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MODEL FOR DETERMINATION THE CONTRIBUTION OF ADVERSE EVENTS DURING DYNAMIC MEASUREMENT OF ROAD MARKING RETROREFLECTION

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Abstract: Retroreflection of road markings should be periodically tested to ensure they are adequately visible to drivers. Dynamic testing of retroreflection using a vehicle-mounted reflectometer offers numerous advantages over static testing, but the overall evaluation of the markings quality, based on its results, may be incorrect due to the influence of various adverse events. These events include the presence of road works, dirt or humidity on the markings, overtaking of a slow vehicle, curves and intersections and the absence of markings. Here we present a model that estimates the contribution that such adverse events make to the total dynamic measurement. We developed the model using a dataset of 912 dynamic measurements collected over a 4-year period on state roads across 20 counties in Croatia, and we validated the final model on an independent set of 80 measurements. The results suggest that this tool may help road authorities to accurately evaluate the results of dynamic measurement and thus quality of the road marking.

Keywords: road markings, retroreflection, dynamic measurements, road asset management, road safety, quality testing.

1. Introduction

Road markings provide drivers with essential route and safety information. These markings contribute significantly to traffic safety, in part because they occupy the driver's central field of view. In fact, the presence of central and edge markings on their own may reduce the total number of traffic accidents by 20% (Miller, 1992). Road markings are only as effective as they are visible to drivers, which highlights the importance of selecting marking materials that provide adequate retroreflection over a sufficiently long service life. Since the choice of marking materials depends on other factors as well, including durability and cost (Cuelho *et al.,* 2003), retroreflection must be regularly assessed to ensure adequate visibility to drivers.

Quality testing of road markings involves measuring their visibility during the day and at night (Benz *et al.,* 2009), as well as measuring their slip resistance. Visibility can be objectively measured using a retroreflectometer, which is usually done statically as the examiner holds the device in his or her hand. Such static testing may take a long time and disrupt traffic substantially, leading some municipalities to rely on dynamic testing, in which the

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retroreflectometer is mounted on a moving vehicle. Although more expensive than static testing, this approach allows the collection of a far larger set of measurements in less time and over a greater surface area of the markings, while causing negligible traffic disruption.

Despite its advantages, dynamic retroreflection measurements may give results which may be rendered less accurate by certain adverse events related to traffic or the environment, such as when the measuring vehicle changes lane to overtake slower vehicles (*overtaking*), when marking is placed across intersection which causes faster degradation of marking due to the frequent passage of the vehicles (*intersection*), when markings are no longer present (*no marking*), when the road curves (*curve*), when road markings are interrupted by road works (*road works*), and when at least part of the marking surface is wet (*wet marking*) or soiled (*dirty marking*). These events, when occur, affect the measurement of road markings retroreflection and with that may cause incorrect evaluation of their quality. These events have been neglected in the relatively small literature devoted to dynamic retroreflection measurement (e.g. Sitzabee *et al.*, 2013; Dale *et al.*, 2012; Sitzabee *et al.*, 2009).

Therefore, the present study used data collected over a 4-year period across 20 counties of Croatia in order to develop a model for adjusting dynamic retroreflection measurements by taking into account the aforementioned events. The model works by estimating the minimal contribution of such events to the actual measurements. This is, to our knowledge, the first report of a quantitative method to increase the reliability of dynamic retroreflection measurements, and it may have important implications for road maintenance and policymaking.

2. Literature Review

The general belief that prevails in the scientific and professional community dealing with the influence of road markings on road safety is that there is a negative correlation, i.e. that with the presence of the markings and the increase of their retroreflectivity, there is a decrease in the number of traffic accidents during nighttime.

Several studies have proved the positive safety effect of road markings presence on the road safety. In 1981. Federal Highways Administration (Washington DC, USA) concluded that the number of traffic accidents with injured and/or fatalities has decreased significantly (from 3% to 16%) with the presence of middle and/or side lines. “Before and after” study conducted by (Tsyganov *et al.*, 2006) showed that roads without edge marks on the roadway have an 11% higher risk of traffic accidents compared to the road with edge lines. Also, the presence of edge markers has shown positive effects on traffic safety in nighttime and reduced visibility conditions.

