td>
<td>60</td>
<td>23</td>
<td>5.165</td>
<td>43.04</td>
<td>0.95</td>
</tr>
<tr>
<td>3</td>
<td>25</td>
<td>M</td>
<td>20/22</td>
<td>45</td>
<td>17</td>
<td>6.988</td>
<td>58.23</td>
<td>0.9</td>
</tr>
<tr>
<td>4</td>
<td>23</td>
<td>F</td>
<td>20/22</td>
<td>40</td>
<td>16</td>
<td>7.425</td>
<td>61.87</td>
<td>0.9</td>
</tr>
<tr>
<td>5</td>
<td>29</td>
<td>M</td>
<td>20/18</td>
<td>30</td>
<td>12</td>
<td>9.9</td>
<td>82.5</td>
<td>1.00</td>
</tr>
<tr>
<td>6</td>
<td>28</td>
<td>F</td>
<td>20/20</td>
<td>50</td>
<td>19</td>
<td>6.253</td>
<td>52.10</td>
<td>0.85</td>
</tr>
<tr>
<td>7</td>
<td>24</td>
<td>M</td>
<td>20/20</td>
<td>30</td>
<td>12</td>
<td>9.9</td>
<td>82.5</td>
<td>0.95</td>
</tr>
<tr>
<td>8</td>
<td>26</td>
<td>F</td>
<td>20/2</td>
<td>35</td>
<td>14</td>
<td>8.486</td>
<td>70.71</td>
<td>1.00</td>
</tr>
<tr>
<td>9</td>
<td>24</td>
<td>M</td>
<td>20/22</td>
<td>35</td>
<td>14</td>
<td>8.486</td>
<td>70.71</td>
<td>0.85</td>
</tr>
<tr>
<td>10</td>
<td>24</td>
<td>M</td>
<td>20/17</td>
<td>35</td>
<td>14</td>
<td>8.486</td>
<td>70.71</td>
<td>1.00</td>
</tr>
<tr>
<td>Avg</td>
<td>25.9</td>
<td></td>
<td>20/20.3</td>
<td>40</td>
<td>16</td>
<td>7.85</td>
<td>65.42</td>
<td>0.94</td>
</tr>
<tr>
<td>St.D.</td>
<td>2.3</td>
<td></td>
<td>2.540</td>
<td>9.4</td>
<td>3.3</td>
<td>1.509</td>
<td>11.92</td>
<td>0.06</td>
</tr>
</tbody>
</table>
Table 11: Subjective judgment of brightness required to improve performance for positive contrast.

<table>
<thead>
<tr>
<th>Subject No</th>
<th>Brightness Perception for Positive Contrast</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L1 (24.79 cd/m²)</td>
</tr>
<tr>
<td>1</td>
<td>H   H   H   H   L   L   L   L   L   L   L   L</td>
</tr>
<tr>
<td>2</td>
<td>L   L   L   L   H   H   H   L   L   L   L   L</td>
</tr>
<tr>
<td>3</td>
<td>H   H   H   H   H   H   H   L   L   L   L   L</td>
</tr>
<tr>
<td>4</td>
<td>H   H   H   H   L   L   L   L   L   L   L   L</td>
</tr>
<tr>
<td>5</td>
<td>H   H   H   H   L   H   L   L   L   L   L   L</td>
</tr>
<tr>
<td>6</td>
<td>H   H   H   L   L   L   L   H   L   L   L   L</td>
</tr>
<tr>
<td>7</td>
<td>H   H   H   H   L   L   L   L   L   L   L   L</td>
</tr>
<tr>
<td>8</td>
<td>H   H   H   H   L   L   L   L   L   L   L   L</td>
</tr>
<tr>
<td>9</td>
<td>H   H   H   H   L   L   L   L   L   L   L   L</td>
</tr>
<tr>
<td>10</td>
<td>H   H   H   H   L   H   H   H   L   L   L   L</td>
</tr>
<tr>
<td>No. of H</td>
<td>9   9   9   8   2   4   2   3   0   0   0   1</td>
</tr>
<tr>
<td>Perc.</td>
<td>90% 90% 90% 80% 20% 40% 20% 30% 0% 0% 0% 10%</td>
</tr>
<tr>
<td>average</td>
<td>88% 28% 3%</td>
</tr>
</tbody>
</table>
Table 12: Subjective judgment of brightness required to improve performance for negative contrast.

<table>
<thead>
<tr>
<th>Subject No</th>
<th>Brightness Perception for Negative Contrast</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L1 (120.29 cd/m^2) L2 (200.49 cd/m^2) L3 (352.13 cd/m^2)</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>L L L L L L L L L L L L</td>
<td>8%</td>
</tr>
<tr>
<td>2</td>
<td>L L L L H H H H H H H H</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>L L L L L L L L L H H H H</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>L L H L L L L L L L L L L</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>L L L L L L H H H L L L L</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>H L L L L L L L L L L L</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>L L L L L L L L L L L L</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>L L L L L L L L L L L L</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>L L L L L L L L L L L L</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>L L H H L L L L L L L L</td>
<td></td>
</tr>
<tr>
<td>No. of H</td>
<td>1 0 2 0 1 2 2 3 2 1 2 2</td>
<td></td>
</tr>
<tr>
<td>Perc.</td>
<td>10% 0% 20% 0% 10% 20% 20% 30% 20% 10% 20% 20%</td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>8% 20% 18%</td>
<td></td>
</tr>
</tbody>
</table>
Table 13: Perceived brightness and corresponding De Boer performance scale ratings.

<table>
<thead>
<tr>
<th>Perceived Brightness</th>
<th>De Boer Scale Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unbearable</td>
<td>1</td>
</tr>
<tr>
<td>Disturbing</td>
<td>2</td>
</tr>
<tr>
<td>Just Acceptable</td>
<td>3</td>
</tr>
<tr>
<td>Satisfactory</td>
<td>4</td>
</tr>
<tr>
<td>Just Noticeable</td>
<td>5</td>
</tr>
</tbody>
</table>

Table 14: Brightness levels perceived by the subjects at different legend luminance levels for positive contrast rated using the De Boer scale.

<table>
<thead>
<tr>
<th>Subject No</th>
<th>L1 24.79 cd/m²</th>
<th>L2 200.49 cd/m²</th>
<th>L3 352.13 cd/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg</td>
<td>7.1</td>
<td>6.3</td>
<td>5.7</td>
</tr>
<tr>
<td>StDev</td>
<td>3.1</td>
<td>2.9</td>
<td>2.7</td>
</tr>
<tr>
<td>O. Avg</td>
<td>6.3</td>
<td>4.8</td>
<td></td>
</tr>
<tr>
<td>StDev</td>
<td>2.7</td>
<td>2.0</td>
<td>1.7</td>
</tr>
</tbody>
</table>
Table 15: Brightness levels perceived by the subjects at different background luminance levels for negative contrast rated using the De Boer scale.

<table>
<thead>
<tr>
<th>Subject No</th>
<th>Brightness Perception</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L1 120.29 cd/m^2</td>
</tr>
<tr>
<td>1</td>
<td>6 6 6 6 6</td>
</tr>
<tr>
<td>2</td>
<td>8 8 9 9 9</td>
</tr>
<tr>
<td>3</td>
<td>5 5 5 5 5</td>
</tr>
<tr>
<td>4</td>
<td>5 3 5 5 5</td>
</tr>
<tr>
<td>5</td>
<td>4 5 5 6 6</td>
</tr>
<tr>
<td>6</td>
<td>7 7 7 7 9</td>
</tr>
<tr>
<td>7</td>
<td>1 3 1 3 3</td>
</tr>
<tr>
<td>8</td>
<td>3 3 3 3 3</td>
</tr>
<tr>
<td>9</td>
<td>3 5 3 3 5</td>
</tr>
<tr>
<td>10</td>
<td>3 3 3 3 3</td>
</tr>
<tr>
<td>Avg.</td>
<td>4.5 4.8 4.7 5.4 4.4</td>
</tr>
<tr>
<td>StDev</td>
<td>2.3 1.9 2.3 2.1 1.8</td>
</tr>
<tr>
<td>O. Avg</td>
<td>4.9</td>
</tr>
<tr>
<td>StDev</td>
<td>2.1</td>
</tr>
</tbody>
</table>
The results of Zwahlen and Badurdeen [8] study have been discussed in previous chapters of this thesis in detail. Briefly, analysis of the results obtained for the average fraction of correct responses revealed an initial increase in legibility performance as the luminance level was increased. The highest average fraction of correct responses for positive contrast was observed at a luminance of 37.13 cd/m². Thereafter, legibility performance gradually decreased as the luminance level was increased. Legibility performance for negative contrast increased up to 134.78 cd/m² and decreased at higher luminance levels. However, the legibility performance with a white Landolt ring was found to be higher than that with a black Landolt ring at all luminance levels (Figure 26). There was also much higher variation in the ability of subjects to identify a black Landolt ring than to identify a white Landolt ring.

Current study results and Zwahlen and Badurdeen study [8] results are compared in Figure 32 and Figure 33. The results of this study simply proved that the conclusion reached by the Zwahlen and Badurdeen study [8] was valid. When it can be observed in Figure 32 that in most cases fraction of correct responses for both studies for both positive and negative contrast is either the same or very close, within ±0.3%. Further, as expected, it is again proved that legibility (fraction of correct responses) decreases as the luminance level increases above the optimum value for both positive and negative contrast. The author finds it worthwhile to mention that with a completely different set of subjects, obtaining results that are very close to each other is a pretty good way of validating the Zwahlen and Badurdeen [8] study results.
Figure 32: Comparison of predicted average fraction of correct responses for positive contrast based on the model and the data from present validation experiments.

Figure 33: Comparison of predicted average fraction of correct responses for negative contrast based on the model and the data from present validation experiments.
The comparison of percentage of “High” ratings (the percentage of subjects who rated that they would have performed better with a higher luminance level) at different luminance levels for Zwahlen and Badurdeen [8] study and the current study are presented in Figure 34 and Figure 35, for positive and negative contrast respectively. As can be seen in the figure, at lower luminance levels subjects felt they could have performed better if the luminance had been higher. However, at higher luminance levels, the subjects feel their performance could have been better if the luminance was lower. It should be noted that even though this is a very subjective way of testing the brightness levels, the results turned out to be comparable for both studies. The only exception is the optimal luminance level for negative contrast, where the current study percentage of “high” ratings is lower than Zwahlen and Badurdeen study [8]. Other than this particular case, the percentages are overlapping for the other two luminance levels for negative contrast and very close to each other for positive contrast.
Figure 34: Comparison of percentage of subjects feeling that they would have performed better if brightness would have been higher at different luminance levels for positive contrast for 2001 Fazleena and Badurdeen [8] study and the present study.

Figure 35: Comparison of percentage of subjects feeling that they would have performed better if brightness would have been higher at different luminance levels for negative contrast for 2001 Fazleena and Badurdeen [8] study and the present study.
The comparison of average De Boer scale ratings [52] of the subject’s perception of the brightness of the Landolt ring or background at different luminance levels in the Zwahlen and Badurdeen study [8] and in the current study is shown in Figure 36 and Figure 37, for positive and negative contrasts respectively. The subjects were required to rate their perception four times during the 20 presentations made at each luminance level and Landolt ring contrast combination. The overall average of the De Boer scale rating given at a particular luminance level is presented as the average. In both studies, the luminance of 37.13 cd/m² (24.79 cd/m² for this study) is found to be most “satisfactory” for positive contrast. This corresponds positively with the highest average fraction of correct responses obtained for positive contrast at this luminance level (Figure 32). As the luminance of the Landolt ring is increased, the brightness is perceived to be less than the “just acceptable” level. However, even the highest luminance level (385.58 cd/m² (352.13 cd/m² for this study) is not considered to be “disturbing” for positive contrast. The same variation could be observed when negative contrast was used except that none of the luminance levels were perceived to be “satisfactory”, but reaching the “just acceptable” level at 37.13 cd/m² (24.79 cd/m² in this study). As the luminance level is increased, subjects’ perception of the brightness decreases to reach below the “disturbing” level at 385.58 cd/m² (352.13 cd/m² for this study). From Figure 36 and Figure 37, it can be observed that, again, the results for both studies are either very close or exactly same for the given luminance levels.
Figure 36: Comparison of average De Boer scale ratings at different luminance levels for positive contrast for 2001 Zwahlen and Badurdeen [8] study and the present study.

