TECH**BRIEF**

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Safety Evaluation of Lane and Shoulder Width Combinations on Rural, Two-Lane, Undivided Roads

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This document is a technical summary of the Federal Highway Administration report, *Safety Evaluation of Lane and Shoulder Width Combinations on Rural, Two-Lane, Undivided Roads* (FHWA-HRT-09-031), which will be available online at http://www.tfhrc.gov/safety.

Objective

The Federal Highway Administration (FHWA) organized a pooled fund study of 26 States to evaluate low-cost safety strategies as part of its strategic highway safety effort. The purpose of the FHWA Low-Cost Safety Improvements Pooled Fund Study is to evaluate the safety effectiveness of several low-cost safety strategies presented in the *National Cooperative Highway Research Program (NCHRP) Report 500 Series.* Although not identified in the *NCHRP Report 500 Series*, one of the strategies selected for evaluation in the pooled fund study was the allocation of lane and shoulder width for fixed pavement widths on rural, two-lane, undivided roads (i.e., given a fixed roadway width for a rural, two-lane, undivided road, is it safer to provide wider shoulders or wider lanes?). The safety effectiveness of various allocations of total paved width had not previously been thoroughly documented, and this study is an attempt to provide an evaluation through scientifically rigorous procedures.

Introduction

State and local agencies are often faced with a decision of how to enhance safety on rural, two-lane roads when the total paved width is to remain the same. More than 42,000 fatalities occur annually on roadways in the United States. Nearly 60 percent of these fatalities are related to roadway departure crashes, 50 percent of which occur on rural, two-lane roads.[(1)] One option for addressing roadway departure crashes without adjusting the total paved width is to reconfigure the combination of lane and shoulder width. As an example of the question at hand, given a 10.97-m (30-ft) total paved width, is it safer to provide 3.66-m (12-ft) lanes with 0.91-m (3-ft) shoulders or 3.35-m (11-ft) lanes with 1.22-m (4-ft) shoulders? The application of this strategy is most likely to be incorporated during new construction or during a resurfacing project. It is not likely that an agency would restripe an existing roadway as a standalone treatment.

Research regarding the safety implications of lane and shoulder width has been conducted for over 20 years and remains of interest today. Among the more recent activities in this area is the work of an expert panel to review previous research results for inclusion in the Interactive Highway Safety Design Model (IHSDM). Several studies were reviewed to develop crash modification factors (CMFs)[1] for lane width and shoulder width.[(2,3,4)] The studies used a variety of data analysis techniques and statistical tools in an attempt to derive the effect of lane and shoulder width on safety. The CMFs developed by the expert panel were later adopted by the *Highway Safety Manual* (HSM).

The literature review indicates that there is fairly substantial evidence of the benefits of adding shoulders to nearly all lane widths. Work by the expert panel for the HSM and IHSDM has established CMFs for lane width and shoulder width individually; however, they do not address the issue of the optimal lane and shoulder width combination given a fixed total paved width. The safety effectiveness of various lane-shoulder width combinations for a fixed paved width is explored empirically in this study to provide better support to the States when selecting a lane-shoulder combination for a given paved width on rural, two-lane, undivided roads.

Methodology

Geometric, traffic, and crash data were obtained for the entire population of rural, two-lane, undivided road segments in Pennsylvania (1997–2001 and 2003–2006) and Washington (1993–1996 and 2002–2003). Several crash types were investigated, emphasizing target crash types likely affected by lane and shoulder width. Analyses included the following:

- All crashes on road segments (excluding intersection crashes).
- Target crashes on road segments, determined as the combination of the following:
    - Run-off road.
    - Head on.
    - Sideswipe same direction.
    - Sideswipe opposite direction.

