RESEARCH OF ROAD MARKINGS VISIBILITY DEGRADATION BASED ON APPLIED MATERIALS ON CROATIAN STATE ROADS

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Abstract

Road markings are integral to effective traffic management, serving as visual cues for drivers and essential components in ensuring road safety. Choosing materials for road markings, whether durable options like plastic materials or conventional paint, presents an important decision point in road infrastructure planning. While durable materials offer long-lasting benefits, paint provides a flexible and cost-effective alternative. Visibility is a critical factor, particularly in low-light conditions, highlighting the crucial role of retroreflection. This research compares the performance of road markings made from durable materials with those made using paint. Research focuses on the Republic of Croatia, analysing road markings across its network of state roads based on available data categorised into five regions. Descriptive statistics will provide insights into the materials used for exploiting road markings across five regions. This research compares the retroreflection of refurbished road markings and post-exposure retroreflection over an annual cycle. The reference year spans from the autumn of one year to the spring of the following year, accounting for winter road maintenance and road marking renewal periods. Statistical analysis employs the One-way ANOVA (analysis of variance) to compare the visibility of road markings in use and the renewed road markings based on the materials used. This analysis provides insights concerning road marking material retroreflection and its degradation depending on traffic exposure and environmental conditions. The results are compared to determine if there is a substantial difference in retroreflection between the two used road marking materials. Data analysis is conducted using the SPSS statistic tool. Findings of this research will help provide insights into the balance between the visibility of road markings based on used materials over time, offering a valuable perspective for road maintenance strategies.

Keywords: road marking, visibility, durability, retroreflection, degradation, road traffic

1 Introduction

Road markings are fundamental elements of traffic management, pivotal in guiding and informing drivers to ensure road safety. They can be categorized using various criteria such as colour, material, function, durability, thickness, retroreflectivity, etc. However, the primary classification is centred around their function and the material from which they are constructed [1]. The selection of materials for road markings is a critical decision in road infrastructure planning, presenting a balance between durable options like plastic materials and the flexible, cost-effective alternative of conventional paint. The relevance of this research lies in the need to understand and address the challenges associated with the degradation of road marking visibility over time.

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Visibility is a significant factor in road safety, particularly under low-light conditions, emphasising the importance of retroreflection. The essential factor for nighttime visibility in vehicle headlights is retroreflection, quantified by the coefficient of retroreflected luminance (R_L) [2]. As road markings age and are worn out, their retroreflective properties diminish, potentially compromising their effectiveness in guiding traffic [2]. In daylight conditions, satisfactory visibility relies on having a noticeable contrast in colour, typically assessed through the luminance coefficient under diffuse illumination (Qd). R_L is achieved because road markings are a dual-layer system: a material layer furnishes Qd, and a glass beads layer on its surface provides R_L [3]. The critical importance of glass beads lies in providing the R_L and protecting the material layer from direct abrasion caused by passing vehicles. Therefore, it is important from the perspective of durability and environmental aspects [4]. Several materials can be utilised for road markings such as paint, thermoplastic, tape or plural component systems [5]. By conducting an experimental study, Gibbons and Hankey [6] found that tape as a road marking material has the best visibility and the longest detection distance in wet conditions. Thermoplastic materials have similar results, while paint scored the lowest. As for the vehicle's position on the road, Vyskočilová et al. found that the vehicle's lateral position was significantly influenced by road marking type, speed, vehicle width, cross slope, and road width. The key takeaway from their research was the substantial impact of road marking type, a parameter that emerged as significant in both models [7]. By all that, the choice between durable materials and paint directly influences the longevity of road markings.

Road marking service life, or in other words, the level and the rate of their retroreflection degradation, affect the timing of the marking renewal and, thus, the overall maintenance costs [8]. Several factors affect the road markings service life, namely: type of material, road marking position (edge or middle), road marking age, annual average daily traffic (AADT), road type/ category, number of road markings (lines), type of asphalt surface on the road, speed limit, amount of abrasives, amount of salt, and rate of winter road maintenance activity [9]. In addition, glass beads are an essential factor since their quality and quantity impact road marking retroreflection and, consequently, their service life [10].