Figure 37: Comparison of average De Boer scale ratings at different luminance levels for negative contrast for 2001 Zwahlen and Badurdeen [8] study and the present study.
Further, the summary of legibility indices is presented in Table 16. The legibility index is increased from 6.48 m/cm to 7.56 m/cm when compared to the Zwahlen and Badurdeen study [8]; however this is not a significant difference. When the combined average of this study and Zwahlen and Badurdeen study [8] is compared to the daytime legibility study [20], it is observed that daytime legibility index is almost twice as high as the nighttime legibility index.

Table 16: Legibility index comparison for the current study, Zwahlen and Badurdeen 2003 study [8] and Daytime legibility study [20].

<table>
<thead>
<tr>
<th></th>
<th>Legibility Index</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>m/cm</td>
</tr>
<tr>
<td>2001 Study (Zwahlen and Badurdeen Study [8])</td>
<td>6.48</td>
</tr>
<tr>
<td>2003 Study (Thesis)</td>
<td>7.56</td>
</tr>
<tr>
<td>Average 2001-2003</td>
<td>7.02</td>
</tr>
<tr>
<td>Daytime Legibility Study [20]</td>
<td>14.1</td>
</tr>
</tbody>
</table>
4.4.8 **ANOVA Results for Average Fraction of Correct Responses**

An Analysis of variance test was conducted on the data in order to identify any statistically significant relationships among the main factors and the interactions between them. For the complete model, the feasible F-test ratios were determined from EMS derivations and marked by arrows for the feasible F-tests. The EMS determination is presented in Table 17. Minitab was used to compute the mean squares used to determine the F ratios in the test. The results of the ANOVA are shown in Table 18.

The ANOVA results of both this study and Zwahlen and Badurdeen [8] show that there is a significant difference between the average fraction of correct responses obtained at different luminance levels at $\alpha = 0.05$ significance level. The p-value of 0.002 for the luminance level indicates that there appears to be a statistically significant difference between the average fraction of correct responses at the different luminance levels. This reinforces the observations that were made from the graphical presentations for average fraction of correct responses at different luminance levels. There appears to be a statistically significant difference ($p$ value = 0.027) between the average fraction of correct responses obtained with both positive and negative contrast.
Table 17: EMS derivations for luminance experiment with ten subjects.

<table>
<thead>
<tr>
<th>source</th>
<th>df</th>
<th>10</th>
<th>3</th>
<th>2</th>
<th>1</th>
<th>EMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Si</td>
<td>9</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>$6\phi_s + \sigma_e^2$</td>
</tr>
<tr>
<td>L_j</td>
<td>2</td>
<td>10</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>$20 \sigma_L^2 + 2 \sigma_{SL}^2 + \sigma_e^2$</td>
</tr>
<tr>
<td>C_k</td>
<td>1</td>
<td>10</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>$30 \sigma_C^2 + 3 \sigma_{SC}^2 + \sigma_e^2$</td>
</tr>
<tr>
<td>SL_{ij}</td>
<td>18</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>$2 \sigma_{SL}^2 + \sigma_e^2$</td>
</tr>
<tr>
<td>LC_{jk}</td>
<td>2</td>
<td>10</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>$10 \sigma_{LC}^2 + \sigma_{SLC}^2 + \sigma_{SC}^2 + \sigma_e^2$</td>
</tr>
<tr>
<td>SC_{ik}</td>
<td>9</td>
<td>1</td>
<td>3</td>
<td>0</td>
<td>1</td>
<td>$3 \sigma_{SC}^2 + \sigma_e^2$</td>
</tr>
<tr>
<td>SLC_{ijk}</td>
<td>18</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>$\sigma_{SLC}^2 + \sigma_e^2$</td>
</tr>
<tr>
<td>E_m(ijk)</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>$\sigma_e^2$</td>
</tr>
</tbody>
</table>

Note that arrows indicate only L_j and C_k can be tested.

Table 18: ANOVA table for the validation experiment.

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td>9</td>
<td>0.22437</td>
<td>0.02493</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>L</td>
<td>2</td>
<td>0.20475</td>
<td>0.10237</td>
<td>9.44</td>
<td>0.002</td>
</tr>
<tr>
<td>C</td>
<td>1</td>
<td>0.42504</td>
<td>0.42504</td>
<td>6.93</td>
<td>0.027</td>
</tr>
<tr>
<td>SL</td>
<td>18</td>
<td>0.19525</td>
<td>0.01084</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>LC</td>
<td>2</td>
<td>0.00008</td>
<td>0.00004</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>SC</td>
<td>9</td>
<td>0.55204</td>
<td>0.06133</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>SLC</td>
<td>18</td>
<td>0.10158</td>
<td>0.00564</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Error</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Total</td>
<td>119</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
4.5 Development of software

After the model was validated, the old version LEGI software was modified. The new software, entitled LEGI_TS, is programmed specifically for legibility analysis. Old LEGI was written in C programming language. The code for LEGI_TS is presented in Appendix B. Further, since LEGI is a part of LEGI_TS, the code of LEGI is also incorporated in LEGI_TS and presented in Appendix B.

LEGI_TS is programmed in Microsoft Visual C++ and developed in Microsoft Visual Studio. Everything explained previously in Section 3.2 of this thesis regarding LEGI is still valid in LEGI_TS and the code for LEGI_TS is very similar to that of LEGI. The user interface has been kept the same (Figure 23). The only difference from the previous software is described in the methodology (section 4) of this thesis.

The main differences between LEGI and LEGI_TS are shown in the flow chart presented in Figure 38. LEGI_TS checks the polarity (positive and negative contrast) as the first step. If legend luminance is higher than background luminance, LEGI_TS recognizes that this is a positive contrast; else it is a negative contrast. If the legend luminance level is lower than 37.13 cd/m² and higher than 0.5 cd/m² for positive contrast and the background luminance value is lower than 134.78 cd/m² and higher than 0.5 cd/m² for the negative contrast, the LEGI_TS runs exactly as LEGI. If the legend luminance is lower than 0.5 cd/m² or higher than 575 cd/m² for positive contrast; or if the background luminance is lower than 0.5 cd/m² or higher than 350 cd/m², LEGI_TS gives error and asks the user input the luminance values again, since LEGI_TS is designed to work only within the specified range.
Figure 38: Flowchart showing the relationship between the old version of LEGI and new LEGI_TS.
If the legend luminance value is higher than 37.13 cd/m² and lower than 575 cd/m² for positive contrast, or if the background luminance is higher than 134.78 cd/m² and lower than 350 cd/m², LEGI_TS runs the correction functions. This is the main difference between LEGI and LEGI_TS.

Correction functions are described in detail in the previous sections of this thesis. Briefly, the correction function for positive contrast is

\begin{equation}
  y = 0.0004L^2 - 0.268145L + 46.3240
\end{equation}

\[0.5 \text{ cd/m}^2 \leq L \leq 385 \text{ cd/m}^2\]

and the correction function for negative contrast is

\begin{equation}
  y = 0.0013L_b^2 - 1.0863L_b + 257.17
\end{equation}

\[0.5 \text{ cd/m}^2 \leq L_b \leq 385 \text{ cd/m}^2\]

where \(L\) is legend luminance, \(L_b\) is background luminance, and \(y\) is the adjusted luminance.

After the user input is processed, LEGI_TS computes and displays the output in a format very similar to old LEGI output, as shown in Figure 24.

The LEGI code is incorporated into LEGI_TS and the flow chart for existing LEGI is shown in Figure 39.
Figure 39: Flow chart for LEGI.
4.5.1 **How does LEGI_TS work?**

In order to calculate the correct fraction of correct responses for a given case, the criterion lines shown in Figure 40 and Figure 41 should be used. It is only possible to calculate the correct fraction of correct responses for the values that are already tested with the experiments. For positive contrast, the legend luminance should be between 35 cd/m² and 385 cd/m² and for the negative contrast the background luminance should be between 134 cd/m² and 385 cd/m² when either the background or the legend is near 0.5 cd/m² for near minimum size threshold conditions.

Trial and error method might be used to calculate the correct fraction of correct responses. One might keep all the input variables constant, but the probability (fraction of correct responses) and conduct experiments with LEGI_TS for a given set of conditions. The output of LEGI_TS is the MOT Contrast (Actual Contrast/Contrast Threshold) and MOT Contrast (Actual Contrast/Contrast Threshold) values are known for the conditions mentioned above. For the intervals mentioned above, one should change the probability (fraction of correct responses) and try to obtain the MOT Contrast (Actual Contrast/Contrast Threshold) value shown in Figure 40 (positive contrast) or Figure 41 (negative contrast).
Figure 40: MOT (Actual Contrast/Contrast Threshold) values for LEGI_TS and LEGI for actual fraction of correct responses for positive contrast.
Figure 41: MOT (Actual Contrast/Contrast Threshold) values for LEGI_TS and LEGI for actual fraction of correct responses for negative contrast.
5 DISCUSSION OF RESULTS

All the data utilized in this study were experimentally obtained and were measured at conditions that are very close to the near minimum size threshold conditions. The near minimum size threshold condition for legibility is at the point farthest from the traffic sign where a driver can read a character for the first time, and where the visual angle is smallest. However, as the driver approaches the sign and the visual angle increases, this initial threshold value does not apply any more. The optimum luminance values are valid only for near minimum size threshold legibility conditions.

LEG1_TS, like the old version of LEGI, is designed to be user-friendly and does not require a user manual. The input screen provides enough detail for the user to enter the necessary variables and the output screen is simple and easy to understand. The field factor determination is the only exception, since it might require further calculations and depend on specific conditions. LEG1_TS, unlike the older version, has built in error messages so that the user will not be able to enter incorrect luminance values.

LEG1_TS provides a wide variety of experimentation alternatives. Researchers might conduct experiments by keeping some of the LEG1_TS inputs constant and some of them variable. For this study, extensive experimentation was conducted with both LEGI and LEG1_TS.

It is expected that LEG1_TS will be very useful for traffic sign and legibility researchers analyzing new microprismatic traffic sign sheeting materials which may have very high luminance levels and contrasts at near threshold legibility conditions at the maximum legibility distance.
6 CONCLUSIONS

A model has been developed and the existing LEGI software has been modified (LEGI_TG: traffic sign) to handle legibility performance (in terms of fraction of correct responses) for high luminance and contrast conditions. (legend luminance >37 cd/m² (contrast 73) for positive contrast and background luminance >135 cd/m² (contrast 269) up to 385 cd/m² when either the background or the legend is near 0.5 cd/m²) near minimum size threshold conditions using Landolt rings.

The model has been validated by an independent laboratory experiment using 10 subjects for three selected high luminance and contrast conditions for positive and negative contrasts for near minimum size threshold conditions using Landolt rings and a good agreement between the predicted and the experimentally obtained legibility performance in terms of the fraction of correct responses has been found.

