Abridgment

Benefit-Cost Evaluation of Left-Turn Lanes on Uncontrolled Approaches of Rural Intersections

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ABSTRACT

Left-turn lanes are provided on uncontrolled approaches of rural intersections to improve the safety and efficiency of traffic operations on these approaches. Although the safety and operational effects of left-turn lanes are well recognized, there are no generally accepted guidelines that define the circumstances under which the costs of these lanes are justified by the benefits that they provide. The objectives of this research were (a) to evaluate the benefits and costs of left-turn lanes on the uncontrolled approaches of intersections on rural two-lane highways and (b) to determine the traffic volumes that warrant these lanes in Nebraska. The road-user cost savings associated with the reductions in accidents, stops, delay, and fuel consumption provided by left-turn lanes were evaluated over a range of traffic volumes and compared with the costs of left-turn lanes over the same range. The safety effectiveness of the lanes was based on accident experience on rural two-lane highways in Nebraska. The NETSIM traffic simulation model was used to determine their operational effectiveness. Volumes for which the road-user cost savings exceeded the lane costs were determined to warrant left-turn lanes. The warrants developed in this research are limited to prevailing conditions typical of those on rural two-lane highways in Nebraska. However, the procedure used to develop these warrants is applicable to other locations.

Left-turn lanes are provided on uncontrolled approaches of rural intersections to improve the safety and efficiency of traffic operations on these approaches. The primary function of these lanes is to remove the deceleration and storage of left-turning vehicles from the through traffic lanes and thereby enable through vehicles to pass by without conflict and delay. Thus, the benefits derived from the provision of these left-turn lanes are reductions in accidents, stops, and delay.

Although the safety and operational effects of left-turn lanes are well recognized by highway engineers, there are no generally accepted guidelines that define the circumstances under which the costs of constructing and maintaining left-turn lanes are justified by the benefits that they provide. Intersection design guides (1-4) currently used by highway engineers contain criteria for the geometric design of the elements of left-turn lanes, such as taper lengths, storage lengths, and lane widths. But these design guides do not contain warrants for left-turn lanes. Without acceptable warrants, the only means highway engineers have to determine the need for left-turn lanes are experience and judgment, which vary considerably among individuals. Acceptable left-turn lane warrants would not only improve the consistency of decisions to construct such lanes, but on the basis of a benefit-cost evaluation would also provide for their cost-effective use. Thus, left-turn lane warrants based on a benefit-cost evaluation would enable the determination of the need for left-turn lanes at specific locations and would promote the most cost-effective allocation of available funds among competing highway projects.

PREVIOUS RESEARCH

Several studies (5-9) have reported the safety effects of left-turn lanes on the uncontrolled approaches of rural intersections. However, few studies have quantified the operational effects of left-turn lanes at these locations. In addition, a review of the literature revealed only three studies that were designed to develop warrants for left-turn lanes on the basis of a benefit-cost analysis (10-12), but the limited scope of these studies made their findings inapplicable for the purposes of this research.

OBJECTIVES

The objectives of the research reported in this paper were (a) to evaluate the benefits and costs of left-turn lanes on the uncontrolled approaches of intersections on rural two-lane highways and (b) to determine the traffic volumes that warrant the construction and maintenance of these lanes in Nebraska. This paper presents the procedure, findings, and conclusions of this research.

PROCEDURE

The benefits provided by left-turn lanes are reductions in accidents, stops, and delay. The road-user cost savings associated with these benefits were evaluated over a range of traffic volumes and compared with the costs of constructing and maintaining left-turn lanes over the same range. Volumes for which the road-user cost savings were greater than the left-turn lane costs were determined to be those volumes that warrant left-turn lanes. A description of the procedure used to evaluate each component of the road-user cost savings and the left-turn lane costs follows.

Accident Cost Savings

An analysis of accidents occurring at rural intersections in Nebraska was conducted to determine the effectiveness of left-turn lanes in reducing accidents on the uncontrolled approaches of intersections on rural two-lane highways. Intersection accident data were obtained from the Nebraska Department of Roads for the 3-year period from January 1, 1977, to December 31, 1979. From these data, the numbers and types of accidents that occurred on each of the intersection approaches were determined. Previous research (6-9) indicated that the primary safety effects of left-turn lanes on rural intersection approaches were reductions in the numbers of rear-end and left-turn accidents. Therefore, rear-end and left-turn accident rates were computed for each approach. Mean rear-end and left-turn accident rates were then computed for each approach category. These mean rates are shown in Table 1. T-tests conducted at the 5 percent level of significance within each shoulder category indicated that there were no statistically significant differences in rear-end and left-turn accident rates between approaches with left-turn lanes and those without left-turn lanes.

TABLE 1 Mean Accident Rates

	No Paved Shoulder		Paved Shoulder	
Accident Type	No LT Lane	LT Lane	No LT Lane	LT Lane
Rear-end	0.44	0.19	0.31	0.28
Left-turn	0.03	0.26	0.000	0.10

Note: Accident rates are expressed as accidents per million entering vehicles. LT = left-turn.

Despite the fact that no statistically significant safety effects of left-turn lanes were found, an accident reduction factor was computed for each accident type from the difference between the mean accident rates with and without left-turn lanes within each shoulder category. The accident reduction factors computed are shown in Table 2 along with accident reduction factors found in the literature (6-8).

