Implementation of edgeline rumble strips

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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.

Summary

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1.1 COLOUR CODE: LIGHT GREEN

On the basis of both study and effect numbers, the implementation of edgeline rumble strips appears to have a predominantly positive effect on road safety. However, there are cases when its impact is not statistically significant or conclusive. Furthermore, the coded studies encompass several topics and have good levels of quality, but the results are not always consistent.

1.2 KEYWORDS

edgeline rumble strips; shoulder rumble strips; edgeline encroachment

1.3 ABSTRACT

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. Five high quality studies regarding different implementations of edgeline rumble strips were coded. Their presence has an impact on road safety levels, causing a reduction in the number of total crashes and the number of encroachments across the edgeline. In most cases the reductions are statistically significant. Additionally, implementation of rumble strips leads to an improvement in vehicular lateral position. No significant effects were found for severe crashes and passing manoeuvre indicators. On the basis of both study and effect numbers, it has been found that rumble strips create a mostly positive impact on road safety, but the results are not always consistent. Results are transferable with caution.

1.4 BACKGROUND

1.4.1 Definition of edgeline rumble strips

Rumble strips are comprised of tactile materials laid along the length of traffic lanes (usually on highways) as a road safety measure. In addition to providing visual delineation, longitudinal rumble strips can also be heard and felt by drivers and riders. When a tire runs over the rumble strips a noise and vibration is produced. This alerts a sleepy or distracted driver when their vehicle starts to leave the road. Longitudinal rumble strips can be employed to reduce run-off road and head-on crashes, to improve visibility of the edgeline or centreline during wet weather, and to give advanced warning of hazards. This synopsis focuses on the effect of rumble strips when used along road edgelines (known as edgeline rumble strips). A separate synopsis is available for centreline rumble strips.

1.4.2 How do edgeline rumble strips affect road safety?

Results of the coded studies showed a reduction in total crashes and in encroachments onto or across the edgeline. Moreover, findings demonstrated that edgeline rumble strips encourage drivers to maintain correct lane positioning, increasing the number of vehicles in a centred position and decreasing the number travelling left or right of the centre.

1.4.3 Which safety outcomes are affected by edgeline rumble strips?

The reviewed studies focus on several outcomes. In some studies, the focus is to estimate the crash reduction, both for severe and total crashes, due to the presence of edgeline rumble strips. This is achieved by utilising an absolute difference before and after installation, between exposed and non-exposed sites, or with the calculation of crash modification factors. Additionally, the safety effectiveness of edgeline rumble strips is also evaluated with behavioural indicators, such as lateral vehicle position, passing manoeuvres, and number of encroachments onto or across the edgeline. Finally, one study also concentrates on crash severity probability.

1.4.4 How is the effect of edgeline rumble strips on road safety studied?

The relevant international literature includes a variety of different approaches to studying the implementation effects of edgeline rumble strips. Often this measure is examined in conjunction with others (e.g. centreline rumble strips, widening of shoulder width) and its examination is adjusted to the models selected to capture the entire situation for the given case.

The preferred approach to testing the effectiveness of edgeline rumble strips is a comparison before and after their implementation, or between exposed and non-exposed sites.

1.5 OVERVIEW OF RESULTS

In many cases, edgeline rumble strips have been shown to increase the level of road safety. Most examined studies show reductions in total crashes and encroachment numbers across the edgeline, and the results are predominantly statistically significant. Significant positive effects were also found on vehicular lateral placement. Conversely, non-statistically significant results were seen for severe crash reduction and passing manoeuvres indicators.

1.6 TRANSFERABILITY

Coded studies are based on studies solely from the United States. Whilst this is a modest sample of developed countries (particularly considering US diversity) there is scope for representation of other areas of the globe, and a respective gap in knowledge, particularly for less motorized regions. The majority of the studies examine all motor vehicles without differentiating between types of road users, while one study focuses on passenger cars, trucks, buses, PTW and recreational vehicles.

1.5.2 Notes on analysis methods

The methods employed for capturing the impact of edgeline rumble strips on road safety vary considerably between studies. The variation is mainly in terms of the mathematical models utilised, but also in the outcomes evaluated as dependent variables. There is also scope for investigating different road user categories and/or other geographical regions. All of these factors make the findings for implementation of edgeline rumble strips transferable with caution.

