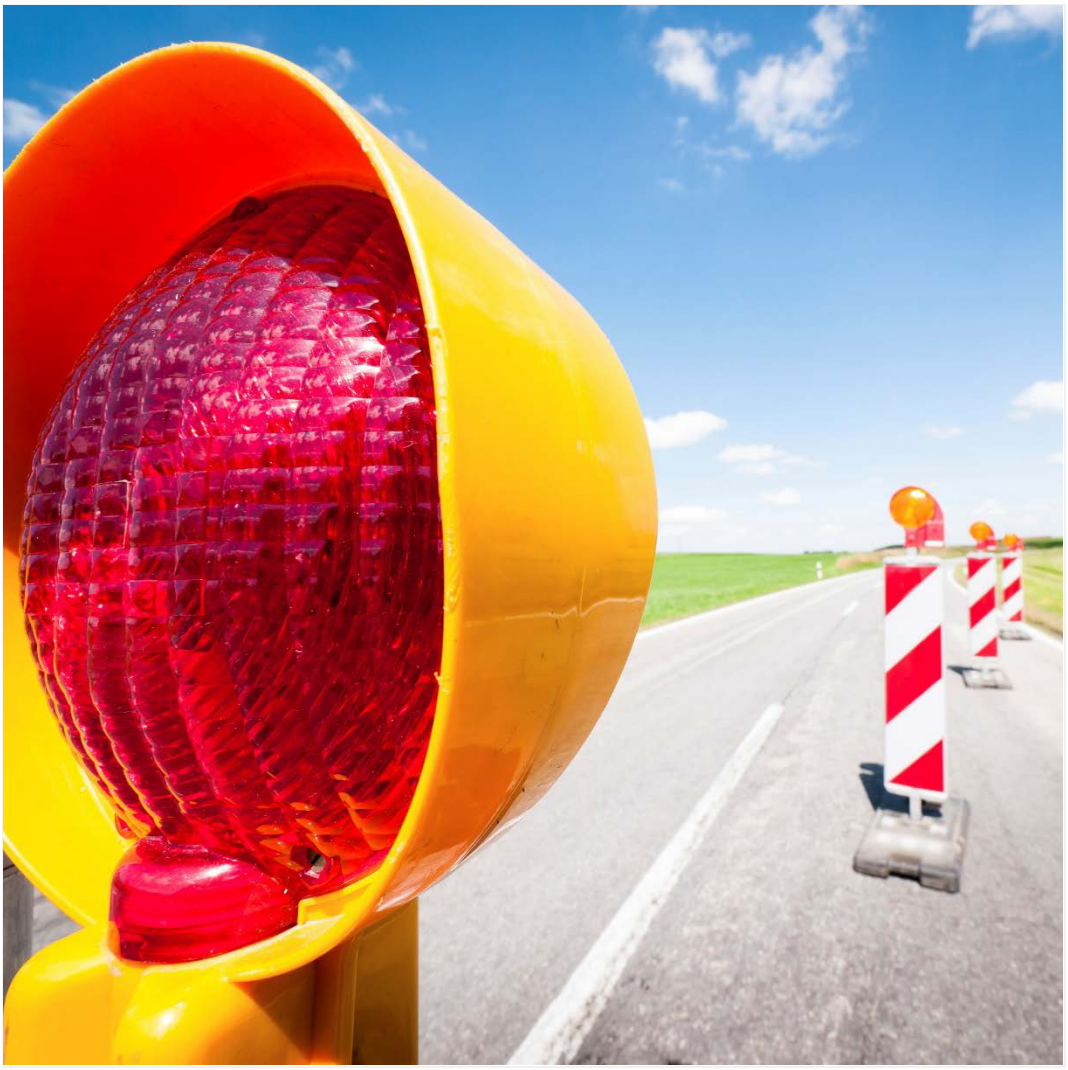
Workzones: Signage installation and improvement

