sciendo

Transport and Telecommunication, 2023, volume 24, no. 4, 385–396
Transport and Telecommunication Institute, Lomonosova 1, Riga, LV-1019, Latvia
DOI 10.2478/ttj-2023-0030

PHANTOMATIC ROAD WORKS IN POLAND: A VIEW FROM A DASHBOARD CAM

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Correct signage belongs to critical factors affecting road traffic safety. During a naturalistic driving study in Poland major mistakes associated with signage were noticed: road works were announced and speed limits were reduced from 120 km/h to 70−80 km/h, but no road construction could be found. These errors were analysed from driver's perspective. Measurements of drivers' speed showed their complete disregard of the imposed limitations: average speed of light vehicles remained at 113 km/h and lorries at 88 km/h. Assessment of the encountered 683 road signs revealed 12.5% of them to be inadequate (10.9% falsely informed drivers). Evaluation of contrast ratio of road markings (their absence and replacement was the claimed reason for road work) showed consistently low values (Weber contrast 0.6). It is hypothesised that erroneous road signage and its contradiction with the visible road features are contributing to the permanent disobedience of traffic rules in Poland and are decreasing road safety.

Keywords: road safety, road signs, speed limit, road markings, contrast ratio, naturalistic driving study

1. Introduction

Road signs are inalienable features on majority of modern roads, informing drivers about the oncoming dangers and organising traffic; their perception and comprehension by drivers are very important aspects of road safety. Numerous studies were done to understand the impact of road signs on drivers' behaviour (Summala and Hietamäki, 1984). The research included certain types of road signs (Shinar and Vogelzang, 2013), influence of the drivers' age on road sign perception (Schulz *et al.*, 2020), studies of road signs recognition by drivers (Shinar *et al.*, 2003), the influence of inappropriate location of traffic signs on drivers' behaviour (Fisher, 1992), and the perception of road signs in work zones (Vignali *et al.*, 2019).

Amongst many methodologies used for analysis of the road environment and driver behaviours, naturalistic driving studies are used relatively seldom despite their numerous advantages (Singh and Kathuria, 2021). Until recently, the use of naturalistic driving studies in Poland was done only within the scope of project UDRIVE (Barnard, *et al.*, 2016; van Nes *et al.*, 2019), without any reported follow-up. While typical naturalistic driving study is concerned with both the drivers' behaviour and the environment and employs large number of drivers, a modification was done by us that changed the focus from the driver to the environment – recordings from a forward-facing dashboard camcorder collected by only one driver were analysed. This permitted for better concentration on the surroundings to which a driver is exposed while the complications associated with dissimilar driving styles were avoided; also, the quantity of data for analysis was reduced to a manageable amount. Dashboard camcorder recordings are really seldom used for such studies despite their broad availability; they were reported as useful for forensic purposes (Lallie, 2020) and for developments related to machine vision sensors (Fujiyoshi *et al.*, 2019). Their rare employment may be due to uncertain status in many countries and concerns related to privacy protection (Štitilis and Laurinaitis, 2016).

Road safety in Poland remains, despite quite steady drop in accidents, one of the poorest in European Union, with 2245 people killed and 26,415 severely injured in 22,816 accidents that occurred in 2021 (POBRD, 2022); these numbers exclude light injuries (i.e. those requiring less than 24 h of hospitalisation) and collisions (i.e. only property damage). There are definitely many reasons for such situation: poor condition of some roads, very low driving culture, absence of road safety culture, personal traits, low driving skills, inadequate driver education, lack of respect toward other road users (particularly pedestrians and bicyclists), very spotty and highly inconsistent enforcement, etc. In addition, anyone driving in Poland immediately notices enormous excess of road signs along with their frequently chaotic and erroneous

placement. During our ongoing similar study (Pashkevich *et al.*, 2021), this was confirmed: at a long work construction zone were found on average 13.3 road signs per kilometre (i.e. 12.7 signs per 1 minute of driving at the posted speed limit), out of which 5.6% were found to be erroneous – giving information that was either false or ambiguous.

The object of the presented research are "phantomatic road works" – such colloquial name was given by the authors to road segments where "road work" signs were installed and speed limit was very significantly lowered, by 40−60 km/h, without any valid reason that could be perceived by the drivers: without any road construction (no equipment, no workers, and no visible location where any road work could be taking place). Hence, at such areas the drivers are falsely informed. In the course of this study five segments of this "phantomatic" type, located at expressways, were selected for the presented case study, but numerous other examples can be provided. This work included the evaluation of drivers' speeds (to assess their response to the imposition of a lower speed limit), assessment of road signs for correctness, visibility, and quality (to evaluate possible differences in signage in comparison with roads not undergoing construction), and evaluation of road markings' contrast ratio (to check whether their visual quality decreased during the "phantomatic road work", particularly since some of it was due to "missing road markings"). To the best of our knowledge, it is the first assessment of this kind concentrating on this Polish specificity. The outcome is provided as an example of the possibilities of the methodology of using recording from a dashboard camcorder for naturalistic driving study. Another goal of this effort was to alert researchers and road administrators to the issue of grossly erroneous road signage in Poland. This publication is envisaged as a method to promote a discussion amongst scientists, road engineers, road administrators, road safety advocates, and lawmakers about the need to reduce the visual clutter at the roadways to bring the attention of drivers back to the road ahead.

