Proceedings of 7th Transport Research Arena TRA 2018, April 16-19, 2018, Vienna, Austria

Can light engineering measures make a difference? An overview of the effect of delineation and signage on road safety

Ziakopoulos A. a*, Botteghi G. b, Macaluso G. b, Theofilatos A. a, Papadimitriou E. a, Yannis G. a, Diamandouros K. c, Arampidou K. c

[a] *Department of Transportation Planning and Engineering, National Technical University of Athens, 5 Heroon Polytechniou str., GR-15773 Athens, Greece*
[b] *Università degli Studi di Firenze, P.zza S.Marco, 4 - 50121 Firenze, Italy*
[c] *ERF - European Union Road Federation, Place Stéphanie 6/B, 1050 Brussels, Belgium*

Abstract

The objective of this study is the examination of several light engineering measures with the explicit purpose of assessing their impact on road safety. Examined categories include delineation and road markings, which can be longitudinal for road segments and transversal for junctions, and installation and maintenance of traffic signs, investigated both in functioning workzones and otherwise. This analysis was carried out within the SafetyCube project. Existing studies were selected and analysed in a set taxonomy consisting of 5 measures: signage installation and improvement for workzones, road markings implementation, installation of chevron signs, edgeline rumble strips and lastly traffic sign installation and traffic sign maintenance. A clearly defined methodology was developed including rigorous literature search, analysis of studies in terms of design, methods and limitations and synthesis of findings and meta-analyses, when feasible. The results of the present study offer valuable insights that were previously undefined can be generalized for other cases with the essential caution due to study particularities.

Keywords: road safety; measure effects; delineation; road markings; traffic signs; rumble strips; workzones; chevron signs; crash reduction; speeding reduction

* *Corresponding author. Tel.: +30-210-7721575; fax: +30-210-7721454.*
E-mail address: apziak@central.ntua.gr

1. Introduction

In modernized countries with high development indices road environments are heavily developed, and thus demanding of more road safety solutions that are less obstructive than infrastructure construction or reconfiguration. These solutions are considered light engineering measures, in the sense that they do not interfere with infrastructure elements and do not involve heavy construction, but rather management and additions in the road environment such as delineation improvements or traffic sign installations. For example, such measures includes delineation and road markings, installation and maintenance of traffic signs, investigated both in functioning workzones and otherwise and so on.

Firstly, workzone measures such as the installation of signage and road safety improvements are commonly implemented to warn drivers of their approach to an unfamiliar and unpredictable environment where construction is taking place. Their presence and effectiveness impacts road safety levels, reducing vehicle speeds and improving lane keeping. On the other hand, road markings implementation measures refer to painted markings on the road, used to convey information to drivers. Several designs are implemented, such as including retroreflective markings, chevron markings, barrier lane and numbered markings. Junction reconfiguration is also considered, such as gantry signs and spiral markings. Chevron signs are widely used as safety devices to warn drivers of the severity of a curve by delineating the alignment of the road around that curve. Therefore, the presence of chevrons, either alone or combined with other devices, affects the level of road safety. Chevrons cause a reduction in the number of crashes and in driving speed, and have beneficial effects on lateral position. Edgeline rumble strips are used to alert inattentive drivers of potential danger by causing tactile vibration and audible rumbling, transmitted through the wheels into the vehicle interior. Their presence and effectiveness impact road safety levels, theoretically causing a reduction in the number of total crashes and encroachments across the edgeline. Lastly, traffic signs are widely used to warn road users and provide them with information. Their presence and effectiveness affects road safety levels, causing a reduction in mean speed and in the number of vehicles travelling over the displayed speed limit. In addition to this, traffic sign installation and maintenance also leads to an improvement of vehicular lateral position.

Consequently, these measures are of particular interest and importance and therefore the present study aims perform an assessment of several light engineering measures in order to provide insight on their impact on road safety.

2. Methodology

This study is based on the SafetyCube project (SafetyCube 2017a and 2017b), which aims to identify and quantify the effects of risk factors and measures related to behaviour, infrastructure or vehicle, and integrate the results in an innovative road safety Decision Support System (DSS). Overall, the methodology consists of three distinct steps. The first step comprises thorough international literature database searches, in order to identify relevant studies, and screening and selecting relevant studies to be included in the assessment analysis on the basis of rigorous selection criteria; priority is given to studies reporting quantitative results, recent studies over older studies (before 1990), and European studies as opposed to overseas ones. The literature searches were carried out in autumn 2016. Each literature search, study coding and synopses creation for a particular risk factor was completed within the same SafetyCube partner organization. The process was documented in a standard format to make the gradual reduction of relevant studies transparent. The main databases used for behavioral risk factors were the following: Scopus, TRID, Google Scholar, ScienceDirect**,** Taylor & Francis Online, Springer Link etc. Studies considering crash data were designated the most important. However, while the actual occurrence of crashes can be seen as the ultimate outcome measure for road safety, Safety Performance Indicators (SPIs) have in recent years been taken into consideration to quantify the road safety level (Gitelman et al., 2014).