Besides the presence of road markings, their visibility has a significant impact on the driver’s behavior and thus road safety especially during low visibility conditions (night, dusk, dawn etc.). Several studies have examined the minimal adequate retroflection of road markings to ensure visibility to drivers under dry conditions (Graham *et al.,* 1996; Zwahlen and Schnell, 1997; Loetterle *et al.,* 2000; Parker and Meja, 2003; Debaillon *et al.,* 2007) as well as wet conditions (Gibbons *et al.,* 2012; Gibbons and Hankey, 2007; Gibbons and Williams, 2012). Several studies have explored how retroreflection varies with marking material (Gibbons and Hankey, 2007; Gibbons and Williams, 2012; Zhang *et al.,* 2010), and how the road marking service life changes with different materials and road conditions (Shahata *et al.,* 2008; Zhang *et al.,* 2010; Grosges, 2008; Dale *et al.,* 2012; Sitzabee *et al.,* 2009; Andrady, 1997; Craig *et al.,* 2007). Other studies have explored how drivers adjust their behavior depending on road marking visibility (Zwahlen and Schnell, 2000).

From all above, it is clear that the retroreflection of the road markings should be inspected in order to assure their adequate visibility needed by drivers and thus increase overall road safety. We are aware of only a handful of studies reporting dynamic measurement of road marking retroreflection (Sitzabee *et al.,* 2013; Dale *et al.,* 2012; Sitzabee *et al.,* 2009). These studies were focused on using the mentioned method to collect the data in order to determine the service life of road markings. Although the authors in mentioned studies used dynamic method they didn't analyze the impact of various events on the quality of measurement results and overall evaluation of markings quality which is crucial for planning the maintenance activities. Therefore, the present study derived a model for assessing the minimal contribution (length) of adverse events to the total road length measured.

3. Methodology

3.1. Retroflection Definition and Dynamic Measurement

Retroreflection coefficient or nighttime visibility (*RL*) is defined as the ratio of the output surface luminance (*L*) to the input surface illuminance (*E*) (EN 1436:2009):

$$R_L = \frac{L}{E} \tag{1}$$

where R_L usually has the units of millicandela per lux per square meter (mcd/lx/m^2). R_L, in this research, was measured using a ZDR 6020 dynamic retroreflectometer (Zehntner, Sissach, Switzerland) mounted onto the left side of a Mercedes Viano minivan (Fig. 1). The measuring device measures retroreflection according to the EU norm EN 1436:2009, which implies a observation angle of 2.29°, an inlet angle of 1.24° and a distance of 30 m, while headlights were set to low beam. This testing geometry is identical to that recommended for static retroreflection measurement (EN 1436:2009).

A dataset of 912 measurements of central and edge road markings on state roads in 20 Croatian counties covering a total length of 33,497.87 km was collected between 2012 and 2015. To ensure the accuracy of the measurement, prior to each measurement the calibration of the device was done according to manufacturer's instructions. Also, as described by Babić et. al., the measurement interval was set to 50 m, which implies that device measures retroreflection every 2 ms and provides an average value every 50 m. Accuracy of the calibration and the dynamic measurements was checked using a hand-held ZRM 6014 retroreflectometer (Zehntner, Sissach, Switzerland).

Fig. 1.
Measurement Vehicle Carrying a ZDR 6020 Retroreflectometer Mounted on the Left Side
Source: Authors' photo

3.2. Contribution of Adverse Events to Dynamic Retroreflection Measurements

For each of the 20 counties, the contribution of dynamic measurements due to the seven adverse events mentioned in section 1 was determined based on visual inspection during the measurement process. In other words, codriver was putting remarks for each event in the measuring software while driving. After the measurement, software exported the total length and percentage share of each event in the whole measurement. These events were selected and defined based on empirical practice by researchers and engineers at the Faculty of Transport and Traffic Sciences in Zagreb and are most common things which may affect the evaluation process of road markings overall.

3.3. Linear Modelling of the Contribution of Adverse Events to Dynamic Retroreflection Measurements

Three linear models were generated based on the complete dataset of retroreflection measurements. To generate Model E1, a coefficient k_i was calculated for each county i according to the expression:

$$k_i = \frac{DE_i}{T_i} \quad i \in \{1, \ldots, 20\} \qquad (2)$$

whereDEi refers to the total event length in county i and Ti refers to the total measurement length in that county. The weighted average of ki across all 20 counties was calculated (0,025395) with the weight being the percentage share of ki for each county. This was used to generate the equation:

$$E_1 = 0.025395 \cdot M_D \pm 0.026857 \quad (3)$$

where T_1 refers to the minimal event length (in meters), and M_D refers to the total measurement length.

