Road surface treatments

Please refer to this document as follows: **Pogačnik Kokol, E. (2017), Road surface treatments, 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

Pogačnik Kokol, E., April 2017

1.1 COLOUR CODE: LIGHT GREEN

Coded studies show that there is a strong statistical relationship between road surface treatments and road safety. Different road surface treatments (resurfacing, improving friction, investing in maintenance) have a positive effect on crash reduction. On the other ha
nd, meta-analyses show a non-significant effect of road surface treatments on road safety.

1.2 KEY-WORDS

Road surface, road maintenance, skid resistance, road safety, infrastructure spending, safety performance function (SPF), crash modification factors (CMF), multiple treatments, roadside elements, highway safety manual (HSM), regulation, safety effectiveness, surface treatment pavement (road covering).

1.3 ABSTRACT

Road surface has to be maintained in such way that it enables secure traffic. Road surface treatments are methods for extending the lifetime of deteriorating road pavement. Well-maintained road surfaces with adequate skidding resistance help to minimize traffic accidents. The relationships between road surface characteristics and crash occurrence have been established in a number of studies. This synopsis deals with improving friction, resurfacing and winter maintenance which are important surface characteristics with regard to safety. Across all four coded studies, results have highlighted that road surface treatments (improving friction and winter maintenance) have positive influence on road accident reduction. On the other side, two meta-analyses have shown that road surface treatments do not appear to cause statistically reliable changes in accident numbers.

1.4 BACKGROUND

1.4.1 What is the effect of road surface treatments on road safety?

Different pavement parameters and other factors contribute to crash occurance. The surface course may become worn or damaged overtime due to ageing, weathering and the action of road traffic. Chan et al. are writing that the rapid growths of population and traffic volume result in accelerated deterioration on highway infrastructure. Excessive pavement distress contributes to lower ride quality, vehicle damage and traffic crashes. Drivers tend to slow down when driving on distressed pavements, which results in more traffic congestion and air pollution. Proper pavement maintenance is critical for ensuring good ride quality and the avoidance of congestion, air pollution, and traffic crashes.

Numerous studies on traffic safety have been conducted over decades. Most of them were focused on various perspectives such as highway geometrics, vehicle conditions, and human factors. Very limited studies have been carried out relating the pavement condition to traffic safety. Before the 1990s, due to the lack of pavement data collection technology, it was very difficult to carry out statewide scale studies relating pavement conditions to traffic safety (Chan et al., 2009).

The contributions of different pavement condition parameters to crash occurance need to be established so that it is clear to the responsible road agency what surface condition parameters need to be also considered in triggering and/or selecting pavement preservation treatment (Hussein).

1.4.2 What is the effect of road surface on accident type?

The relationships between crashes or crash victims and road scenario can be represented by many confounding variables that can influence crash occurrence or injury severity. Some available research in the scientific literature has focused more on the effects on the crashes of demographic, psychological, situational andbehavioural factors (Norris et al., 2000; Abbas and Al-Hossieny, 2004;Chandraratna et al., 2006; Bouaoun et al., 2015) than others, that focused on the relationships between the driver perception of the evolution of the geometric road features of a traveled path and risk of a crashes, as well as number of crashes during a study period (AASHTO, 2010;Aarts and Van Schagen, 2006; Elvik et al., 2004). It seems, therefore, that one way to powerfully help reduce crash casualties and the number of the crashes is to design a roadway that meets driver expectations in improving road alignment consistency (Russo et al., 2016).

1.4.3 How is the effect of road surface studied?

The most commonly used methods are observational and before-after methods. There are generally four approaches used to perform observational before-after studies: (1) naïve before-after study, (2) before-after study with yoked comparison, (3) before-after study with comparison group and (4) before-after study with the Empirical Bayes (EB) approach. For the majority of presented studies, their national accident or other traffic related database was used as a starting point. Studies deal with winter maintenance, infrastructure maintenance, intersections and skid resistance classifications.