The second step includes the analysis of the studies in terms of design, analysis methods and limitations. For the full list of information provided per study the reader is referred to Martensen et al (2017). For each study the following information was coded; Road system element (Road User, Infrastructure, Vehicle) and level of taxonomy, basic information of the study (title, author, year, source, origin, abstract), road user group examined, study design, measures of exposure to the risk factor, measures of outcome (e.g. number of injury crashes), type of effects (within SafetyCube this refers to the numerical and statistical details of a given study in a manner to quantify a particular association between exposure (either to a risk factor or a countermeasure) and a road safety outcome), effects (including corresponding measures e.g. confidence intervals), limitations, summary of the information relevant to SafetyCube (this may be different from the original study abstract).

The third step concerns the synthesis - and meta-analysis, when feasible - or research results per topic, for the estimation of overall effects, general trends and the assessment of the transferability of results. The syntheses of studies for each topic were made available in the form of a 'synopsis' indicating the main findings for a particular risk factor derived from meta-analyses or another type of comprehensive synthesis of the results (e.g. vote-count analysis), according to the guidelines and templates available in Martensen et al. (2017). The synopses contain contextual information for each risk factor and measure from literature that could not be coded (e.g. literature reviews or qualitative studies). However, not all the coded studies are included in the analysis of the synopsis.

In order to achieve the aims of the present study, existing international studies were selected and analysed in a set taxonomy consisting of 5 measures: signage installation and improvement for workzones, road markings implementation, installation of chevron signs, edgeline rumble strips and lastly traffic sign installation and traffic sign maintenance. For each measure a clearly defined methodology was developed including rigorous literature search, analysis of studies in terms of design, methods and limitations and synthesis of findings and meta-analyses, when feasible.

3. Results

3.1. Signage installation and improvement for workzones

Most studies reported speed reductions after workzone signage installation or improvement (Bai et al. 2010, Bernhardt et al., 2001, Chu et al., 2005, and Takemoto et al., 2008). It should be mentioned that for the results of Takemoto et al. (2008) and some of Bai et al. (2010) no statistical significance testing was conducted or presented, and thus the findings are interpreted with caution. The remaining study (Brewer et al., 2006) offers mixed results, but there are reasons that can be posed for these unclear conclusions, including interpretation of the results by the authors: Firstly, the outcome parameter is speed limit compliance rate, which is a very indirect road safety indicator; roads are known to be designed with lower speeds than the upper safe speed limit (85th percentile speed-V85). Secondly, results include locations quite farther upstream of the workzone, where the drivers did not perceive any direct changes of the road environment. Lastly, several effects concern removal of signage to determine if there would be rebounding effects (the equivalent of "stable equilibriums"). Bernhardt et al. (2001) reported improvements regarding lane distribution as well. The lane distribution parameter is considered to be improved if fewer vehicles remain in the lane closed downstream in the after case than in the before case. Overall it would be safe to assume that workzone signage installation or signage improvement has positive impacts on road safety. This result is intuitive considering the nature of the measure and the particular alertness that workzones induce on drivers, stemming from the change of the more predictable road environment to a less well known and potentially more dangerous one. An overview of the main features of the coded studies (sample, method and outcome) is illustrated on Table 1.

Table 1. Description of coded studies regarding signage installation and improvement for workzones.

Author(s); Year; Country;	Sampling frame for workzone measures studies	Method for workzone measures impact investigation	Outcome indicator
Bai, Y., Finger, K., & Li, Y.; 2010; USA	Field experiments were conducted on two two-lane work zones with flagger control for 4 days, with 876 vehicles as a total sample.	Absolute proportion comparisons for several quantities	Mean speed
Bernhardt, K., Virkler, M., & Shaik, N.; 2001, USA	The research site was an Interstate freeway (I-70) passing through Columbia, Missouri. Instruments for data collection were installed at four locations along the approach to the work zone, and data were collected in 15-min intervals before and after the measures	Significance testing used a two-tailed Student's t-test with a level of significance $\alpha = 0.05$. An F-test was also conducted (again $\alpha = 0.05$) to find significant differences in the speed variance.	Lane distribution, Mean speed and speed variance characteristics
Brewer, M., Pesti, G., & Schneider IV, W.; 2006; USA	Researchers field-tested three devices in that project: a speed display trailer, changeable message sign with radar, and orange-border speed limit sign. devices at two study sites in Texas: Site 1 was on a rural Interstate highway, and Site 2 was on a U.S. highway within the city limits of a small town.	A multifactor analysis of variance (ANOVA) for several effects	Speed Limit Compliance Rates Comparison

Chu, L., Kim, H. K., Chung, Y., & Recker, W.; 2005; USA	This is a study on the effectiveness of an automated work zone information system, which was deployed in the work zone site located in the city of Santa Clarita, north of Los Angeles, on freeway I-5.	F and Z-tests were conducted to statistically compare speed variances of two populations for the before-and-after scenarios.	Sample variance of speeds
Takemoto, A., Hirasawa, M., & Asano, M.; 2008; Japan	An experiment was carried out, in which 28 subjects were asked to drive at 50 km/h on a 250-m test track from the starting point to the end of the construction zone; a data recorder and a video camera recorded driver data.	Descriptive statistics - no statistical analysis conducted	Speed reduction