2. Methodology

2.1. Equipment and analysed areas

Data collection was done with a dashboard camcorder (video recorded at the speed of 29.97 frames per second at resolution 1920×1080 pixels, with the field of view 140°), positioned at the front windshield of a passenger car, at the height about 1.2 m above the ground, at a location not obscuring the driver's view. The camcorder was equipped with a receiver of Global Positioning System data, which was recorded at frequency 1 Hz in NMEA text files, a standard format designed by National Marine Electronics Association (NMEA) – vehicle location, with the claimed accuracy of 10 m, and its speed were thus obtained for the analyses. The test driver relied on cruise control to maintain constant speed, which minimised errors in some of the calculations, and attempted to follow the rules of the road and obey the speed limits.

The recordings were evaluated with open-source software: VSDC Free Video Editor for frame-by-frame analysis of vehicle speeds and road signs and GNU Image Manipulation Program for the assessment of contrast ratio of road markings. Throughout data processing, all of the ethical guidelines set by Politechnika Krakowska and standards related to privacy protection were followed; only anonymous averages are provided and all reasonable care was taken to prohibit disclosure of any information that could cause privacy violations. There is no law that would prohibit or limit the use of dashboard camcorder recordings in Poland, as long as no identifiable data about any person is disclosed; contrariwise, police is encouraging drivers to make such recordings and they are considered an admissible evidence in Courts.

The analysis was made on five segments of two expressways (both four-lane limited access highways with nominal speed limit 120 km/h) that were travelled during a two-month period: route S7 between interchanges Szydłowiec Południe and Radom Zachód ("road work") and route S8 between interchanges Wólka Jagielczyńska and Radziejowice (four cases of road work with additional information "no road markings"; two in each direction). Each of the analysed segments was divided into sections 'no zone' – one interchange before and one interchange after the marked road work, circa 10 km each, and 'zone' – road segments 5.4−8.8 km long with speed limit reduced due to the "phantomatic road works". The total analysed carriageway length was 134.4 km, out of which 33.1 km were within the 'zone' segments. At some of the analysed stretches speed limit was lowered for other purposes to 90−100 km/h at distances 1.6−5.4 km (analysis of the plethora of such limitations cluttering the expressways is a separate research topic); herein, data was merged with the sections of the nominal speed limit. The assessed road stretches carried annual average daily traffic of 21,136−26,478 vehicles, including 5393−6562 (20−31%) of those classified as heavy (i.e. all buses and vehicles >3.5 t gross weight rating) (GDDKiA, 2022). Information about the length of each of the analysed stretches and speeds of the test vehicle is shown in

Table 1. It should be added that in vast majority of cases the traffic was free flowing, without hindrance that would demand slowing below the posted speed limit.

Table 1. Speed limits, analysed distances, and speeds of the test vehicle

Description	**Road work**		**No road markings I**		**No road markings II**		**No road markings III**		**No road markings IV**	
Section	'No zone'	'Zone'	'No zone'	'Zone'	'No zone'	'Zone'	'No zone'	'Zone'	'No zone'	'Zone'
Section length [km]	20.6	5.6	20.5	5.7	20.2	5.4	20.0	7.6	20.0	8.8
Speed limit [km/h]	120	80	120	70	120 (90)[(a)]	70	120 (100)[(b)]	70	120 (100)[(c)]	70
Average speed [km/h][(d)]	124	84	123	75	123 (104)	76	120 (104)	75	122 (104)	75

[(a)]Speed limit reduced to 90 km/h and then to 100 km/h at 1.6 km section. [(b)]Speed limit reduced to 100 km/h at 5.4 km section. [(c)]Speed limit reduced to 100 km/h at 4.7 km section. [(d)]In parentheses, average travel speed within the short segments with reduced speed limit; these were excluded from the other averages.