A matched case-control analysis was conducted to determine the safety effectiveness of lane and shoulder width configurations for total paved widths from 7.92 to 10.97 m (26 to 36 ft) on rural, two-lane, undivided roads. Matching

[1] A crash reduction factor (CRF) indicates the percent crash reduction that might be expected after implementing a given countermeasure. A crash or accident modification factor (CMF or AMF, respectively) is a multiplier to adjust the number of expected crashes based on the estimated safety benefit for a particular countermeasure. The CMF or AMF is calculated as 1-(CRF/100).

was used to control for the effects of average annual daily traffic (AADT) and segment length while other variables were included in the model as covariates to account for potential confounding effects. Segment lengths are not equal for all segments included in the analysis, but case-control pairs were matched on similar values of segment length.[5] The average segment lengths in Pennsylvania and Washington were approximately 0.80 and 0.64 km (0.5 and 0.4 mi), respectively. For Pennsylvania, additional covariates included speed limit, unpaved right shoulder width, and regional indicators. For Washington, additional covariates included speed limit and indicators for horizontal and vertical curvature. For narrow pavement widths (less than 7.92 m (26 ft)), a supplemental analysis was conducted using data from Pennsylvania only.

One advantage of the case-control method is the careful adjustment for confounding variables such as AADT. For this study, an added benefit is the format and interpretation of the analysis. Conditional logistic regression models were applied to the matched case-control design, producing an odds ratio. The odds ratio represents the expected percent change in crashes compared with the baseline. The baseline is indicated by an odds ratio of 1.0. An odds ratio less than 1.0 represents an expected reduction in crashes while an odds ratio greater than 1.0 represents an expected increase in crashes (e.g., odds ratio of 1.10 indicates a 10 percent increase in crashes compared with the baseline). The odds ratio can be interpreted as a CMF. This greatly facilitates the interpretation of complex modeling and produces results that are readily applied by practitioners.

The full report includes a detailed explanation of the methodology, including a description of how to estimate the odds ratio.

Results

Wide Pavement Widths

A series of models were estimated for pavement widths from 7.92 to 10.97 m (26 to 36 ft). Separate models were developed for total crashes and target crashes; the process was repeated for both Pennsylvania and Washington datasets. The sample included relatively few segments with AADT less than 1,000 vehicles per day, and posted speeds were 40 km/h (25 mi/h) or greater. Therefore, results generally apply to rural, two-lane roads with AADTs greater than 1,000 vehicles per day and posted speeds of 40 km/h (25 mi/h) or greater.

The objective of this study was to examine the results of specific lane-shoulder combinations. Considering Pennsylvania and Washington individually, some configurations show that additional lane width is favorable to additional shoulder width while others indicate the opposite trend. However, small sample sizes make it difficult to show a definitive trend for some configurations. As the results for each fixed pavement width are based on three lane-shoulder combinations, it is important to develop three reliable points to determine if a clear trend exists.

An additional analysis was undertaken to compare the study findings to the literature. Specifically, results were compared with the draft chapter on rural, two-lane roads from the HSM and a report on design decisions by the Texas DOT (TxDOT) that includes an analysis of lane and shoulder width.[6,7] The HSM considers lane and shoulder width separately and does not consider the interaction between the two variables.[6] The HSM implicitly assumes that a given shoulder width would have the same effect on safety for roadways with different lane widths (e.g., a 1.22-m (4-ft) shoulder would have the same effect on safety for roadways with a

