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IMPACT OF SHOULDER AS A ROAD SAFETY COUNTERMEASURE: A LITERATURE REVIEW

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ABSTRACT

The review included 31 studies of which 14 were before-after analysis, 13 used cross-section analysis, seven case-control, a cohort analysis and a review. Some studies used more than one type of study design for analysis. Twenty seven studies were conducted in the USA, one in South Korea, France and Australia each and no studies from low or middle income countries. The evidence from these studies indicate mixed results for influence of shoulder as an intervention on crash outcome. Most studies indicate that increase in shoulder width up to 8 feet leads to reduction in crash outcomes whereas shoulder width exceeding 8ft leads to increase in crashes or no crash reduction is observed. Narrow shoulders show higher crash rates as compared to wider shoulders. Studies also report that upgradation of unpaved shoulders to stabilized or composite shoulder type also reduces crash outcomes. The results of this review suggest that shoulder implementation, increasing shoulder width up to 8ft and upgrading shoulder type may prove to be a promising countermeasure for reducing all types of road traffic crashes. However, the evidence of effectiveness of these countermeasuresmay not be replicable in other parts of the world, hence, further evaluations are needed.

Review Paper

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Keywords: Impact, Road, Shoulder, Safety.

INTRODUCTION

As Dr. William Haddon, a public health professional, promoted the concept of road injuries to be a serious public health concern, this led to the design of safer built environments and traffic management systems (Haddon, 1968). This also shifted road safety approach focusing human error to a broader pragmatic approach based on interventions such as road infrastructure, vehicles and post-crash care (Gangloff, 2006; Haddon, 1972; MacLennan, 1988). Despite these efforts, presently 1.35 million people are dying annually from road traffic crashes, making it the eighth leading cause of death for all age groups and the leading death cause for children and young adults (5-29 years) (World Health Organization, 2018). The condition is worse in low-income countries as compared to high-income countries, however, the evidence from low-income countries of the effectiveness of various road safety interventions is sparse (Staton et al., 2016).

The road traffic management needs asystematic approach involving interaction of all integral components with each other including road infrastructure, vehicles and the road users.Since road design is an integral part of road safety, there is a need to investigate the relationship between road infrastructure and safety more as not known completely. Improved infrastructure will improve road safety which is the main goal

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to achieve. Evolving knowledge on road safety has served as a basis for development of a safe road environment and continuous investigation is vital, mainly in Low and Middle Income Countries (LMICs), to develop safe roadways.

The shoulder is a part of roadside infrastructure which serves as a recovery area for vehicles diverting from their normal traffic course and for allowing avoidance maneuvers. This area is also utilized for stopping vehicles. The shoulders type can be paved, unpaved or composite. As shoulder is a safety zone on road, its implementation, width and type are the countermeasures to affect safety on roads. Implementation of shoulders on roadways is an intervention to reduce traffic crashes. Change in shoulder width and type are the factors affecting crashes on roads including fatal, injury and Property Damage Only (PDO) crashes.

In this review, the evidence on the impact of road shoulders on crashes as outcomes has been discussed. Only single previous review done in 1987 on the effect of shoulder width and shoulder type on highway safety has been found (Zegeer and Deacon, 1987). Hence, this review has been conducted to provide an up-to-date evidence of impact of shoulders on road safety. The term 'accident' is not used in this review as by definition, it will mean an unpredictable and hence, uncontrollable event. 'Crash', 'collision', 'incident', 'injury' are specific terms for such events and hence is extensively used instead of 'accident' in this review. The objective of the review is to assess the impact of shoulder width, type and implementation as a road safety countermeasure for reducing road traffic fatalities and injuries.

MATERIALS METHODS

The studies were considered for this review on the basis of following criteria:

Study design

The studies were included for the following study designs only-

1. Case-Control
2. Before-After analysis (controlled and uncontrolled)
3. Cross-sectional analysis

Countermeasures

The studies included are screened for three countermeasures: shoulder implementation, change in shoulder width and shoulder type.

Outcomes

The outcomes evaluated for the study to meet the inclusion criteria is as follows:

1. Fatal crashes
2. Injury crashes
3. PDO crashes

Participants

The different types of roads receiving the shoulder implementation, change in shoulder width and shoulder type countermeasure. The publications included were only English language. Those publications were excluded which reported conflicts, but crashes were not examined or those which measured only subjective risk perception.