2.2. Data processing: speeds and violations

The overtaking or overtaken vehicles were assigned to several classes and their speeds were calculated based on the simple assumption that, with known speed of the test vehicle (from the NMEA file) and known length of the analysed vehicle (estimated based on the vehicle class), the time of the manoeuvre (from a frame-by-frame analysis of the recordings) would be proportional to the speed. The time of manoeuvre was the number of frames between the first appearance of the front and rear bumpers of the analysed vehicle in the camcorder's field of view. Hence, eq. 1 was utilised for the overtaking vehicles and eq. 2 for the overtaken; where v_1 – speed of the overtaking vehicle [km/h], v_2 − speed of the overtaken vehicle [km/h], d – distance travelled by the test vehicle during the manoeuvre [m], l – length of the analysed vehicle [m], and t – time of the manoeuvre [s].

$$v_1 = \frac{d+l}{t} \cdot 3.6 \quad (1)$$

$$v_2 = \frac{d-l}{t} \cdot 3.6 \quad (2)$$

The validation of this approach was done using hectometre posts and road markings as fixed objects with the known distances. The associated errors were found to be caused mainly by the difference in speeds between the test and analysed vehicles; typical error encountered herein would be 2 frames (i.e. 0.067 s). Because the distance travelled during the manoeuvre was much larger than the length of the analysed vehicle, the errors associated with approximation of the lengths could be considered as not significant for the purpose of this effort; it was rather the difference in speeds that played a role in the accuracy of the measurements. Acceleration or deceleration by the analysed vehicles could affect the calculations; for convenience, their speed was assumed as steady – nonetheless, its variation is hereby acknowledged as a source of error. Exactness of the speed provided in the NMEA files was not questioned, even though due to its frequency minor variations could occur. Overall, based on a prior similar analysis (Pashkevich *et al.*, 2021), where video recordings from two coordinated camcorders observing both the front and the back were used, error should not exceed 5% in vast majority of cases. To account for uncertainty of the measurements, the total inaccuracy of the vehicles' speedometers, natural variations of travel speed, and the aforementioned sources of errors, it was assumed that accuracy was 5 km/h; any discussions about this would bring no added value to this report. As speeding violations were considered those where the posted speed limit was exceeded by >10 km/h. Any observed violations of the traffic rules were recorded separately.

2.3. Data processing: road signs

A subjective self-devised scale for evaluation of road signs was utilised (Pashkevich *et al.*, 2021). Each sign was assessed for correctness, visibility, and quality and was given a rating 0−3, as described in Table 2. Errors, inconsistencies, uncertainties, visibility obstructions, and redundancies of road signs were crosschecked for coherence with road features, other signs, and road markings. In case of pendant

complementary tablets, the sign with the tablet was assessed as a whole, even though they were counted as separate signs (hence, some given numbers may appear not to match at the first sight). In Poland there are exact specifications related to the road signs that define their dimensions, colours, shapes, silhouettes, lettering, and placement, so such assessment can be considered reliable. Poor lighting or glare that could affect the ratings were not encountered, so their potential influence could be evaluated disregarded. It is possible that some road signs were missed due to being obscured by other vehicles; this inadequacy is acknowledged, but is not believed to play any meaningful role in the outcome. If a sum of rating in the three categories was less than 8, a particular road sign was considered as inadequate.

Table 2. Assessment scale for road signs

Rating	Correctness	Visibility	Quality of sign face
3	Appropriate	Good (no obstructions)	Good (clearly legible, appropriately reflective in headlights)
2	Counterintuitive, information unclear, might cause confusion	Poorly positioned, possibility of not noticing, crooked, spaced inappropriately	Quality inadequacy not affecting overall visibility or legibility but may be at the border of the specifications, slightly defaced, unequally reflective in headlights
1	Erroneous or inappropriate, confusing	Positioned incorrectly, poorly visible, obscured at some angles, blending with similarly coloured background, obscured by other road signs	Damaged, poor quality, but still might be perceived at some angles and in some circumstances, grossly defaced, inadequate reflectivity in headlights
0	Missing or plainly erroneous, providing false information	Invisible, mostly obscured, missing when necessary	Not legible, damaged to become ambiguous

2.4. Data processing: road markings

Evaluation of road markings was done based on their contrast ratio, which is critical for visibility (Brémond, 2020). The loss of luminance was not assessed because the road markings, in all of the cases structured, were not damaged to any perceptible extent. The evaluation was done only on four stretches of S8 expressway, with concrete surface; S7 expressway was excluded from the assessment because it had asphalt surface, which would make fair comparison inadequate due to different background.

Randomly selected images, without interference from other vehicles or excessive shadows, were analysed for luminance of the road markings and their neighbouring road surfaces as background. The images were not subjected to any digital manipulation. The measurements were done through obtention of average L* for area 3×3 pixels; three readings per image per line were done and the results were averaged. Of course, the short segments (total 1.1 km) where road markings were absent indeed were excluded from the analysis.

Calculation of contrast ratio was done according to the equation for Weber contrast shown in eq. 3, where: CR_W – Weber contrast ratio, L_m – luminance of the road marking, L_b – luminance of the neighbouring background (all parameters are unitless).

$$CR_W = \frac{L_m - L_b}{L_b} \tag{3}$$

3. Results

3.1. Speeds and violations

Speeds of the analysed vehicles, divided into various classes, are presented in Table 3 and visualised in Figure 1. The raw data was not varying meaningfully between the analysed segments, so for clarity of presentation all of the results were combined, including the short regions of reduced speed limits (from the standard 120 km/h to either 90 or 100 km/h); the same was done for speeds within the analysed "phantomatic road work" zones, where data from 70 km/h and 80 km/h zones was merged.