1.5 MAIN CONCLUSION

Two (2) meta-analyses and four (4) studies present the effect of different road surface treatments in various countries. Studies deal with improving friction, road re-surfacing and winter maintenance. The methods used in the studies are: meta-analysis, negative binomial regression analysis, observational and before-after.
Here are the main conclusions:

- resurfacing has a positive influence on reducing crashes,
- improving road surface friction reduces the number of accidents,
- investing in maintenance produces a safety benefit in terms of a reduction in the fatality rate,
- spending on road maintenance reduces the rate of fatalities and casualties,
- increases in accidents, thought not statistically significant, were found when ceasing to salt roads that were previously salted,
- implementing salting for the season is found to reduce person injury accidents (on the section with salting the entire winter season),
- in the dangerous sections the level of skid resistance should be increased in order to achieve the same level of safety as in the non-dangerous section,
- 1 monetary unit spent on the improvements of skid resistance on relevant road sections can bring savings of up to 10 monetary units by preventing loss of lives, injuries and material losses due to accidents.

2 Scientific overview

2.1 LITERATURE REVIEW

There are not a lot of studies dealing with road surface treatment countermeasures. Lots of studies deal with the risk factors.

2.2 DESCRIPTION OF STUDIES

Coded studies on road surface treatment deal with these main objectives:

- to assess the contributions of different pavement condition parameters and other factors to crash occurance,
- to evaluate the accuracy of the combined CMFs for multiple treatments estimated by the existing methods based on actual evaluated combined CMFs.

One meta-analysis study deals with road resurfacing, while the other meta-analysis deals with winter maintenance. Two coded studies deal with re-surfacing and two deal with improving friction.

2.2.1 Winter maintenance

The number of accidents appears to be higher when road surface is covered by snow or ice. Road network operation within winter maintenance as a road surface treatment includes clearing the road of snow, gritting with salt and sand, clearing the view, road marking, realiging traffic signs, traffic control and traffic information. Maintenance includes intiatives to attend to the physical infrastructure and the road surfaces. A number of winter maintenance measures contribute to maintaining mobility during the winter period. To ensure safe use of roads in winter, national road authorities primarily use road salt (sodium chloride) to melt snow and ice, and sand to provide traction for vehicular traffic. While much can be said about the environmental impacts of using salt and sand, their application is effective, convenient and inexpensive. To create a balance between safety and environmental protection is therefore important to use a variety of different strategies to enhance winter road maintenance. In general, winter maintenance of roads improves safety. Nevertheless winter maintenance of roads does not always appear to reduce the number of accidents.

Høye & Bjørnskau's (2013) meta-analysis studies focus on the effect of winter maintenance on accidents. This section is on the effect of salting during the entire winter season. Implementing salting for the season is found to reduce person injury accidents by 15 %, and damage only accidents by 19 % (the latter is not statistically significant). Similary, increases in accidents, thought not statistically significant, were found when ceasing to salt roads that were previously salted. All studies are fairly old. The results of the studies vary greatly, and results from studies have found a positive effect of salting may possibly be partly or fully explained by differences between salted and non-salted roads in terms of average speed, road standard and traffic volume. The literature review explores weather, how often the road is slippery, preventive salting and summer time effects of winter time salting.

2.2.2 Road re-surfacing to improve evenness

Evenness is a measure of the regularity of road surface. All types of road surfaces deteriorate at a rate that varies according to the combined action of several factors (for example, the axial load of vehicles, the traffic volumes, the weather conditions, the quality of materials and the construction techniques). These deteriorations have an impact on the road surface roughness by causing cracking, deformation or disintegration. Water concentration on these deteriorations increases the risk of vehicles skidding. When the evenness of a whole road section has sharply deteriorated, users tend to reduce their speed in order to maintain their comfort at an acceptable level, thus minimizing potential safety impacts. Pavement roughness can be more detrimental to safety when problems are localized, unexpected and significant. Such situations can generate dangerous avoidance manoeuvres, losses of control or mechanical breakdowns of vehicles, therby increasing the risk of accidents. Reductions in skid resisitance caused by vertical oscillations of vehicles on uneven road surfaces can prove problematic, especially for heavy vehicles and when the problems are isolated. However, an improvement in the evenness quality associated with resurfacing might result in speed increases. That means it has a slightly negative safety effect.