Search Methodology

We searched the following electronic databases: Safetylit, Pubmed, MEDLINE, Web of Science and Embase. The standard search strategy used was the search term "shoulder*" combined with operator "AND" to "crash* OR collision* OR accident* OR traffic OR road* OR street* OR highway* or vehicle*" to obtain results.We also searched websites of various road safety organizations such as Transportation Research Board (TRB), Australian Road Research Board (ARRB) and Institute of Transportation Engineers, USA(ITE). We also checked the references of SafetyCube, a European research project, which published study synthesis for various road safety measures and risk factors, including road shoulders (Ammari and Usami, 2017; Noella, 2017; Usami, 2017). The publication full texts were obtained wherever possible and the authors screened each study obtained and reconciled their decisions.

Study Data Extraction

The studies obtained from the search were screened firstly at title and abstract and then at full text for inclusion on interventions, outcomes and study design. The data from each study; such as countermeasure, country of study, participants, study design and outcomes; were obtained for analysis.

RESULTS AND DISCUSSION

All our searches identified a total of 1679 publications which were initially screened on title and abstractextracting 45 included studies and the full texts of 33 studies could be obtained of which 31 met all our inclusion criteria (Abboud and Bowman, 2001; Abdel-Rahim and Sonnen, 2012; Bamzai et al., 2011; Barbaresso and Bair, 1983; Bauer et al., 2004; Belmont, 1956; Blensly and Head, 1960; Choi et al., 2019; Dixon et al., 2016; Galgamuwa and Dissanayake, 2017; Gross et al., 2009; Gross and Donnell, 2011; Gross and Jovanis, 2007; Hallmark et al., 2013; Lee et al., 2007; Li et al., 2013, 2011; Martin, 2001; Meuleners et al., 2011; Ogden, 1997; Park et al., 2014; Park and Abdel-Aty, 2016a, 2016b; Peng et al., 2012; Rogness et al., 1982; Stamatiadis et al., 2009; Zegeer et al., 1981; Zegeer and Deacon, 1987; Zeng et al., 2013; Zeng and Schrock, 2013, 2012).

The studies are presented in detail in **Table 1**. Out of 31 studies assessing the impact of shoulders on crashes, we found 7 case-control studies, 14 before-after analysis, 13 cross-sectional analysis and a literature review. 28 studies reviewed were conducted in the US and one each in South Korea, France and Australia. We obtained no study from LMICs. The earliest study reviewed was published in 1956.

Six of the 31 studies investigated the impact of only shoulder implementation, three studies examined only shoulder type and fourteen studies investigated only shoulder width impact on crashes. Two studies examined both shoulder width and shoulder implementation, three examined both shoulder width and shoulder type and two studies investigated the impact of all three countermeasures on road traffic crashes.

Impact of shoulder implementation

Ten studies assessed the effectiveness of shoulder implementation on roadways in terms of road crashes. Six studies observed significant decrease in all crash types conducted on various roadway types including freeways, highways, low volume, moderate volume and high volume roads. Two studies Abboud and Bowman, 2001 and Lee et al., (2007) found no significant relationship between crash rates and shoulder implementation and two studies Bauer et al., (2004), and Choi et al., (2019) conducted on freeways found statistically significant increase in crashes after shoulder implementation as an additional lane.

Impact of increase in shoulder width

The impact of increase in shoulder width on road traffic crashes was analyzed by 19 studies. 13 studies reported reduction in total, injury, PDO, ROR and OD crashes at freeways, urban and rural interstate, multilane and two-lane highway segments (Bamzai et al., 2011; Dixon et al., 2016; Gross et al., 2009; Gross and Donnell, 2011; Gross and Jovanis, 2007; Hallmark et al., 2013; Li et al., 2011; Park et al., 2014; Park and Abdel-Aty, 2016a, 2016b; Peng et al., 2012; Stamatiadis et al., 2009; Zegeer et al., 1981).