The speeds of light vehicles were 111 km/h and 114 km/h, correspondingly for the regions 'no zone' and 'zone'; similar median speeds and values for 25th and 75th percentile demonstrate only marginal influence of the outliers. The speeds of heavy vehicles also remained constant, at 88 km/h, regardless of lowering the speed limit. Limited statistical analysis (Student's t-test, two-tailed distribution,

heteroscedastic) indicated that the differences in measured speeds within or outside the "phantomatic road work" zones were not significant at 95% confidence level, with p-values 0.44 and 0.52, correspondingly for light and heavy vehicles. Due to relatively low number of the recorded vehicles in some classes, deeper statistical analysis would be burdened with high error and as such was not performed. The apparent average speeds of overtaking vehicles were lower within the 'zone' section (average 114 km/h) as compared to 'no zone' section (average 135 km/h); however, this was an artefact of including amongst them vehicles that would normally be overtaken – this serves as confirmation that drivers did not change their speed in response to the lowered permitted maximum.

Amongst the 260 analysed vehicles 297 violations were observed: 170 (65%) vehicles were speeding more than 10 km/h, 21 (8%) used improper traffic lane (i.e. continued to use of left lane while the right lane was free), 12 (5%) vehicles failed to properly signal the intention to change lane, 91 (35%) followed the preceding vehicle too closely (i.e. maintaining less than 1.8 s from the preceding vehicle, which is the minimum required in Poland – the shortest measured was 0.17 s, which at the vehicle speed of 124 km/h would give the distance of 5.9 m), 1 lorry overtook where it was forbidden, 1 driver was aggressively trying to force an already overtaking vehicle to accelerate more, and 1 vehicle had conflicting registration signage (while it had Polish number plates, it was simultaneously identified as registered abroad based on the oval international registration vehicle code; one wonders how such vehicle could pass the technical control). In 100 cases, there were more than one observed violation. Noteworthy is threefold increase in the number of violations (other than speeding) within the 'zone' as compared to 'no zone'; this issue demands verification and further research before any valid conclusions could be drawn.

Throughout the analysed segments, there were only 2 vehicles parked on a shoulder: an SUV stopped by an unmarked police car; the car had blue flashing lights on, but it was standing in front of the stopped vehicle, so it was not visible from a distance. No persons were seen.

Table 3. Analysed vehicles and their speeds

Section	**'No zone'**	**'Zone'**
Speed limit [km/h]	**90-120 km/h (heavy: 80 km/h)**	**70 or 80 km/h**
Total number of analysed vehicles	117	143
Light vehicles speed [km/h]: average / median (range)	111 / 107 (70−154)	114 / 112 (83−159)
Heavy vehicles speed [km/h]: average / median (range)	87 / 88 (78−90)	88 / 88 (85−89)
Vehicles that test driver overtook [number of vehicles]	86	0
Average speed [km/h][(a)], range (all overtaken)	94 (10), 70−123	–
: cars and passenger vans (33 vehicles)	98 (9), 77−118	–
: SUV and pick-ups (5 vehicles)	102 (11), 88−116	–
: delivery (15 vehicles)	94 (11), 70−123	–
: lorries and coaches (33 vehicles)	87 (3), 78−90	–
Vehicles that overtook test driver [number of vehicles]	31	143
Average speed [km/h][(a)], range (all overtaking)	135 (12), 110−154	114 (14), 83–159
: cars and passenger vans (127 vehicles)	135 (11), 110−152	113 (14), 83–159
: SUV and pick-ups (28 vehicles)	138 (12), 121−154	119 (12), 87–137
: delivery (11 vehicles)	133 (12), 120−145	110 (13), 90–129
: lorries and coaches (8 vehicles)	–	88 (1), 85-89
Number of observed violations	53	244
Number of observed violations other than speeding	26	101
[(a)]Standard deviations given in parentheses.		

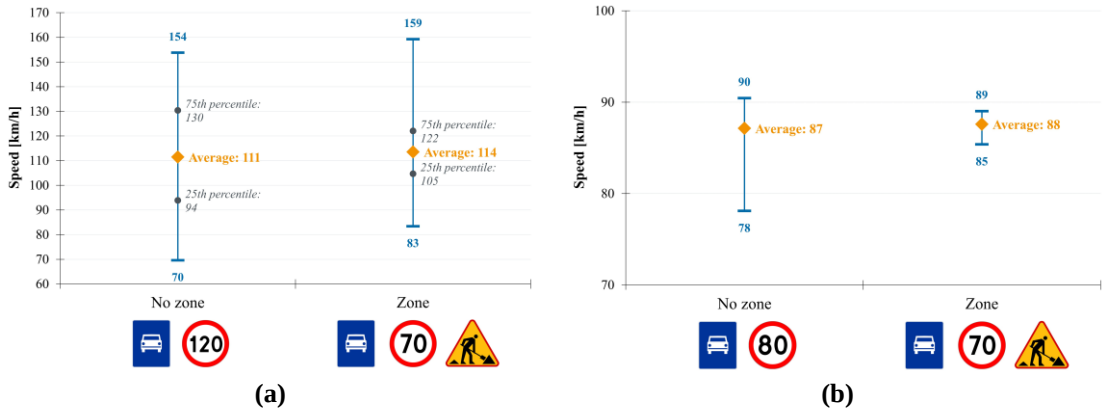


Figure 1. Speeds ranges of the analysed vehicles: (a) light vehicles, (b) heavy vehicles