Table 1. Comparison of study results with CMFs from literature.									
Total Width (m)	**Lane Width (m)**	**Shoulder Width (m)**	**Sample Size (PA)**	**PA CMF**	**Sample Size (WA)**	**WA CMF**	**TxDOT CMF**	**HSM CMF**	**Selected CMF from Research and Literature**
7.92	3.05	0.91	3,510	1.13	*60*	*1.95*	1.22	1.53	1.13
	3.35	0.61	2,649	1.12	449	1.79	1.13	1.36	1.12
	3.66	0.30	*135*	*1.85*	*33*	*1.71*	1.09	1.40	1.09*
8.53	3.05	1.22	2,799	1.20	*20*	*0.75*	1.18	1.46	1.20
	3.35	0.91	4,188	1.19	673	1.43	1.10	1.29	1.19
	3.66	0.61	882	1.16	*120*	*1.15*	1.07	1.30	1.16
9.14	3.05	1.52	*382*	*1.22*	*17*	*1.25*	1.15	1.38	1.15*
	3.35	1.22	6,403	1.14	501	1.58	1.07	1.22	1.14
	3.66	0.91	1,411	1.11	*272*	*1.27*	1.05	1.23	1.11
9.75	3.05	1.83	*246*	*0.75*	*12*	*1.49*	1.11	1.30	1.11*
	3.35	1.52	1,893	1.06	*178*	*1.22*	1.05	1.14	1.06
	3.66	1.22	2,986	1.04	529	1.07	1.03	1.16	1.04
10.36	3.05	2.13	*54*	*1.96*	*1*	*0.00*	1.08	1.24	1.08*
	3.35	1.83	1,597	0.84	*256*	*1.15*	1.02	1.06	0.84
	3.66	1.52	702	0.87	*191*	*0.89*	1.02	1.08	0.87
10.97	3.05	2.44	*42*	*0.38*	*14*	*0.47*	1.05	1.17	1.05*
	3.35	2.13	*188*	*0.90*	*115*	*1.08*	1.00	1.00	1.00*
	3.66	1.83	932	1.00	382	1.00	1.00	1.00	1.00

Note: Values in italics for Pennsylvania and Washington imply insufficient sample size for a reliable CMF.
* Selected CMF was based on the TxDOT research.
1 ft = 0.305 m

3.05-m (10-ft) lane as roadways with a 3.66-m (12-ft) lane). The TxDOT report explicitly considers interactions between lane width and shoulder width in the model formulation, allowing the effects of shoulder width to vary across different lane widths.[7] The approach adopted for this research also explicitly considers the interaction between lane and shoulder width by obtaining separate estimates of safety effectiveness for each lane-shoulder pair.

The findings from the three studies are compared in table 1, and a CMF value is selected for each lane-shoulder configuration. The selected values represent a compromise that emphasizes findings from this study. In cases where the CMF from this study had an insufficient sample size (i.e., number of segments), the TxDOT CMF was used to provide an estimated value. If there was a choice between using the CMF from Pennsylvania or Washington, the one with the larger sample size was chosen; this was always the Pennsylvania estimate.

The last column in table 1 presents the selected CMFs for various lane-shoulder configurations compared with a baseline configuration with 3.66-m (12-ft) lanes and 1.83-m (6-ft) shoulders. As a result of combining the research findings, there is a more apparent trend with respect to the optimal configuration of lane and shoulder width for a given pavement width. For total paved widths from 7.92 to 9.14 m (26 to 30 ft), the CMF decreases only slightly as lane width increases from 3.05 to 3.35 m (10 to 11 ft). The CMF then decreases more substantially as

Table 2. Selected CMFs from table 1 for comparison within a given paved width.			
Pavement Width (m)	**3.05-m Lanes**	**3.35-m Lanes**	**3.66-m Lanes**
7.92	1.00	0.99	0.96
8.53	1.00	0.99	0.97
9.14	1.00	0.99	0.97
9.75	1.00	0.95	0.94
10.36	1.00	0.78	0.81
10.97	1.00	0.95	0.95

lane width increases from 3.35 to 3.66 m (11 to 12 ft). For total paved widths from 9.75 to 10.97 m (32 to 36 ft), the most substantial reduction in the CMF occurs as lane width increases from 3.05 to 3.35 m (10 to 11 ft). Results indicate a light benefit to adding lane width compared with shoulder width for a given paved width.

Comparing the magnitude of CMFs across studies in table 1, it is clear that the HSM values are generally high, while the values from the Pennsylvania analysis and the TxDOT study are relatively similar in magnitude. The Washington CMFs are a bit more inconsistent, owing largely to lower sample sizes for many lane-shoulder combinations. Considering the differing methodologies and data employed, the CMFs from TxDOT and Pennsylvania are remarkably similar.