Three studies Barbaresso and Bair, (1983), Blensly and Head, (1960) and Zeng and Schrock, (2013) found no significant crash reduction for shoulder width variances except for one of them which found significant increase in total crashes only for roadways with 2000-2999ADT (Blensly and Head, 1960). Two studies (Belmont, 1956; Li et al., 2013) showed shoulder widening to increase injury crashes for multilane highways and rural two-lane roadways with greater than 2000 veh/day traffic flow respectively. One study Abdel-Rahim and Sonnen, (2012) observed that extremely narrow (<1ft) and wide shoulders (≥8ft) results in increasing crashes. 3-8ft shoulder width is an effective countermeasure for crash reduction.

Impact of shoulder type

Effectiveness of shoulder type as a road safety countermeasure is reported by eight included studies in this review. Seven studies (Bamzai et al., 2011; Li et al., 2013, 2011; Ogden, 1997; Zeng et al., 2013; Zeng and Schrock, 2013, 2012) found upgrading unpaved or turf shoulders to paved or composite shoulders to be an effective countermeasure in total, fatal, injury and PDO crash reduction. The studies are conducted on different road types including rural and urban interstates, multilane highways and two-lane highways. One study Martin, (2001) reviewed found no significant effect of barrier equipped shoulders on occurrence of crashes, however, the impact severity was found twice for first impact on right shoulder with barrier than with no barrier.

A literature review Zegeer and Deacon, (1987) is also included in this review which analyzed the impact of shoulder type and width on crashes. The review concluded that increasing shoulder width reduces ROR and OD crash rates and similar effect is observed for stabilized and paved shoulder.

Discussion

The results obtained from this literature review show that shoulder implementation, increasing shoulder width and upgrading shoulder type may be an effective countermeasure for road safety. The results in included studies analyzed road traffic crashes including fatal, injury, PDO and total crashes. It is noteworthy that 90 percent of the studies are conducted in the US and 100 percent in high income countries. Hence, there is a lack of evidence of the effectiveness of this intervention in road safety from LMICs.

The studies reviewed show basic trends of effectiveness of all three countermeasures related to shoulders in crash reduction on different road types. Most of the included studies examined the impact of increasing shoulder width followed by assessment of effectiveness of shoulder implementation and upgradation of shoulder type. All the three countermeasures showed reduction in total, fatal, injury and PDO crashes on various roadway types. Few studies which found increase in crashes were mainly where either the shoulder is implemented as an auxiliary lane or the width of shoulders increased beyond 8ft.

Inclusion of only English language literature is the major limitation of this review as some studies may only be published on other languages. There were also problems searching the unpublished literature which could not be included. This is one of the few literature reviews on the effects of shoulders on road safety and hence, more evidence is required for further impact assessments.

CONCLUSION

This review highlights the need to enrich road safety evidence of effectiveness of shoulder interventions. Although, this review concludes that the implementation of shoulders, increase in shoulder width and upgradation of shoulder type is a promising countermeasure for crash reduction, there is a need of further impact evaluations to conclusively report effectiveness. Road infrastructure evidence from high income countries cannot always be reciprocated to LMICs, hence, the gap of evidence of effectiveness of these interventions from LMICs needs to be addressed.

Table 1 Studies included in the review that investigated the impact of shoulders on road traffic crashes