3.2. Road Markings

The studies reported mostly positive results regarding outcomes of variables for road safety. The meta-analysis (Van Driel et al., 2004) examined road markings implementation treatments via the investigation of the effects of an edgeline on speed and lateral position of motorized road users. Considerable significant correlations were found between changes in mean speed and alteration of road markings, and between changes in mean lateral position and road delineators. The meta-analysis study presented several ranges of results for the parameters of speed and lateral position (without statistical verification) and concluded that the effects of an edgeline on speed are related to the presence of a centreline. A further conclusion is that shoulder width and road environment contribute to the effects of an edgeline on lateral position. Wong et al. (2006) investigated the impacts on a toll plaza of a trial traffic guidance scheme and the erection of a gantry sign that clearly distinguishes the respective auto-toll lane. Results for crash counts showed a reduction that was significant, ranging from -26.2% to -61.7%. Absolute differences for lane changing rates ranged from -32.8% to -41.5%. Wong et al. (2012) further investigated the implementation of a spiral marking system on four roundabouts in Hong Kong. Similar variables were investigated, but the confidence intervals provided for conflict counts confirmed that despite showing mostly reductions, the figures were not statistically significant. Model slopes ranged from -0.602 to 0.303.

Daniels et al. (2010) investigated the effect of line and number marking installation on median speeds. It can be concluded that overall, this study reveals mixed and unclear effects. Some speed increases can be accounted for by the provision of a sense of security after installation of certain road markings. Similarly, Hunter et al. (2010), showed that mean speed changes were ranging from -0.29 to -2.55 km/h. Richter and Zierke, (2010) focused on the impacts of a new cross-sectional design involving the merging of two lanes into to one, by reconfiguring the painting on a test track. All reported results showed decreases when comparing the initial condition with those three months or one year afterwards. Räsänen, (2005) investigated the effects of repainting the barrier lane on vehicle encroachments, lateral position and average speed, conducting separate analyses for cars and trucks, and taking various traffic flow states into consideration. The results were mostly positive for the encroachment parameter, although several effects were not statistically significant. The results were not as clear for average vehicle speeds or for lateral position. The final study (Montella et al., 2011), performed a major simulation experiment, involving the implementation of different perceptual cues. Results showed that the most effective treatments were the dragon teeth markings, and combined treatments were significantly more effective than single treatments. There were significant speed reductions beginning 250 m before the intersection in the range between 13 and 23 km/h. An overview of studies regarding road markings is shown on Table 2.

Table 2. Description of coded studies regarding road markings (studies with junctions as their focus are denoted with [j]).

Author(s); Year; Country;	Sampling frame for road markings investigation	Method for road markings investigation	Outcome indicator
Van Driel, C. J., Davidse, R. J., & van Maarseveen, M. F.; 2004; Netherlands, United States [meta-analysis]	Summary of effects that can be expected from road marking implementation extracted from previous research.	Association measures calculation [Pearson's correlation and Cohen's κ], various homogeneity, ANOVA and regression analyses.	Speed and lateral position
Daniels, S., Vanrie, J., Dreesen, A., & Brijs, T.; 2010; Belgium	Both a field study and a simulator study on the effects of additional road markings on speed behaviour were presented.	Median speed evolution comparison algorithms [field] and repeated-measures ANOVA [simulation]	Median absolute speeds

Räsänen, M.; 2005; Finland	Vehicles were unobtrusively video recorded along a curve on a two-lane road section, before and after lane painting.	Before - after comparison of parameters with descriptive statistics, F and P testing.	Line encroachment; lateral position variation; average speed;
Richter, T., & Zierke, B.; 2010; Germany	Local measurements were taken at certain locations along the test track. Furthermore, the driving behaviour of a single vehicle was monitored with the following-car technique along the entire test track.	Empirical analysis was used in with-and-without and before-and-after studies to evaluate road sections.	Mean speed
Wong, S. C., Sze, N. N., Hung, W. T., Loo, B. P., & Lo, H. K.; 2006; China	An observational before-and-after study to assess the effects of a scheme placing reflective road markings on approach lanes to the toll plaza and erection of a gantry sign to distinguish the auto-toll lane.	Multi-factor ANOVA and Before-and-after comparison	Lane changing rate; Conflict count;
Hunter, M., Bonusprint, S., Guin, A., Rodgers, M., & Jared, D.; 2010; United States [j]	An investigation into the effectiveness of chevron markings in reducing vehicle speeds on two-lane freeway-to-freeway directional ramps. Statistical comparison at preselected sites of speeds before and after the installation of the chevron markings.	Lead Vehicle (free flow) Analysis and Monte Carlo Analysis	Change in the mean speed across the before and the 9th month after time periods
Montella, A., Aria, M., D'Ambrosio, A., Galante, F., Mauriello, F., & Pernetti, M.; 2011; Italy [j]	23 drivers drove in a simulation a test route two times. The order of the ten design conditions was counterbalanced for all drivers to minimize the presentation order effect.	Cluster and categorical analyses and ANOVA testing	Speed, deceleration and lateral position
Wong, S. C., Sze, N. N., Loo, B. P., Chow, A. S., Lo, H. K., & Hung, W. T.; 2012; China [j]	Observational and questionnaire surveys were conducted to assess how a proposed roundabout marking system affected driver behaviour, level of service, and safety performance.	A multivariable regression approach was used to assess the influence of the spiral-marking system on the operational efficiency of the roundabouts.	Approach lane choice, circulating time, lane-crossing rate, conflict count