3.2. Road signs

Exemplary images of the "phantomatic road work" are shown as Figure 2; the entire road segment with speed limit lowered to 80 km/h looked similar – no traces of any construction activities or road narrowing. It is not known whether the road signs were not removed from previous activities or whether they were posted in anticipation of some road work, or for how long they were present. In any case – drivers were informed that "road work" may mean "no road work ahead" and that "road narrows" may mean "road shall not narrow", which is absurd.

The number of encountered road signs and their ratings are presented in Table 4. There were a total of 683 road signs (558 were rated due to considering for the assessment the pendant tablets together with the main signs). Besides enormous excess of road signs (overall average 5.1 per 1.0 km of roadway or, which seems more appropriate for limited access roads, 20.1 signs per interchange), one should foremost note that 70 (12.5%) of them were rated as substandard, including 61 (10.9%) that were erroneous based on the observed road features. It might be worth noting that in none of these cases there was any information about the end of road work zone, so intersections signalled cancellation of the previous limits and warnings. The number of road sign within the 'zone' sections was not statistically different within 95% confidence interval from other road segments (Student's t-test, two-tailed distribution, heteroscedastic), with p-value 0.098. The measured difference in evaluation of road signs within the 'zone' and the 'no zone' was statistically significant with p-value <0.001.

The most dense road signs agglomeration was 18 of them at the distance of 335 m. Since median observation time for a road sign was reported to be 0.154 s (Costa *et al.*, 2014), observation of these many signs would take a driver travelling at the posted speed limit at least 2.77 s (i.e. not less than 21% of the time). That would result in inattention to either the road signs or the traffic and road ahead (Hughes and Cole, 1986). Nonetheless, due to the enormous excess of road signs in Poland, these prior results might be inadequate representation; a separate case study with an eye tracker is intended.



(a) **(b)**

Figure 2. Exemplary images from the "phantomatic road work" zone: (a) entrance to the 'zone' (observe crooked road sign "road narrows", rated 2 for visibility; all of these road signs were rated 0 for correctness due to the absence of road work and false information about narrowed road ahead; the information about the length of 5.0 km was additionally false because the 'zone' was 5.6 km long; furthermore, the order of the signs on road sides was reversed), (b) circa 3 km after entrance to the 'zone' (similarly absent road work activities were visible throughout the 'zone' segment)

Table 4. Number of analysed road signs and their rating

Section	**'No zone'**	**'Zone'**
Number of all road signs	462	221
– warning[(a)]	69 (43)	44 (39)
– prohibitory and mandatory[(a)]	62 (6)	41 (3)
– information[(a)]	64 (10)	12 (5)
– direction[(a)]	120 (14)	45 (4)
– all other[(a)]	73 (1)	28
– complementary (pendant tablets)	74	51
Road signs per km / per intersection / per 1 minute drive at posted speed limit	4.6 / 17.8 / 8.9	6.7 / 27.6 / 8.0
Average rating (all signs)	2.95	2.55
– correctness	2.98	1.95
– correctness, except associated with 'zone'[(b)]	2.98	2.95
– visibility	2.91	2.79
– quality	2.96	2.91
Number of substandard[(c)]	8	62
Number of substandard, except associated with 'zone'[(b)(c)]	8	4

[(a)]In parentheses, number of signs with pendant tablets (complementary signs); the complementary tablets were counted as separate road signs, but rated together with the main sign. [(b)]Without considering the road signs creating the analysed "phantomatic road work" zones. [(c)]As substandard were counted all road signs with sum of individual ratings lower than 8.

One ought to additionally note that at the analysed 134.4 km of roadway, there were 33 changes of speed limit for light vehicles (i.e. on average, speed limit change per 4.1 km or 25 changes per 1 h of drive at the posted maximum), including decreases due to the "phantomatic road works". The issue of very frequent changes in speed limits in Poland, at almost all road classes, is a separate research topic under both field and simulator conditions; as such, it is not to be discussed herein except for providing this data.

3.3. Road markings

Road markings were assessed because the speed limit at four analysed locations was lowered to 70 km/h with information "no road markings", as shown in Figure 3a and Figure 3b; however, the test driver has seen them clearly and they were also visible on the analysed images. Out of 5.4−8.8 km of the zones with reduced speed limit, road markings were absent only at 0.07−0.49 km (1.2−6.5% of the distances with reduced speed); i.e. out of the total 27.5 km, at only 1.1 km road markings were missing indeed, as shown in Figure 3c and Figure 3d. Consequently, the drivers were informed that "no road markings" may mean "there might be a short stretch without road markings", which is absurd.