No.	Reference	Countermeasure	Country	Participants	Methodology	Outcomes
1	(Barbaresso and Bair, 1983)	Shoulder width	USA	Roadways with shoulder width < 3ft and ≥ 9ft in Oakland county	Case-Control	The study results show that roadways with shoulders ≥ 8ft do not experience lesser crashes than those with shoulder width < 8ft. Also, the frequency of fixed-object crashes are related to shoulder width whereas the frequency of overturn and head-on crashes are not related to shoulder width.
2	(Bauer et al., 2004)	Shoulder Implementation (as additional travel lane)	USA	Treatment sites involved an urban freeway segments in Los Angeles and San Diego Counties in southern California for conversion projects of four-to-five lanes and five-to-six lanes Control sites were urban freeway sites without interventions located in six counties in southern California (Los Angeles, Orange, Riverside, San Bernardino, San Diego, and Ventura).	Before-After Analysis	Shoulder-use-lanes to convert an urban freeway from four-to-five lanes in single travel direction increase crash frequency on an average by 10% to 11% for all crash types (Statistically significant). Shoulder-use-lanes to convert an urban freeway from five-to-six lanes in single travel direction increase crash frequency on an average by 3% to 4% for all crash types and 7% for fatal and injury crash types (Statistically not significant)
3	(Choi et al., 2019)	Shoulder Implementation (as additional travel lane), shoulder width	South Korea	Treatment sites include 22 hard shoulder running sections with a total length of 162.15 Km consisting 14 eight-lane, 1 six-lane and 7 four-lane freeways in South Korea Reference sites include 86 freeway sections having similar geometric and traffic conditions.	Before-After Analysis	The crash frequency increased for a four-five lane conversion with HSR by an estimate of 45 crashes with only 3.6% of serious crashes. However, two-three lane conversion with HSR leads to an estimated increase in crashes by 8.7 crashes with 25.3% serious crashes. A small reduction of 1.4 crashes was estimated in three-four lane conversion. No relationship found between shoulder or lane width and crash frequency.
4	(Dixon et al., 2016)	Shoulder Width	USA	Urban freeway segments in Dallas, Houston and San Antonio, Texas.	Cross-sectional	Increase in left and right shoulder width has a positive effect on crash reduction. A reduction of 5% per additional foot of left

						shoulder and 9% per additional foot of right shoulder is estimated.
5	(Galgamuwa and Dissanayake, 2017)	Shoulder Implementation	USA	10,495 miles long rural two- lane undivided road segments of Kansas roadway network	Cross-sectional and Case-Control	12–18 % reduction in all crashes and a 6–16 % decrease in fatal and injury crashes on tangent road segments with implementation of 2-ft paved shoulders. Also, 11–34 % reduction in all crashes and up to 7-11 % reduction in fatal and injury crashes with implementation of 2-ft paved shoulders on curved segments.
6	(Lee et al., 2007)	Shoulder Implementation (as additional travel lanes)	USA	Urban freeway Interstate-66 i.e. 6.5 miles long with three travel lanes and shoulders on both sides in each direction carrying heavy traffic between Washington D.C. and northern Virginia	Cross-sectional	The analysis of right shoulder lane shows no significance with crash rate and other independent variables do not have any predictive effect on crashes in either direction. Right shoulders with merge and diverge areas only shows an increase in crashes by 38% during adverse light conditions.
7	(Li et al., 2011)	Shoulder Implementation, shoulder type (paving) and shoulder width	USA	Urban and rural interstate, multilane, and two-lane highway segments of Illinois	Before-After Analysis	New paved shoulder implementation seems to be more effective than increasing outside paved shoulder width and repaving the same. For interstate highways, paved shoulder width not exceeding 8ft is most effective in reducing injury and PDO crashes and for multilane and two-lane highways, it is between 4ft-8ft. Paving of shoulders was found to be most effective for multilane highways followed by two-lane and rural Interstate highways.
8	(Li et al., 2013)	Shoulder Implementation, shoulder type (paving) and shoulder width	USA	Treated and untreated highway segments of rural and urban interstate, multilane, and two-lane highways of Illinois	Before-After Analysis	New paved shoulder implementation has been more effective in crash reduction than increasing existing shoulder width and paving the existing deteriorated shoulder.

9	(Martin, 2001)	Shoulder type	France	Two-lane and three-lane motorways comprising 2300 Km of motorways located in plains.	Case-Control	Though the presence of barriers on shoulders doesn't have a significant impact on crash occurrence, the impact severity when the first impact occurs on right shoulders equipped with barriers is twice as high when there is no barrier.
10	(Park and Abdel-Aty, 2016)	Shoulder width	USA	Rural multilane roadways in Florida	Before-After Analysis	Shoulder widening results in 12% reduction of all-severity crashes, 21% severe crashes and 18% injury crashes. In terms of run-off-road crashes, the treatment resulted in reduction of 25% of all severity crashes, 31% severe crashes and 28% injury crashes.
11	(Rogness et al., 1982)	Shoulder Implementation	USA	Low, moderate and high-volume roadways of Texas which suitable for evaluating the treatments. 60 sites (394 miles) were selected for analysis.	Before-After analysis	Implementation of paved shoulders was positively related to crash reduction for all as well as non-intersection crashes. The reduction was found significant for both high and low volume roadways. Data suggest that crash severity will decrease on low and moderate volume roadways on addition of shoulder whereas it increases on high volume category. On conversion of paved shoulders to travel lanes (two-lane to four-lane roadway) without shoulder, decrease in total crashes was observed for roadway volumes > 3000 vehicles/day. Although, the reduction on only moderate volume roadway was found significant.
12	(Zegeer and Deacon, 1987)	Shoulder Type and shoulder width	USA	9 Studies were included in the review analyzing the impact of lane width, shoulder width and shoulder type on various roadway segments	Review	Only four studies with relevant data and supportable results were used to develop crash relationships. Collectively, these studies conclude that-