More experiments at different background and legend luminance levels are required to determine the fraction of correct responses when the background (positive contrast) or legend (negative contrast) luminance level is higher and not near 0.5 cd/m² or that dark (less contrast).
References


[8] Zwahlen, H., and Badurdeen, F., “Legibility Performance and Brightness Perception as a Function of Text or Background Luminance in Nighttime


Appendix A: Institutional Review Board Approval

The following research study has been approved by the Institutional Review Board at Ohio University for a period of one year. This review was conducted through an expedited review procedure as defined in the federal regulations as Category(ies):

Project Title: Legibility Performance as a Function of Text or Background Luminance in Nighttime Surrounds

Project Director: Sahika Vatan

Faculty Advisor (if applicable): Helmut Zwahlen

Department: IMSE

Rebecca G. Cale, Assoc. Director, Research Compliance
Institutional Review Board

5/12/03
Date
Appendix B: LEGI_TS Code
Source Files

INPUT_DIALOG.cpp
LEGI.cpp
LEGI_TS.cpp
LEGI_TS.rc
LEGI_TSDoc.cpp
LEGI_TSView.cpp
MainFrm.cpp
NRUTIL-1.cpp
StdAfx.cpp
INPUT_DIALOG.cpp
******************************************************************************
//Created by: Sahika Vatan
//Creation Date: June 2003
******************************************************************************
// INPUT_DIALOG.cpp : implementation file
//
#include "stdafx.h"
#include "LEG155.h"
#include "INPUT_DIALOG.h"
#ifdef _DEBUG
#define new DEBUGNEW
#undef THIS_FILE
static char THIS_FILE[] = __FILE__;
#endif

/******************************************************************************/
// INPUT_DIALOG dialog
INPUT_DIALOG::INPUT_DIALOG(CWnd* pParent /*=NULL*/)
: CDialog(INPUT_DIALOG::IDD, pParent)
{
    //{{AFX_DATA_INIT(INPUT_DIALOG)
    m_age = 0.0;
    m_ffactor = 0.0;
    m_h = 0.0;
    m_sw = 0.0;
    m_L = 0.0;
    m_Lb = 0.0;
    m_ratio = 0.0;
    m_t = 0.0;
    m_td = 0.0;
    m_zscore = 0.0;
    //}}AFX_DATA_INIT
}

void INPUT_DIALOG::DoDataExchange(CDataExchange* pDX)
{
    CDlgolong::DoDataExchange(pDX);
    //{{AFX_DATA_MAP(INPUT_DIALOG)
    DDX_Text(pDX, IDC_EDIT_age, m_age);
    DDX_Text(pDX, IDC_EDIT_ffactor, m_ffactor);
    DDX_Text(pDX, IDC_EDIT_h, m_h);
    DDX_Text(pDX, IDC_EDIT_sw, m_sw);
    DDX_Text(pDX, IDC_EDIT_L, m_L);
    DDX_Text(pDX, IDC_EDIT_Lb, m_Lb);
    DDX_Text(pDX, IDC_EDIT_ratio, m_ratio);
    //}}AFX_DATA_MAP
}
DDX_Text(pDX, IDC_EDIT_t, m_t);
DDX_Text(pDX, IDC_EDIT_td, m_td);
DDX_Text(pDX, IDC_EDIT_zscore, m_zscore);
//}}AFX_DATA_MAP

BEGIN_MESSAGE_MAP(INPUT_DIALOG, CDialog)
//{{AFX_MSG_MAP(INPUT_DIALOG)
//}}AFX_MSG_MAP
END_MESSAGE_MAP()

// INPUT_DIALOG message handlers
void INPUT_DIALOG::OnOK()
{
    // TODO: Add extra validation here
    UpdateData(TRUE);
    /*char k[10];
     sprintf(k,"%f",m_Lb);
     AfxMessageBox(k);*/
    if (!(0.5<m_Lb && (m_Lb<385)))
    {
        AfxMessageBox("Background Luminance should be between 0.5 and 385");
        return;
    }
    if (!(0.5<m_L && (m_L<385)))
    {
        AfxMessageBox("Target Luminance should be between 0.5 and 385");
        return;
    }
    ready=1;
    CDialog::OnOK();
}
void INPUT_DIALOG::OnCancel()
{
    // TODO: Add extra cleanup here
    ready=0;
    CDialog::OnCancel();
}
LEGI.cpp
******
/*Program description: This program computes the threshold contrasts using
---------- the three following basic methods:
/* 1). Precise 2D interpolation for original Blackwell 1946 data
/* 2). PCDETECT model as from TRR1213
/* 3). Adrian's model as from private correspondence with HTZ (BASIC Program)
/*
/* PCDETECT remains untouched. The Blackwell algorithm is used to determine the
/* following:
/* 1). Blackwell's data as from paper (1946) but using an exposure time factor
/* 2). Blackwell's data as from paper (1946) but using an exposure time factor
/*    age factor, and probability of detection conversion (50%-->any)
/*    This is used to obtain the detection contrast of a target
/* 2). Blackwell's data as from paper (1946) but using an exposure time factor
/* 3). Blackwell's data as from paper (1946) but using an exposure time factor
/*    age factor, legibility factor (0.518), and subject field factor (1.309)
/*    and probability of detection conversion (50%-->any)
/* This is used to obtain the legibility threshold of an average driver
/*
/*Author: (C) Tom Schnell, Ohio University, Department of ISE, Athens, OH
/*
/*Version: 1.1
/*
/*Date: 2-22-1994
/*Revision Date: 11-12-1995
/*Revises By: Xiaoyang Dong
******
#include "stdafx.h"
#include <windows.h>
#include <stdio.h>
#include <stdlib.h>
#include <math.h>
define NEGHOR 12 //array size
define NEGVER 12
#define POSHOR 7
#define POSVER 9
#define POSHORI 5
#define POSVERI 9
#define AGENUM 5
#define LUMNUM 7
#if defined __cplusplus
   // needed for the hunting season
   int mymax (int value1, int value2);
   int mymax(int value1, int value2)
   {
      return ( (value1 > value2) ? value1 : value2);
   }
   int mymin (int value1, int value2);
   int mymin(int value1, int value2)
   {
      return ( (value1 < value2) ? value1 : value2);
   }
#endif

// defined in nrutil-l.c
void nrerror(char error text[]);
double *vector(long nl, long nh);
double **convert_matrix(double *a, long nrl, long nrh, long ncl, long nch);
void free_vector(double *v, long nl, long nh);
void free_convert_matrix(double **b, long nrl, long nrh, long ncl, long nch);

/*****Global Variable******
extern HWND hwndEdit;      // text window handle
double **PositiveMatrixI;  // Blackwell data (1946) straight from paper, Part I
double **PositiveMatrix;   // Blackwell data (1946) straight from paper, Part III
double **NegativeMatrix;   // Blackwell data, smoothed by Shaolin
   // (Non-Thesis), Part II
double **AgeFactorMatrix;  // Age Factors as fct of Lb and Age
   // the statics are required because dynamically allocated arrays cannot be
   // initialized like that

double PositiveStatic[POSVER][POSHOR]=
   {{3.397,1.837,0.975,0.444,-0.239,-0.562,-0.866},
    {2.813,1.253,0.396,-0.094,-0.686,-0.967,-1.205},
    {2.179,0.622,-0.208,-0.614,-1.096,-1.324,-1.519},
    {1.246,-0.3,-1.041,-1.341,-1.666,-1.818,-1.959},
    {0.607,-0.924,-1.672,-1.914,-2.131,-2.212,-2.272},
    {0.196,-1.322,-2.051,-2.276,-2.428,-2.464,-2.478},
    {-0.06,-1.569,-2.241,-2.428,-2.538,-2.553,-2.558},
    {-0.248,-1.721,-2.328,-2.46,-2.547,-2.561,-2.566},
    {-0.383,-1.812,-2.339,-2.46,-2.547,-2.561,-2.566}};
double PositiveStatic[POSVERI][POSHORI] =
{
    {{2.821}, {1.95}, {1.467}, {0.666}, {0.238}},
    {{2.017}, {1.196}, {0.716}, {-0.069}, {-0.461}},
    {{1.41}, {0.615}, {0.137}, {-0.59}, {-0.91}},
    {{0.911}, {1.124}, {-0.325}, {-0.996}, {-1.198}},
    {{0.182}, {-0.326}, {-0.928}, {-1.5}, {-1.64}},
    {{-0.385}, {-1.07}, {-1.421}, {-1.857}, {-1.959}},
    {{-0.812}, {-1.437}, {-1.738}, {-2.02}, {-2.114}},
    {{-1.11}, {-1.658}, {-1.857}, {-2.06}, {-2.13}},
    {{-1.5}, {-1.73}, {-1.889}, {-2.062}, {-2.132}}
};

double NegativeStatic[NEGVER][NEGHOR] =
{
    {{3.083}, {2.283}, {1.683}, {1.083}, {0.278}, {-0.279}, {-0.750}, {-1.188}, {-1.438}, {-1.641}, {-1.798}, {-1.845},
     {2.750}, {1.953}, {1.351}, {0.751}, {-0.049}, {-0.580}, {-1.032}, {-1.431}, {-1.647}, {-1.824}, {-1.956}, {-1.996},
     {2.458}, {1.670}, {1.070}, {0.470}, {-0.333}, {-0.854}, {-1.265}, {-1.614}, {-1.832}, {-1.958}, {-2.066}, {-2.094},
     {2.160}, {1.391}, {0.789}, {0.187}, {-0.614}, {-1.107}, {-1.485}, {-1.772}, {-1.949}, {-2.065}, {-2.148}, {-2.171},
     {1.884}, {1.100}, {0.500}, {-0.102}, {-0.829}, {-1.293}, {-1.620}, {-1.868}, {-2.023}, {-2.117}, {-2.184}, {-2.201},
     {1.618}, {0.822}, {0.221}, {-0.378}, {-1.037}, {-1.465}, {-1.734}, {-1.936}, {-2.060}, {-2.148}, {-2.203}, {-2.218},
     {1.364}, {0.572}, {-0.033}, {-0.592}, {-1.195}, {-1.567}, {-1.798}, {-1.979}, {-2.082}, {-2.161}, {-2.212}, {-2.226},
     {1.117}, {0.339}, {-0.266}, {-0.784}, {-1.338}, {-1.646}, {-1.841}, {-2.007}, {-2.095}, {-2.168}, {-2.217}, {-2.229},
     {0.941}, {0.150}, {-0.439}, {-0.916}, {-1.427}, {-1.696}, {-1.866}, {-2.021}, {-2.104}, {-2.172}, {-2.219}, {-2.230},
     {0.785}, {-0.010}, {-0.581}, {-1.028}, {-1.496}, {-1.732}, {-1.883}, {-2.030}, {-2.109}, {-2.174}, {-2.220}, {-2.231},
     {0.661}, {-0.132}, {-0.691}, {-1.115}, {-1.543}, {-1.758}, {-1.899}, {-2.035}, {-2.112}, {-2.176}, {-2.221}, {-2.232},
     {0.553}, {-0.229}, {-0.780}, {-1.177}, {-1.580}, {-1.779}, {-1.914}, {-2.040}, {-2.113}, {-2.177}, {-2.222}, {-2.232}}
};