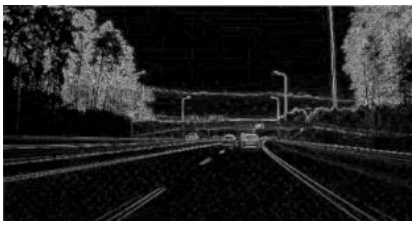


Figure 3. Exemplary images from road segments signed with "no road markings": (a) speed limit, (b) entrance to the 'zone' with information "no road markings", (c) area 220 m long where the road markings were absent indeed, (d) area 70 m long where the road markings were absent indeed, albeit not entirely

Upon measuring contrast ratio in the road sections 'zone' and 'no zone', the claim that road markings were missing could have been considered as partly confirmed, with average CR_W = 0.3 (range 0.1−0.8) and CR_W = 0.5 (range 0.2−0.8), correspondingly for the 'zone' and the 'no zone'. The difference was statistically significant at 95% confidence level (Student's t-test, two-tailed distribution, heteroscedastic) with p-value <0.001. However, doubts arose about validity of such data because during repeated drives it was observed that the 'no zone' road segment became 'zone', and vice versa. Hence, the study was modified to evaluate the changes in the contrast ratio for one 'zone' before, during, and after its imposition. The new analysis was limited to 4.5 km because it was the only road segment, where the changes could be precisely identified. Assessment has shown that there was no statistically significant change when one compared the contrast ratio in the periods before and after imposition of the 'zone' (Student's t-test, two-tailed distribution, paired, 95% confidence interval) with p-value 0.87, which confirms that the removal and subsequent replacement of road markings was done for a purpose other than the improvement of their visibility. The results, along with exemplary images are provided in Table 5 and shown graphically in Figure 4.

Because the recognition of edges is as important as the contrast ratio for both human and for machine vision (Watt and Morgan, 1983; Szeliski, 2022), the exemplary images were subjected to edge detection according to Sobel algorithm: sufficient distinction of RM was thus confirmed, as shown in Table 5. The consistently low measured contrast ratio, which could be problematic, was most likely due to the lightly coloured roadway concrete roadway surface. Unfortunately, there is no known efficient solution to this issue (maybe except the occasional use of black paint to increase the contrast, as is done in North America).

Table 5. Contrast ratio before, during, and after road work

Period	Picture	Edge detection according to Sobel	Contrast ratio[(a)]
Before road work			Edge line: CR_W = 0.38 Middle line: CR_W = 0.48 Section 4.5 km average: CR_W = 0.56 (0.3 − 0.7)
'Zone'			Edge line: CR_W = 0.14 Middle line: CR_W = 0.14 Section 4.5 km average: CR_W = 0.20 (0.1 − 0.4)
After road work			Edge line: CR_W = 0.43 Middle line: CR_W = 0.53 Section 4.5 km average: CR_W = 0.56 (0.4 − 0.8)

[(a)]Analysed was section 4.5 km long, in the same locations, 10 images per period. In parentheses are given the measured ranges.

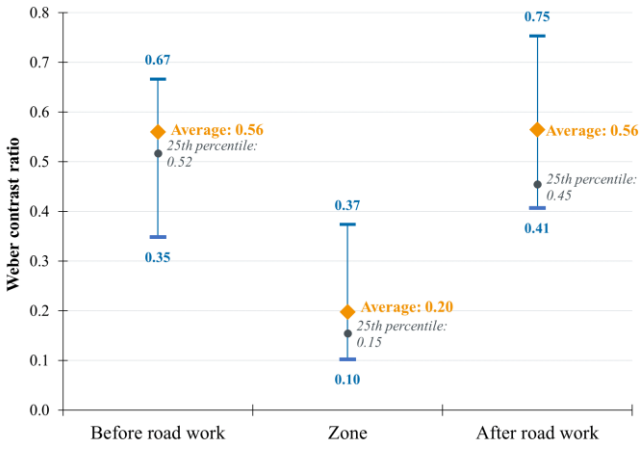


Figure 4. Contrast ratio at the analysed 4.5 km long road segment

At this point, one must observe that the reason for these "missing road marking" zones was their mechanical removal before reinstallation (that is why the same road segment that was 'no zone' became 'zone'). The purpose of such work is unknown because under normal circumstances structured road markings (such as those that were analysed) with the structure mostly intact are renewed with thin-layer applications of paint or sprayed cold plastic (Burghardt *et al.*, 2021). Hence, with appropriate selection of materials and good workmanship, mechanical removal of road markings should be a very rare effort. Moreover, one must note extremely slow work pace: a typical grinding machine operates at the speed of 1.5−2.0 km/h (European Committee for Standardization, 2017). Hence, the entire operation at the analysed segments, including re-marking, should not take two months, but no longer than one week (42−55 hours of actual work time) and the work should have been done on a line-by-line basis, with removal and installation on the same day.