This research examines Croatia's state roads, specifically seasonal variations, winter maintenance, and road marking renewal. The hypothesis posits significant retroreflection differences between road markings made from durable materials and paint, considering both the material and the region's impact. The goal is to enhance road maintenance strategies and traffic safety insights. For this purpose, the paper is divided into four sections. After the introduction, data collection and analysis were explained in the methodology section. Results and discussion are divided into three subsections. The first compares retroreflection degradation by region, the second relates to a comparison of retroreflection drop between regions, and the third compares renewed and existing road markings concerning the material. The conclusions are shown at the end of the paper.

2 Methodology

2.1 Data collection

Data collection for this research focused on the state roads of the Republic of Croatia, encompassing a network exceeding 7340 kilometres [11]. State roads are categorised as secondary roads of the Republic of Croatia. They are mostly rural and are the primary connections between multiple counties. Data on longitudinal road marking retroreflection measurements on state roads of the Republic of Croatia have been used for this research. The data considered spanned the five years, specifically 2019-2023. The Republic of Croatia comprises 21 counties, grouped for this research based on their geographic position, climate characteristics, traffic type and structure into five regions.

The data sample involves 50 state roads. It is important to emphasise that most state roads extend through several counties, i.e., regions, so they are divided into road sections, so one section is assigned to one county. The summary of collected data is shown in Table 1.

Table 1 Arrangement of counties according to selected regions

Region	Number of state roads	Paint pairs	Plastic pairs	Right marking pairs	Middle marking pairs	Left marking pairs
Istria and Northern Coast	21	20	0	6	8	6
Mountainous Croatia	2	7	0	3	1	3
Southern Croatia	8	14	0	4	8	3
Central Croatia	19	31	2	7	18	8
Eastern Croatia	20	66	0	16	34	16

Data were collected using a dynamic method for measuring retroreflection (R_L). This is achieved by employing a retroreflectometer attached to either the left or right side of a measuring vehicle, depending on whether the middle or edge line is being inspected. This method allows for continuous retroreflection measurement along the entire road section, with a predefined measuring interval of the 50 meters, meaning that the relevant retroreflection value was determined by calculating the arithmetic mean of the retroreflection values across each of 50-meter intervals on the road. State roads are generally evaluated twice yearly, inspecting the renewed markings between 30 and 60 days after the application and existing road markings (after the winter maintenance period). These periods are defined by the Guidelines and Technical Requirements in Croatia [12]. This methodology facilitates comparative analysis by pairing measurements of existing and renewed road markings, creating a structured framework for evaluating the retroreflective properties over specific intervals.

2.2 Data analysis

Statistical tools used in this research are one-way ANOVA (Analysis of Variance) and paired sample t-tests, with the SPSS software for data analysis. The choice of the paired sample t-test as the statistical method was motivated by its suitability for examining mean differences within the same set of subjects - in this case, the same road sections. Specifically, one group consisted of refurbished road markings, while the other comprised the existing markings that had yet to undergo maintenance. Pairs were formed by merging identical road sections from the same counties or regions to ensure a meaningful comparison. This pairing strategy allowed for a direct assessment of the degradation of retroreflective properties, considering regional and climate factors and facilitating an understanding of the differences between the two groups. ANOVA was employed to assess and compare the retroreflection degradation across different regions. This statistical technique is a powerful tool for examining whether the observed differences in retroreflection levels among various groups are statistically significant.

3 Results and discussion

Table 2 provides descriptive statistics for three variables: “Refurbished marking retroreflection” (RMR), “Existing marking retroreflection” (EMR), and “Retroreflection drop” (RD), measured in mcd*lx^{-1}*m^{-2}. The RD was calculated as the difference between the initial and control measurements of the road marking. The sample has 141 valid cases for each variable, with no missing data. The descriptive statistics in Table 2 reveal a significant contrast between the maximum and minimum values of the sample. This substantial difference can be attributed to the analysis of durable materials with high retroreflection, in contrast to the lower retroreflection values associated with paint.