3.3. Chevron signs

The first of the studies examining speed reduction (Rè et al., 2010) reports a significant difference from the baseline evaluation, but results between the two different treatments (chevrons and full-post chevrons) are quite similar. The same findings are provided for the vehicle lateral lane position. Similarly, the second relevant study (Gates et al., 2004) shows beneficial effects on speed both for Flashing Yellow (FY) chevrons and for Flashing Yellow (FY) signposts (in addition to FY chevrons). Conversely, the combination of FY chevrons and FY curve signs was found to have a small and inconsistent effect. The third study (Zhao et al., 2015) describes significant positive effects on speed reduction, further affected by curve direction, but not curve radius. Findings demonstrate that the presence of chevrons also encourages participants to drive with better lane positioning, which was more appropriate to negotiate the respective curves. Conversely, Rose and Carlson (2005) find that additional chevron signs on a curve provide small benefits in reducing speed during the day, and more noticeable benefits at night. They also find more pronounced benefits on sharp curves than on moderate curves. Little benefit is found in the percentages of vehicles exceeding the speed limit.

When examining chevron signs, another popular outcome is crash frequency data. Montella (2010) found a significant crash reduction in total, night-time, daytime, rainy, non-rainy, run-off-road, and property damage-only crashes. Similarly, Choi et al. (2015) report a positive effect on road safety in terms of crash reduction, but no statistical analyses were performed. With regard to various behavioural variables, the last study (Wu et al., 2013) presented findings for exposure to the presence of chevrons using a driving simulator. Results showed that drivers pay more attention to the roadside near chevrons (chevrons attracted more fixation points from the drivers, and the duration of fixation points was also longer with the presence of chevrons). Regarding the degree of deceleration, the brake and accelerator data show that applying the brake and releasing the accelerator are more frequent in the scenario with chevrons, namely the pedals were used more repeatedly. This finding indicates that chevron signs do provide advance warning and positive guidance and make drivers tend to reduce their speed more through curves, improving road safety. An overview of studies regarding chevron signs is shown on Table 3.

Table 3. Description of coded studies regarding chevron signs.

Author(s); Year; Country;	Sampling frame for chevron signs investigation	Method for chevron signs investigation	Outcome indicator
Choi Y.Y., Kho S.Y., Lee C., Kim D.K.; 2015; South Korea	To create the dataset, data for the crash count, crash location and Annual average daily traffic (AADT) were collected from the database of the Korea Expressway Corporation. The analyses were performed on three freeways; the number of sites considered were 100, with a total length of 27.6 Km.	Before-after Empirical Bayes method	Crash Frequency
Gates T.J., Carlson P.J., Hawkins H.G. Jr.; 2004; USA	14 sites were used for field evaluations of various enhanced conspicuity sign applications. This included 4 curves on rural two-lane roadways, 2 curves on freeway exit ramps, 4 urban/suburban stop-controlled intersections, 3 rural stop-controlled intersections, and one rural speed zone.	Absolute difference comparison between before and after the installation [with ANOVA]	Mean Speed ~500 ft. Upstream of Point of Curve (PC)
Montella A.; 2009; Italy	A divided motorway (A16) with two lanes for each direction, access control, and interchanges. The treatment sites are in the section Naples–Candela, with a length of 127.5 km. 383 crashes in 15 curves were considered.	Generalized linear model with negative binomial distribution error structure	Crash Reduction
Ré J.M.,Hawkins H.G. Jr.,Chrysler S.T.; 2010; USA	Two separate horizontal curves, on a rural two-lane road, were considered. Vehicle speed and lateral position data were measured using a traffic classifier and three roadway sensors. Data collection equipment was placed at Point of Curve (PC) and Curve Midpoint (MP) curve locations.	Absolute difference comparison between exposed and non-exposed sites [With MANOVA & the Tukey's HSD test]	Mean speed Mean lateral position
Rose E.R., Carlson P.J.; 2005; USA	Three curves, located in rural areas, were chosen for this study: one gentle, one moderate and one sharp curve. Researchers obtained speed data for at least 24 hours at four locations on each curve using automated counters connected to pneumatic tubes.	Absolute difference comparison between before and after the installation [with ANOVA and z-test]	Mean Speed; Exceeding speed limit vehicles
Wu Y., Zhao X., Rong J., Ma J.; 2013; China	Simulation tests were performed on an interchange of the Fourth Ring Road, in different daytime scenarios. The ramp, with a radius of 85 m, is about 340 m long, and has just one lane. 20 healthy young men, aged 21-31, participated at the experiment.	Absolute difference comparison between exposed and non-exposed sites [t-test]	Fixed Points; Fixed Duration; Overall mean of MADOSV; Degree of deceleration
Zhao X., Wu Y., Rong J., Ma J.; 2015; China	The driving simulator experiment was performed with the fixed-base driving simulator in Beijing University of Technology. Horizontal curves with different roadway geometries, on two-lane rural undivided highway, were considered. 30 healthy male drivers, between 20-34 years, participated at the experiment.	Absolute difference comparison between exposed and non-exposed sites [ANOVA with repeated measures]	Average Speed; Average Lane Position