Selected CMFs for Comparison within a Given Paved Width

The CMFs in table 1 represent the expected change in target crashes compared with a baseline scenario of 3.66-m (12-ft) lanes and 1.83-m (6-ft) shoulders. When comparing lane-shoulder configurations for a total paved width other than 10.97 m (36 ft), it is necessary to adjust the CMFs by creating a new baseline. The CMFs in table 2 have been adjusted to reflect a baseline scenario with 3.05-m (10-ft) lanes for each total paved width (i.e., CMF = 1.00). For fixed total paved widths from 7.92 to 10.97 m (26 to 36 ft), CMFs are shown to decrease as lane width increases (i.e., wider lanes and narrower shoulders appear to be the optimal configuration with respect to safety). Specifically, configurations with 3.66-m (12-ft) lanes appear to be the optimal configuration with respect to safety for total paved widths from 7.92 to 9.75 m (26 to 32 ft). For 10.36-m (34-ft) total paved widths, configurations with 3.35-m (11-ft) lanes are associated with the lowest CMF. For 10.97-m (36-ft) total paved widths, the CMF is identical for both 3.35- and 3.66-m (11- and 12-ft) lanes.

Narrow Pavement Widths

This section presents results from Pennsylvania for narrow paved widths (i.e., 7.32 m (24 ft)). The odds ratios developed for the narrow pavement widths were not significantly different from the baseline. However, a clear relationship was exhibited between low-volume roadways and narrow pavement widths. The odds ratio was shown to increase nonlinearly with AADT. Also, the rate of increase differed for each lane-shoulder configuration, validating the use of interaction terms in addition to the main effects in the model.

Results were estimated in relation to a baseline configuration with 3.66-m (12-ft) lanes and 0-m (0-ft) shoulders. At low AADTs (less than 1,000 vehicles per day), odds ratios were generally less than 1.0. When AADT was greater than approximately 1,000 vehicles per day, the odds ratios exceeded 1.0. These results are not statistically significant but are intended to show the importance of considering AADT when estimating the odds ratio for low-volume, narrow roadways. Taken as a whole, these results indicate some reduction in the odds ratio by adding shoulder width compared with lane width, but, in general, only when AADT is very low.

Economic Analysis

Completion of the economic analysis requires careful consideration of the project scope. The objective of this study, *Given a fixed roadway width for a rural, two-lane, undivided road, is it safer to provide wider shoulders or wider lanes?,* implies the activity of interest is not a restriping project or a change in total paved width. Rather, for a given total paved width, there is a decision to be made regarding the allocation of lane and shoulder width. Given this description, the cost of alternatives is essentially equal; therefore, it is reasonable to just consider the benefits.

The CMFs presented in table 2 represent the expected percent change in target crashes compared with a configuration with 3.05-m (10-ft) lanes for given total paved widths. The most safety-effective configuration for a given paved width is indicated by the lowest CMF. Using the 9.75-m (32-ft) paved width as an example, the adjusted CMFs are 1.00, 0.95, and 0.94 for the 3.05-, 3.35-, and 3.66-m (10-, 11-, and 12-ft) lane configurations, respectively. The 3.66-m (12-ft) lane configuration is associated with the lowest CMF; therefore, a 3.66-m (12-ft) lane with a 1.22-m (4-ft) shoulder is the most safety-effective configuration within the 9.75-m (32-ft) paved width group.

Crash cost savings are based on the expected reduction in crash frequency. To compute the expected reduction in crash frequency, the CMFs must be applied to actual crash data for a given location. Again, using the example of a 9.75-m (32-ft) paved width and the adjusted CMFs (table 2), the expected change in target crashes by reallocating the lane and shoulder width from a configuration with 3.05-m (10-ft) lanes and 1.83-m (6-ft) shoulders to a configuration with 3.66-m (12-ft) lanes and 1.22-m (4-ft) shoulders would be a 6 percent decrease. Assuming a long-term expected crash experience of 100 target crashes per year for the base condition, the configuration with 3.66-m (12-ft) lanes and 1.22-m (4-ft) shoulders would yield a reduction of 6 crashes per year. Estimated crash costs are then applied to the expected change in crashes to estimate the annual dollar savings. Crash costs typically vary by State but can be estimated from the recent FHWA crash cost guide when State-specific crash cost data are not available.[8]

Summary and Conclusions

The objective of this study was to determine the safety effectiveness of specific combinations of lane and shoulder width on rural, two-lane, undivided roads. This strategy is intended to reduce the frequency of roadway departure crashes. Matched case-control analyses were applied to geometric, traffic, and crash data for road segments in Pennsylvania and Washington to estimate CMFs.