2 SCIENTIFIC OVERVIEW

2.1 ANALYSIS OF STUDY DESIGNS AND METHODS

After appropriate use of available search tools and databases, five (5) high quality studies were selected and coded, to evaluate the effectiveness of the implementation of edgeline rumble strips on road safety. Four studies (Park et al., 2014; Park et al., 2015; Torbic et al., 2010; Wu et al., 2014) investigate the changes in crash frequency, both for total and severe crashes. One study (Wu et al., 2014) also analyses the crash severity probability (the probability of a crash being a severe crash). Conversely, Gates et al. (2012) evaluates behavioural characteristics, such as the passing manoeuvres, the lateral lane placement, and the edgeline encroachments.

To examine the relationship between the edgeline rumble strips exposure and outcome indicators, the studies employed multivariate parameter significance testing, univariate parameter testing with multivariate data input, or as a minimum, conducted a basic descriptive statistical analysis. In Wu et al. (2014) the crash frequency and severity models are constructed using the hybrid method. This method provides robust estimates as FE (Fixed Effects) models, and also incorporates the advantages of the ME (mixed Effects) models.

2.2 LITERATURE REVIEW

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 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 the major features of the coded studies (sample, method, outcome and results) is illustrated in Table 1.

Number	Author(s); Year; Country;	Sampling frame for rumble strips investigation	Method for rumble strips investigation	Outcome indicator	Main Result
1	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 [absolute difference]; Total Passing Attempts [absolute difference]; Aborted Passing Attempts [absolute difference]; Left of centre [percent change]; Centred in lane [percent change]; Right of centre [percent change]; Encroaching onto or across edgeline [percent change]	Treatment does not affect the percentage of vehicles attempting to pass and the aborted passing attempts. Moreover, vehicles tended to maintain a more centralized lateral lane position when rumble strips were present. Concerning the encroachments, rumble strips greatly reduced the occurrence of drivers laterally shifting to the inside while manoeuvring through curves.
2	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 CMF with lower standard error) was chosen.	CMF [Crash modification factor]	The results show that the single treatments and the combined treatments produced safety improvement. It was found that safety effects were higher for the roadway segments with edgeline rumble strips and wider shoulder width and for the roadway segments with narrower original shoulder width in the before period.
3	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	CMF [Crash modification factor]	Results indicate that SRS and SRS +WSW will reduce crash frequencies. In particular, the estimated CMFs show higher safety effects on KABCO crashes than KABC. In addition, the CMFs for SVROR (KABCO) crashes are lower than the CMFs for all (KABCO) crashes. The safety effects of combination of multiple treatments were higher than single treatments.
4	Torbic D.J., Hutton J.M., Bokenkroger C.D., Bauer K.M., Donnell E.T., Lyon C., Persaud B.;	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	Before–after comparison using the empirical Bayes method	Crash frequency [percent change]	Results of the before after comparison showed a reduction in SVROR crashes and in SVROR FI crashes on rural freeways and a reduction in SVROR crashes and in SVROR FI crashes on rural two-lane roads crashes.

Number	Author(s); Year; Country;	Sampling frame for rumble strips investigation	Method for rumble strips investigation	Outcome indicator	Main Result
	2010; USA	vehicle run off road (SVROR) crashes, and SVROR FI crashes.			
5	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 [Slope]; Total number of crashes [Slope]; Severe crashes [slope]	Findings of the hybrid models for both crash frequency and severity are: - no evidence that the presence of edgeline rumble strips affects severe crash outcomes; - estimated reduction of the total number of crashes by seven percent.

Table 1 *Description of coded studies*

There are a few limitations in the current literature examining the effects of the implementation of edgeline rumble strips. Firstly, all available studies originate in the United States, and consequently there is a lack of information for different environments such as less motorized countries, European and Asian countries, etc. Moreover, while the US is a developed country and advanced in road safety issues, this sample cannot be said to be representative of the impact of edgeline rumble strips worldwide.