Høye's 2014 meta-analysis study deals with the effect of road resurfacing (asphalt) on accident rates for fatal accidents and all accidents, and wet and dry roads, as well as on all roads (with no distinction between wet and dry). The measure does not appear to cause statistically reliable changes in accident numbers. All results are based on before-after studies, and most have not controlled for regression to the mean. However, no systematic differences were found between studies that had and had not controlled for regression to the mean. Most studies do not distinguish between wet and dry road surface. Non-coded analyses indicate that the effect of road resurfacing does not change over time, and that the effect of the measure does not differ between straight and curved road segments.

In the study of Hussein et al. (2016), EB approaches were used to evaluate safety performance at 136 intersections in a metropolitan region of Melbourne, Australia, which were identified to have been resurfaced with asphalt over the period 2005-2010. Crash frequencies at signalised intersections could be a reflection of poor pavement surface condition, and the relationship of road surface characteristics with crash occurance has been established in a number of studies. The safety effectiveness of surface treatment was evaluated using Empirical Bayes (EB) approach to account for regression to the mean bias and traffic volume change through using safety performance function (SPF). Safety effects were estimated for total casualty, high severity (fatality and serious injury) and other injury crashes. For conducting EB method a reference group was selected with similar traffic volumes and site characteristics to the treated sites. Negative Binomial regression was applied to develop SPFs that were used to predict the expected number of crashes at the treated sites. The main aim of the study was to assess the contributions of different pavement condition parameters and other factors to crash occurance.

The data collected for studying safety performance of the identified signalised intersections included:
- crash data at the treated approach of each site for 5 years before and 3 to 5 years after treatment year,
- traffic volume data for the years before treatment and after treatment covering the same number of years as available crash data ,
- the evaluation period of 5 years before and 3-5 years after treatment year was selected as multiples 12 month periods to control for seasonal bias in the evaluation.

Crash data were collected from VicRoads (2014) which contains information on crashes that occured during a 13-year period of interest (2000-2013) as provided by the Victorian police.

The results of EB approach revealed that the treatment effect was found to be significant at 95 % confidence level for all crash severity levels. The evaluation results also showed that total casualty crashes were reduced by 21.3 % with a standard error of 3.13 % and high severity (fatality and serious injury) crashes were reduced by 15.3 % with a standard error of 5.56 %. Pavement surface treatment was found to reduce other injury crashes by 21.4 % with a standard error of 3.75 %.

In Spain public authorities have been active in improving road safety outcomes by (1) providing new or better infrastructure (infrastructure spending) and (2) enforcing public measures (regulation). After constructing a panel data set with road safety outcomes for all Spanish provinces between 1990 and 2009, Albalate et al. evaluated the role of the technical characteristics of infrastructure and recent infrastructure spending together with the main regulatory changes introduced. Information was from the Spanish Transport Ministry and included 50 provinces monitored between 1990 and 2010 (1050 observations).

The results show the importance of considering both types of determinants in a unified framework. Moreover, the study highlights the importance of maintenance spending given its effectiveness in reducing fatalities and casualties in the current economic context of austerity that is having such a marked impact on investment efforts in Spain. The fact that spending on maintenance is much more relevant to road safety than construction spending should encourage governments to implement maintenance programmes not only to guarantee efficient connections, but also to enhance safety standards and so reduce the economic and social costs of accidents.