By analyzing the share of each event, it has been determined that the event *no marking* is predominant in relation to other events (the average share of the said event is 33,69% of the total events). Due to this extreme, that is, large discrepancy with respect to other events in each county, the respective event has been excluded from the analysis in order to obtain a more accurate model ($E2$). Weighted average of ki in this case is 0.016577. Final expression of model E2 is:

$$E_2 = 0.016577 \cdot M_D \pm 0.030056 \quad (4)$$

Even though the second model is more accurate, it does not take into account the *no marking* event which is, as previously mentioned, significantly present in the total share of events. For this reason Model E3 was generated by modifying Model E2 based on the weighted mean of P_a which represents the contribution of *no marking* events in the total measured length:

$$E_2 = 0.016577 \cdot M_D | P_a \quad (5)$$

Since weighted mean of P_a in our dataset was found to be 0.498818, the final optimal model took the form:

$$E_3 = 0.03323 \cdot M_D \pm 0.035551 \quad (6)$$

4. Results

Analysis of the entire dataset across all 20 counties showed that the total length of all events was 702 875 m, accounting for 2.10% of the total measured length (absolute deviation, 0.147%) (Table 1). The events making up the greatest proportions of the total measured length were *no marking* (0.695%) and *road works* (0.595%).

Table 1

Lengths of the Seven Adverse Events Affecting Retroreflection and their Contribution to total Measured Length, based on Data from 20 Croatian Counties

Event	Event Length (m)	% of Total Length
Overtaking	80,500.00	0.240
Intersection	73,175.00	0.128
No marking	232,950.00	0.695
Curve	23,550.00	0.070
Road works	199,250.00	0.595
Wet marking	37,600.00	0.112
Dirty marking	55,850.00	0.167
Total	**702,875.00**	**2.10**

Analysis of the data for each county separately (Table 2) showed that there is a significant difference between the length of events in total measurements length in each county from the lowest share in Dubrovnik-Neretva County (0,010%) to 3.315 % in Split-Dalmatia County. This shows that these events are affected by the road geometry, quality of the road surface, maintenance activities etc. Therefore, three linear models were generated in an effort to derive a general method for estimating the minimum content of adverse events in dynamic retroreflection measurements.

Table 2
Lengths of the Seven Adverse Events Affecting Retroreflection and their Contribution to Total Measured Length, by Croatian County

County	No. Measurements	Total Length (m)	Event Length (m)	Event Length as % of Total
Bjelovar-Bilogora	31	944,950.00	8,500.00	0.899
Brod-Posavina	17	306,050.00	5,200.00	1.699
Dubrovnik-Neretva	21	1,221,950.00	129,600.00	0.010
Istra	129	3,645,950.00	62,350.00	1.710
Karlovac	52	2,276,150.00	20,600.00	0.905
Koprivnica-Križevci	34	1,138,950.00	17,050.00	1.496
Krapina-Zagorje	39	841,200.00	13,400.00	1.593
Lika-Senj	68	3,726,000.00	28,250.00	0.758
Međimurje	20	458,850.00	8,500.00	1.852
Osijek-Baranja	42	1,962,550.00	45,500.00	2.318
Požega-Slavonia	17	467,550.00	9,900.00	2.117
Primorje-Gorski Kotar	32	1,702,550.00	30,450.00	1.788
Šibenik-Knin	76	2,766,100.00	42,600.00	1.540
Sisak-Moslavina	44	1,707,300.00	56,250.00	3.294
Split-Dalmatia	46	2,479,250.00	82,200.00	3.315
Varaždin	30	1,082,600.00	16,850.00	1.556
Virovitica-Podravina	22	1,396,400.00	22,900.00	1.640
Vukovar-Srijem	35	1,298,075.00	38,675.00	2.979
Zadar	81	3,082,050.00	50,900.00	1.651
Zagreb	83	993,400.00	13,200.00	1.328
Total/Average	**912**	**33,497,875.00**	**702,875.00**	**2.098**