double AgeStatic[LUMNUM][AGENUM] =
{
    {{1}, {2.87}, {5.78}, {15.49}, {26.26}},
    {{1}, {3.41}, {5.55}, {14.08}, {23.79}},
    {{1}, {2.10}, {2.83}, {7.98}, {13.23}}
};
double AgeGroupStatic[AGENUM]={25,35,45,55,65};
double LumbStatic[LUMNUM]={0.00343,0.0343,0.343,3.43,34.3,343,1715};
//the vectors for the data labels matching the matrices (Blackwell 1946, and
//Shaolin)
double LgLsPositiveStaticI[POSVERI]=(-5.46518,-4.46518,-3.46518,
-2.46518,-1.46518,0.53482,1.53482,2.53482);
double LgAlphaPositiveStaticI[POSHORI]=[0.556303,0.985875,1.260071,
1.741939,2.082785];
double LgLsPositiveStatic[POSVER]=(-4.46518,-3.46518,-2.46518,
-1.46518,-0.46518,0.53482,1.53482,2.53482,3.53482);
double LgAlphaPositiveStatic[POSHOR]=[0.22548,0.556303,0.985875,
1.260071,1.741939,2.082785,2.556303];
double LgLsNegativeStatic[NEGVER]=
{-2,-1.5,-1,-0.5,0,0.5,1,1.5,2,2.5,3,3.5};
double LgAlphaNegativeStatic[NEGHOR]={-0.69897,-0.30103,0,0.30103,
0.69897,1,1.30103,1.698897,2,2.30103,2.69897,3};
//dynamically allocatable vectors (*) and matrices (**) such that the
//Lagrangian
//algorithm does not need to be programmed for both sizes
double *LglsNegative ;//Blackwell 1946, Part II
double *LglsPositive ;//Blackwell 1946, Part III
double *LgLsPositiveI ;//Blackwell 1946, Part I
double *LgAlphaNegative ;
double *LgAlphaPositive ;
double *LgAlphaPositiveI;
double *Lumb ;//Age Function Luminance Background Array
double *AgeGroup ;//from 156 normal observers
//----------> Log Alpha
//|
//|
//|
//V Log Lb
int CalculateSeeingDistance(double L, double alpha, double Age,
   double t, double ZScore,
   double pol);
void hunt(double *xx, int n, double x, int *jlo)
{
    //stolen from numerical recipes in C by Shalolin
    int jm, jhi, inc, ascnd;
    ascnd = (xx[n] > xx[1]);
    if (*jlo <= 0 || *jlo > n) {
        *jlo = 0;
        jhi = n + 1;
    } else {
        inc = 1;
        if (x >= xx[*jlo] == ascnd) {
            if (*jlo == n) return;
            jhi = (*jlo) + 1;
            while (x >= xx[jhi] == ascnd) {
                *jlo = jhi;
                inc += inc;
                jhi = (*jlo) + inc;
                if (jhi > n) {
                    jhi = n + 1;
                    break;
                }
            }
        }
    }
    jhi = (*jlo);
    *jlo = 1;
    while (x < xx[*jlo] == ascnd) {
        jhi = (*jlo);
        inc += inc;
        *jlo = jhi - inc;
        if (*jlo < 1) {
            *jlo = 0;
            break;
        }
    }
    while (jhi - (*jlo) != 1) {
        jm = (jhi + (*jlo)) >> 1;
        if (x > xx[jm] == ascnd) *jlo = jm;
    } else
\[ jhi=jm; \]

```c
void polint(double xa[], double ya[], int n, double x, double *y, double *dy)
    //Given arrays xa[1...n] and ya[1...n], and given a value x, this routine
    //returns value y, and an error estimate dy. If P(x) is the polynomial of
    //degree N-1 such that P(xai)=ya_i, i=1,...,n, then the returned value y=P(x).
{
    //stolen from from numerical recipes in C
    //this is the Lagrangian interpol. algorithm
    int i, m, ns = 1;
    double den, dif, dift, ho, hp, w;
    double *c, *d;
    dif = fabs(x-xa[1]);
    c = vector(1, n);
    d = vector(1, n);
    for (i = 1; i <= n; i++) {
        if ( (dift = fabs(x-xa[i])) < dif ) {
            ns = i;
            dif = dift;
        }
        c[i] = ya[i];
        d[i] = ya[i];
    }
    *y = ya[ns--];
    for (m = 1; m <= n; m++) {
        for (i = 1; i <= n - m; i++) {
            ho = xa[i] - x;
            hp = xa[i+m] - x;
            w = c[i+1] - d[i];
            if ( (den = ho-hp) == 0.0 ) nrerror("Error in routine POLINT");
            den = w / den;
            d[i] = hp * den;
            c[i] = ho * den;
        }
        *y += (*dy = (2*ns < (n-m) ? c[ns+1] : d[ns-1]));
    }
    free_vector(d, 1, n);
    free_vector(c, 1, n);
}
```

```c
double polin2(double *x1a, double *x2a, double **ya, int m, int n,
    double x1, double x2, int order)
    //Given arrays x1a[1...m] and x2a[1...n] of independent variables, and a
    //submatrix of function values ya[1...m][1...n], tabulated at the grid points
    //defined by x1a and x2a; and given values values x1 and x2 of
```
//the independent variables; this routine returns an interpolated function
//value y, and an accuracy indication by(based only on the interpolation in
//the x1 direction,however)
} //stolen from from numerical recipes in C  //for 2D
int k,j,kk,ll;
int jj,mm;
double *ymtmp;
double yy, dy;
hunt(x1a,m,x1,&ll);
mm = mymin(mymax(ll-(order-1)/2,1),m+1-order);
hunt(x2a,n,x2,&jj);
kk = mymin(mymax(jj-(order-1)/2,1),n+1-order);
ymtmp=vector(1,order);
// ytmp=vector(1,m);
m=n=order;
for (j=1;j<=m;j++) {
    // polint(x2a,ya[j],n,x2,&ymtmp[j],&dy);
polint(&x2a[kk-1],&ya[j]+mm-1][kk-1],order,x2,&ymtmp[j],&dy);
    // polint(&x1a[mm-1],ymtmp,order,x1,&yy,&dy);
    polint(x1a,ymtmp,m,x1,&yy,&dy);
    free_vector(ymtmp,l,m);
}
return yy;
}
double CthBwell(double L, double alpha, double Age, double time,
double ZScore, double pol)

/***********************************************************/
*****/

/*Module description: */
/*----------------------*/
/*Blackwell's data (1946) for DETECTION, average subjects. The exposure */
/*time */
/*factor and the age factor and the prob.mult. have been taken from Shaolin */
/*Creation Date: 2-22-1994 */
/**************************************************************/
*****/
{
double Cth ; //Computed threshold contrast
int UpCr=0 ; //Crossed threshold from visible
int DnCr=1 ; //Crossed threshold from invisible
double Fage ; // Age factor according to Blackwell
double Fet ; //Exposure time factor
double kl ;
double Lgk;
double ProbMult; //Probability Factor
ProbMult = (1 + 0.48*ZScore); //see Shaolin's Thesis
Fage = 1 + 0.15*\(10^{-3.633+2.556*\log_{10}(Age)-0.122*\log_{10}(L)}\) ;
if ((\log_{10}(time) \geq -2) \&\& (\log_{10}(time) \leq -0.5))
    {Fet = 1.074 + 0.5678*\log_{10}(time)+3.8646*\log_{10}(time),2)+
        4.0336*\log_{10}(time),3)+2.0728*\log_{10}(time),4);}
else if ((\log_{10}(time) > -0.5) \&\& (\log_{10}(time) \leq 1))
    {Fet = 1.074-0.2778*\log_{10}(time)+0.4526*\log_{10}(time),2)-
        0.3455*\log_{10}(time),3)+0.0972*\log_{10}(time),4);}
else
    {Fet = 1;}
if (pol > 0)
    {
        Lgk = \log_{10}(Fage*ProbMult*10*Fet); //accounts for average subjects
        //legibility and exposure time
        Cth = polin2(LgLsPositive,LgAlphaPositive,
                      PositiveMatrix,POSVER,POSHOR,
                      \log_{10}(L),
                      \log_{10}(alpha),4)+Lgk;
    }
else
    {
        Lgk = \log_{10}(10*Fage*ProbMult*Fet); //accounts for average subjects
        //legibility and exposure time
        Cth = polin2(LgLsNegative,LgAlphaNegative,
                      NegativeMatrix,NEGVER,NEGHOR,
                      \log_{10}(L),
                      \log_{10}(alpha),4)+Lgk;
    }
Cth = pow(10,Cth); //Transform back to norm //units
//Now we can compare whether the target is still visible return Cth;
}
**Module description:**

Blackwell's data (1946) for legibility with well trained subjects. The exposure time factor and the age factor and the prob. mult. have been taken from Shaolin.