Please refer to this document as follows: **Ziakopoulos, A., Botteghi,G., Papadimitriou, E. (2017), Workzones: Signage installation and improvement, European Road Safety Decision Support System, developed by the H2020 project SafetyCube. Retrieved from www.roadsafety-dss.eu on DD MM YYYY**



Please note: The studies included in this synopsis were selected from those identified by a systematic literature search of specific databases (see supporting document). The main criterion for inclusion of studies in this synopsis and the DSS was that each study provides a *quantitative effect estimate*, preferably on the number or severity of crashes or otherwise on road user behaviour that is known to be related to the occurrence or severity of a crash. Therefore, key studies providing qualitative information might not be included in this synopsis.

1. Summary

Ziakopoulos, A., Botteghi,G., Papadimitriou, E., May 2017

1.1 COLOUR CODE: GREEN

The effects of workzone measure implementations relate to road safety level improvements, with a large number of literature studies presenting findings indicating a reduction in speed and speed variance, and improved lane keeping. In areas that are located a large distance before the workzone environments, where no active work seems to be taking place, workzone signage seems to be counter-effective, namely reducing speed limit compliance rates, thus indicating that there are optimal and sub-optimal points for workzone measures application. The examined studies have good levels of quality, and are overall consistent in their results.

1.2 KEYWORDS

workzone signs; signage installation; workzone improvements

1.3 ABSTRACT

Workzone measures such as signage installation and improvement are commonly implemented to warn drivers of their transition into a more unfamiliar and unpredictable environment where construction is taking place. Their presence impacts road safety levels, reducing vehicle speeds and improving lane keeping. Five high quality studies regarding various workzone measure implementations were coded. On a basis of both study and effect numbers, it can be concluded that workzone signage creates mostly positive impacts on road safety. There were cases, however, that showed opposite results, indicating decreases in speed limit compliance rates. However, these were farther from the working sites and therefore less reliable. The results seem generally transferable with caution.

1.4 BACKGROUND

1.4.1 Definition of workzone signage measures

By the term workzone, experts define any road section in which construction or maintenance of the road environment takes place. Workzones are in general, an unfamiliar road environment for most road users, due to special circumstances (lane closures, traffic disruptions, presence of barriers, obstacles, workers etc.). Workzone safety measures usually include the installation of warning signs and markings to inform drivers and other road users that they are entering a more unpredictable and unusual road environment. As scientific and practical knowledge progresses, workzone signage improvements are also being implemented, in order to further increase road safety levels in these environments.

1.4.2 How do workzone signage measures affect road safety?

In most countries where motor vehicles are commonplace there are several rules and regulations that are applied to workzone environments. As discussed in this document, workzone signage has a positive effect in road safety. This is primarily achieved by reducing vehicle speeds and increasing speed compliance and lane confinement behaviour. It should

be noted here, that potentially detrimental factors like workzone length and duration are treated as measures and examined in the respective part of the SafetyCube project.

1.4.3 How is the effect of workzone signage measures on road safety studied?

Workzone environment conditions are usually applied to specific segment lengths only. Consequently, as road crashes are a relatively rare occurrence for these locations and trying to compile a database for the limited time a workforce exists on a road site is unfeasible, the direct measure of crashes is not useful. With that in mind, most researchers examine secondary safety parameters, speed being the most prominent. Speeding, speed variance and speed limit compliance rates can all provide a useful picture on the effects of workzone signage on road safety, while driver behaviour such as lane keeping parameters can also be evaluated.

1.5 OVERVIEW OF RESULTS

Overall, the effects of workzone signage measures on road safety tend to be positive. Most of the examined studies show consistent speeding reductions. One study showed mixed reports on the effects of speed limit compliance rates, but it should be noted that the negative results were reported from sites away from the active workzones. It could be postulated that drivers felt that the signage was not representative of what they were experiencing on the road. Furthermore, the lane distribution parameter was reported as improved in the only study examined.