						• Lane and shoulder elements affect ROR and OD crashes directly whereas other crash types are not directly affected. • Increasing lane width and shoulder width reduces ROR & OD crash rates. However, lane width has greater impact. Stabilized or paved shoulders exhibit lesser crash rates than unstabilized ones.
13	(Zeng and Schrock, 2013)	Shoulder Type, shoulder width	USA	Roadway segments of rural two-lane highways with different shoulder types including turf, composite and paved shoulders	Cross-Sectional	Index of safety effectiveness were used to find that total number of crashes are expected to decline as a result of widening or upgrading 2ft turf shoulders, however, their safety advantage is less in winter than in non-winter periods. Safety effectiveness variances were not found significant for fatal, injury and related crashes between winter and non-winter periods.
14	(Abboud and Bowman, 2001)	Shoulder implementation	USA	Two-foot and four-foot shoulder implementation on two-lane highways in 11 rural Alabama counties	Before-After Analysis	No significant differences in either severity or crash rate was found between two-foot and four-foot shoulder implementation. However, a reduction in total and single vehicle crashes was observed for both the treatments.
15	(Belmont, 1956)	Shoulder width	USA	Rural two-lane roadways with uniform paved or treated shoulders in California	Cross-Sectional	Injury crashes were found to have an increasing tendency with shoulder width, however the trend gets reversed for roads with traffic volume < 2000 veh/day.
16	(Blensly and Head, 1960)	Shoulder width	USA	Oregon State primary rural two-lane highways with paved shoulders of width classified into: 4ft or less (narrow shoulder) and 8ft or more (wide shoulder)	Cross-sectional	According to the partial correlation technique results, no significant relationship between paved shoulder width and crash frequency was evident except in the 2,000-2,999 ADT range. In this range, a significant increase in property damage and total

						crashes was observed with the increase in paved shoulder width.
17	(Gross et al., 2009)	Shoulder width	USA	Rural two-lane roadways of Washington and Pennsylvania	Case-control	There was a general reduction in the odds of crash as shoulder width is increased.
18	(Gross and Donnell, 2011)	Shoulder width	USA	21,688 two-lane rural highway segments in Pennsylvania	Cross-sectional and case-control	The results of cross-sectional design suggest that shoulder widths of 2.7 and 3m are associated with significantly fewer expected crashes than baseline 1.8m. It also shows that atleast 1.2m of additional unpaved shoulder width beyond paved shoulder increased safety benefits. The results of case-control study shows similar results to cross-sectional design as it suggests that 2.7 and 3m shoulder widths are associated with statistically significant safety benefits compared to baseline 1.8m.
19	(Hallmark et al., 2013)	Shoulder implementation and shoulder width	USA	Rural non-interstate roadway sections of Iowa where paved shoulders have been installed	Before-After Analysis	Results indicate a 4.1% reduction in expected number of total crashes for each additional foot width of right shoulder and 8.8% reduction after first year of shoulder paving. Expected decrease in ROR crash rate is 1.3% for first year and 12.9% after 10 years of shoulder installation.
20	(Meuleners et al., 2011)	Shoulder implementation	USA	Albany Highway and their corresponding matched control sites on South Western Highway	Before-After analysis	Results indicate a significant reduction of all-severity crash by 58% and causality crashes by 80%
21	(Ogden, 1997)	Shoulder type	Australia	Two-lane two-way rural highways with shoulder paving in Victoria	Before- After analysis	A statistically significant reduction of casualty crashes by 41% on a per vehicle kilometer basis
22	(Zegeer et al., 1981)	Shoulder width	USA	Two-lane rural highways	Case control	Shoulder widening from 0.5 to 2.5m are expected to reduce ROR and opposite direction (OD) crashes by 16%