2.2.3 Improving friction

Road friction is very important for traffic safety. It is defined as the resistance to motion between two surfaces in contact. Its magnitude is expressed by the coefficient of friction (SFC) which is ratio of two forces, one parallel to the surface of contact between two bodies and opposed to their motion (the friction force) and the other perpendicular to this surface of contact (the normal force). In the context of road transportation, the surface of contact is the road-tyre interface and the normal force is the wheel load. The coefficient of friction ranges from nearly 0 under icy conditions up to above 1.0 under the best surface conditions. Accident risk due to vehicle skidding on pavements with friction coefficient (SFC) less than 0.45, is 20 times higher than on pavement surface with a SFC higher than 0.60. Moreover, if the SFC of a aroad is less than 0.30, accident risk is 300 times higher (Transport Department, 1994-2). A high number of accidents on a wet surface can therefore be an indicator of friction deficiency.

The association between road friction and accidents is generally well documented in the international research literature – the poorer the friction, the higher the rate of accidents. Dry bare roads have better friction and lower accidents rates than snow or ice-covered roads, and wet bare roads have better friction and lower accident rates than snow or ice-covered roads. The effects are greatest on wet roads, in sharp bends and where friction initially is low. Friction seems to be more important for accidents rates than unevenness.

Kudrna et al., in their study, describe that the relative number of fatal road accidents in Central and East European countries of EU is several times higher than in the advanced EU countries. To address this problem a research project focusing on road skid resistance and its classification has been launched in the Czech Republic. The international comparative measurements (using SCRIM, SKIDDOMETER, GripTesters and Tatra Runway Tester (TRT)) were carried out in the Czech Republic in order to identify the correlations among these types of measurement devices and improve the Czech road skid resistance classification. The measured and classified skid resistance data of South Moravian road network and crash accidents were incoroporated into the Pavement Management System RoSy. It was found that on the road sections requiring the prediction of traffic speed or

change of travel direction (cross sections, slopes and low radius of curves) the skid resistance was lower than on the adjacent sections. At the same time, an exponential increase of accidents depending on skid resistance occured at these sections. A programme for decreasing the number of accidents on the main road network based on the identification and the improvement of skid resistance on dangerous road sections was proposed.

In the study of Pardillo Mayora et al. (2009) skid resistance measured with SCRIM (the sideway-force coefficient routine investigation machine) and crash data for a 10 year period from over 1750km of two-lane rural roads in the Spanish National Road System were analyzed to determine the influence of pavement conditions on safety and to assess the effects of improving pavement friction on safety. Both wet- and dry-pavement crash rates presented a decreasing trend as skid resistance values increased. Thresholds in SCRIM coefficient values associated with significant decreases in wet-pavement crash rates were determined. Pavement friction improvement schemes were found to yield significant reductions in wet-pavement crahs rates averaging 68%. The results confirm the importance of maintaining adequate levels of pavement friction to safeguard traffic safety and the potential of pavement friction improvement schemes to achieve significant crash reductions.

2.3 DESCRIPTION OF ANALYSIS CARRIED OUT

The following table presents the main outcomes from the coded studies. The effects on road safety are coded as

↗ = significant increase of crash/victim numbers = threat to road safety
↘ = significant decrease of crash/victim numbers = improvement of road safety
\- = no significant change

Table: Summary of study results

Author, Year, Country	Exposure variable	Outcome variable	Effects for Road Safety	Main outcome - description
Høye, A.	Road resurfacing (asphalt)	Accident number/count	Percent change in accident numbers, based on random effects meta-analysis Non-significant effect on road safety	The measure does not appear to cause statistically reliable changes in accident numbers.
Høye, A. & Bjørnskau, T.	Salting roads (Introduction or cessation of salting the entire winter season)	Accident numbers	Percent change in accidents from fixed effects meta-analysis Non-significant effect on road safety	Salting for the season is found to reduce person injury accidents and damage only (the latter is not statistically significant). Similarly, increases in accidents, though not statistically significant, were found when ceasing to salt roads that were previously salted.
Albalate, D., Fernandez, L., Yarygina, A.	Infrastructure maintenance	Fatalities and non-urban fatalities	↘ Negative binomial fixed effects fatalities = -0.2537 (-0.3284) Infrastructure	The impact of road maintenance investment on total fatalities is statistically significant. The sign of this coefficient indicates that spending in maintenance is effective in reducing both fatalities and casualties.