1.6 TRANSFERABILITY

Coded studies are primarily from the United States, with one study being from Japan. While this is a modest sample of developed countries, especially due to US diversity, there is still room for representation of other areas of the globe, and a respective gap of knowledge, especially concerning less motorized regions. All studies examined their respective sections uniformly, examining all road users, while the aforementioned lack of crash analyses further reduces the room for variance (for example there is no possibility of examining different crash types).

1.6 NOTES ON ANALYSIS METHODS

The methodology applied for capturing the impact of workzone signage measures was similar in all studies: Either examining before-after measure approaches or cross-sectional approaches where measures are applied in specific sites and then findings are compared with those of unchanged sites. Several measure types were examined: varying sign types and layout as well as road markings such as rumble strips and lane drop arrows. Some results did not reach statistical significance but are still very informative on the effects of the examined measures. Lastly, there is considerable room for investigating different road user categories and/or other geographical regions. All aforementioned factors make the findings for workzone signage installation and improvement transferable with caution.

2. Scientific overview

2.1 ANALYSIS OF STUDY DESIGNS AND METHODS

After appropriate use of various search tools and databases, five high quality studies were selected and coded for the measures of workzone sign installation and improvement. A noteworthy fact is that all studies investigated vehicle speeds in one form or another: Bai et al. (2010), Bernhardt et al. (2001) and Takemoto et al. (2008) investigated changes of mean vehicle speeds, while Brewer et al. (2006) compared speed limit compliance rates and Chu et al. (2005) compared speed variances and standard deviations before and after measure applications. Furthermore, Bernhardt et al. (2001) also explored the parameter of lane distribution. It should be noted that this study examines the effect of rumble strips as well as signage, which is included for completion, since a unified synopsis is compiled for all workzone measures.

In order to examine the relationship between the various configurations of workzone signage measures (either installation or replacement), the studies either deployed multivariate parameter significance testing (for example Student's t-test and F-test or analysis of variance - ANOVA) or at least conducted basic descriptive statistical analysis.

2.2 LITERATURE REVIEW

Regarding the results, 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 (V_{85}). 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.

2.2.1 Limitations

A few limitations can be arguably found in the current literature for the effects of workzone signage on road safety. Firstly, all studies focus on indirect indicator parameters for road safety; mostly various forms of vehicle speed. This is understandable due to the fact that road crashes are a relatively rare occurrence for specific locations, and trying to compile a database examining the limited amount of time a workzone exists on a road site is unfeasible. Both Bernhardt et al. (2001) and Chu et al. (2005) explicitly mentioned this, and the first study conducted an abstract theoretical evaluation. Generally, the limitation of attempting to estimate road safety levels from parameters that are not crashes or casualties remains, however. This limitation is also present in the fact that only a single study examining behavioural variables was located (lane distribution in particular), which consists of quite a small sample to draw solid conclusions from, hinting perhaps a gap of knowledge in road safety.

Secondly, all identified and included studies originated from the United States. While the US is a developed country and advanced in road safety issues, this sample cannot be said to be representative of the workzone measure impacts worldwide.

An overview of the main features of the coded studies (sample, method, outcome and results) is illustrated on Table 1.

Number	Author(s); Year; Country;	Sampling frame for workzone measures studies	Method for workzone measures impact investigation	Outcome indicator	Main Result
1	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 [Absolute proportion]	A visible portable changeable message sign was effective in reducing truck speeds in rural, two-lane work zones. The temporary traffic sign (W20-1) was more effective in reducing the vehicle speeds of passenger cars and semitrailers.
2	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 [Absolute and Relative difference]	Removable lane-drop arrows may encourage earlier merging for a work zone. The arrows and CB message result in changes in mean speed and rumble strips in conjunction with the CB message are associated with improvements in mean speed than the CB message alone. Compliance with speed limits increased, and the magnitude of all effects increased closer to the work-zone taper.
3	Brewer, M., Pesti, G., & Schneider IV, W.; 2006; USA	Researchers field-tested the 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 [Relative difference]	Devices with the ability to display drivers' speeds seem to reduce speeds and improve compliance. Orange borders improve the visibility of speed limit signs, but their effects on compliance were minimal. Other sign interaction effects were also observed.
4	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	F and Z-tests were conducted to statistically compare speed variances of two populations for the before-and-	Sample variance of speeds [Absolute difference]	The results showed that from the study of the effects of traffic speed variance, the driving environment after the use of CHIPS appeared safer.

