Predicting the service life of road signs based on their retroreflectivity and color using Logistic Regression

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Abstract

Road signs play a vital role in providing drivers with crucial information for safe driving in both day and nighttime. The color of road signs enhances visibility during daylight hours, while retroreflectivity is essential for improving visibility during nighttime conditions. Road authorities, responsible for maintaining road signs, primarily consider the levels of retroreflectivity when deciding to replace them, ensuring optimal visibility for drivers. This study focuses on examining the degradation of road signs based on retroreflectivity and color to ensure safe driving through adequate visibility in both day and nighttime conditions. The study underscores the significance of regulating the deterioration of road sign colors to enhance visibility and legibility, while minimizing maintenance and replacement costs. The primary objective of this paper is to predict the age (service life) of road signs by considering both retroreflectivity and color status and using logistic regression. The results indicate that the age of road signs can be influenced by either retroreflectivity or color. For instance, approximately 50\% of red road signs are projected to lose their color after 16 years, while their retroreflectivity remains acceptable. Similarly, around 50\% of yellow and white road signs experience retroreflectivity degradation after 20 and 16 years, respectively, while their color remains acceptable. Finally, blue road signs demonstrate acceptable retroreflectivity and color levels even after 35 years.

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1. Introduction

Road signs are crucial for safe navigation on roads, providing important information to drivers. However, inadequate visibility of road signs at day or night can lead to confusion and accidents. During the daytime, the colors of road signs help drivers recognize and differentiate them from one another (Saleh and Fleyeh 2022), while retroreflective sheeting assists in improving nighttime visibility by reflecting light from vehicle headlights back to the driver (Saleh et al. 2022).

Over time, the retroreflectivity and colors of road signs gradually deteriorate, resulting in reduced visibility. When the retroreflectivity or color of a road sign fades below the accepted levels necessary for visibility (European Committee for Standardization 2007), it must be replaced. Currently, road authorities only regulate the deterioration of road signs based on retroreflectivity levels (Harris et al. 2009), while the regulation of color deterioration is overlooked.

This study aims to predict the age of road signs by analyzing a dataset from Sweden, considering either retroreflectivity or color. The importance of color deterioration is emphasized in this study, enhancing the understanding of retroreflective sheeting deterioration and facilitating informed decision-making regarding sign specification and procurement. The main contribution of this study is to determine whether the age of road signs is influenced by retroreflectivity or by color deterioration.

While several previous studies have focused on predicting the age (service life) of road signs (Alkhulaifi et al. 2021) (Babić et al. 2017) (Jamal et al. 2022) (Preston et al. 2014) (Saleh and Fleyeh 2022) (Swargam 2004), their age was primarily forecasted based on retroreflectivity. Although road sign deterioration over time affected by both color and retroreflectivity, there are only few studies (Brimley et al. 2010) (Preston et al. 2014) on the degradation of color.

Brimley et al. (2010) conducted a study to evaluate the performance of sign sheeting concerning retroreflectivity and color criteria. The study found that a majority of the tested products failed to meet the color chromaticity requirements before retroreflectivity, particularly in the case of orange, red, and yellow sheeting. However, this study had limitations, such as using samples of sheeting placed on aluminum substrates for a duration of only 10 years.

While previous studies have focused primarily on retroreflectivity degradation or have examined limited aspects like specific materials, colors, or short lifespans when studying color degradation, no research has been conducted to predict color degradation for in-suite road signs to the best of our knowledge.

To address this research gap, this study conducted a comprehensive comparative analysis of degradation, considering both retroreflectivity and color simultaneously. The study encompassed a wide range of sheeting classes and colors for road signs, spanning from brand new signs to those aged up to 45 years. The objective of this study is to fill this gap in the field by simultaneously predicting and comparing the aging process of road traffic signs based on both retroreflectivity and color.

The remainder of the paper is organized as follows: Section 2 presents the methods and materials, including a description of the dataset used. The results and discussion are presented in Section 3. Finally, Section 4 provides the conclusions drawn from the study.

2. Methods-material and experiments

2.1. Data description and pre-processing

The dataset used in this study was collected from road signs in Sweden, as shown in Fig. 1. The dataset consisted of 683 records obtained between 2018 (Kjellman et al. 2018) and 2021 (Saleh et al. 2023), covering a range of road sign ages from brand new to 45 years old. To ensure data quality, a cleaning process was performed to eliminate records with missing, incomplete, incorrect, and irrelevant information, resulting in a cleaned dataset containing 636 records.
Fig. 1. The locations of the road signs included in the analyzed data.