Table 2 Descriptive statistics of RMR, EMR and RD

		RMR (mcd*lx^{-1}*m^{-2})	EMR (mcd*lx^{-1}*m^{-2})	RD (mcd*lx^{-1}*m^{-2})
N	**Valid**	**141**	**141**	**141**
	Missing	**0**	**0**	**0**
Mean		297,15	199.49	97.66
Std. Deviation		76,690	62.861	65.113
Range		591	369	446
Minimum		159	39	2
Maximum		750	408	448
Percentiles	25	256.50	156.00	50.50
	50	284.00	201.00	91.00
	75	319.00	238.00	132.50

3.1 Comparison of retroreflection degradation by region

As shown in Table 3, the results unveil significant retroreflection degradation in existing markings compared to refurbished markings across all regions. Central Croatia displayed the most considerable mean degradation, indicating a substantial decline in retroreflection with existing markings. Additionally, the effect size analyses (Cohen’s d and Hedges’ correction) reaffirmed the substantial retroreflection degradation observed across all regions. As presented in Table 3, the findings reveal a retroreflection degradation in existing markings compared to refurbished markings across all regions. Sitzabee, Hummer, & Rasdorf (2009) have developed linear models for predicting road marking service life. Their model for paint and thermoplastic road markings showed that retroreflection is a function of time, AADT, road marking colour and position (edge or middle lines) [13]. It is noteworthy that Central Croatia, with the highest retroreflection degradation, experiences higher AADT due to its transit nature [14] and has colder climatic conditions than warmer regions such as the Istria and Northern Coast.

Table 3 Paired Samples test by regions

		Mean	Std. Dev.	Std. Error Mean	95% Confidence Interval of the difference		t	df	Two-Sided p
					Lower	Upper			
Southern Croatia	RMR – EMR	85.400	41.598	10.741	62.364	108.436	7.951	14	<0.001
Mountainous Croatia	RMR – EMR	77.143	47.460	17.938	33.249	121.036	4.300	6	0.005
Eastern Croatia	RMR – EMR	94.682	48.030	5.912	82.875	106.489	16.015	65	<0.001
Istria and Northern Coas	RMR – EMR	67.050	32.544	7.277	51.819	82.281	9.214	19	<0.001
Central Croatia	RMR – EMR	132.091	100.327	17.465	96.516	167.665	7.563	32	<0.001

3.2 Comparison of retroreflection drop between regions

In order to compare whether the differences in the retroreflection degradation between regions are significantly different, the analysis of variance was performed. The F-statistic, which compares the variability between groups to the variability within groups ($F(4, 136) = 4.084$, $p = 0.004$), indicates a statistically significant difference in retroreflection drop among the regions. The robust test of equality of means confirmed the findings from the ANOVA (Welch statistic value of 3.789, $p = 0.013$), supporting the conclusion that there are significant differences in retroreflection drop across the investigated regions.
The Tests of Homogeneity of Variances, indicated by the Levene Statistic, showed that the assumption of equal variances across regions is violated, associated with highly significant p-values ($p < 0.001$), reinforcing the evidence against equal variances assumption based on median differences. Because of that, the Games-Howell post hoc test was performed to determine among which regions the most significant difference in retroreflection decline was detected (Table 4). It is important to note that while the ANOVA has shown overall differences among regions, the subsequent post hoc tests specify that not all regions differ significantly. Significant differences in retroreflection drop are observed between Eastern Croatia and the Istria and Northern Coast and between Central Croatia and the Istria and Northern Coast. These findings suggest regional variations in the effectiveness of retroreflection, potentially influenced by factors such as road conditions, maintenance practices, varying traffic intensities, or environmental factors specific to each region. Additionally, relevant insights can be drawn from a study by Mull and Sitzabe, who investigated 5128 km of road markings applied in solvent-borne paint. Their research found that the Annual Average Daily Traffic (AADT) had a statistically significant but weak impact on retroreflection degradation [15]. This suggests that while traffic intensity plays a role, it might not be the sole determining factor, and other regional-specific factors may also contribute to the observed differences in retroreflection decline among the mentioned regions.

Table 4 Multiple Comparisons with dependent variable in retroreflection drop

(I) Region	(J) Region	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Southern Croatia	Mountainous Croatia	8.257	20.908	0.994	-59.93	76.44
	Eastern Croatia	-9.282	12.260	0.940	-45.48	26.92
	Istria and Northern Coast	18.350	12.974	0.624	-19.66	56.36
	Central Croatia	-46.691	20.503	0.171	-104.91	11.53
Mountainous Croatia	Central Croatia	-54.948	25.036	0.223	-130.05	20.16
	Eastern Croatia	-17.539	18.887	0.878	-84.18	49.10
	Istria and Northern Coast	10.093	19.358	0.983	-56.65	76.83
Eastern Croatia	Istria and Northern Coast	27.632*	9.376	0.038	1.02	54.24
	Central Croatia	-37.409	18.438	0.271	-90.10	15.28
Istria and Northern Coast	Central Croatia	-65.041*	18.920	0.011	-118.96	-11.12

*. The mean difference is significant at the 0.05 level.