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			maintenance has significant positive effect on road safety.	
Kudrna, J., Vojtešek, A., Mališ, L., Nekula, L.	Road maintenance	Crashes		1 monetary unit spent on the improvements of skid resistance on relevant road sections can bring savings of up to 10 monetary units by preventing loss of lives, injuries and material losses due to accidents.
Pardillo Mayora J.M., Jurado Pina R.	Road maintenance	Crashes		Results confirmed the importance of maintaining adequate levels of pavement friction to safeguard traffic safety and the potential of pavement friction improvement schemes to achieve significant crash reductions.
Nasreen Ahmed Hussein & Rayya A. Hassan	Road treatment (resurfacing)	Crash severity levels (Total casualty, high severity, other injury)	 Safety effectiveness Resurfacing has significant positive effect on road safety	Results indicated that for the types of crashes assessed/considered herein, resurfacing has a positive effect on reducing them. Results of EB approach revealed that the treatment effect is significant at the (approximate) 95 % confidence level in reducing the total casualty crashes by 21.3 %, high severity crashes (fatality and serious injury) by 15.3 % and other injury crashes by 21.4 %.

3 Supporting document

3.1 METHODOLOGY

3.1.1 Literature search strategy

A literature search was conduced in December 2016. It was carried out in 1 database-Scopus. Details of search terms used are listed in the following tables. Search results were limited to journal papers and conference proceedings in English language, published after 2000.

The following criteria were applied to a key word search in the database Scopus

- *Search field: TITLE-ABS-KEY*
- *published: 2000 to current*
- *Document Type: "Review" and "Article"*
- *Language: "English"*
- *Source Type: „Journal"and "Conference Proceedings"*
- *Exclusion of several countries*

Database: Scopus **Date:** 02th of December 2016

search no.	search terms / operators / combined queries	hits
#1	road surface	12,222
#2	road surface treatment	679
#3	improve friction OR improve resurfacing OR ice prevention OR improve evenness	8,272
#4	improve AND friction OR resurfacing OR ice prevention OR evenness	7,441
#5	#2 AND #3	19
#6	#2 AND #4	15
#7	#2 AND improve AND crash AND road safety AND road resurfacing OR friction OR ice prevention OR evenness	4

Database: Scopus **Date:** 05th of December 2016

search no.	search terms / operators / combined queries	hits
#1	road surface AND treatment AND accident OR crash OR road safety OR prevention	85
#2	road surface AND treatment AND measure AND crash	3
#3	Road surface AND treatment AND countermeasure AND crash	5

References from Scopus "road surface" search

- Wang, D., Oeser, M. (2015). Interface treatment of longitudinal joints for porous asphalt pavement. International Journal of Pavement Engineering, Volume 17, Issue 8, 13 September 2016, Pages 741-752.
- Nasreen Ahmed Hussein & Rayya A. Hassan, (2016) Evaluating safety effectiveness of surface treatment at signalised intersections: a before and after study. International Journal of Pavement Engineering, http://dx.doi.org/10.1080/10298436.2016.1234279.
- Ma, J. and Li, Z. (2010) Bayesian Modeling of Frequency-Severity Indeterminacy with an Application to Traffic Crashes on Two-Lane Highways. ICCTP 2010: pp. 1022-1033. doi: 10.1061/41127(382)110 (NO FREE ACCESS)