Additionally, in Gates et al. (2012) the effects of edgeline rumble strips on driver behaviour cannot be considered in isolation, since the treatment is implemented in conjunction with centreline rumble strips.

2.3 ANALYSIS METHODS AND RESULTS FOR IMPLEMENTATION OF EDGELINE RUMBLE STRIPS

2.3.1 Introduction

The effects of the implementation of edgeline rumble strips on road safety can be summarized as follow:

- 4 studies with a significant reduction in total crashes (both for single treatments, edgeline rumble strips only, and combined treatments, edgeline rumble strips and widening of shoulder width);
- 2 studies with a reduction in fatal and injury crashes (both for single treatments, edgeline rumble strips only, and combined treatments, edgeline rumble strips and widening of shoulder width);
- 2 studies with a non-statistically significant effect of edgeline rumble strips on road safety (both for single treatments, edgeline rumble strips only, and combined treatments, edgeline rumble strips and widening of shoulder width);
- 1 study with a non-statistically significant effect on crash severity probability;
- 1 study with positive effects on lateral position indicators, such as a decrease in the percentage of vehicles travelling left or right of the centre, and an increase in the percentage of vehicles travelling in a centred position;

- 1 study with a positive effect on encroachments onto or across the edgeline;
- 1 study with a non-significant effect on passing manoeuvres indicators, such as vehicles in passing position, total passing attempts and aborted passing attempts.

The quantitative results of the coded studies and their general effects on road safety are presented in Table 3, included in the supporting document.

After collectively reviewing the results, in possible consideration of a meta-analysis, the following points were observed:

a) There is an adequate number of studies. However,
b) The studies use different models for analysis.
c) There are different indicators, and even when they coincide they are not measured in the same way.
d) The sampling frames were different.

2.4 DESCRIPTION OF ANALYSIS CARRIED OUT

After considering the previous points it was decided that a meta-analysis was not appropriate for finding the overall impact of edgeline rumble strips on road safety. Therefore, the vote count analysis was conducted. In vote count analyses, each study is considered to have one vote for or against the countermeasure. The results are summarized in Table 2.

Outcome definition	Tested in number of studies	Result (number of studies)		
		↑	-	↓
Total Crashes	4	-	-	4
Severe crashes	4	-	2	2
Crash severity probability	1	-	1	-
Lateral position Indicators	1	-	-	1
Encroaching onto or across edgeline	1	-	-	1
Passing manoeuvre indicators	1	-	1	-
Total Studies = 5				

Table 2 *Vote count analysis for edgeline rumble strips*

2.4.1 Overall estimate for road safety

On the basis of the coded studies, it can be asserted that the implementation of edgeline rumble strips has a mostly positive effect on road safety. However, inconclusive and non-statistically significant results were present for severe crashes and passing manoeuvre indicators. Whilst the results are not completely consistent, the majority show a decrease in the number of crashes and beneficial effects on lateral lane position. These factors lead to the assignment of the light green colour code for edgeline rumble strips. The variation between indicators, models, framing and general details between studies made the circumstances for conducting a meta-analysis inappropriate.

2.5 CONCLUSION

The vote count analysis carried out showed that 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.

3 Supporting document

3.1 SUPPORTING QUANTITATIVE TABLE

Table 3 is shown below, and includes the quantitative effects from the coded studies for the measure of edgeline rumble strips implementation. For two of the studies (Gates et al., 2012; Torbic et al., 2014) only a proportionate sample of representative results is presented.