Creation Date: 05-4-1993

```c
{ 
    double Cth;       //Computed threshold contrast
    int UpCr=0;       //Crossed threshold from visible
    int DnCr=1;       //Crossed threshold from invisible
    double Fage;     //Age factor according to Blackwell
    double Fet;      //Exposure time factor
    double k1;
    double Lgk;
    double ProbMult;  //Probability Factor
    ProbMult = (1 + 0.48*ZScore);    //see Shaolin's Thesis
    Fage = 1+0.15*pow(10,-3.633+2.556*log10(Age)-0.122*log10(L));
    if ((log10(time) >= -2) && (log10(time) <= -0.5))
    {
        Fet = 1.074+0.5678*log10(time)+3.8646*pow(log10(time),2)+
             4.0336*pow(log10(time),3)+2.0728*pow(log10(time),4);
    }
    else if ((log10(time) > -0.5) && (log10(time) <= 1))
    {
        Fet = 1.074-0.2778*log10(time)+0.4526*pow(log10(time),2)-
             0.3455*pow(log10(time),3)+0.0972*pow(log10(time),4);
    }
    else
    {Fet = 1;}
    if (pol > 0)
    {
        Lgk = log10(Fage*ProbMult*2.307*Fet);
        //accounts for average subjects
        //legibility and exposure time
        Cth = polin2(LgLsPositive,LgAlphaPositive,
                     PositiveMatrix,POSVER,POSHOR,
                     log10(L),
                     log10(alpha),4)+Lgk;
    }
}
else
{
    Lgk = log10(0.306*Fage*ProbMult*Fet);
    //accounts for average subjects
    //legibility and exposure time
    Cth = polin2(LgLsNegative,LgAlphaNegative,
        NegativeMatrix,NEGVER,NEGHOR,
        log10(L),
        log10(alpha),4)+Lgk;
}
Cth = pow(10,Cth);       //Transform back to norm
                        //units
//Now we can compare whether the target is still visible
return Cth;
/*end Blackwell*/

int DetermineSeeingDistance(double Lb, double alpha, double Age,
    double t, double ZScore,
    double L)

{   //Computed threshold contrast
    double Cth;
    double pol;
    FILE *ad,*adad,*pc,*bw,*bwad,*bwleg,*lg,*bwI;
    char szBuffer[200],lpBuffer[2000];
    if(L>Lb)pol=1;
    else pol=-1;
    if ((bwleg = fopen("bwellleg.dat","a")) == NULL)
    {printf("Cannot open Bwellleg.dat
");return -1;}
    if((bw = fopen("bwell.dat","a")) == NULL)
    {printf("Cannot open bwell.dat
");return -1;}
    Cth = CthBwell(Lb, alpha, Age, t,ZScore, pol);
    sprintf(szBuffer,"Observation Condition:
        Luminance		:	%5.2fl[cd/mA2]
        `,L);
    strcpy(lpBuffer,szBuffer);
    sprintf(szBuffer,"\tObservation Condition:\r\n\n",L);
    strcpy(lpBuffer,szBuffer);
    sprintf(szBuffer,"\tObservation Condition:\r\n\n",L);
    strcpy(lpBuffer,szBuffer);
strcat(lpBuffer,szBuffer);
sprintf(szBuffer,"Background Luminance \t \%5.2f [cd/m^2]\n",Lb);
strcat(lpBuffer,szBuffer);
sprintf(szBuffer,"Visual Angle (Alpha) \t \%5.2f [min]\n",alpha);
strcat(lpBuffer,szBuffer);
sprintf(szBuffer,"Age \t \%3.0f [years]\n",Age);
strcat(lpBuffer,szBuffer);
sprintf(szBuffer,"Exposure time \t \%5.2f [sec]\n",t);
strcat(lpBuffer,szBuffer);
sprintf(szBuffer,"ZScore \t \%5.2f\n",ZScore);
strcat(lpBuffer,szBuffer);
sprintf(szBuffer,"Polarity \t \%2.0f\n",pol);
strcat(lpBuffer,szBuffer);

Result:'

Blackwell straight, neg=Shaolin, pos=partIII\n
Blackwell adjusted for Legibility and Average Observers

Cth = CthBwellLeg(Lb, alpha, Age, t,ZScore,pol);
sprintf(szBuffer,"\n\nBlackwell adjusted for Landolt Ring (Average Observers)\n\n(FPpos=3.147, FPneg=0.43915615, neg=Shaolin, pos=partIII)\n\nContrast Threshold \t \%5.2f\nM, Cth\n\nActual Contrast \t \%5.2f\n(L-Lb)/Lb\n\nConclusion\t\%5.2f\nCth\n\nIllegible!\n\n\nif(fabs(L-Lb)/Lb<Cth)
{
  printf(szBuffer,"Illegible!\n\n", (L-Lb)/Lb);
  strcat(lpBuffer,szBuffer);
}
else
{ 
    sprintf(szBuffer,"Legible!\r\n", (L-Lb)/Lb);
    strcat(lpBuffer,szBuffer);
}
fprintf(bwleg,"Blackwell adjusted for Landholt Ring
FFpos=3.147, FFneg=0.43915615, neg=Shaolin, pos=partIII \"");
fprintf(bwleg,"Lb [cd/m^2] \t %f\t" , L);
fprintf(bwleg,"Alpha [min] \t %f\t", alpha);
fprintf(bwleg,"Age [years]\t %f\t", Age);
fprintf(bwleg,"Exposure time [sec]\t%f\t", t);
fprintf(bwleg,"ZScore \t %f\t", ZScore);
fprintf(bwleg,"Polarity \t %f\t", pol);
fprintf(bwleg,"Cth= \t %f\n", Cth);
//Blackwell adjusted for legibility and super observers
/*/ 
Cth = CthBwellLeg(L, alpha, Age, t, ZScore, pol);
fprintf(bw,"Blackwell Legibility FF=0.518, neg=Shaolin, Neg=partIII \"");
fprintf(bw,"Lb [cd/m^2] \t %f\t" , L);
fprintf(bw,"Alpha [min] \t %f\t", alpha);
fprintf(bw,"Age [years]\t %f\t", Age);
fprintf(bw,"Exposure time [sec]\t%f\t", t);
fprintf(bw,"ZScore \t %f\t", ZScore);
fprintf(bw,"Polarity \t %f\t", pol);
fprintf(bw,"Cth= \t %f\n", Cth);
sprintf(szBuffer,"Blackwell Legibility FF=0.518, neg=Shaolin, Neg=partIII\r\n");
strcat(lpBuffer,szBuffer);
sprintf(szBuffer,"Cth= \t %5.2f\r\n", Cth);
strcat(lpBuffer,szBuffer);
/*/ 
fclose(bw);
fclose(bwleg);
//SetWindowText(hwndEdit,lpBuffer);
return 1; /* success */
}

/*end Determine Seeing Distance */

/*******************************************************
/*Main CalculateSeeingDistance description: */
/*The main function grabs the commandline parameters (usually called from */
/*a batch program. The three blackwell models, the Adrian, and PCDETECT  */
/*model are then called and the Cth is written to corresponding files. */
/*A number of functions for which the credit goes to Numerical Recipes */
/*have been used. */
/*Creation Date: 2-22-1994 */


int CalculateSeeingDistance(double Lb, double alpha, double Age, double t, double ZScore, double L) {
    int status,i ; //array index pointer
    double pol ; //contrast polarity
    double alpha ; //Actual visual angle
    double Lb ; //Background Luminance
    double Age ; //Observer age between 20 and 70
    double t ; //Observation time
    char answer[1] ;
    double ZScore ;
    double Cth ;
    char szBuffer[140],lpBuffer[2000];
    LgLSPositive =vector(1,POSVER); //dynamically allocate room for
    LgLSPositiveI =vector(1,POSHOR); //dynamically allocate room for
    LgAlphaPositive=vector(1,POSHOR); //the Blackwell matrices and vectors
    LgAlphaPositive=vector(1,POSHOR); //the Blackwell matrices and vectors
    LgLsNegative =vector(1,NEGVER);
    LgAlphaNegative =vector(1,NEGHOR);
    // Lumb =vector(1,LUMNUM); //Age Function Luminance
    //Background Array
    // AgeGroup =vector(1,AGENUM); //from 156 normal observers
    //transfer the static Blackwell matrices into the dynamic matrices
    PositiveMatrix=convert_matrix(&PositiveStatic[0][0],POSVER,1,POSHOR);
    PositiveMatrixI=convert_matrix(&PositiveStaticI[0][0],1,POSHORI,1,POSHORI);
    NegativeMatrix=convert_matrix(&NegativeStatic[0][0],NEGVER,1,NEGHOR,1,NEGHOR);
    // AgeFactorMatrix=convert_matrix(&AgeStatic[0][0],1,LUMNUM,1,AGENUM);
    for (i=1;i<=POSVER;i++)
        LgLsPositive[i] = LgLSPositiveStatic[i-1];
    for (i=1;i<=POSVERI;i++)
        LgLSPositiveI[i] = LgLSPositiveStaticI[i-1];
    for (i=1;i<=NEGVER;i++)
        LgLsNegative[i] = LgLsNegativeStatic[i-1];
    for (i=1;i<=POSHOR;i++)
        LgAlphaPositive[i] = LgAlphaPositiveStatic[i-1];
    for (i=1;i<=POSHORI;i++)
        LgAlphaPositiveI[i] = LgAlphaPositiveStaticI[i-1];
    for (i=1;i<=NEGHOR;i++)
        LgAlphaNegative[i] = LgAlphaNegativeStatic[i-1];
// for (i=1;i<=AGENUM;i++)
// AgeGroup[i] = AgeGroupStatic[i-1];
// for (i=1;i<=LUMNUM;i++)
// Lumb[i] = LumbStatic[i-1];

 /*
  if (argc != 7)
  {
    printf("Usage : CONBAT <Lb [cd/sq m]>\n, Visual Angle [min"]);
    printf("<observer age [years]> <Obs. time [s]>\n");
    printf("<ZScore> \n <Contrast Polarity> [1/-1]");
  }
  else
  {
    Lb = atof(*++argv);
    alpha = atof(*++argv);
    Age = atof(*++argv);
    t = atof(*++argv);
    ZScore = atof(*++argv);
    pol = atof(*++argv);
    printf("lb %f\n",Lb);
    printf("lb %f\n",alpha);
    printf("age %f\n",Age);
    printf("time %f\n",t);
    printf("ZScore %f\n",ZScore);
    printf("polarity %f\n",pol);
    status = DetermineSeeingDistance(Lb,alpha,Age, t,ZScore, pol);
  }
  */
  status = DetermineSeeingDistance(Lb,alpha,Age, t,ZScore, L);
  free_vector(LgLsPositive,1,POSVER);
  free_vector(LgLsPositive1,1,POSVER1);
  free_vector(LgAlphaPositive,1,POSHOR);
  free_vector(LgAlphaPositive1,1,POSHOR1);
  free_vector(LgLsNegative,1,NEGVER);
  free_vector(LgAlphaNegative,1,NEGHOR);
  // free_vector(Lumb,1,LUMNUM);
  // free_vector(AgeGroup,1,AGENUM);
  // free_convert_matrix(PositiveMatrix,1,POSVER,1,POSHOR);
  // free_convert_matrix(PositiveMatrix1,1,POSSVERI,1,POSHORI);
  // free_convert_matrix(NegativeMatrix,1,NEGVER,1,NEGHOR);
  // free_convert_matrix(AgeFactorMatrix,1,LUMNUM,1,AGENUM);*/
  return 0;

/*end main*/