		of Los Angeles, on freeway I-5.	after scenarios.		
5	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 [Absolute difference]	The experiment results for the effect of sign information type on driving behaviour show that there is a considerable reduction in average speeds based on sign display.

Table 1: Description of coded studies

2.3 RESULTS FOR WORKZONE MEASURES

The effects of workzone signage installation and improvement identified can be summarized as follows:

- 3 studies with a significant decrease on vehicle speeds
- 1 study with an unverified decrease on vehicle speeds
- 1 study with mixed results on speed limit compliance rates

The quantitative results of the coded studies alongside with their general effects on road safety are presented on Table 2 in the supporting document.

After the results were reviewed together, the following points were observed:

a) There is an adequate number of studies, however;
b) Studies have not used the same methods for analysis but somewhat different ones.
c) There are similar indicators but at times expressed differently
d) The sampling frames were quite different, and there was lack of statistical verification in critical studies

2.4 DESCRIPTION OF ANALYSIS CARRIED OUT

2.4.1 Review-count type analysis

After considering the previous points, it was decided that a meta-analysis could not be carried out in order to find the overall estimate of workzone measures on road safety levels. Therefore, the review type analysis was selected - the effect of the workzone signage measures is given via qualitative analysis.

The positive effects of speed reduction appear to apply on several vehicle types (passenger cars, trucks and semi-trailers) and for several locations, and also both on urban and rural study sites. It is also important to note that some studies examined workzone signage in several sites which provides insight into the optimal points and manner of placing signage; some points even seem to be not just subpar but detrimental to road safety. Those points, however, tend to be farther from the workzone, so it could be assumed that drivers felt a sense of invalidity for the signs, thus ignoring them. Furthermore, several speed levels were tested and found to be reduced by signage measures, which hints towards their effectiveness in a variety of environments.

2.4.2 Overall estimate for road safety

On a basis of both study and effect numbers, it can be argued that workzone signage measures have a positive effect on road safety. However, there are cases when its impact is inconclusive, or even some isolated negative effects, but these are a minority and occur due to unexpected circumstances. As mentioned before, these particular studies have good levels of quality, and are overall consistent in their results. In short, results consistently show that the measure reduces road safety risk. This leads to the assignment of the green colour code for the workzone measures.

2.5 CONCLUSION

The qualitative review-type analysis 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.

3. Supporting document

3.1 SUPPORTING QUANTITATIVE TABLE

Below follows Table 2, which includes all quantitative effects from the coded studies for the measures of work safety signage installation and improvement.