23	(Zeng and Schrock, 2012)	Shoulder type	USA	Rural two-lane roadway segments in Kansas where the shoulder had been upgraded from unpaved or non-existent to 3ft paved and remainder unpaved	Before-After analysis	Results indicate an expected reduction of 61% in total crashes by upgrading narrow unpaved shoulders to composite shoulders and 31% in fatal and injury crashes
24	(Bamzai et al., 2011)	Shoulder type and shoulder width	USA	Urban and rural Interstates, multilane non-Interstates, and two-lane highways in Illinois receiving shoulder paving treatment	Before-after and Cross-sectional analysis	Paving of shoulders is reported as more effective measure in reduction of injury and PDO crashes than fatal crashes. Maintaining 6ft paved shoulder and 8ft paved shoulder for urban and rural interstate highways respectively is found most effective. For rural and urban multilane highways, preserving 4ft or 6ft shoulders is beneficial and similar effect is observed for rural two-lane highways paving, widening, and adding paved shoulders up to 8ft wide. Urban two-lane highways show desirable effects on crash reduction for shoulder countermeasures of paving 8ft, widening from 4ft to 8ft, and adding 6ft or 8ft wide paved shoulders.
25	(Zeng et al., 2013)	Shoulder type	USA	Rural two-lane highway segments in Kansas where shoulder upgrading project has been conducted	Before-after and Cross-sectional analysis	Both study design methods suggest that upgrading narrow unpaved shoulders to composite shoulders can result in significant fatal and injury crash reduction up to 31% and shoulder related crashes up to 61%
26	(Peng et al., 2012)	Shoulder width	USA	Rural two-lane roadway segments in four districts in Texas with crash and roadside feature data	Cross-sectional	Results indicate significant positive impact of increase in shoulder width on single vehicle run-off-road crash reduction.
27	(Stamatiadis et al., 2009)	Shoulder width	USA	Rural multilane highway segments in California, Minnesota and Kentucky having shoulder widths ranging between 0 to >8 ft.	Case-control	Analysis indicate beneficial effect of increase in shoulder width on reduction of crashes for both divided and undivided four lane highways

28	(Abdel-Rahim and Sonnen, 2012)	Shoulder width	USA	Two-lane rural state highway segments in Idahowith right paved shoulder widths of 0, 1, 2, 3, 4, 5, 6, 7, and 8 or more ft	Cross-sectional	Results show that highways with very narrow shoulders of < 1ft leads to an average 16% increase in all, single-vehicle and multi-vehicle crashes as compared to highways with a 3ft shoulder width. For shoulder width of < 8ft, results indicate an average reduction of 13% for all crashes, single-vehicle and multi-vehicle crashes as compared to 3ft shoulder width. The probability for a pedestrian/bicycle crash increases significantly for roadway sections with shoulder widths > 3ft. The likelihood of a crash also increases for roadway sections with shoulder widths of 8 ft or more.
29	(Gross and Jovanis, 2007)	Shoulder width	USA	Two-lane, rural, undivided highway segments in Pennsylvania having 0 to >9 ft shoulder width	Case-control and cohort analysis	Estimates from both case-control and cohort analysis indicate reduction in crashes as shoulder width increases.
30	(Park et al., 2014)	Shoulder width	USA	257 and 676 Rural multi-lane highway segments in Florida for treatment and comparison groups, respectively receiving widening shoulder width treatment	Before-After and cross-sectional analysis	Both before–after and cross-sectional analysis methods show that shoulder width as single treatment produces beneficial effect on crash reduction. The roadway segments with narrower original shoulder width in the before period resulted in lower CMF.
31	(Park and Abdel-Aty, 2016)	Shoulder width	USA	6420 urban arterial roadway segments having a range of shoulder width between 2 (base) to 12 ft in Florida	Cross-sectional	Study results show that increasing shoulder width reduces crash frequency as the CMF for shoulder width consistently decrease with increase in width.