void init()
{
    char answer[1] ;
    int i;
    double Cth ;
    char szBuffer[140], lpBuffer[2000];
    LgLsPositive = vector(1, POSVER); // dynamically allocate room for
    LgLsPositiveI = vector(1, POSVER); // dynamically allocate room for
    LgAlphaPositiveI = vector(1, POSHOR); // the Blackwell matrices and vectors
    LgAlphaPositive = vector(1, POSHOR); // the Blackwell matrices and vectors
    LgLsNegative = vector(1, NEGVER);
    LgAlphaNegative = vector(1, NEGHER);
    // transfer the static Blackwell matrices into the dynamic matrices
    PositiveMatrix = convert_matrix(&PositiveStatic[0][0], POSVER, POSHER);
    PositiveMatrixI = convert_matrix(&PositiveStaticI[0][0], POSVERI, POSHERI);
    NegativeMatrix = convert_matrix(&NegativeStatic[0][0], NEGVER, NEGHER);
    for (i=1;i<=POSVER;i++)
        LgLsPositive[i] = LgLsPositiveStatic[i-1];
    for (i=1;i<=POSVERI;i++)
        LgLsPositiveI[i] = LgLsPositiveStaticI[i-1];
    for (i=1;i<=NEGVER;i++)
        LgLsNegative[i] = LgLsNegativeStatic[i-1];
    for (i=1;i<=POSHOR;i++)
        LgAlphaPositive[i] = LgAlphaPositiveStatic[i-1];
    for (i=1;i<=POSHORI;i++)
        LgAlphaPositiveI[i] = LgAlphaPositiveStaticI[i-1];
    for (i=1;i<=NEGHOR;i++)
        LgAlphaNegative[i] = LgAlphaNegativeStatic[i-1];
}

double CthBwellLegSah(double L, double alpha, double Age, double time,
                       double ZScore, double pol, double ffactor)
{ /*Module description: */
    /*Blackwell's data (1946) for legibility with well trained subjects. */
    /*The exposure time */
    /*factor and the age factor and the prob.mult. have been taken from Shaolin */
    /*Creation Date: */
    
    double Cth ; // Computed threshold contrast
    int UpCr=0 ; // Crossed threshold from visible
int DnCr=1; //Crossed threshold from invisible
double Fage;  //Age factor according to Blackwell
double Fet;  //Exposure time factor
double k1;
double Lgk;
double ProbMult;  //Probability Factor
ProbMult = (1 + 0.48*ZScore); //see Shaolin's Thesis
Fage = 1+0.15*pow(10,-3.633+2.556*log10(Age)-0.122*log10(L));
if ((log10(time) >= -2) && (log10(time) <=-0.5))
{
Fet = 1.074+0.5678*log10(time)+3.8646*pow(log10(time),2)+
4.0336*pow(log10(time),3)+2.0728*pow(log10(time),4);
}
else if (((log10(time) > -0.5) && (log10(time) <=1))
{
Fet = 1.074-0.2778*log10(time)+0.4526*pow(log10(time),2)-
0.3455*pow(log10(time),3)+0.0972*pow(log10(time),4);
}
else
{Fet = 1;}
if (pol > 0)
{
Lgk = log10(Fage*ProbMult*ffactor*Fet);
    //accounts for average subjects
    //legibility and exposure time
Cth = polin2(LglsPositive,LgAlphaPositive,
PositiveMatrix,POSVER,POSHOR,
log10(L),
log10(alpha),4)+Lgk;
}
else
{
Lgk = log10(ffactor*Fage*ProbMult*Fet);
    //accounts for average subjects
    //legibility and exposure time
Cth = polin2(LglsNegative,LgAlphaNegative,
NegativeMatrix,NEGVER,NEGHor,
log10(L),
log10(alpha),4)+Lgk;
}
Cth = pow(10,Cth); //Transform back to norm units
//Now we can compare whether the target is still visible
return Cth;
LEGIT_S.cpp
******************************************************************************
// Created on June 2003
Sahika Vatan
******************************************************************************
// LEGIT_S.cpp: Defines the class behaviors for the application.
//
#include "stdafx.h"
#include "LEGIT_TS.h"
#include "MainFrm.h"
#include "LEGIT_TSDoc.h"
#include "LEGIT_PTRView.h"
#ifdef _DEBUG
#define new DEBUG_NEW
#endif
static char THIS_FILE[] = __FILE__;
#endif
ARGVhesive/

BEGIN_MESSAGE_MAP(LEGIT_TSApp, CWinApp)
 // { {AFX_MSG_MAP(LEGIT_TSApp)
 ON_COMMAND(ID_APP_ABOUT, OnAppAbout)
      // NOTE - the ClassWizard will add and remove mapping macros here.
      // DO NOT EDIT what you see in these blocks of generated code!
     //} }AFX_MSG_MAP
 // Standard file based document commands
 ON_COMMAND(ID_FILE_NEW, CWinApp::OnFileNew)
 ON_COMMAND(ID_FILE_OPEN, CWinApp::OnFileOpen)
 // Standard print setup command
 ON_COMMAND(ID_FILE_PRINT_SETUP, CWinApp::OnFilePrintSetup)
ENDIF_MESSAGE_MAP()
ARGVhesive/

// CLEGIT_TSApp construction
CLEGIT_TSApp::CLEGIT_TSApp()
{
   // TODO: add construction code here,
   // Place all significant initialization in InitInstance
}
ARGVhesive/

// The one and only CLEGIT_TSApp object
CLEGIT_TSApp theApp;
ARGVhesive/

// CLEGIT_TSApp initialization
BOOL CLEGIT_TSApp::InitInstance()
AfxEnableControlContainer();
// Standard initialization
// If you are not using these features and wish to reduce the size
// of your final executable, you should remove from the following
// the specific initialization routines you do not need.
#ifdef _AFXDLL
    Enable3dControls(); // Call this when using MFC in a shared DLL
#else
    Enable3dControlsStatic(); // Call this when linking to MFC statically
#endif
    
    // Change the registry key under which our settings are stored.
    // TODO: You should modify this string to be something appropriate
    // such as the name of your company or organization.
    SetRegistryKey(_T("Local AppWizard-Generated Applications"));
    LoadStdProfileSettings(); // Load standard INI file options (including MRU)
    Register the application's document templates. Document templates
    // serve as the connection between documents, frame windows and views.
    CSingleDocTemplate* pDocTemplate;
    pDocTemplate = new CSingleDocTemplate(
        IDR_MAINFRAME,
        RUNTIME_CLASS(CLEGI_TSDoc),
        RUNTIME_CLASS(CMainFrame), // main SDI frame window
        RUNTIME_CLASS(CLEGI_TSVView));
    AddDocTemplate(pDocTemplate);
    // Parse command line for standard shell commands, DDE, file open
    CCommandLineInfo cmdInfo;
    ParseCommandLine(cmdInfo);
    // Dispatch commands specified on the command line
    if (!ProcessShellCommand(cmdInfo))
        return FALSE;
    // The one and only window has been initialized, so show and update it.
    m_pMainWnd->ShowWindow(SW_SHOW);
    m_pMainWnd->UpdateWindow();
    return TRUE;

} // end of class CMainFrame

// CAboutDlg dialog used for App About
class CAboutDlg : public CDialog
{
public:
    CAboutDlg();
  
  // Dialog Data
/{AFX_DATA(CAboutDlg)
enum { IDD = IDD_ABOUTBOX };  
/}
AFX_DATA
// ClassWizard generated virtual function overrides  
/{
   AFX_VIRTUAL(CAboutDlg)
protected:
   virtual void DoDataExchange(CDataExchange* pDX);  // DDX/DDV support
/}
AFX_VIRTUAL
// Implementation protected:
/{
   AFX_MSG(CAboutDlg)
   // No message handlers
   /}
AFX_MSG
DECLARE_MESSAGE_MAP()
};
CAboutDlg::CAboutDlg() : CDialog(CAboutDlg::IDD)
{
   AFX_DATA_INIT(CAboutDlg)
   /}
AFX_DATA_INIT

void CAboutDlg::DoDataExchange(CDataExchange* pDX)
{
   CDialog::DoDataExchange(pDX);
   AFX_DATA_MAP(CAboutDlg)
   }AFX_DATA_MAP
BEGIN_MESSAGE_MAP(CAboutDlg, CDialog)
   AFX_MSG_MAP(CAboutDlg)
   // No message handlers
   /AFX_MSG_MAP
END_MESSAGE_MAP()
// App command to run the dialog
void CLEGI_TSAp::OnAppAbout()
{
   CAboutDlg aboutDlg;
   aboutDlg.DoModal();
}

// CLEGI_TSAp message handlers
LEG1_TSDoc.cpp

/*implementation of the CLEG1_TSDoc class*/

#include "stdafx.h"
#include "LEGI_TS.h"
#include "LEGI_TSDoc.h"
#ifdef _DEBUG
#define new DEBUG_NEW
#undef THIS_FILE
static char THIS_FILE[] = __FILE__;
#endif

-CLEGI_TSDoc
IMPLEMENT_DYNCREATE(CLEG1_TSDoc, CDocument)
BEGIN_MESSAGE_MAP(CLEG1_TSDoc, CDocument)
//{{AFX_MSG_MAP(CLEG1_TSDoc)
    // NOTE - the ClassWizard will add and remove mapping macros here.
    // DO NOT EDIT what you see in these blocks of generated code!

   //}}AFX_MSG_MAP
END_MESSAGE_MAP()

-CLEGI_TSDoc construction/destruction
CLEGI_TSDoc::CLEGI_TSDoc()
{
    // TODO: add one-time construction code here
}
CLEGI_TSDoc::~CLEGI_TSDoc()
{
}
BOOL CLEG1_TSDoc::OnNewDocument()
{
    if (!CDocument::OnNewDocument())
        return FALSE;
    // TODO: add reinitialization code here
    // (SDI documents will reuse this document)
    return TRUE;
}

-CLEGI_TSDoc serialization
void CLEG1_TSDoc::Serialize(CArchive& ar)
```cpp
{
    if (ar.IsStoring())
    {
        ar<<L;
        ar<<Lb;
        ar<<Age;
        ar<<t;
        ar<<ZScore;
        ar<<td;  // target distance
        ar<<h;  // font height
        ar<<sw;  // stroke width
        ar<<ffactor;  // TODO: add storing code here
        ar<<ratio;
    }
    else
    {
        ar>>L;
        ar>>Lb;
        ar>>Age;
        ar>>t;
        ar>>ZScore;
        ar>>td;  // target distance
        ar>>h;  // font height
        ar>>sw;  // stroke width
        ar>>ffactor;  // TODO: add loading code here
        ar>>ratio;
        ready=1;
        ::InvalidateRect(NULL,NULL,TRUE);
    }
}