3.4. Edgeline rumble strips

The first study examining crash frequency (Park et al., 2014) uses the KABCO scale (K-fatal, A-incapacitating injury, B-non-incapacitating injury, C- possible injury, O-property damage only). Results showed an improvement in road safety both for single treatments (edgeline rumble strips only) and combined treatments (edgeline rumble strips and widening of shoulder width). It was also found that the treatments were more safety effective (i.e. lower Crash Modification Factor-CMF) for the roadway segments with narrower original shoulder width in the 'before' period. It is worth noting that CMFs were calculated using two observational before–after approaches (Comparison Group and Empirical Bayes) and the most reliable method (i.e. the CMF with lower standard error) was chosen. Results were statistically significant in all cases except one. Similarly, the second study concerning crash frequency (Park et al., 2015) reports a reduction for both single and combined treatments. In particular, estimated crash modification factors show higher safety effects on total crashes than severe crashes. Moreover, the reduction for all types of crashes was lower than for single vehicle run-off road crashes, and the safety effects for the combination of multiple treatments were higher than for single treatments. Again, results were statistically significant in all cases except for the cases of KABCO single-vehicle crashes.

Additionally, findings from Torbic et al. (2010) demonstrate a reduction in all single-vehicle run-off road crashes, in single-vehicle run-off road fatal and injury crashes on rural freeways, and on rural two-lane roads. No significant results in terms of crash reduction were found on urban freeways and rural multilane divided highways. For rural multilane highways, the result for all single-vehicle run-off road crashes was statistically significant, but counterintuitive. This appears to be an anomaly in the data for this roadway type and was not considered credible. The last study regarding crash frequency (Wu et al., 2014) shows that the presence of edgeline rumble strips does not affect the occurrence of severe crashes. Conversely, a statistically significant reduction of the total number of crashes by seven percent was found. With regard to various behavioural variables, the last study (Gates et al., 2012) reports a non-significant effect of edgeline rumble strips on the percentage of vehicles attempting a passing manoeuvre, and on the percentage of aborted passing attempts. In contrast, the presence of edgeline rumble strips encourages vehicles to maintain a more centralized lateral lane position. With regard to the encroachments, rumble strips greatly reduced the occurrence of drivers laterally shifting to the inside while manoeuvring through curves. An overview of studies regarding edgeline rumble strips is shown on Table 4.

Table 4. Description of coded studies regarding edgeline rumble strips.

Author(s); Year; Country;	Sampling frame for rumble strips investigation	Method for rumble strips investigation	Outcome indicator
Gates T.J., Savolainen P.T., Datta T.K., Todd R.G., Russo B., Morena J.G.; 2012; USA	Video recordings of driver behaviour were obtained at 18 passing zones and 12 curves along 10 roadway segments on rural two-lane roadways throughout Michigan. Nearly 78000 vehicles were observed during review of the passing zone videos, and more than 50000 vehicles were observed during review of the curve videos.	Absolute difference comparison between before and after the installation [Bonferroni corrected z-score]	Vehicles in passing position; Total Passing Attempts; Aborted Passing Attempts; Left of centre; Centred in lane; Right of centre; Encroaching onto or across edgeline
Park J., Abdel-Arty M., Lee C.; 2014; USA	A total of 257 treated road segments, with a length of 180722 miles, was used to evaluate the safety effects of two single treatments (edgeline rumble strips and widening shoulder width) and combined treatment (edgeline rumble strips + widening shoulder width) on rural multilane roadways in Florida.	The most reliable method between the before-after Comparison Group and Empirical Bayes methods (i.e. the Crash Modification Factor (CMF) with lower standard error) was chosen.	Crash Modification Factor (CMF)
Park J., Abdel-Aty M.; 2015; USA	Data was collected for rural two-lane roadways in Florida; crash records were collected for 2 years (2004–2005) for before period and 2 years (2010–2011) for after period. The total numbers of treated segments for SRS (Edgeline Rumble Strips) and SRS+WSW (Widening Shoulder Width) were 70 and 68, respectively.	Before–after comparison using the empirical Bayes method	Crash Modification Factor (CMF)
Torbic D.J., Hutton J.M., Bokenkroger C.D., Bauer K.M., Donnell E.T., Lyon C., Persaud B.; 2010; USA	Data were collected in urban and rural freeways, rural multilane divided highways and rural two-lane roads in Minnesota, Missouri, and Pennsylvania. The safety evaluation investigated the change in crash frequency for total (TOT) crashes, fatal and injury (FI) crashes, single vehicle run off road (SVROR) crashes, and SVROR FI crashes.	Before–after comparison using the empirical Bayes method	Crash frequency
Wu K.F., Donnell E.T., Aguero-Valverde J.; 2014; USA	310 segments in Pennsylvania during 2002–2009 were studied. Edgeline rumble strips were installed during 2004 and 2006. There were 5629 reported crashes in total, of which were categorized as fatal and major injury, moderate/minor injury, and property damage only crashes.	A hybrid method, which incorporates the advantages of FE (fixed effects) models and ME (mixed effects) models, has been proposed.	Crash severity probability; Total number of crashes; Severe crashes