The dataset included sheeting in various colors and classes as shown in Table 1. The retroreflective sheeting used on road signs differs across the classes, with Class 1 exhibiting lower reflectivity and Class 3 exhibiting the highest. The retroreflectivity of the road signs was measured using a handheld Retroreflectometer, specifically capturing the retroreflection coefficient (RA) at a 5° entrance angle (β1) and a 0.33° observation angle (α) (Saleh and Fleyeh 2022).

Table 1 Summary of the dataset

<table>
<thead>
<tr>
<th>Color</th>
<th>Total (before cleaning the dataset)</th>
<th>Class 1</th>
<th>Class 2</th>
<th>Class 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue</td>
<td>110</td>
<td>51</td>
<td>24</td>
<td>35</td>
</tr>
<tr>
<td>Red</td>
<td>150</td>
<td>42</td>
<td>31</td>
<td>72</td>
</tr>
<tr>
<td>White</td>
<td>319</td>
<td>132</td>
<td>61</td>
<td>123</td>
</tr>
<tr>
<td>Yellow</td>
<td>104</td>
<td>48</td>
<td>9</td>
<td>45</td>
</tr>
</tbody>
</table>

In addition to retroreflectivity, the dataset also incorporated measurements of daylight chromaticity. The daylight chromaticity was assessed using a Konica Minolta spectrometer CM-25cG system and expressed in terms of X and Y chromaticity coordinates (European Committee for Standardization 2007). These coordinates (daylight chromaticity) represent the color's position within a two-dimensional CIE color diagram, providing information on the color's relative position. Fig. 2 illustrates the location of the measured road signs on the CIE diagram, with points falling outside the respective color boxes indicating a rejected color state.
2.2. Retroreflectivity and color status

The retroreflectivity and colors of the road signs deteriorate over time and thus the visibility worsens, therefore, maintaining the road signs is one of the important issues to improve the safety of the roads. Thus, it is important to judge whether the retroreflectivity and colors of the road sign are within the accepted levels for visibility and whether the status of the signs is accepted (status = 1) or rejected (status = 0) and needs to be replaced.

For the analysis in this study, the retroreflectivity status and color status were used as output variables, while the age of the road signs served as the input variable. Retroreflectivity status (accepted/rejected) was evaluated by determining whether the road sign's retroreflectivity met the minimum acceptable levels of retroreflectivity established by the Swedish Transport Administration and European standards (European Committee for Standardization 2007).

The color status of the road signs was evaluated based on the daylight chromaticity requirements specified by European standards (European Committee for Standardization 2007). If a road sign's color fell within the acceptable range of daylight chromaticity, within the color boxes, it was considered "accepted". However, if it deviated from the acceptable range, the road sign was considered rejected and in need of replacement.

2.3. Logistic Regression

To ascertain the age at which the retroreflectivity status or color status of road signs transitions from accepted to rejected, logistic regression was employed. Logistic regression is a statistical approach and a machine learning algorithm commonly used for classification problems (Stoltzfus 2011) (Maalouf 2011). It relies on the concept of probability and utilizes the sigmoid function to determine the probability of either zero or one based on specified threshold values (Maalouf 2011). The Logistic function equation to predict the probability is expressed as in Eq. (1).

\[
\hat{Y}_i = \frac{e^{\beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_i x_i}}{1 + e^{\beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_i x_i}}
\]  
(1)

Where:

- $\beta_0$ is the intercept, or the point at which the regression line touches the vertical Y axis. This is considered a constant value.
- $\beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_i x_i$ is the value of each independent variable ($x_i$) weighted by its respective beta coefficient ($\beta$). Beta coefficients give the slope of the regression line or how much the outcome increases for each 1-unit increase in the value of the independent variable.
- $\hat{Y}_i$ represents the estimated probability of being in one binary outcome category (i) versus the other.
3. Results and discussion

3.1. Predicting the age of road signs based on retroreflectivity status

Logistic regression was employed to predict the age at which the retroreflectivity status transitions from accepted to rejected. Fig. 3 illustrates the percentage of road signs that remain accepted based on their retroreflectivity status across different ages.

The results indicate that for road signs with red, blue, yellow, and white retroreflective sheeting, only 50% of road signs remain accepted after 25, 20, and 16 years, respectively, for red, yellow, and white sheeting. In the case of road signs with blue sheeting, the dataset contained signs with ages up to 35 years, and at this age, 65% of road signs were accepted. These findings highlight the differences in durability and longevity among road signs with different retroreflective sheeting colors.