// CLEGI_TSDoc diagnostics
#ifdef _DEBUG
void CLEGI_TSDoc::AssertValid() const
{
    CDocument::AssertValid();
}

void CLEGI_TSDoc::Dump(CDumpContext& dc) const
{
    CDocument::Dump(dc);
}
#endif  // _DEBUG

// CLEGI_TSDoc commands
```
LEG1_TSVi ew.cpp

// LEG1_TSVi ew.cpp : implementation of the CLEG1_TSVi ew class
//
#include "stdafx.h"
#include "LEGI_TS.h"
#include "LEGI_TSDoc.h"
#include "LEGI_TSVi ew.h"
#include <math.h>
double L=0;
double Lb=0;
double Age=0;
double t=0;
double ZScore=0;
double td=0; //target distance
double h=0; //font height
double sw=0; //stroke width
double ffactor=0;
double ratio=0;
int ready=0;
#ifdef _DEBUG
#define new DEBUG-NEW
#undef THIS-FILE
static char THIS-FILE[] = __FILE__;
#endif

// CLEG1_TSVi ew
IMPLEMENT_DYNCREATE(CLEG1_TSVi ew, CView)
BEGIN_MESSAGE_MAP(CLEG1_TSVi ew, CView)
   //{{AFX_MSG_MAP(CLEG1_TSVi ew)
      // NOTE - the ClassWizard will add and remove mapping macros here.
      // DO NOT EDIT what you see in these blocks of generated code!

//}}AFX_MSG_MAP
   // Standard printing commands
   ON_COMMAND(ID_FILE_PRINT, CView::OnFilePrint)
   ON_COMMAND(ID_FILE_PRINT_DIRECT, CView::OnFilePrint)
   ON_COMMAND(ID_FILE_PRINT_PREVIEW, CView::OnFilePrintPreview)
END_MESSAGE_MAP()
// CLEGI_TsView construction/destruction
CLEGI_TsView::CLEGI_TsView()
{
   // TODO: add construction code here
}

CLEGI_TsView::~CLEGI_TsView()
{
}

BOOL CLEGI_TsView::PreCreateWindow(CREATESTRUCT& cs)
{
   // TODO: Modify the Window class or styles here by modifying
   // the CREATESTRUCT cs
   return CView::PreCreateWindow(cs);
}

// CLEGI_TsView drawing
void CLEGI_TsView::OnDraw(CDC* pDC)
{
   CLEGI_TsDoc* pDoc = GetDocument();
   ASSERT_VALID(pDoc);
   // TODO: add draw code for native data here
   init();
   pDC->SetMapMode(MM_LOMETRIC);
   char szBuffer[200], lpBuffer[2000];
   double L=0.3;
   double Lb=2.5;
   double Age=25;
   double t=2;
   double ZScore=0.01;
   double td=11.88;  //target distance
   double h=0.001;  //font height
   double sw=0.0002;  //stroke width
   double ffactor=2;  /**<
   if (ready!=0)
   {
      double pol;
      double Cth;
      double alpha;
      if (L>Lb) {pol=1;}
      else {pol=-1;}
      double pol;
      double Cth;
      double alpha;
      if (L>Lb) {pol=1;}
      else {pol=-1;}
      alpha=360*60*(sw/(2*PI*td));
Cth=CthBwellLegSah(Lb,alpha,Age,t,ZScore,pol,ffactor);
int y=-100;
sprintf(szBuffer,"Observation Condition : ");
pDC->TextOut(1,y,szBuffer);
y=y-150;
sprintf(szBuffer,"Target Luminance : %5.6f [cd/m^2]", L);
pDC->TextOut(1,y,szBuffer);
y=y-75;
sprintf(szBuffer,"Background Luminance : %5.6f [cd/m^2]", Lb);
pDC->TextOut(1,y,szBuffer);
y=y-75;
sprintf(szBuffer,"Age : %5.0f [years]", Age);
pDC->TextOut(1,y,szBuffer);
y=y-75;
sprintf(szBuffer,"Exposure Time : %5.2f [seconds]", t);
pDC->TextOut(1,y,szBuffer);
y=y-75;
sprintf(szBuffer,"ZScore : %5.4f", ZScore);
pDC->TextOut(1,y,szBuffer);
y=y-75;
if (pol==1)
{
    sprintf(szBuffer,"Polarity : Positive");
}
else
{
    sprintf(szBuffer,"Polarity : Negative");
}
pDC->TextOut(1,y,szBuffer);
y=y-75;
sprintf(szBuffer,"Target Distance (m) : %5.2f [m]", td);
pDC->TextOut(1,y,szBuffer);
y=y-75;
sprintf(szBuffer,"Font Height (m) : %5.5f [m]", h);
pDC->TextOut(1,y,szBuffer);
y=y-75;
sprintf(szBuffer,"Stroke Width (m) : %5.5f [m]", sw);
pDC->TextOut(1,y,szBuffer);
y=y-150;
sprintf(szBuffer,"Result : ");
pDC->TextOut(1,y,szBuffer);
y=y-75;
sprintf(szBuffer,"Visual Angle : %5.4f [min]", alpha);
pDC->TextOut(1,y,szBuffer);
y=y-75;
if (L-Lb>O)
{
    sprintf(szBuffer,"Actual Contrast : %5.4f", ((L-Lb)/Lb));
}
else
{
    sprintf(szBuffer,"Actual Contrast : %5.4f", ((Lb-L)/Lb));
}
pDC->TextOut(1,y,szBuffer);
y=y-75;
sprintf(szBuffer,"Actual Contrast Ratio : %5.4f", (L/Lb));
pDC->TextOut(1,y,szBuffer);
y=y-75;
sprintf(szBuffer,"Ratio of SW and H (SW/H) : %5.4f", sw/h);
pDC->TextOut(1,y,szBuffer);
y=y-75;
sprintf(szBuffer,"Field Factor : %5.4f", ffactor);
pDC->TextOut(1,y,szBuffer);
y=y-75;
sprintf(szBuffer,"Contrast Threshold : %5.6f", Cth);
pDC->TextOut(1,y,szBuffer);
y=y-75;
if (L-Lb>O)
{
    sprintf(szBuffer,"MOT (Actual Contrast / Threshold Contrast): %5.6f", (((L-Lb)/Lb)/Cth));
}
else
```c
// MOT (Actual Contrast / Threshold Contrast): %5.6f
((Lb-L)/Lb)/Cth));