- Persaud, B., Eccles, K., Amjadi, R. (2010). Recent U.S. Research on Safety Evaluation of Low-Cost Road Engineering Safety Countermeasures – Lessons for Canada. TAC/ATC 2010 - 2010 Annual Conference and Exhibition of the Transportation Association of Canada: Adjusting to New Realities.
- Uzarowski, L., Maher, M., Farrington, G. (2005). Thin Surfacing - Effective Way of Improving Road Safety within Scarce Road Maintenance Budget. TAC/ATC 2005 - 2005 Annual Conference and Exhibition of the Transportation Association of Canada: Transportation - Investing in Our Future.
- Amjadi, R., Merritt, D., & Sherwood, J. (2014). Gaining Traction on Roadway Safety. *Public Roads*, *78*(1), 2-11.
- De Rome, L., Senserrick, T. (2011). Factors Associated with Motorcycle Crashes in New South Wales, Australia, 2004 to 2008. Transportation Research Record Journal of the Transportation Research Board · December 2011 DOI: 10.3141/2265-06.

Studies, which were already found in previous search for the Task 5.1, and are related to countermeasures:

- Leden, L., Hamalainen, O., Manninen, E. (1997). The effect of resurfacing on friction, speeds and safety on main roads in Finland. Accid. Anal. and Prev., Vol. 30, No. 1, pp. 75-85, 1998.
- Abeysekera, J., Gao, C. (2001). The identification of factors in the systematic evaluation of slip prevention on icy surfaces. International Journal of Industrial Ergonomics 28 (2001) 303–313.
- Kudrna, J., Vojtešek, A., Mališ, L, Nekula, L. (2003). Road skid resistance influence on the number of crash accidents.
- Lord, D., Mannering, F. (2010). The statistical analysis of crash-frequency data: A review and assessment of methodological alternatives. Transport Research Part A 44, 291-305.
- Shively, T.S., Kockelman, K., Paul, D. (2010). A Bayesian semi-parametric model to estimate relationships between crash counts and roadway characteristics. Transportation Research Part B 44, 699-715.
- Morgan, A., Mannering. F.L. (2011). The effects of road-surface conditions, age, and gender on driver-injury severities. Accident Analysis and Prevention 43, 1852-1863.
- Chan, C.Y., Huang, B., Yan, X., Richards, S. (2010). Investigating effects of asphalt pavement conditions on traffic accidents in Tennessee based on the pavement management system (PMS). Journal of Advanced Transportation 44, 150-161.
- Albalate, D., Fernandez, L., Yarygina, A. (2013). The road against fatalities: Infrastructure spending vs. regulation. Accident Analysis and Prevention 59, 227-239.
- Russo, F., Busiello, M., Dell'Acqua, G. (2016). Safety performance functions for crash severity on undivided rural roads. Accident Analysis and Prevention 93, 75-91.
- Barišić, I., Dimter, S., Netinger, I. (2010). Possibilities of application of slag in road construction. Technical Gazette 17, 4, 523-528.
- Jateikiene, L., Andriejauskas, T., Lingyte, I., Jasiuniene, V. (2016). Impact assessment of speed calming measures on road safety. Transportation research Procedia 14, 4228-4236.

Meta-analysis:
Høye, A. (2014). Resurfacing of roads. The Handbook of Traffic Safety Measures, Norwegian (online) edition
Høye, A. & Bjørnskau, T. (2013). Winter maintenance. The Handbook of Road Safety Measures, Norwegian (online) version

3.1.2 Analysis of study design and methods

Two meta-analyses and four studies researching the measures of road surface treatment have been coded, analysed and summarised. Two coded studies deal with re-surfacing and two deal with improving friction.
The most commonly used methods in the presented studies were observational and before-after.

3.1.3 Summarising the results

Across all 4 coded studies, results have highlighted that road surface treatments have a positive influence on reducing road accidents. The Hussein et al. study indicated that resurfacing has a positive effect on reducing crashes. The Albalate et al. study highlighted the importance for road safety studies of jointly considering the characteristics of road infrastructure and investment in that infrastructure. In the Kudrna et al. study it was found that on the road sections requiring the reduction of traffic speed or change of travel direction (cross sections, slopes and low radius of curves) the skid resistance was lower than on the adjacent sections. At the same time, an exponential increase of accidents depending on skid resistance occurred at these sections. In Pardillo Mayora et al. study the importance of maintaining adequate levels of pavement friction to safeguard traffic safety and the potential of pavement friction improvement schemes to achieve significant crash reduction were confirmed.