Author's declaration

Authors' contributions and responsibilities

The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation and discussion of results. The authors read and approved the final manuscript.

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Availability of data and materials

All data are available from the authors.

Competing interests

The authors declare no competing interest.

REFERENCES

Abboud, N.K., Bowman, B.L., 2001. Evaluation of two-and four-foot shoulders on two-lane state routes. ITE J. 71, 34–39.

Abdel-Rahim, A., Sonnen, J., 2012. Potential Safety Effects of Lane Width and Shoulder Width on Two-Lane Rural State Highways in Idaho.

Ammari, A., Usami, D., 2017. Shoulder implementation (shoulder type). European Road Safety Decision Support System, developed by the H2020 project SafetyCube. Retrieved from www.roadsafety-dss.eu.

Bamzai, R., Lee, Y., Li, Z., 2011. Safety Impacts of Highway Shoulder Attributes in Illinois.

Barbaresso, J.C., Bair, B.O., 1983. Accident Implications of Shoulder Width on Two-Lane Roadways.

Bauer, K.M., Harwood, D.W., Hughes, W.E., Richard, K.R., 2004. Safety effects of narrow lanes and shoulder-use lanes to increase capacity of urban freeways. Transp. Res. Rec. 1897, 71–80.

Belmont, D.M., 1956. Accidents versus width of paved shoulders on California two-lane tangents-1951 and 1952. Highw. Res. Board Bull. 117, 1–16.

Blensly, R.C., Head, J.A., 1960. Statistical determination of effect of paved shoulder width on traffic accident frequency. Highw. Res. Board Bull. 240, 1–23.

Choi, J., Tay, R., Kim, S., Jeong, S., Kim, J., Heo, T.-Y., 2019. Safety Effects of Freeway Hard Shoulder Running. Appl. Sci. 9, 3614.

Dixon, K., Fitzpatrick, K., Avelar, R., 2016. Operational and Safety Trade-Offs: Reducing Freeway Lane and Shoulder Width to Permit an Additional Lane. Transp. Res. Rec. 2588, 89–97.

Galgamuwa, U., Dissanayake, S., 2017. Estimating Crash Modification Factors Using Cross-Sectional And Case-Control Methods For Rumble Strips And Paved Shoulders 2.

Gangloff, A.B., 2006. Medicalizing the Automobile: Public Health, Safety, and American Culture, 1920-1967. Stony Brook University.

Gross, F., Donnell, E.T., 2011. Case–control and cross-sectional methods for estimating crash modification factors: Comparisons from roadway lighting and lane and shoulder width safety effect studies. J. Safety Res. 42, 117–129.

Gross, F., Jovanis, P.P., 2007. Estimation of Safety Effectiveness of Changes in Shoulder Width with Case Control and Cohort Methods. Transp. Res. Rec. 2019, 237–245. https://doi.org/10.3141/2019-28

Gross, F., Jovanis, P.P., Eccles, K., 2009. Safety effectiveness of lane and shoulder width combinations on rural, two-lane, undivided roads. Transp. Res. Rec. 2103, 42–49.

Haddon, W., 1968. The changing approach to the epidemiology. Prevention, and amelioration of trauma: the transition to approaches etiologically rather than descriptively based 8.

Haddon, W.J., 1972. A Logical Framework For Categorizing Highway Safety Phenomena And Activity. J. Trauma Acute Care Surg. 12, 193–207.

Hallmark, S.L., Qiu, Y., Pawlovitch, M., McDonald, T.J., 2013. Assessing the safety impacts of paved shoulders. J. Transp. Saf. Secur. 5, 131–147.

Lee, J.-T., Dittberner, R., Sripathi, H., 2007. Safety impacts of freeway managed-lane strategy: Inside lane for high-occupancy vehicle use and right shoulder lane as travel lane during peak periods. Transp. Res. Rec. 2012, 113–120.

Li, Z., Kepaptsoglou, K., Lee, Y., Patel, H., Liu, Y., Kim, H.G., 2013. Safety effects of shoulder paving for rural and urban interstate, multilane, and two-lane highways. J. Transp. Eng. 139, 1010–1019.