void CLEGI_TSVIEW::AssertValid() const
{
    CView::AssertValid();
}

void CLEGI_TSVIEW::Dump(CDumpContext& dc) const
{
    CView::Dump(dc);
}
```
CLEGI_TSDoc* CLEGI_TSVIEW::GetDocument() // non-debug version is inline
{
    ASSERT(m_pDocument->IsKindOf(RUNTIME_CLASS(CLEGI_TSDoc)));
    return (CLEGI_TSDoc*)m_pDocument;
}
#endif  //_DEBUG

// CLEGI_TSVIEW message handlers
MainFrm.cpp
// MainFrm.cpp : implementation of the CMainFrame class

#include "stdafx.h"
#include "LEGIT-S.h"
#include "MainFrm.h"
#include "globals.h"
#ifdef DEBUG
#define new DEBUG_NEW
#undef THIS_FILE
static char THIS_FILE[] = __FILE__;
#endif

IMPLEMENT_DYNCREATE(CMainFrame, CFrameWnd)
BEGIN_MESSAGE_MAP(CMainFrame, CFrameWnd)
   // {AFX_MSG_MAP(CMainFrame)
   ON_WM_CREATE()
   ON_COMMAND(ID_FILE_NEW, OnFileNew)
   ON_COMMAND(ID_FILE_SAVE, OnFileSave)
   ON_COMMAND(ID_FILE_SAVE_AS, OnFileSaveAs)
   // }AFX_MSG_MAP
END_MESSAGE_MAP()

static UINT indicators[] =
{
   ID_SEPARATOR,         // status line indicator
   ID_INDICATOR_CAPS,
   ID_INDICATOR_NUM,
   ID_INDICATOR_SCRL,
};

CMainFrame::CMainFrame()
{
   // TODO: add member initialization code here
}

CMainFrame::~CMainFrame()
{
}

int CMainFrame::OnCreate(LPCREATESTRUCT lpCreateStruct)
{
   if (CFrameWnd::OnCreate(lpCreateStruct) == -1)
      return -1;
if (!m_wndToolBar.CreateEx(this, TBSTYLE_FLAT, WS_CHILD |
    WS_VISIBLE | CBRS_TOP |
    CBRS_GRIPPER | CBRS_TOOLTIPS | CBRS_FLYBY |
    CBRS_SIZE_DYNAMIC))
{
    TRACE0("Failed to create toolbar\n");
    return -1; // fail to create
}
if (!m_wndStatusBar.Create(this))
{
    !m_wndStatusBar.SetIndicators(indicators, sizeof(indicators)/sizeof(UINT))
    TRACE0("Failed to create status bar\n");
    return -1; // fail to create
}
// TODO: Delete these three lines if you don't want the toolbar to
// be dockable
m_wndToolBar.EnableDocking(CBRS_ALIGN_ANY);
EnableDocking(CBRS_ALIGN_ANY);
DockControlBar(&m_wndToolBar);
return 0;
}

BOOL CMainFrame::PreCreateWindow(CREATESTRUCT& cs)
{
    if (!CFrameWnd::PreCreateWindow(cs))
        return FALSE;
    // TODO: Modify the Window class or styles here by modifying
    // the CREATESTRUCT cs
    cs.style= WS_MAXIMIZE | WS_OVERLAPPED | WS_SYSMENU |
    WS_BORDER | WS_MAXIMIZEBOX | WS_MINIMIZE | WS_THICKFRAME |
    cs.cy = ::GetSystemMetrics(SM_CYSCREEN);
    cs.cx = ::GetSystemMetrics(SM_CXSCREEN);
    return TRUE;
}

USICMainFrame diagnostics
#endif

void CMainFrame::AssertValid() const
{
    CFrameWnd::AssertValid();
}

void CMainFrame::Dump(CDumpContext& dc) const
CFrameWnd::Dump(dc);
}
#endif // _DEBUG

// CMainFrame message handlers
void CMainFrame::OnFileNew()
{
    // TODO: Add your command handler code here
    INPUT_DIALOG mydialog;
    mydialog.m_L=L;
    mydialog.m_Lb=Lb;
    mydialog.m_age=Age;
    mydialog.m_t=t;
    mydialog.m_zscore=ZScore;
    mydialog.m_td=td;  //target distance
    mydialog.m_h=h;  //font height
    mydialog.m_sw=sw;  //stroke width
    mydialog.m_ffactor=ffactor;
    mydialog.m_ratio=ratio;
    mydialog.DoModal();
    L=mydialog.m_L;
    Lb=mydialog.m_Lb;
    Age=mydialog.m_age;
    t=mydialog.m_t;
    ZScore=mydialog.m_zscore;
    td=mydialog.m_td;  //target distance
    h=mydialog.m_h;  //font height
    sw=mydialog.m_sw;  //stroke width
    ffactor=mydialog.m_ffactor;
    ratio=mydialog.m_ratio;
    //ready=1;
    Invalidate(TRUE);
}
void CMainFrame::OnFileSave()
{
    // TODO: Add your command handler code here
}

void CMainFrame::OnFileSaveAs()
{
    // TODO: Add your command handler code here
}
nrutil-1.C -- numeric recipe 1 program
Purpose: Revised from numeric recipe
Copyright(c) Xiaoyang Dong, 1995

#include "stdafx.h"
#include <windows.h>
#include <mmsystem.h>
#include <assert.h>
#include <windowsx.h>
#include <stdlib.h>
#include <math.h>
#include <string.h>
#include <stdio.h>
#define NR_END 1
#define FREE_ARG char*
void nrerror(char error_text[]);
double *vector(long nl, long nh);
double **convert_matrix(double *a, long nrl, long nrh, long ncl, long nch);
void free_vector(double *v, long nl, long nh);
void free_convert_matrix(double **b, long nrl, long nrh, long ncl, long nch);
void nrerror(char error_text[])
/* Numerical Recipes standard error handler */
{
    fprintf(stderr,"Numerical Recipes run-time error...
");
    fprintf(stderr,"%s
",error_text);
    fprintf(stderr,"...now exiting to system...
");
    exit(1);
}
double *vector(long nl, long nh)
/* allocate a double vector with subscript range v[nl..nh] */
{
    double *v;
    v=(double *)malloc((size_t)((nh-nl+1+NR_END)*sizeof(double)));
    if (!v) nrerror("allocation failure in vector()");
    return v-nl+NR_END;
}
double **convert_matrix(double *a, long nrl, long nrh, long ncl, long nch)
/* allocate a double matrix m[nrl..nrh][ncl..nch] that points to the matrix
declared in the standard C manner as a[nrow][ncol], where nrow=nrh-nrl+1
and ncol=nch-ncl+1. The routine should be called with the address
&a[0][0] as the first argument. */
{

long i,j,nrow=nrh-nrl+1,ncol=nch-ncl+1;
double **m;
/* allocate pointers to rows */
m=(double **) malloc((size_t) ((nrow+NR_END)*sizeof(double*)));
if (!m) nrerror("allocation failure in convert_matrix()");
m += NR_END;
m -= nrl;
/* set pointers to rows */
m[nrl]=a-ncl;
for(i=1,j=nrl+1;i<nrow;i++,j++) m[j]=m[j-1]+ncol;
/* return pointer to array of pointers to rows */
return m;
}
void free_vector(double *v, long nl, long nh)
/* free a double vector allocated with vector() */
{
    free((FREE_ARG) (v+nl-NR_END));
}
void free_convert_matrix(double **b, long nrl, long nrh, long ncl, long nch)
/* free a matrix allocated by convert_matrix() */
{
    free((FREE_ARG) (b+nrl-NR_END));
}
*****************************************************************************
StdAfx.cpp

// stdafx.cpp : source file that includes just the standard includes
//    LEGI_TS.pch will be the pre-compiled header
//    stdafx.obj will contain the pre-compiled type information

#include "stdafx.h"
Header Files

globals.h
INPUT_DIAL0G.h
LEGI_TS.h
LEGI_TSDoc.h
LEGI_TSView.h
MainFrm.h
Resource.h
StdAfx.h
#if !defined( EXAMPLE_H )
#define EXAMPLE_H

extern double L;
    extern double Lb;
    extern double Age;
    extern double t;
    extern double ZScore;
extern double td;  //target distance
    extern double h;  //font height
extern double sw;  //stroke width
    extern double ffactor;
    extern int ready;
    extern double ratio;
#endif
INPUT_DIALOG.h

#ifndef AFX_INPUT_DIALOG_H_773733C6_82FA_4846_8A58_0F801E867F97_INCLUDED__
#define AFX_INPUT_DIALOG_H_773733C6_82FA_4846_8A58_0F801E867F97_INCLUDED__
#endif

#if _MSC_VER > 1000
#pragma once
#endif

// INPUT_DIALOG .h : header file

// //~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
// // INPUT_DIALOG dialog
#include "globals.h"
const WM_DATAREADY = WM_USER + 50;
class INPUT_DIALOG : public CDialog
{
    // Construction
    public:
        INPUT_DIALOG(CWnd* pParent = NULL); // standard constructor
    // Dialog Data
        {{AFX_DATA(INPUT_DIALOG)
            enum { IDD = IDD_DIALOG1 }; 
            double m_age;
            double m_ffactor;
            double m_h;
            double m_sw;
            double m_L;
            double m_Lb;
            double m_ratio;
            double m_t;
            double m_td;
            double m_zscore;
        }AFX_DATA
    // Overrrides
        // ClassWizard generated virtual function overrides
        {{AFX_VIRTUAL(INPUT_DIALOG)
            protected:
                virtual void DoDataExchange(CDataExchange* pDX); // DDX/DDV support
        }AFX_VIRTUAL
LEGI_TS.h
// LEGI_TS.h : main header file for the LEGI_TS application

#endif !defined(AFX_LEGI_TS_H__FDBB075A_5091_410F_99BF_245BF899A937__INCLUDED_)
#define AFX_LEGI_TS_H__FDBB075A_5091_410F_99BF_245BF899A937__INCLUDED__
#if _MSC_VER > 1000
#pragma once
#endif _MSC_VER > 1000
#ifndef _AFXWIN_H_
#define _AFXWIN_H_
#error include 'stdafx.h' before including this file for PCH
#endif
#include "resource.h" // main symbols

// CLEGI_TSApp:
// See LEGI_TS.cpp for the implementation of this class

class CLEGI_TSApp : public CWinApp
{
public:
    CLEGI_TSApp();

    // Overrides
    // ClassWizard generated virtual function overrides
   //{{AFX_VIRTUAL(CLEGI_TSApp)
    public:
        virtual BOOL InitInstance();
   //}}AFX_VIRTUAL

    // Implementation
   //{{AFX_MSG(CLEGI_TSApp)
    afx_msg void OnAppAbout();
    // NOTE - the ClassWizard will add and remove member functions here.
    // DO NOT EDIT what you see in these blocks of generated code!
   //}}AFX_MSG

    DECLARE_MESSAGE_MAP()
};

//{{AFX_INSERT_LOCATION}}
// Microsoft Visual C++ will insert additional declarations immediately before the
// previous line.
#endif // !defined(AFX_LEGI_TS_H__FDBB075A_5091_410F_99BF_245BF899A937__INCLUDED_)


LEGI_TSDoc.h
#if _MSC_VER > 1000
#pragma once
#endif
#include "globals.h"
class CLEGI_TSDoc : public CDocument
{
protected: // create from serialization only
    CLEGI_TSDoc();
    DECLARE_DYNCREATE(CLEGI_TSDoc)

// Attributes
public:
// Operations
public:
// Overrides
    // ClassWizard generated virtual function overrides
   //{{AFX_VIRTUAL(CLEGI_TSDoc)
    public:
    virtual BOOL OnNewDocument();
    virtual void Serialize(CArchive& ar);
   //}}AFX_VIRTUAL

// Implementation
public:
    virtual ~CLEGI_TSDoc();
#ifdef _DEBUG
    virtual void AssertValid() const;
    virtual void Dump(CDumpContext& dc) const;
#endif
protected:
// Generated message map functions
protected:
   //{{AFX_MSG(CLEGI_TSDoc)
    // NOTE - the ClassWizard will add and remove member functions here.
    // DO NOT EDIT what you see in these blocks of generated code !
   //}}AFX_MSG
    DECLARE_MESSAGE_MAP()
};

//Microsoft Visual C++ will insert additional declarations immediately before the previous line.
#endif // !defined(AFX_LEGI_TSDOC_H__21991D79_4A4D_4100_A573_8E952F90E0C5_INCLUDED_)
#include "globals.h"

#define PI 3.14159265

double CthSwellLegSah(double L, double alpha, double Age, double time,double ZScore, double pol,double ffactor);

void init();

/*double L;
 double Lb;
 double Age;
 double t;
 double ZScore;
 double td; //target distance
 double h; //font height
 double sw; //stroke width
 double ffactor;*/

class CLEG1-TSView : public CView
{
    protected: // create from serialization only
        CLEG1-TSView();
        DECLARE_DYNCREATE(CLEG1-TSView)

    // Attributes
    public:
        CLEG1_TSDoc* GetDocument();

    // Operations
    public:
    // Overrides
        // ClassWizard generated virtual function overrides
       //}}AFX_VIRTUAL(CLEG1-TSView)
    public:
        virtual void OnDraw(CDC* pDC); // overridden to draw this view
        virtual BOOL PreCreateWindow(CREATESTRUCT& cs);
protected:
    virtual BOOL OnPreparePrinting(CPrintInfo* pInfo);
    virtual void OnBeginPrinting(CDC* pDC, CPrintInfo* pInfo);
    virtual void OnEndPrinting(CDC* pDC, CPrintInfo* pInfo);
    /**} }AFX_VIRTUAL
     // Implementation
    public:
      virtual ~CLEGIT_SView();
    #ifdef _DEBUG
      virtual void AssertValid() const;
      virtual void Dump(CDumpContext& dc) const;
    #endif
    protected:
     // Generated message map functions
    protected:
      /**} {AFX_MSG(CLEGIT_SView)
       // NOTE - the ClassWizard will add and remove member functions here.
       // DO NOT EDIT what you see in these blocks of generated code!
      /**} }AFX_MSG
     DECLARE_MESSAGE_MAP()
    };
    #ifndef _DEBUG // debug version in LEGIT_SView.cpp
    inline CLEGIT_SDoc* CLEGIT_SView::GetDocument()
      { return (CLEGI_TSDoc*)m_pDocument; }
    #endif
    ///////////////////////////////////////////////////////////////////////////
    // {AFX_INSERT_LOCATION}
    // Microsoft Visual C++ will insert additional declarations immediately before the
    previous line.
    #endif
    !defined(AFX_LEGIT_SVIEW_H__9119EE8E_DD8B_47AA_8A1D_26F663E53E60_
    _INCLUDED)}
MainFrm.h
// MainFrm.h : interface of the CMainFrame class
#
///////////////////////////////////////////////////////////////////////////////
#endif
#define AFX_MAINFRM_H__D66DAF2F_15AA_416E_ACCF_F04418AD0E4AINCLUDED
#endif
afxmainfrm.h
#define _MSC_VER > 1000
#pragma once
#endif // _MSC_VER > 1000
#include "LEGITSDoc.h"
#include "INPUT_DIALOG.h"
//#include "globals.h"
class CMainFrame : public CFrameWnd
{
    protected: // create from serialization only
        CMainFrame();
        DECLARE_DYNCREATE(CMainFrame)
    // Attributes
    public:
    // Operations
    public:
    // Overrides
        // ClassWizard generated virtual function overrides
        {{AFX_VIRTUAL(CMainFrame)
            virtual BOOL PreCreateWindow(CREATESTRUCT& cs);
        }AFX_VIRTUAL
    // Implementation
    public:
        virtual ~CMainFrame();
    #ifdef _DEBUG
        virtual void AssertValid() const;
        virtual void Dump(CDumpContext& dc) const;
    #endif
    protected: // control bar embedded members
        CStatusBar m_wndStatusBar;
        CToolBar m_wndToolBar;
    // Generated message map functions
    protected:
        {{AFX_MSG(CMainFrame)
afx_msg int OnCreate(LPCREATESTRUCT lpCreateStruct);
afx_msg void OnFileNew();
afx_msg void OnFileSave();
afx_msg void OnFileSaveAs();
//}}AFX_MSG
DECLARE_MESSAGE_MAP()
};

Microsoft Visual C++ will insert additional declarations immediately before the previous line.
#endif

!defined(AFX_MAINFRM_H__D66DAF2F_15AA_416E_ACCF_F04418AD0E4A_INCLUDED)
StdAfx.h

// stdafx.h: include file for standard system include files,
// or project specific include files that are used frequently, but
// are changed infrequently
#if !defined(AFX_STDAFX_H__C96E8907_59C6_40CE_8C10_38A84366794B__INCLUDED_)
#define AFX_STDAFX_H__C96E8907_59C6_40CE_8C10_38A84366794B__INCLUDED_
#if _MSC_VER > 1000
#pragma once
#endif
#endif // _MSC_VER > 1000
#define VC_EXTRALEAN // Exclude rarely-used stuff from Windows headers
#include <afxwin.h>   // MFC core and standard components
#include <afxext.h>   // MFC extensions
#include <afxdisp.h>  // MFC Automation classes
#include <afxdtctl.h> // MFC support for Internet Explorer 4 Common Controls
#ifndefAFX_NO_AFXCMN_SUPPORT
#include <afxcmn.h>   // MFC support for Windows Common Controls
#endif // _AFX_NO_AFXCMN_SUPPORT
//}}AFX_INSERT_LOCATION
// Microsoft Visual C++ will insert additional declarations immediately before the previous line.
#endif //
#endif // !defined(AFX_STDAFX_H__C96E8907_59C6_40CE_8C10_38A84366794B__INCLUDED_)

}
MICROSOFT FOUNDATION CLASS LIBRARY : LEGI_TS

AppWizard has created this LEGI_TS application for you. This application not only demonstrates the basics of using the Microsoft Foundation classes but is also a starting point for writing your application. This file contains a summary of what you will find in each of the files that make up your LEGI_TS application.

LEGI_TS.dsp
This file (the project file) contains information at the project level and is used to build a single project or subproject. Other users can share the project (.dsp) file, but they should export the makefiles locally.

LEGI_TS.h
This is the main header file for the application. It includes other project specific headers (including Resource.h) and declares the CLEGI_TSAppl application class.

LEGI_TS.cpp
This is the main application source file that contains the application class CLEGI_TSAppl.

LEGI_TS.rc
This is a listing of all of the Microsoft Windows resources that the program uses. It includes the icons, bitmaps, and cursors that are stored in the RES subdirectory. This file can be directly edited in Microsoft Visual C++.

LEGI_TS.clw
This file contains information used by ClassWizard to edit existing classes or add new classes. ClassWizard also uses this file to store information needed to create and edit message maps and dialog data maps and to create prototype member functions.

res\LEGI_TS.ico
This is an icon file, which is used as the application's icon. This icon is included by the main resource file LEGI_TS.rc.

res\LEGI_TS.rc2
This file contains resources that are not edited by Microsoft Visual C++. You should place all resources not editable by the resource editor in this file.

For the main frame window:
MainFrm.h, MainFrm.cpp
These files contain the frame class CMainFrame, which is derived from CFrameWnd and controls all SDI frame features.

res\Toolbar.bmp
This bitmap file is used to create tiled images for the toolbar.
The initial toolbar and status bar are constructed in the CMainFrame class. Edit this toolbar bitmap using the resource editor, and update the IDR_MAINFRAME TOOLBAR array in LEGI_TS.rc to add toolbar buttons.

AppWizard creates one document type and one view:
LEG1_TSDoc.h, LEGI_TSoc.cpp - the document
  These files contain your CLEI_TSDoc class. Edit these files to add your special document data and to implement file saving and loading (via CLEI_TSDoc::Serialize).
LEG1_TSVi ew.h, LEGI_TSVi ew.cpp - the view of the document
  These files contain your CLEI_TSVi ew class.
  CLEI_TSVi ew objects are used to view CLEI_TSDoc objects.

Other standard files:
StdAfx.h, StdAfx.cpp
  These files are used to build a precompiled header (PCH) file named LEGI_TS.pch and a precompiled types file named StdAfx.obj.
Resource.h
  This is the standard header file, which defines new resource IDs.
  Microsoft Visual C++ reads and updates this file.

Other notes:
AppWizard uses "TODO:" to indicate parts of the source code you should add to or customize.
If your application uses MFC in a shared DLL, and your application is in a language other than the operating system's current language, you will need to copy the corresponding localized resources MFC42XXX.DLL from the Microsoft Visual C++ CD-ROM onto the system or system32 directory, and rename it to be MFCLOC.DLL. ("XXX" stands for the language abbreviation. For example, MFC42DEU.DLL contains resources translated to German.) If you don't do this, some of the UI elements of your application will remain in the language of the operating system.