Fig. 3. Age analyses based on retroreflectivity status (a) Red; (b) Yellow; (c) White; and (d) Blue.
3.2. Predicting the age of road signs based on color status

The percentage of road signs that remain accepted based on their color status at different ages is depicted in Fig. 4. The results reveal the following findings for road signs with red, blue, yellow, and white retroreflective sheeting:

- After 16 years, only 50% of road signs with red sheeting are still accepted. The red sheeting may experience faster color degradation compared to other colors, potentially impacting their visibility and effectiveness on the road.
- For yellow sheeting, approximately 80% of road signs remain acceptable after 45 years.
- Similarly, around 90% of road signs with white sheeting are still accepted after 35 years.
- The dataset included road signs with blue sheeting up to 35 years old, and at this age, more than 50% of road signs were accepted. This suggests that blue sheeting may have a relatively longer lifespan compared to other colors, as the majority of signs remained visually acceptable even for 35 years.

Fig. 4. Age analyses based on color status (a) Red; (b) Yellow; (c) White; and (d) Blue.
3.3. Do road signs fail in retroreflectivity before color?

The results demonstrate differing levels of durability and longevity among road signs with different retroreflective sheeting colors. Differences in durability and longevity among road signs with different retroreflective sheeting colors can be attributed to several factors. Pigment stability, printing process, and material composition impact the performance and longevity of the colors. Certain pigments may have varying abilities to withstand environmental conditions, resist fading or discoloration, and maintain UV stability. These properties affect color vibrancy and visibility over time, influencing retroreflectivity lifespan.

The printing techniques used on retroreflective sheeting also influence color durability. Factors like ink quality, adhesion, and protective coatings determine how well colors endure UV radiation, moisture, and abrasion. The material composition of retroreflective sheeting, which includes microprismatic or glass bead technology, adhesives, and coatings, can vary, affecting overall durability. However, if colors are printed on the same sheeting, material composition itself would not be the primary reason for differences in durability and longevity. UV radiation from sunlight degrades materials, and some colors are more susceptible to UV damage, resulting in reduced retroreflectivity and shorter lifespan.

Based on the results from Logistic regression analyses, Table 2, it was observed that only red road signs experience color deterioration before retroreflectivity degradation. On the other hand, yellow and white road signs first experience a decline in retroreflectivity, which is followed by color deterioration after more than 20 years. Blue road signs, however, maintain acceptable retroreflectivity and color even after 35 years.

<table>
<thead>
<tr>
<th>Color</th>
<th>Based on Retroreflectivity status (years)</th>
<th>Based on Color status (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td>25</td>
<td>16</td>
</tr>
<tr>
<td>Yellow</td>
<td>20</td>
<td>More than 45</td>
</tr>
<tr>
<td>White</td>
<td>16</td>
<td>More than 35</td>
</tr>
<tr>
<td>Blue</td>
<td>More than 35</td>
<td>More than 35</td>
</tr>
</tbody>
</table>

4. Conclusions

In this study, the age of road signs is predicted using logistic regression models. The findings highlight the significance of both retroreflectivity and color in understanding the degradation of road signs. It was observed that red road signs may experience color fading before their retroreflectivity declines, emphasizing the importance of considering both factors for effective traffic maintenance.

The study provides valuable insights into the expected lifespan of road signs with different colors, enabling road authorities to make informed decisions regarding maintenance and replacement strategies.

The results indicate varying levels of durability and longevity among road signs with different retroreflective sheeting colors. Factors such as pigment stability, printing process, material composition, UV susceptibility, and environmental resilience contribute to the varying durability and longevity of road signs with different retroreflective sheeting colors. The red sheeting may experience faster color degradation compared to other colors. On the other hand, road signs with yellow and white sheeting exhibited better durability compared to red sheeting. Interestingly, blue road signs demonstrated greater durability compared to red, yellow, and white road signs.

Overall, these findings emphasize the importance of considering the color of retroreflective sheeting when assessing the durability and longevity of road signs. By considering these factors, road authorities can make informed decisions regarding the maintenance and replacement of road signs to ensure optimal traffic safety.

A limitation of this study is that the collected data only included road signs with ages up to 35 years for white and blue signs. Future studies should consider incorporating longer age ranges to further investigate the age of blue signs.

Additionally, the influence of different classes of retroreflective sheeting should be taken into account when predicting the age of road signs in further research. Different classes of retroreflective sheeting have varying levels of
performance and durability. By considering these variations, researchers can gain a more accurate understanding of how different classes of sheeting degrade over time and how they affect the overall age of road signs.

References


Kjellman, Erik, Carina Fors, and S Lundkvist. 2018. Analysis of life-cycle costs for traffic signs with focus on retroreflective sheeting materials. In Swedish National Road and Transport Research Institute, VTI