In general, results were consistent with previous research efforts, showing crash reductions for wider paved widths, wider lanes, and wider shoulders, all else being equal. More specific to the research objective, CMFs were provided for various lane-shoulder configurations. Individual State analyses did not indicate a clear preference for lane or shoulder width given a fixed paved width. However, the individual State analyses were supplemented with previous research, producing a more apparent trend as follows:

- For 7.92- to 9.75-m (26- to 32-ft) total paved widths, 3.66-m (12-ft) lanes provide the optimal safety benefit. The CMF ranges from 0.94 to 0.97, indicating a 3–6 percent crash reduction for 3.66-m (12-ft) lanes compared with 3.05-m (10-ft) lanes.

- For 10.36-m (34-ft) total paved width, 3.35-m (11-ft) lanes provide the optimal safety benefit. The CMF for 3.35-m (11-ft) lanes is 0.78 compared with the 3.05-m (10-ft) baseline.
- For 10.97-m (36-ft) total paved width, 3.35- or 3.66-m (11- or 12-ft) lanes provide the optimal safety benefit. The CMF is 0.95 for 3.35- and 3.66-m (11- and 12-ft) lanes compared with the 3.05-m (10-ft) baseline.

These results apply, in general, to rural, two-lane roads with traffic volumes greater than 1,000 vehicles per day and posted speeds of 40 km/h (25 mi/h) or greater. While 3.66-m (12-ft) lanes appear to be the optimal design for 7.92- to 9.75-m (26- to 32-ft) total paved widths, 3.35-m (11-ft) lanes perform equally well or better than 3.66-m (12-ft) lanes for 10.36- to 10.97-m (34- to 36-ft) total paved widths. There may be additional benefits to providing a 3.35-m (11-ft) lane width compared with a 3.66-m (12-ft) lane width for specific scenarios. For example, the American Association of State Highway and Transportation Officials recommends, as a minimum, that 0.61 m (2 ft) of the shoulder width should be paved to provide for pavement support, wide vehicles, collision avoidance, and additional pavement width for bicyclists.[9] The 3.35-m (11-ft) lane will also provide an extra 0.30 m (1 ft) of shoulder, given a fixed paved width, which may provide the necessary additional shoulder width to accommodate disabled vehicles. From a maintenance perspective, it may be desirable to provide 3.35-m (11-ft) lanes compared with 3.66-m (12-ft) lanes to help keep drivers off of the edge of the pavement, particularly for very narrow total paved widths.

For narrow paved widths (i.e., 7.32 m (24 ft)), there is a slight reduction in crash odds by adding shoulder width compared with lane width, but only when traffic volume is very low (i.e., less than 1,000 vehicles per day). However, configurations with relatively narrow lanes may not be appropriate for roadways with notable truck traffic. This is due to issues related to off-tracking, where the rear wheels of trucks generally track inside the front wheels on horizontal curves. Therefore, the design vehicle should be considered when identifying potential lane-shoulder configurations.

This study updates earlier research on the safety effectiveness of lane and shoulder width. While there has been fairly substantial evidence of the benefits of adding shoulders to nearly all lane widths, previous work does not address the issue of the optimal lane-shoulder configuration for a given total paved width. Based on the results of this study, reallocating lane and shoulder width for a fixed total paved width can be a cost-effective treatment for reducing crashes on rural, two-lane, undivided roadways. Comparing the results of this study with previous research, it is apparent that the effects of lane and shoulder width should be considered in the context of each other (i.e., the CMF for a given shoulder width may not be applicable across various lane widths).

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