The initial finding of statistically significant difference between the 'zone' and 'no zone', which was in this case inappropriate due to relocating of the 'zone', can be given as an example for the necessity of

very cautious approach to any data and search for alternative explanations, along with thorough examination of the reasons for particular results. Scientific scrutiny and careful observation of the road features, combined with repeated data collection campaigns, permitted for pinpointing the source of incoherence, which allowed for elimination of the confounder.

4. Discussion

It is hypothesised that the issue addressed herein, incorrect road signage, may be amongst meaningful contributors to the permanent extreme disobedience of traffic rules in Poland. Given that drivers are exposed to false information – in this case about the presence of road works while they were absent or the absence of road markings while they were present – they cannot rely on any road signs. An alternative plausible explanation for such behaviour might be the issue of freedom to take own risks and rejection of paternalistic regulations (speed limits can be considered as such) (Elvebakk, 2015), which may be associated with the local culture and risk perception, as was reported for the case of Greece (Nævestad *et al.*, 2022). Further research would be demanded to confirm or disprove our hypothesis.

Based on the provided easy scale for expedient assessment of road signs, 10.9% of signs were judged to be providing drivers with false information (total of 12.5% were rated as inadequate). This erroneous signage may be causing dissonance even amongst those drivers who under normal circumstances would obey the traffic rules and speed limits to ignore those that may be associated with the "phantomatic road works", as can be deduced from the assessment of speeds of the overtaking vehicles. Although one might consider that the observed behaviour was "only speeding" and that in vast majority of cases the road construction would be real and not "phantomatic", one must consider that a natural human response to conflicting information include its avoidance, suppression, or disregarding (Hirsch, 2012).

It was established that amongst detrimental factors of road safety was mistaken recognition and interpretation of road signs (Shinar *et al.*, 2003). Whereas the issue of recognition was not addressed herein, the encountered signage was quite likely to decrease drivers' confidence of safety and reliance on road features due to conflicting messages, disconnected from the observed reality. Hence, it may be hypothesised that erroneous signage may have caused drivers not to *obey* the road signs or traffic rules, but to *interpret* them. Consequently, the drivers may, for example, *interpret* "speed limit 80 km/h" instead of "drive not more than 80 km/h" as "someone forgot to remove the speed limit sign – drive 140 km/h, which looks appropriate for the road ahead"; in the absence of visual cues confirming the need to reduce speed, drivers would subconsciously accelerate beyond the posted speed limit. Thus, according to Driver Behaviour Questionnaire classification (Özkan, *et al.*, 2006; de Winter and Dodou, 2010), in Poland it may be possible to reclassify numerous violations (intentional actions) as errors (unintentional actions). The incorrect, counterintuitive, and sometimes conflicting and plainly inappropriate road signage – completely departing from the concept of self-explaining roads (Theeuwes and Godthelp, 1995) – may be teaching the drivers that many road signs and traffic rules in Poland are not to be obeyed and should be rather treated as recommendations instead. Unfortunately, majority of roads in Poland are self-unexplaining and the examples given herein confirm this claim. One should additionally note that some road signs commonly used in Poland do not seem to bring any added value to the drivers, their usefulness is highly doubtful but they increase the visual clutter; this is yet another broad topic that demands investigation and quite possibly lobbying for a systemic change. Furthermore, constant changes in speed limit, sometimes at very short distances, often without apparent reason and quite frequently to unreasonably low permitted maximum, definitely do not seem to be effective, but are rather prompting drivers to ignore them – this topic also requires separate attention.

It is very likely that the road administrator may provide technical explanations for the given signage that was classified herein as "phantomatic" – a preparation for a road work or signs that were not yet removed after the construction activities were finished would be likely answers to enquiries. Nonetheless, any such explanation would be based on information inaccessible to a casual driver. Even if for this article only five examples of the "phantomatic road works" were analysed, recordings collected during this ongoing naturalistic driving study contain a plethora of other similar examples, at all classes of roads. All of this strongly suggests a systemic problem and not an isolated issue. The incorrect signage analysed herein was associated with road works; it is surprising that the road construction crews, whose efforts should comprise increasing road safety, so meaningfully contribute to the chaos amongst road signalisation in Poland. No research about this issue could be found, but it is most likely due to the simultaneous lack of supervision from the road administrators and the absence of safety culture (Neal and Griffin, 2013).

At this point, one should mention that even a Court of law in Poland in a final judgement acquitted a person who was driving at a road with speed limit 70 km/h with speeds exceeding 240 km/h (not to

mention illegal overtaking, forcing numerous other drivers to evading manoeuvres to avoid a collision, running red lights, driving wrong way, and escaping from police), explained in the justification that "the driver was in full control of the vehicle" (Sąd, 2022). It is possible that such Court's ruling could have been partially influenced by the aforementioned common *interpretation* of the traffic rules, as being taught through the given examples of "phantomatic road works", instead of their *obedience*.