In Model E1, data were analyzed on a per-county basis (see coefficients in Appendix 1). The event *no marking* accounted for 33.7% of all adverse events in the measurements. Therefore, we generated a potentially less biased Model E2 by removing *no marking* events from the dataset first. While this gave a more accurate model for our particular dataset, we were concerned that such a model would not be useful in the general case because it completely ignores *no marking* events. Therefore, we developed Model E3 by adjusting Model E2 based on the weighted mean of the contribution of *no marking* events to the total measured length. Model E3 was validated against a different dataset of 80 randomly selected dynamic retroreflection measurements carried out on state roads throughout the Croatia. These validation dataset was not previously used for developing a final model (E3) and represent 10.66 % of the dataset used for modeling. For the total measured length of 3,571,550 m, events amounted to 113,027 m, which compares favorably to the value of 118,682.61 m predicted by Model E3. This discrepancy of 5% is reasonable and successful. To statistically test the difference between measured and modeled length of events we used *t test*. Before conducting the t test two main assumptions were tested: normality of the data and homogeneity of variances. The normal distribution of data was assumed according to the *Central limit theorem*. To test the homogeneity of variances we used *F test*. The results of F test show that the variances of data are equal (F 1.155 > F Critical one-tail 1.451). Therefore, we used a two-sample *t* test assuming equal variances which indicated no significant difference (Two-tailed P (T t) two-tail > 0.05) between the model-predicted event length and the actual event length (Table 3).

Table 3
Statistical Analysis of the Difference Between Adverse Event Length Predicted by Model 3 and Actual Event Length

Measure	Observed	Predicted
Mean	1412.8375	1483.532581
Variance	588935.2517	680458.2778
Observations	80	80
Hypothesized mean difference	0	
degrees of freedom	158	
t statistic	-0.561223763	
Two-tailed P ($T \leq t$) two-tail	0.575440115	
Two-tailed critical *t*	1.975092073	

5. Discussion

This work represents the first attempt to improve the accuracy of dynamic retroreflection measurements by estimating the minimal contribution of seven common types of adverse events to dynamically measured retroreflection. The main goal of this research was to explore in which way adverse events that occur during the dynamic retroreflection measurement affect the road marking evaluation process. We found out that overall these events account for 2.10% of the total measured length of road markings. Since retroreflection in this 2.10% of the measurement is zero or relatively low it may significantly affect the accuracy of the final evaluation of the road markings quality.

Therefore, we developed model (E3) which is able to accurately predict the share of this events based on the total measured length of road markings. The developed model was validated with the new dataset, not previously used in the developing phase, and showed satisfactory accuracy (5% difference of the real values) from which one may conclude that the model is applicable when evaluating the quality of road markings. In other words, developed model may help road authorities to predict the length of adverse events and eliminate them from the results of dynamic measurements in order to accurately evaluate the quality of the marking.

The limitation of this study is that it takes into account only measurement done on the state roads in Croatia which are single carriageway roads. Future modelling work should explore the share of these events on other road types and incorporate a larger array of adverse events not covered here in the Croatian context.

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Appendix 1

Coefficients Used for Developing the Models

County	Coefficient k_i for model E_1	Coefficient k_i for model E_2	P_a
Bjelovar-Bilogora	0.009	0.00814	0.09412
Brod-Posavina	0.01699	0.01699	0
Dubrovnik-Neretva	0.05405	0.03396	0.37169
Istra	0.0171	0.00831	0.51403
Karlovac	0.00905	0.00707	0.21845
Koprivnica-Križevci	0.01497	0.01102	0.26393
Krapina-Zagorje	0.01593	0.01153	0.27612
Lika-Senj	0.00758	0.00607	0.2
Međimurje	0.02318	0.00826	0.64396
Osijek-Baranja	0.02117	0.0046	0.78283
Požega-Slavonia	0.01852	0.00915	0.50588
Primorje-Gorski Kotar	0.01788	0.01101	0.38424
Šibenik-Knin	0.0154	0.01034	0.32864
Sisak-Moslavina	0.03295	0.00917	0.72178
Split-Dalmatia	0.03316	0.03037	0.08394
Varaždin	0.01556	0.00951	0.38872
Virovitica-Podravina	0.0164	0.01425	0.131
Vukovar-Srijem	0.02976	0.00946	0.6822
Zadar	0.0167	0.01461	0.12531
Zagreb	0.01329	0.01299	0.02273
Weighted Mean Value	**0.0025395**	**0.016577**	**0.498818.**