Li, Z., Lee, S.H., Lee, Y., Zhou, B., Bamzai, R., 2011. A Methodology for Assessing Safety Impacts of Highway Shoulder Paving, in: Transportation and Development Institute Congress 2011: Integrated Transportation and Development for a Better Tomorrow. pp. 1105–1117.

MacLennan, C.A., 1988. From Accident to Crash: The Auto Industry and the Politics of

Injury. Med. Anthropol. Q. 2, 233–250. https://doi.org/10.1525/maq.1988.2.3.02a00040

Martin, J.L., 2001. Severity of run-off-crashes whether motorway hard shoulders are equipped with a guardrail or not, in: Traffic Safety on Three Continents: International Conference in Moscow, Russia, 19-21 September, 2001. Statens väg-och transportforskningsinstitut, p. 11.

Meuleners, L.B., Hendrie, D., Lee, A.H., 2011. Effectiveness of sealed shoulders and audible edge lines in Western Australia. Traffic Inj. Prev. 12, 201–205.

Noella, K., 2017. Change Shoulder Type. European Road Safety Decision Support System, developed by the H2020 project SafetyCube. Retrieved from www.roadsafety-dss.eu.

Ogden, K.W., 1997. The effects of paved shoulders on accidents on rural highways. Accid. Anal. Prev. 29, 353–362.

Park, J., Abdel-Aty, M., 2016. Safety effects of widening shoulders on rural multilane roads: Developing crash modification functions with multivariate adaptive regression splines. Transp. Res. Rec. 2583, 34–41.

Park, J., Abdel-Aty, M., Lee, C., 2014. Exploration and comparison of crash modification factors for multiple treatments on rural multilane roadways. Accid. Anal. Prev. 70, 167–177. https://doi.org/10.1016/j.aap.2014.03.016

Peng, Y., Geedipally, S.R., Lord, D., 2012. Effect of Roadside Features on Single-Vehicle Roadway Departure Crashes on Rural Two-Lane Roads. Transp. Res. Rec. 2309, 21–29. https://doi.org/10.3141/2309-03

Rogness, R.O., Fambro, D.B., Turner, D.S., 1982. Before-after accident analysis for two shoulder upgrading alternatives. Texas Transportation Institute, Texas A & M University.

Stamatiadis, N., Pigman, J.G., Sacksteder, J., Ruff, W., Lord, D., 2009. Impact of Shoulder Width and Median Width on Safety. National Academies Press.

Staton, C., Vissoci, J., Gong, E., Toomey, N., Wafula, R., Abdelgadir, J., Zhou, Y., Liu, C., Pei, F., Zick, B., Ratliff, C.D., Rotich, C., Jadue, N., de Andrade, L., von Isenburg, M., Hocker, M., 2016. Road Traffic Injury Prevention Initiatives: A Systematic Review and Metasummary of Effectiveness in Low and Middle Income Countries. PLOS ONE 11, e0144971. https://doi.org/10.1371/journal.pone.0144971

Usami, D., 2017. Increase shoulder width. European Road Safety Decision Support System, developed by the H2020 project SafetyCube. Retrieved from www.roadsafety-dss.eu.

World Health Organization, 2018. Global status report on road safety 2018. World Health Organization.

Zegeer, C.V., Deacon, J.A., 1987. Effect of lane width, shoulder width, and shoulder type on highway safety. State Art Rep. 6, 1–21.

Zegeer, C.V., Deen, R.C., Mayes, J.G., 1981. The Effect of Lane and Shoulder Widths on Accident Reductions on Rural, Two-Lane Roads.

Zeng, H., Schrock, S.D., 2013. Safety Effectiveness of Various Types of Shoulders on Rural Two-Lane Roads in Winter and Non-winter Periods.

Zeng, H., Schrock, S.D., 2012. Estimation of Safety Effectiveness of Composite Shoulders on Rural Two-Lane Highways. Transp. Res. Rec. 2279, 99–107. https://doi.org/10.3141/2279-12

Zeng, H., Schrock, S.D., Mulinazzi, T.E., 2013. Evaluation of safety effectiveness of composite shoulders, wide unpaved shoulders, and wide paved shoulders in Kansas.