Number	Author(s); Year; Country;	Outcome indicator	Exposure	Quantitative Estimate				Effect on road safety
1	Gates T.J., Savolainen P.T., Datta T.K., Todd R.G., Russo B., Morena J.G.; 2012; USA	Vehicles in passing position [absolute difference]	Implementation of edgeline rumble strips	All types of vehicles			Abs. Diff.: vpp=0.41%, a=0.05	-
		Total Passing Attempts [absolute difference]		All types of vehicles			Abs. Diff.: tpa=1.59%, a=0.05	-
		Aborted Passing Attempts [absolute difference]		All types of vehicles			Abs. Diff.: apa=9.09%, a=0.05	-
		Left of centre [percent change]		All types of vehicles	tangents		Per.ch.: lc= -70.7%; a=0.05	↓
					Left curves		Per.ch.: lc= -77.4%; a=0.05	↓
					Right curves		Per.ch.: lc= -91.6%; a=0.05	↓
		Centred in lane [percent change]		All types of vehicles	tangents		Per.ch.: cl= 96.8%; a=0.05	↓
					Left curves		Per.ch.: lc= 114.9%; a=0.05	↓
					Right curves		Per.ch.: lc= 94.8%; a=0.05	↓
		Right of centre [percent change]		All types of vehicles	tangents		Per.ch.: arc= -32.9%; a=0.05	↓
					Left curves		Per.ch.: rc= -50.4%; a=0.05	↓
					Right curves		Per.ch.: rc= -30.0%; a=0.05	↓
		Encroaching onto or across edgeline [percent change]		All types of vehicles	tangents		Per.ch.: e= -37.1%; a=0.05	↓
					Left curves		Per.ch.: e= -65.7%; a=0.05	↓
					Right curves		Per.ch.: e= -43.7%; a=0.05	↓
2	Park J., Abdel-Aty M., Lee C.; 2014; USA	CMF [Crash Modification Factor]	Implementation of edgeline rumble strips	All crashes	KABCO		CMF=0.763, SE=0.056, a=0.05	↓
					KABC		CMF=0.643, SE=0.074, a=0.05	↓
				Single vehicle Run-off Road crashes	KABCO		CMF=0.651, SE=0.077, a=0.05	↓
					KABC		CMF=0.625, SE=0.117, a=0.05	↓
				All crashes	4 ft≤ shoulder width ≤6 ft	KABCO	CMF=0.614, SE=0.103, a=0.05	↓
						KABC	CMF=0.565, SE=0.137, a=0.05	↓
					8 ft≤ shoulder width ≤12 ft	KABCO	CMF=0.792, SE=0.064, a=0.05	↓
						KABC	CMF=0.659, SE=0.086, a=0.05	↓

Number	Author(s); Year; Country;	Outcome indicator	Exposure	Quantitative Estimate			Effect on road safety
			Implementation of shoulder rumble strips + widening shoulder width	All crashes	KABCO		CMF=0.608, SE=0.059, a=0.05	↓
					KABC		CMF=0.66, SE=0.112, a=0.05	↓
				Single vehicle Run-off Road crashes	KABCO		CMF=0.541, SE=0.085, a=0.05	↓
					KABC		CMF=0.661, SE=0.147, a=0.05	↓
				All crashes	4 ft≤ shoulder width ≤6 ft	KABCO	CMF=0.351, SE=0.062, a=0.05	↓
						KABC	CMF=0.451, SE=0.109, a=0.05	↓
					8 ft≤ shoulder width ≤12 ft	KABCO	CMF=0.807, SE=0.096, a=0.05	↓
						KABC	CMF=0.839, SE=0.142, a=N/A	-
3	Park J., Abdel-Aty M.; 2015; USA	CMF [Crash Modification Factor]	Implementation of edgeline rumble strips	All crashes	KABCO		CMF=0.830, SE=0.07, a=0.05	↓
					KABC		CMF=0.840, SE=0.08, a=0.10	↓
				Single vehicle Run-off Road crashes	KABCO		CMF=0.750, SE=0.14, a=0.10	↓
					KABC		CMF=0.800, SE=0.16, a=N/A	-
			Implementation of edgeline rumble strips + widening of shoulder width	All crashes	KABCO		CMF=0.75, SE=0.10, a=0.05	↓
					KABC		CMF=0.78, SE=0.11, a=0.10	↓
				Single vehicle Run-off Road crashes	KABCO		CMF=0.68, SE=0.17, a=0.10	↓
					KABC		CMF=0.75, SE=0.21, a=N/A	-
4	Torbic D.J., Hutton J.M., Bokenkroger C.D., Bauer K.M., Donnell E.T., Lyon C., Persaud B.; 2010; USA	Crash frequency [percent change]	Implementation of Edgeline Rumble Strips	Single vehicle Run-off Road crashes	Total crashes	Urban freeways	Perc.Ch.: cf=-5.8%, SE=7.3, test statistic=0.79	-
						Rural freeways	Perc.Ch.: cf=-9.7%, SE=5.2, test statistic=1.86, a=0.10	↓
						Rural two-lane roads	Perc.Ch.: cf=-16.2%, SE=8.1, test statistic=2.01, a=0.05	↓
					Fatal + Injury crashes	Urban freeways	Perc.Ch.: cf=-7.4%, SE=9.9, test statistic=0.75	-
						Rural freeways	Perc.Ch.: cf=-17.1%, SE=7.3, test statistic=2.35, a=0.05	↓
						Rural multilane divided highways	Perc.Ch.: cf=-2.6%, SE=13.5, test statistic=0.20	-
						Rural two-lane roads	Perc.Ch.: cf=-36.4%, SE=9.7, test statistic=3.75, a=0.05	↓
5	Wu K.F., Donnell E.T., Aguero-Valverde J.; 2014; USA	Crash severity probability [Slope]	Implementation of edgeline rumble strips	Slope: P= 0.149, SE=0.183, p=0.417				-
		Total number of crashes [Slope]		Slope: TC= -0.072, SE=0.04, p=0.07, a=0.10				↓
		Severe crashes [slope]		Slope: SC= -0.004, SE=0.148, p=0.976				-