The issue of correctness of road markings in Poland has not been, to the best of our knowledge, addressed so far in literature, which is quite surprising given the importance of such signalisation. The evaluation of contrast ratio has shown it to be low, but the road markings remained visible and their edges could be detected, so it appears that advanced driver assistance systems should be able to function properly under most of weather and lighting conditions. Based on professional expertise and observations, majority of existing inadequacies of the quality of road markings in Poland are associated with improper selection of materials, the lack of supervision, and the prevailing policy of rewarding in tenders the lowest bid price – the combination of these factors is a strategy that can be described as designed-to-fail: there is no motivation whatsoever for the road marking contractors to maximise the quality, so only the cheapest materials that are available on the spot market are utilised, with the hope that the applied road markings would somehow pass the minimum requirement. In a series of articles originating from our research, it was repeatedly shown that the use of high-end materials for road markings would not only prolong their service life (Burghardt *et al.*, 2021; Burghardt *et al.*, 2019), but also enhance the retroreflectivity for driver comfort (Horberry *et al.*, 2016; Diamandouros and Gatscha, 2016; Pashkevich *et al.*, 2017) and increased road safety (Avelar and Carlson, 2014). Very importantly, it was calculated that from long-term perspective the use of such materials would not cause increase in the total price (Burghardt and Pashkevich, 2020). Prolonged functional service life was also clearly associated with sustainability of the applied road markings (Burghardt *et al.*, 2022). It is surprising that at a major road its administrator would not organise immediate emergency renewal of road marking when they failed (if they failed indeed), but instead permitted for the extremely sluggish work speed and allowed that drivers were falsely informed about the absence of road marking at quite long distances for about 2 months, which created a major traffic obstruction. Should any work crews be present, they would also be endangered because of the prevalent speeding that, as is hypothesised, was caused by the false messages. The easy solution to many of such cases would be including in tenders appropriate stipulations related to the time of road closure and correct signage, along with strict supervision; constant demands for the highest quality, even at the expense of slightly higher unit cost, would also be advantageous.

The presented research method that utilises a dashboard camcorder was shown as quite efficient, easy to use, inexpensive, and readily accessible technique. Nonetheless, because the methodology is weakly explored, there might be yet unknown aspects, either strengths or deficiencies, associated with its employment to assess roads and drivers' behaviour as seen by other drivers. While the main weakness of the utilised research technique was a perspective from only one driver, it could simultaneously be considered as an advantage because the driving style remained relatively constant. Errors and limitations associated with any obstruction of the camcorder view, caused either by other vehicles, reflecting light, or even bugs on the windshield would be also encountered by the drivers, so their influence could be discounted as being just a naturalistic representation of visibility. The proposed scale for road signs assessment may need additional refinements; for example, it was noticed that a road sign posted at a crooked post may be classified as not meeting the quality requirement (because the law defines that a sign must be positioned straight) or the visibility requirement (because it is positioned improperly). Such situations and uncertainties demand supplementary research and unification for any future assessment (herein, the situation was classified as the issue with the visibility). Additional error analysis or deeper statistical validation of the results were beyond the scope of this report.

As the study is ongoing, additional work associated with other roads in Poland and elsewhere is being done and shall be promptly reported; analysis of accident frequencies within work zones would be included. The topic of improper signage and the absence of self-explaining roads in Poland is planned to be explored in more depth, as it is seen amongst meaningful contributors to poor safety record. Proposing solutions to this important issue addressed herein was not amongst the purposes of this first effort; nonetheless, evaluation of the road signs for correctness and coherence with road features and elimination of the erroneous signalisation should be done by the road administrators immediately and road signage should be improved — to benefit the drivers and, through possible reduction of the accident rate, also the entire society. There are many systemic errors that create overloading of drivers with road signs that are mandated by legislation; correction of the statutes is necessary to eliminate them.

5. Conclusions

It is hypothesised that errors in road signage and the lack of self-explaining road features might meaningfully contribute to the permanent disobedience of traffic rules in Poland and are negatively affecting road safety. The results of this analysis based on dashboard camcorder recordings confirmed (1) incorrect road signage related to road work zones, (2) the associated improperly set speed limits, which (3) were notoriously ignored. Consequently, in spite of lowering the speed limit by 40−50 km/h, the average speeds did not change and remained at 113 km/h (maximum 159 km/h) for light vehicles and at 88 km/h for lorries. The number of road signs was large (5.1 signs per 1.0 km of roadway) and 12.5% of them were classified as inadequate, based on an easy visual assessment scale that was proposed. An additional value for this work was presentation of the research method based on the use of an inexpensive dashboard camcorder and utilisation of public domain software for the analyses – they were an economical, yet powerful research tool.

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