3.5. Traffic signs

Regarding crash frequency, the first study (Chen et al., 2013) shows that the reduction of the displayed speed limit is found to have a limited impact on crashes, including injurious and fatal crashes. Similarly, Schattler et al. (2015) observe a non-statistically significant reduction in left-turn crashes with the installation of supplemental traffic signs. When examining traffic signs, another popular outcome is the reduction of vehicular speed. Hallmark et al. (2013) report a significant decrease in mean speed for all the traffic-calming devices installed (speed limit sign with radar-activated light-emitting diodes (LEDs) embedded around the border, and a displayed vehicle speed sign). In the same way, Kay et al. (2014) show that vehicular speed reduces significantly with the installation of a bicycle warning sign with a "share the road" plaque. Furthermore, Hallmark et al. (2013) also focus on the fraction of vehicles exceeding the displayed speed limits, and results show a significant reduction for all the different speed exceedance intervals. In addition to vehicular speed, Kay et al. (2014) analyse changes in motor vehicle lateral placement at the time of the passing manoeuvre. The sign treatment is found to shift motor vehicles away from the rightmost lane positions, though the signs did not significantly affect the mean buffer distance between the bicyclists and passing motorists, or the propensity of crowding events during passing. Finally, another study (Clark et al., 1996) aims at testing the effects of the maintenance of existing signs with fluorescent SYG (Strong Yellow Green) warning signs, and findings demonstrate marginal improvements in perceived safety at the crossing sites. The occurrence of motorists slowing and stopping increased significantly at three of the seven test sites, while the proportion of vehicle/pedestrian conflicts did not change significantly.

An overview of the major features of the coded studies for traffic signs (sample, method, outcome and results) is illustrated on Table 5. Apart from their numbers, the studies are marked with [TSI] or [TSR] to denote whether they originally belonged to traffic sign installation [TSI] or to traffic sign maintenance [TSR].

Table 5. Description of coded studies regarding traffic signs.

Author(s); Year; Country;	Sampling frame for traffic sign measures	Method for traffic sign measures	Outcome indicator
Chen L., Chen C., Ewing R., McKnight C.E., Srinivasan R., Roe M.; 2013; USA	4672 crashes, occurred in 270 locations in New York City, were considered. Five types of crashes are studied: all, multiple vehicle, pedestrian, bicycle crashes and crashes with injuries and fatalities.	Absolute difference comparison between before and after the installation [ANCOVA regression approach]	Observed crashes
Clark K.L., Hummer J.E., Dutt N.; 1996; USA	A safety evaluation of several pedestrian crossings before and after the implementation of SYG warning signs was conducted. The test sites represented a variety of pedestrian environments (a college campus, a recreational area, a shopping district, and multiple environments within central business districts) and were chosen from among several North Carolina Cities.	Absolute difference comparison between before and after the installation [Z-test] and between exposed and non-exposed sites	Slowing/stopping motorists; Pedestrians in Conflict with Vehicles
Hallmark S.L., Knickerbocker S.; Hawkins N.; 2013; USA	Two traffic-calming devices were evaluated to determine their effectiveness in reducing speeds along the main road through a small rural community. Data were typically collected for 48 hours on a Monday through Friday under mostly dry weather conditions.	Absolute difference comparison between before and after the installation	Mean speed; Fraction of Vehicles Traveling Over The displayed Speed Limit
Kay J.J., Savolainen P.T., Gates T.J., Datta T.K.; 2014; USA	A series of four field behavioural studies were conducted along two sections of a two-lane rural highway (109) in the north western Lower Peninsula, which serves as a popular bicyclist route. A total of 1200 passing events were observed during the pre-installation studies and 1225 events were observed post-installation.	Multiple linear regression model & logistic regression model	Buffer distance Crowding Rightmost lane position Vehicular speed]
Schattler K.L., Gulla C.J., Wallenfang T.J., Burdett B.A., Lund J.A.; 2015; USA	Supplemental traffic signs (with text "Left Turn Yield on Flashing Yellow Arrow") were mounted at signalized intersections in the Peoria (Illinois), adjacent to the left turn signal. A total of 164 approaches located at 86 test intersections were included in the evaluation: 90 had supplemental signs, while the other 74 did not.	Poisson test was conducted to statistically compare crash reduction for the before-and-after scenarios	Crash reduction

4. Conclusions

The present study aimed to carry out a comparative assessment of several light engineering measures with the explicit purpose of evaluating their impact on road safety. Examined categories included delineation and road markings, which can be longitudinal for road segments and transversal for junctions, and installation and maintenance of traffic signs, investigated both in functioning workzones and otherwise. This analysis was carried out within the SafetyCube project (SafetyCube 2017a and 2017b), which aims to identify and quantify the effects of risk factors and measures related to behaviour, infrastructure or vehicle, and integrate the results in an innovative road safety Decision Support System (DSS). For each measure examined in this paper clearly defined methodology was developed including rigorous literature search, analysis of studies in terms of design, methods and limitations and synthesis of findings and meta-analyses, when feasible. For that reason, 33 high quality studies were selected and finally analysed for the aforementioned measures.