On the other hand, the meta analysis of Høye, A. (2014) shows that resurfacing does not appear to cause statistically reliable changes in accident numbers.

The meta-analysis of Høye, A. & Bjørnskau, T., **which deals with** winter maintenance (salting) shows that implementing salting for the season is found to reduce person injury accidents by 15 %, and damage only accidents by 19 % (the latter is not statistically significant). Similarly, increases in accidents, though not statistically significant, were found when ceasing to salt roads that were previously salted.

Table: Description of coded studies design

Author(s), Year	Sample and study design	Method of analysis	Outcome indicator	Main result
Høye, A. **(2014)**	Resurfacing of roads	Meta-analysis (random effects) Before-after	All accidents (accident number/count)	Literature review and meta-analysis on the effect of road resurfacing (asphalt) on accident rates for fatal accidents and all accidents, and on wet and dry roads, as well as on all roads (with no distinction between wet and dry). The measure does not appear to cause statistically reliable changes in accident numbers.
Høye, A. & Bjørnskau, T. (2013)	Winter maintenance	Meta-analysis (fixed effects)	Accident numbers	Implementing salting for the season is found to reduce person injury accidents by 15 %, and damage only accidents by 19 % (the latter is not statistically significant). Similarly, increases in accidents, though not statistically significant, were found when ceasing to salt roads that were previously salted.
Albalate, D., Fernandez, L., Yarygina, A.	Information from the Spanish Ministry of Transport, 50 provinces monitored between 1990 and 2010. The model contains variables that capture specific	Observational, Cross-sectional	Fatalities Non-urban fatalities	Investing in maintenance produces a safety benefit in terms of a reduction in the fatality rate.

	features of the infrastructure and spending on construction and maintenance, as well as traffic rules and others controls.			
Kudrna, J., Vojtešek, A., Mališ, L., Nekula, L.	23 sections from 2 districts' road networks were chosen. International comparative measurements (using SCRIM, SKIDDOMETER, GripTesters and Tatra Runway Tester (TRT)) were used. The Czech skid resistance classification was developed on the basis of measurements in previous 35 years. All the accidents causing personal injuries or physical damages are registered in Police Traffic Department Database.	Observational	Mean year accidents number per kilometre of road	The research suggests that even under conservative assumptions, 1 monetary unit spent on the improvements of skid resistance on relevant road sections can bring savings of up to 10 monetary units by preventing loss of lives, injuries and material losses due to accidents.
Nasreen Ahmed Hussein & Rayya A. Hassan	Crash data collected from VicRoads (2014), for 5 years before and 3 to 5 years after treatment. Traffic volume data-Annual Average Daily Traffic (AADT).	Before-after	Total casualty High severity Other injury	Results of EB approach revealed that the treatment effect is significant at the (approximate) 95% confidence level in reducing the total casualty crashes by 21.3%, high severity crashes (fatality and serious injury) by 15.3% and other injury crashes by 21.4%.
Pardillo Mayora J.M., Jurado Pina R.	Skid resistance measured with SCRIM and crash data for a 10 year period from over 1750km of two-lane rural roads in the Spanish National Road System were analyzed to determine the influence of pavement conditions on safety and to assess the effects of improving pavement friction on safety.	Before-after	Accident numbers	Results confirmed the importance of maintaining adequate levels of pavement friction to safeguard traffic safety and the potential of pavement friction improvement schemes to achieve significant crash reductions.