Number	Author(s); Year; Country	Measure Exposure	Outcome indicator	Quantitative Estimate	Effect on road safety
1	Bai, Y., Finger, K., & Li, Y.; 2010; USA	Portable Changeable Message Sign (PCMS) present but off	Mean speed reduction [Percent change]	Passenger cars: Mean speed change = -3.90%	↑*
		Portable Changeable Message Sign on		Passenger cars: Mean speed change = -6.70%	↑*
		Temporary traffic sign (TTS) W20-1, "Road Work Ahead"		Passenger cars: Mean speed change = -10.30%	↑*
		Portable Changeable Message Sign present but off		Trucks: Mean speed change = -6.20%	↑*
		Portable Changeable Message Sign on		Trucks: Mean speed change = -8.30%	↑*
		Temporary traffic sign W20-1, "Road Work Ahead"		Trucks: Mean speed change = -5.80%	↑*
		Portable Changeable Message Sign present but off		Semi-trailer: Mean speed change = -4.80%	↑*
		Portable Changeable Message Sign on		Semi-trailer: Mean speed change = -5.20%	↑*
		Temporary traffic sign W20-1, "Road Work Ahead"		Semi-trailer: Mean speed change = -10.20%	↑*
		PCSMS on vs. PCMS off	Mean speed reduction [Relative difference]	Passenger cars: Relative Difference = -1.5860 km/h, s.e. = 0.6360, p=0.9870, CI [95%] = [-2.8390, -0.3380]	↑
		TTS vs. PCMS off		Passenger cars: Relative Difference = -2.8250 km/h, s.e. = 0.7690, p=1.000, CI [95%] = [-4.3360, -1.3130]	↑
		TTS vs. PCMS on		Passenger cars: Relative Difference = -1.2360 km/h, s.e. = 0.8130, p=0.8710, CI [95%] = [-2.8360, 0.3630]	-
		PCSMS on vs. PCMS off		Trucks: Relative Difference = -1.0430 km/h, s.e. = 0.6420, p=0.8950, CI [95%] = [-2.3050, -0.2190]	-
		TTS vs. PCMS off		Trucks: Relative Difference = 0.8860 km/h, s.e. = 0.9100, p=0.6690, CI [95%] = [-0.9040, 2.6750]	-
		TTS vs. PCMS on		Trucks: Relative Difference = 1.9280 km/h, s.e. = 0.9240, p=0.9620, CI [95%] = [0.1120, 3.7450]	↑
2	Bernhardt, K., Virkler, M., & Shaik, N.; 2001, USA	Lane drop arrows	Lane Distribution [Relative difference]	Sites 1-2 vs sites 3 and 4; all times; Rel. dif. = -0.20% (min), -5.00% (max), p < 0.050	↑
			Mean Speed Characteristics [Absolute difference]	Sites 1-2 vs sites 3 and 4; daytime; Abs. dif. = -27.40 km/h, p < 0.050	↑
				Sites 1-2 vs sites 3 and 4; nighttime; Abs. dif. = -1.60 km/h (min), -4.80 km/h (max), p < 0.050	↑