Results were found for a variety of outcome indicators, from direct road safety variables such as crash counts to more indirect behavioural effects. The qualitative analysis that was carried out showed that workzone signage installation and improvement have a positive impact on road safety. There is evidence to support that there are improper points (mainly sites way upstream or without intrusion denoting active work) but these are not directly relevant to workzones, and the overall benefits of these measures are not negated and should thus be considered accordingly.

Road markings implementation measures have a mostly positive impact on road safety, for the aspects of conflict number reduction and lane changing rate reduction. Conversely, the outcomes regarding median and average speeds were unclear and mixed, showing increases, decreases, and marginal effects. There are several road markings configurations that can be explored and implemented. Overall, there are a considerable number of positive effects, with sufficient statistical verification, to consider this measure mostly beneficial and to suggest it for field implementation. The positive effects outnumber the negative effects by a considerable margin, and many outcomes are statistically significant. Chevron signs are usually associated with a reduction in crash frequency and mean speed. In addition, the presence of chevrons encourages drivers to maintain a lane position that enables them to better negotiate curves. Beneficial effects are also observed on behavioural safety indicators, such as drivers' eye movement (fixed points and fixed duration) and driving performance (degree of deceleration). No significant correlation was found between chevron presence and number of vehicles exceeding the speed limit. Similarly, edgeline rumble strips are usually associated with a reduction in total crashes. In addition, the presence of edgeline rumble strips, together with centreline rumble strips, encourages drivers to maintain correct lane position. Inconsistent results were found for severe crashes, while no significant correlation was found between edgeline rumble strips presence and passing manoeuvre indicators.

Finally, traffic sign installation and maintenance have a positive impact on road safety. The results are mostly consistent and show a marginal decrease in crashes, and similarly positive effects on slowing/stopping motorists and speeding reduction. There are some limitations in the examined areas and indirect methods used, but an overall effect of traffic signs can be deduced nonetheless.

In conclusion, the core findings of this study offer valuable insights on road safety issues that were previously undefined. Each measure has been evaluated based on its documented impacts in synopses that are useful both for researchers and practitioners. A last remark is that all findings are particularly useful for developing road safety policy measures and can be generalized for other cases with the essential caution due to study particularities.

Acknowledgements

This paper is based on work carried out within the SafetyCube project of the H2020 programme of the European Commission (Grant number 633485). The information and views set out in this paper are those of the authors and may not reflect the official opinion of the European Commission. The authors would like to thank all the partners involved in the "Infrastructure" Work Package 5 of the SafetyCube project for their valuable comments.

References

Bai, Y., Finger, K., Li, Y., 2010. Analyzing motorists' responses to temporary signage in highway work zones. Safety science, 48(2), 215–221.