3.3 Comparison of renewed and existing road markings concerning the material

Table 5 presents sample statistics. For road markings made with paint, the mean retroreflection for renewed markings was 291.22, and for existing markings was 197.84. Regarding road markings made of plastic material, there were only two observations for renewed and existing markings. The mean retroreflection for new markings made of plastic was 709.00, while for existing road markings was 314.00. However, it is crucial to highlight the limitation in the sample size for road markings made with plastic material.

Table 5 Paired Samples Statistic between marking materials

Marking material		**Mean**	**N**	**Std. Deviation**	**Std. Error Mean**
Paint	RMR	291.22	139	58.724	4.981
	EMR	197.84	139	60.728	5.151
Plastic material	RMR	709.00	2	57.983	41.000
	EMR	314.00	2	132.936	94.000

The paired samples test compares the mean differences between two related groups based on the applied road marking material (Table 6). The mean difference between the refurbished and existing marking retroreflection for the paint marking is 93.381, indicating a significant difference ($p < 0.001$). On the other hand, the mean difference between the renewed and existing marking retroreflection for the plastic material is 395. Based on the conventional threshold, the difference between the refurbished and existing marking retroreflection for plastic material is not statistically significant at the 0.085 level, which confirms that plastic materials for road markings retain good visibility longer. However, the interpretation should consider the sample size and other contextual factors, like much higher initial retroreflection.

Table 6 Paired Samples Test between marking materials

Material		Paired Differences					t	df	Significance	
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				One-Sided p	Two-Sided p
					Lower	Upper				
Paint	RMR - EMR	93.381	54.412	4.615	84.256	102.507	20.234	138	<0.001	<0.001
Plastic material	RMR - EMR	395.000	74.953	53.000	-278.429	1068.429	7.453	1	0.042	0.085

When the retroreflection measurements are grouped according to the material, the variance homogeneity test indicates no significant difference in variances between the groups for retroreflection drop (all p-values > 0.05). In other words, the assumption of homogeneity of variances is met. Based on the provided ANOVA analysis, there is a statistically significant difference in retroreflection drop between the paint road markings and plastic road markings ($F(1, 139) = 60.195$, $p < 0.001$). This suggests that the type of road marking material influences retroreflection drop.

4 Conclusions

This research investigated the retroreflection degradation of road markings, considering various factors such as material type and geographic region. The analysis involved data collected over five years from state roads in the Republic of Croatia. The findings provide valuable insights into the dynamics of retroreflection degradation and its implications for road safety and infrastructure planning.

- Regional Dissimilarities: The research revealed significant variations in retroreflection degradation across different regions. Central Croatia exhibited the most substantial mean degradation, potentially influenced by its higher Annual Average Daily Traffic (AADT) and colder climatic conditions. Regional differences were evident, emphasizing the need for tailored road maintenance strategies considering local conditions.
- Material Influence: Road markings made from durable materials, particularly plastic, showed a significant difference in retroreflection drop compared to paint markings. Road markings made from plastic material retained better visibility over time, emphasizing the importance of material selection for road infrastructure planning. However, the interpretation should consider the small sample size for plastic material observations.
- Practical Implications: The research's findings underscore the practical relevance of understanding retroreflection degradation patterns. Insights into driving behaviours, regional variations, and material impact can inform road maintenance strategies and enhance traffic safety. The observed differences in retroreflection emphasize the need for adaptive measures considering specific regional and material characteristics.
- Limitations and Further Research: The research acknowledges limitations, particularly the small sample size for road markings made with plastic material. Further research with larger sample sizes and extended observation periods can enhance the reliability of conclusions. Additionally, exploring the impact of specific environmental factors on retroreflection degradation could provide a better understanding.

In conclusion, this research contributes valuable knowledge to road safety and infrastructure planning. By examining retroreflection patterns across diverse conditions, the research offers a foundation for evidence-based decision-making in the maintenance and selection of road marking materials. The findings can guide practitioners, policymakers, and researchers in optimizing road infrastructure for enhanced visibility and safety.

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