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Number	Author(s); Year; Country	Measure Exposure	Outcome indicator	Quantitative Estimate	Effect on road safety
			Speed Variance Characteristics (St. Dev.) [Absolute difference]	Site 4 only; daytime; Abs. dif. = -11.30 [km/h], p < 0.050	↑
				Sites 1-2 only; nighttime; Abs. dif. = -16.09 [km/h], p < 0.050	↑
		Citizens band (CB) wizard alert system	Lane Distribution [Relative difference]	Sites 1-2 vs site 3; daytime; Rel. dif. = -1.20% (min), -13.00% (max), p < 0.050	↑
				Site 1 only; daytime; Rel. dif. = -15.00% (max), p < 0.050	↑
				Site 1 only; nighttime; Rel. dif. = -60.00% (min), p < 0.050	↑
			Mean Speed Characteristics [Absolute difference]	Site 2 vs site 3; daytime; Abs. dif. = -1.10 km/h (min), -4.80 km/h (max), p < 0.050	↑
				Sites 1-2 vs sites 3 and 4; nighttime; Abs. dif. = -1.60 km/h (min), -4.80 km/h (max), p < 0.050	↑
				Site 2 vs site 3; nighttime; Abs. dif. = -2.40 km/h (min), p < 0.050	↑
				Sites 1-2 vs site 3; nighttime; Abs. dif. = -5.60 km/h (max), p < 0.050	↑
			Speed Variance Characteristics (St. Dev.) [Absolute difference]	Site 4 only; daytime; Abs. dif. = -11.30 [km/h], p < 0.050	↑
				Site 1-2 only; nighttime; Abs. dif. = -16.09 [km/h], p < 0.050	↑
		Rumble strips	Lane Distribution [Relative difference]	Site 4 only; daytime; Rel. dif. = -5.00% (min), -20.00% (max), p < 0.050	↑
				Site 2 only; daytime; Rel. dif. = -5.00% (min), p < 0.050	↑
				Site 2 only; nighttime; Rel. dif. = -1.50% (min), p < 0.050	↑
			Mean Speed Characteristics [Absolute difference]	Sites 1-2 vs sites 3-4; daytime; Abs. dif. = -3.20 km/h (min), -32.00 km/h (max), p < 0.050	↑
				Site 4 only; nighttime; Abs. dif. = -8.00 km/h (min), -16.00 km/h (max), p < 0.050	↑
3	Brewer, M., Pesti, G., & Schneider IV, W.; 2006; USA	Portable changeable message sign (PCSM) installation at merge taper point	Speed Limit Compliance Rates Comparison (Site 1) [Percent change]	Speed limit: 70 km/h, Location 1: Approximately 1 mi upstream of work zone. Speed Limit Compliance Rates = -25.00%, p < 0.05	↓
				Speed limit: 60 km/h, Location 2: First advance warning sign. Speed Limit Compliance Rates = 0.00%, p = N/A	-
				Speed limit: 60 km/h, Location 3: Completion of merge taper from two westbound lanes to one. Speed Limit Compliance Rates = -11.00%, p < 0.05	↓
				Speed limit: 60 km/h, Location 4: Approximate midpoint of work zone Speed Limit Compliance Rates = 10.00%, p < 0.05	↑
				Speed limit: 60 km/h, Location 5: Beginning of diverge taper from one lane to two Speed Limit Compliance Rates = -5.00%, p < 0.05	↓
				Speed limit: 60 km/h, Location 6: Approximately 1 mi downstream of work zone Speed Limit Compliance Rates = 2.00%, p < 0.05	↑

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Number	Author(s); Year; Country	Measure Exposure	Outcome indicator	Quantitative Estimate	Effect on road safety
		PCMS removal from merge taper point		Speed limit: 70 km/h, Location 1: Approximately 1 mi upstream of work zone. Speed Limit Compliance Rates = -26.00%, p < 0.05	↓
				Speed limit: 60 km/h, Location 2: First advance warning sign. Speed Limit Compliance Rates = -1.00%, p = N/A	-
				Speed limit: 60 km/h, Location 3: Completion of merge taper from two westbound lanes to one. Speed Limit Compliance Rates = -3.00%, p < 0.05	↓
				Speed limit: 60 km/h, Location 4: Approximate midpoint of work zone Speed Limit Compliance Rates = 6.00%, p < 0.05	↑
				Speed limit: 60 km/h, Location 5: Beginning of diverge taper from one lane to two Speed Limit Compliance Rates = -8.00%, p < 0.05	↓
				Speed limit: 60 km/h, Location 6: Approximately 1 mi downstream of work zone Speed Limit Compliance Rates = 1.00%, p = N/A	-
		PCMS installation at merge taper point and at near the midpoint of the work zone.		Speed limit: 70 km/h, Location 1: Approximately 1 mi upstream of work zone. Speed Limit Compliance Rates = -21.00%, p < 0.05	↓
				Speed limit: 60 km/h, Location 2: First advance warning sign. Speed Limit Compliance Rates = -2.00%, p < 0.05	↓
				Speed limit: 60 km/h, Location 3: Completion of merge taper from two westbound lanes to one. Speed Limit Compliance Rates = 10.00%, p < 0.05	↑
				Speed limit: 60 km/h, Location 4: Approximate midpoint of work zone Speed Limit Compliance Rates = 27.00%, p < 0.05	↑
				Speed limit: 60 km/h, Location 5: Beginning of diverge taper from one lane to two Speed Limit Compliance Rates = -7.00%, p < 0.05	↓
				Speed limit: 60 km/h, Location 6: Approximately 1 mi downstream of work zone Speed Limit Compliance Rates = 2.00%, p < 0.05	-
		PCMR removal, Orange-border speed limit sign (OBSLS) installation upstream of merge taper and near the midpoint of the work zone		Speed limit: 70 km/h, Location 1: Approximately 1 mi upstream of work zone. Speed Limit Compliance Rates = -25.00%, p < 0.05	↓
				Speed limit: 60 km/h, Location 2: First advance warning sign. Speed Limit Compliance Rates = 0.00%, p = N/A	-
				Speed limit: 60 km/h, Location 3: Completion of merge taper from two westbound lanes to one. Speed Limit Compliance Rates = 2.00%, p < 0.05	↑
				Speed limit: 60 km/h, Location 4: Approximate midpoint of work zone Speed Limit Compliance Rates = -3.00%, p < 0.05	↓
				Speed limit: 60 km/h, Location 5: Beginning of diverge taper from one lane to two Speed Limit Compliance Rates = -24.00%, p < 0.05	↓
				Speed limit: 60 km/h, Location 6: Approximately 1 mi downstream of work zone Speed Limit Compliance Rates = 1.00%, p = N/A	-
		Speed display trailers (SDTs) installation at the beginning of the	Speed Limit Compliance Rates	Speed limit: 70 km/h, Location 1: Approximately 1 mi upstream of work zone. Speed Limit Compliance Rates = -5.00%, p < 0.05	↓