3.1.4 Full list of studies

Table 3 Final list of coded studies, and reason to exclude studies that should have been coded

Authors	Title	Year	Country	Status	Reason for exclusion
Høye, A.	Resurfacing of roads	2014	United Kingdom, United States, Sweden, Finland	Meta-analysis	
Høye, A. & Bjørnskau, T.	Winter maintenance	2013	Norway, Sweden, Finland	Meta-analysis	
Russo, F., Busiello, M., Dell'Acqua, G.	Safety performance functions for crash severity on undivided rural roads	2016	Italy	Not coded	Not relevant
Albalate, D., Fernandez, L., Yarygina, A.	**The road against fatalities: Infrastructure spending vs. regulation**	**2013**	**Spain**	Coded only road surface treatments	

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Abeysekera, J., Gao, C.	The identification of factors in the systematic evaluation of slip prevention on icy surfaces	2001	Sweden	Not coded	Not relevant
Shively, T.S., Kockelman, K., Paul, D.	A Bayesian semi-parametric model to estimate relationships between crash counts and roadway characteristics	2010	United States	Not coded	Risk factor (horizontal and vertical alignment)
Kudrna, J., Vojtešek, A., Mališ, L., Nekula, L.	**Road skid resistance influence on the number of crash accidents**	**2003**	**Czech Republic**	**Coded**	
Morgan, A., Mannering. F.L.	The effects of road-surface conditions, age, and gender on driver-injury severities	2011	United States	Not coded	Not relevant
Persaud, B., Eccles, K., Amjadi, R.	Recent U.S. Research on Safety Evaluation of Low-Cost Road Engineering Safety Countermeasures – Lessons for Canada	2010	United States	Not coded	Not relevant
Nasreen Ahmed Hussein & Rayya A. Hassan	**Evaluating safety effectiveness of surface treatment at signalised intersections: a before and after study**	**2016**	**Australia**	**Coded**	
Leden, L., Hamalainen, O., Manninen, E.	The effect of resurfacing on friction, speed and safety on main roads in Finland	1997	Finland	Not coded	Not relevant
Mountain, L., Maher, M., Fawaz, B.	The influence of trend on estimates of accidents at junctions	1998	United Kingdom	Not coded	Risk factor (road surface condition)
Chun Yip Chan , Baoshan Huang , Xuedong Yan & Stephen Richards	Relationship Between Highway Pavement Condition, Crash Frequency, and Crash Type	2009	United States	Not coded	
Bryan Pidwerbesky, Gerard Killick, Jeff Waters	Innovative Surfacing Treatments Delivering Safer Roads	2011	Australia	Not coded	Not relevant
Jonas Norrman, Marie Eriksson, Sven Lindqvist	Relationships between road slipperiness, traffic accident risk and winter road maintenance activity	2000	Sweden	Not coded	Risk factor
P. Cairney and P. Bennett	An Exploratory study of Surface Characteristics and Crash Occurrence on Selected Roads in Australia	2013	Australia	Not coded	
Pardillo Mayora J.M., Jurado Pina R.	**An assessment of the skid resistance effect on traffic safety under wet-pavement conditions**	**2009**	**Spain**	**Coded**	

Coded studies (sorted by author)

Albalate, D., Fernandez, L., Yarygina, A. (2013). The road against fatalities: Infrastructure spending vs. Regulation.

Høye, A. (2014). Resurfacing of roads.

Høye, A. & Bjørnskau, T. (2013). Winter maintenance.

Kudrna, J., Vojtešek, A., Mališ, L., Nekula, L. (2003). Road skid resistance influence on the number of crash accidents.

Nasreen Ahmed Hussein & Rayya A. Hassan (2016). Evaluating safety effectiveness of surface treatment at signalised intersections: a before and after study.

Pardillo Mayora, J.M. & Jurado Pina, R. (2009). An assessment of the skid resistance effect on traffic safety under wet-pavement conditions

Additional references for further background information (sorted by author)

Elvik, R. (2009). The Handbook of Road Safety Measures.

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