Bernhardt, K., Virkler, M., Shaik, N., 2001. Evaluation of supplementary traffic control measures for freeway work-zone approaches. Transportation Research Record: Journal of the Transportation Research Board, 1745, 10–19.
Brewer, M., Pesti, G., & Schneider IV, W., 2006. Improving compliance with work zone speed limits effectiveness of selected devices. Transportation Research Record: Journal of the Transportation Research Board, 1948, 67–76.
Chen, L., Chen, C., Ewing, R., Mcnight, C.E., Srinivasan R., Roe, M., 2013. Safety countermeasures and crash reduction in New York City—Experience and lessons learned. Accident Analysis and Prevention, 50, 312–322.
Choi, Y.Y., Kho, S.Y., Lee, C., Kim, D.K., 2015. Development of crash modification factors of alignment elements and safety countermeasures for Korean freeways. Transportation Research Board 94th Annual Meeting.
Chu, L., Kim, H. K., Chung, Y., Recker, W., 2005. Evaluation of effectiveness of automated work zone information systems. Transportation Research Record: Journal of the Transportation Research Board, 1911, 73–81.
Clark, K.L., Hummer, J.E., Dutt, N., 1996. Field Evaluation of Fluorescent Strong Yellow-Green Pedestrian Warning Signs. Transportation Research Record Journal of the Transportation Research Board, 1538, 39–46.
Daniels, S., Vanrie, J., Dreesen, A., Brijs, T., 2010. Additional road markings as an indication of speed limits: Results of a field experiment and a driving simulator study. Accident Analysis & Prevention, 42(3), 953–960.
Gates, T.J., Carlson, P.J., Hawkings, H.G. Jr., 2004. Field Evaluations of Warning and Regulatory Signs with Enhanced Conspicuity Properties. Transportation Research Record: Journal of the Transportation Research Board, 1862, pp. 64–76.
Gates, T.J., Savolainen, P.T., Datta, T.K., Todd, R.G., Russo, B., Morena, J.G. 2012. Use of Both Centreline and Shoulder Rumble Strips on High-Speed Two-Lane Rural Roadways. Transportation Research Record: Journal of the Transportation Research Board, 2301, 36–45.
Gitelman, V., Vis, M., Weijermars, W. & Hakkert, S., 2014. Development of Road Safety Performance Indicators for the European Countries. Advances in Social Sciences Research Journal, 1(4), 138–158.
Hallmark, S. L., Knickerbocker, S., & Hawkins, N. (2013). Dynamic Speed Feedback Signs for Rural Traffic Calming. Tech Brief.
Hunter, M., Boonsiripant, S., Guin, A., Rodgers, M., Jared, D., 2010. Evaluation of effectiveness of converging chevron pavement markings in reducing speed on freeway ramps. Transportation Research Record: Journal of the Transportation Research Board, 2149, 50–58.
Martensen, H. et al., 2017. Methodological framework for the evaluation of road safety measures. Deliverable Number 3.3 of the H2020 project SafetyCube, 2017.
Kay, J. J., Savolainen, P. T., Gates, T. J., & Datta, T. K. (2014). Driver behavior during bicycle passing maneuvers in response to a Share the Road sign treatment. Accident Analysis & Prevention, 70, 92-99.
Montella, A., 2009. Safety Evaluation of Curve Delineation Improvements Empirical Bayes Observational Before-and-After Study. Transportation Research Record: Journal of the Transportation Research Board, 2103, 69–79.
Montella, A., Aria, M., D'Ambrosio, A., Galante, F., Mauriello, F., Pernetti, M., 2011. Simulator evaluation of drivers' speed, deceleration and lateral position at rural intersections in relation to different perceptual cues. Accident Analysis & Prevention, 43(6), 2072–2084.
Park, J., Abdel-Aty, M., 2015. Development of adjustment functions to assess combined safety effects of multiple treatments on rural two-lane roadways. Accident Analysis and Prevention 75, 310–319.
Park, J., Abdel-Aty, M., Lee, C., 2014. Exploration and comparison of crash modification factors for multiple treatments on rural multilane roadways. Accident Analysis and Prevention, 70, 167–177.
Räsänen, M., 2005. Effects of a rumble strip barrier line on lane keeping in a curve. Accident Analysis & Prevention, 37(3), 575–581.
Re, J.M., Hawkings, H.G. Jr., Chrysler, S.T., 2010. Assessing Benefits of Chevrons with Full Retroreflective Signposts on Rural Horizontal Curves. Transportation Research Record: Journal of the Transportation Research Board, 2149, 30–36.
Richter, T., Zierke, B., 2010. Effect of a New Cross-Section Design on Low-Volume Roads. Transportation Research Record: Journal of the Transportation Research Board, 2195, 14–19.
Rose, E.R., Carlson, P.J., 2005. Spacing Chevrons on Horizontal Curves. Transportation Research Record: Journal of the Transportation Research Board, 1918, 84–91
Safety CaUsation, Benefits and Efficiency – Project Website [Online], 2017a. Available at: http://www.safetycube-project.eu/
Safety CaUsation, Benefits and Efficiency – European Road Safety Decision Support System [Online], 2017b Available at: https://www.roadsafety-dss.eu/
Schattler, K. L., Gulla, C. J., Wallenfang, T. J., Burdett, B. A., & Lund, J. A. (2015). Safety effects of traffic signing for left turn flashing yellow arrow signals. Accident Analysis & Prevention, 75, 252-263.
Takemoto, A., Hirasawa, M., Asano, M., 2008. Improving the nighttime visibility of signs and workers in road work zones in Japan. In Proceedings of the 87th TRB Annual Meeting. Transportation Research Board, Washington, DC, January 13-17.
Torbic, D.J., Hutton, J.M., Bokenkroger, C.D., Bauer, K.M., Donnell, E.T., Lyon, C., Persaud, B., 2010. Guidance on Design and Application of Rumble Strips. Transportation Research Record: Journal of the Transportation Research Board, 2149, 59–69.
Van Driel, C. J., Davidse, R. J., van Maarseveen, M. F., 2004. The effects of an edgeline on speed and lateral position: a meta-analysis. Accident Analysis & Prevention, 36(4), 671–682.
Wong, S. C., Sze, N. N., Hung, W. T., Loo, B. P., Lo, H. K., 2006. The effects of a traffic guidance scheme for auto-toll lanes on traffic safety at toll plazas. Safety science, 44(9), 753–770.
Wong, S. C., Sze, N. N., Loo, B. P., Chow, A. S., Lo, H. K., Hung, W. T., 2012. Performance evaluations of the spiral-marking roundabouts in Hong Kong. Journal of transportation engineering, 138(11), 1377–1387.
Wu, Y., Zhao, X., Rong, J., Ma, J., 2013. Effects of Chevron Alignment Signs on Driver Eye Movements, Driving Performance, and Stress. Transportation Research Record: Journal of the Transportation Research Board, 2365, 10–16.
Wu, K.F., Donnell, E.T., Aguero-Valverde, J., 2014. Relating crash frequency and severity: Evaluating the effectiveness of shoulder rumble strips on reducing fatal and major injury crashes. Accident Analysis and Prevention, 67, 86–95
Yun, M., Ji, J., 2013. Delay Analysis of Stop Sign Intersection and Yield Sign Intersection Based on VISSIM. Procedia - Social and Behavioral Sciences, 96, 2024–2031.
Zhao, X., Wu, Y., Rong, J., Ma, J., 2015. The effect of chevron alignment signs on driver performance on horizontal curves with different roadway geometries. Accident Analysis and Prevention, 75, 226–235.