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Number	Author(s); Year; Country	Measure Exposure	Outcome indicator	Quantitative Estimate	Effect on road safety
		work zone	Comparison (Site 2) [Percent change]	Speed limit: 55 km/h, Location 2: Beginning of work zone and reduced speed limit. Speed Limit Compliance Rates = 23.00%, p < 0.05	↑
				Speed limit: 55 km/h, Location 3: Approximate midpoint of work zone. Speed Limit Compliance Rates = 4.00%, p < 0.05	↑
				Speed limit: 55 km/h, Location 4: Approximately 0.5 mi upstream of end of work zone. Speed Limit Compliance Rates = -8.00%, p < 0.05	↓
				Speed limit: 55 km/h, Location 5: Approximately 1 mi downstream of work zone. Speed Limit Compliance Rates = -5.00%, p < 0.05	↓
		SDTs removal from the beginning of the work zone		Speed limit: 70 km/h, Location 1: Approximately 1 mi upstream of work zone. Speed Limit Compliance Rates = -5.00%, p < 0.05	↓
				Speed limit: 55 km/h, Location 2: Beginning of work zone and reduced speed limit. Speed Limit Compliance Rates = -15.00%, p < 0.05	↓
				Speed limit: 55 km/h, Location 3: Approximate midpoint of work zone. Speed Limit Compliance Rates = -3.00%, p < 0.05	↓
				Speed limit: 55 km/h, Location 4: Approximately 0.5 mi upstream of end of work zone. Speed Limit Compliance Rates = -11.00%, p < 0.05	↓
				Speed limit: 55 km/h, Location 5: Approximately 1 mi downstream of work zone. Speed Limit Compliance Rates = -4.00%, p < 0.05	↓
		OBSLS installation at the beginning of the work zone		Speed limit: 70 km/h, Location 1: Approximately 1 mi upstream of work zone. Speed Limit Compliance Rates = -10.00%, p < 0.05	↓
				Speed limit: 55 km/h, Location 2: Beginning of work zone and reduced speed limit. Speed Limit Compliance Rates = 1.00%, p = N/A	-
				Speed limit: 55 km/h, Location 3: Approximate midpoint of work zone. Speed Limit Compliance Rates = N/A, p = N/A	-
				Speed limit: 55 km/h, Location 4: Approximately 0.5 mi upstream of end of work zone. Speed Limit Compliance Rates = -3.00%, p < 0.05	↓
				Speed limit: 55 km/h, Location 5: Approximately 1 mi downstream of work zone. Speed Limit Compliance Rates = 3.00%, p < 0.05	↑
4	Chu, L., Kim, H. K., Chung, Y., & Recker, W.; 2005; USA	Computerized highway information processing system implementation.	Speed parameter difference [Abs.Dif.]	Location 1: Speed variance: Abs. Dif. = 29.80 [km/h]^2, St. dev. difference = 1.80 km/h, p < 0.05	↑
				Location 2: Speed variance: Abs. Dif. = 18.90 [km/h]^2, St. dev. difference = 2.00 km/h, p < 0.05	↑
5	Takemoto, A., Hirasawa, M., & Asano, M.; 2008; Japan	Three different types of sign displays: "LANE ENDS" "LANE ENDS" + pictograph "MERGE 100 M AHEAD" + pictograph	Speed reduction [Absolute difference]	"LANE ENDS": Speed reduction = 4.60 km/h	↑*
				"LANE ENDS" + pictograph: Speed reduction = 7.70 km/h	↑*
				"MERGE 100 M AHEAD" + pictograph: Speed reduction = 3.60 km/h	↑*
↑	denotes positive road safety effects		-	denotes unclear or marginal road safety effects	
↓	denotes negative road safety effects		* denotes that no statistical analysis was conducted for the significance of the effects		