↓	denotes positive road safety effects	-	denotes not statistical significance, or not statistical significance, or unclear/marginal road safety effects
↑	denotes negative road safety effects	*	denotes that no statistical analysis was conducted for the significance of the effects

Table 3 *Quantitative results of coded studies for edgeline rumble strips and impacts on road safety*

3.2 IDENTIFYING RELEVANT STUDIES

Measure: implementation of edgeline rumble strips

3.2.1 Literature search strategy

The search strategy aimed at identifying recent studies concerning the implementation of edgeline rumble strips. Three main databases were consulted: Scholar, TRID and Science Direct. In general, only recent (after 1990) journal studies were considered.

Limitations/ Exclusions:

- Published: 1990 to 2016
- Document source: ALL, Documents: Articles and papers, reports if needed to complete study numbers, Subject area: ALL
- Language: English

Database: TRID **Date:** 3rd February 2017

search no.	search terms / operators / combined queries	hits
#1	Rumble strips	658
#2	Edgeline rumble strips	17
#3	Implementation of edgeline rumble strips	3

Database: Google Scholar **Date:** 3rd February 2017

search no.	search terms / operators / combined queries	hits
#1	"rumble strips"	4780
#2	edgeline "rumble strips"	588
#3	implementation "rumble strips"	3030
#4	implementation of edgeline "rumble strips"	578
#5	implementation of "edgeline rumble strips"	79

Database: ScienceDirect **Date:** 3rd February 2017

search no.	search terms / operators / combined queries	hits
#1	rumble strips	33
#2	Edgeline rumble strips	3
#3	Implementation of rumble strips	10
#4	Implementation of edgeline rumble strips	0

3.3 RESULTS LITERATURE SEARCH

Database	Hits
Google Scholar	9055
TRID	678
ScienceDirect	66
Total number of studies to screen title	9799

3.4 SCREENING

The abstracts of relevant studies from the initial literature search results were examined to narrow the scope, and to detect the most appropriate studies at a first stage. The abstracts indicate whether the full text warrants close examination for coding and inclusion in the project.

Total number of studies to screen title	9799
Number of articles remaining after screening of the title = Total number of studies to screen abstract	165
Remaining studies after abstract screening	21
Total number of studies to screen full text	21

3.5 ELIGIBILITY

Total number of studies to screen full-text	21
Full-text could be obtained	14
Reference list examined Y/N	Yes (+0 papers)
Eligible papers prioritized	5

3.6 PRIORITIZING CODING

- Prioritizing Step A (most recent studies)

- Prioritizing Step B (Journals over conferences and reports)

- Prioritizing Step C (Prestigious journals over other journals and conference papers)

- Prioritizing Step D (Studies from Europe)

3.7 LIST OF CODED STUDIES

1. 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, No. 2301, pp. 36–45.
2. 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, p. 167–177.

3. 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, pp. 310–319.
4. 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, No. 2149, pp. 59–69.
5. 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, p.86–95