Table 2: Quantitative results of coded studies and impacts on road safety.

3.2 LITERATURE SEARCH

In this chapter the literature search that was carried out will be presented for the measures of workzone signage installation and improvement that were examined in this synopsis. The search results are summarized in relevant tables.

3.3 IDENTIFYING RELEVANT STUDIES FOR WORKZONE SIGNAGE INSTALLATION AND IMPROVEMENT

Measure: workzone signage installation and improvement

Database: Scopus **Date:** 20th of December 2016

search no.	search terms / operators / combined queries	hits
#1	"workzone" OR "construction zone" AND "sign*"	6
#2	AND "install*" OR "improv*"	1
	All years	8

Database: TRID (trid.trb.org) **Date:** 20th of December 2016

search no.	search terms / operators / combined queries	hits
#1	Workzone OR construction zone sign install* OR improv*	3
	All years	4

Database: Science Direct **Date:** 20th of December 2016

search no.	search terms / operators / combined queries	hits
#1	"workzone" OR "construction zone" AND "sign*" AND "install*" OR "improv*"	135
#2	AND ("effect" OR "measure")	127

Limitations/ Exclusions:

- Search field: TITLE-ABS-KEY
- Published: 1990 to current
- Document Type: "Review" and "Article"
- Language: "English"
- Source Type: "Journal"
- Only Transport Journals were considered
- Subject Area: "Engineering"

Results of Literature Search

Database	Hits
Scopus (remaining papers after several limitations/exclusions)	8
TRID	4
Science Direct	127
Total number of studies to screen title/ abstract	139

3.4 SCREENING

Total number of studies to screen title/ abstract	139

-De-duplication	0
-exclusion criteria A (not related to the topic/not relevant measure)	121
-exclusion criteria B (part of meta-analysis)	0
Remaining studies	18
Not clear (full-text is needed)	18
Studies to obtain full-texts	18

3.5 ELIGIBILITY

Total number of studies to screen full-text	18
Full-text could be obtained	8
Reference list examined Y/N	Yes (+0 papers)
Eligible papers prioritized	5

3.6 PRIORITIZING CODING

- Prioritizing Step A (crashes over other performance indicators)
- Prioritizing Step B (Journals over conferences and reports)
- Prioritizing Step C (journal quality)
- Prioritizing Step D (more recent studies)

No meta-analyses were found.

3.7 LIST OF CODED STUDIES FOR WORKZONE SIGNAGE INSTALLATION AND IMPROVEMENT

1. Bai, Y., Finger, K., & Li, Y. (2010). Analyzing motorists' responses to temporary signage in highway work zones. Safety science, 48(2), 215-221.
2. 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.
3. 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.
4. 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.
5. 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 (pp. 13-17).