TABLE 2 Accident Reduction Factors

	Accident Type	
Source	Rear-End (%)	Left-Turn (%)
Nebraska		
Without shoulder[a]	60	-770[c]
With shoulder[b]	10	$-\infty$[d]
NCHRP *(6)*	20	-
FHWA *(7)*	80	50
Hammer *(8)*	85	37

[a]Approaches without paved shoulders.
[b]Approaches with paved shoulders.
[c]Increase in mean left-turn accident rate was 770 percent.
[d]Undefined percentage of increase in mean accident rate because approaches without left-turn lanes had a zero mean left-turn accident rate.

The accident reduction factors computed for rear-end accidents indicated that left-turn lanes were more effective in reducing rear-end accidents on approaches without paved shoulders than on approaches with paved shoulders. The rear-end accident reduction factor computed for approaches without paved shoulders was within the range of the rear-end accident reduction factors found in the literature, whereas the rear-end accident reduction factor computed for approaches with paved shoulders was lower than those found in the literature. However, it was not apparent from the literature that the effects of paved shoulders had been considered in the previous research. Therefore, the rear-end accident reduction factors computed from the Nebraska data were used for the purposes of this research.

The accident reduction factors computed for left-turn accidents indicated that left-turn lanes were not effective in reducing left-turn accidents but were associated with increases in left-turn accidents. In the Nebraska data, a left-turn accident was defined as a collision between a left-turning vehicle and an opposing vehicle. Consequently, these findings suggested that perhaps sight-distance problems between left-turning and opposing vehicles were created by the provision of left-turn lanes or that the intersection approaches with left-turn lanes had more left-turn accidents merely because they had higher left-turn volumes. However, as shown in Table 2, these findings were contrary to those reported by previous research (7,8), but the definition of left-turn accidents used in these studies may have included collisions between left-turning vehicles and other vehicles than opposing ones. For this reason, and because properly designed left-turn lanes would not be expected to create sight-distance problems between left-turning and opposing vehicles, it was assumed that left-turn lanes provided no reductions in left-turn accidents on approaches with and without paved shoulders.

Therefore, accident reduction benefits of left-turn lanes used in this research were reductions in rear-end accidents only. The accident cost savings provided by left-turn lanes were computed by using the rear-end accident rates and the rear-end accident reduction factors shown in Tables 1 and 2 for uncontrolled approaches at intersections of rural two-lane highways in Nebraska.

Operational Cost Savings

The benefits of reduction in stops and delay provided by left-turn lanes result in operational cost savings to the road users. The operational cost savings are composed of reductions in motor vehicle operating costs and time costs because of fewer stops and less delay. Previous studies (10-14) have found the reductions in stops and delay provided by left-turn lanes to be functions of approach volume, opposing volume, left-turn volume, approach speed, and percentage of trucks. However, none of these studies formulated an expression for the total operational cost savings resulting from these reductions.

In order to determine the effectiveness of left-turn lanes in reducing stops and delay on the uncontrolled approaches of intersections on rural two-lane highways, a series of computer runs was conducted over a range of approach conditions using the NETSIM traffic simulation model (15). One set of runs was made with left-turn lanes on the approaches and a second set without left-turn lanes on the approaches. Both sets of runs were made over the same range of volumes, approach speeds, and truck percentages. The effects of left-turn lanes on stops and delay were then determined by a pairwise comparison of the NETSIM stops and delay output from the two sets of runs for identical combinations of volumes, approach speeds, and truck percentages. Because the NETSIM output included fuel consumption, the effect of left-turn lanes on fuel consumption was also determined in this manner. Thus, for every combination of volume, approach speed, and truck percentage, the effects of left-turn lanes on stops, delay, and fuel consumption were computed as the differences between the respective outputs of the two runs for the approaching traffic. By using a modified response surface experimental design (16,17), more than 2,500 pairs of simulation runs were made. The details of these runs are documented elsewhere (18).

A multiple-regression analysis of the results of the simulation runs was conducted to determine the relationships between the benefits of left-turn lanes and the approach conditions. As a result of this analysis, three regression equations were determined for the prediction of the reductions in stops, delay, and fuel consumption provided by left-turn lanes, which were used to compute the operational cost savings.

The operational cost savings were computed by using (a) unit vehicle operating costs determined by Claffey (19) for passenger cars and updated to the year 1983 on the basis of changes in the national consumer price index (CPI) [private transportation: tires (new, tubeless), motor oil, and automobile repairs and maintenance (20,21)], (b) the unit value of time established by AASHTO (22) for the year 1975 and updated to the year 1983 on the basis of the change in the CPI (20,21), and (c) the fuel economy of the weighted 1971 composite vehicle in the NETSIM model (23) corrected for the increased fuel economy of the 1983 vehicle fleet in accordance with the fuel economy adjustment factors obtained by Apostolos (24). The annual operational cost savings were computed for the average vehicle mix, average vehicle occupancy, and average hourly distribution of daily traffic that existed on rural two-lane highways in Nebraska during 1983 (25).

Left-Turn-Lane Costs

The costs of a left-turn lane were computed to be the additional costs required to construct and maintain a painted left-turn lane on an uncontrolled intersection approach within the existing right-of-way on rural two-lane highways in Nebraska. Based on a review of left-turn-lane projects constructed in 1983, the Nebraska Department of Roads estimated the additional costs of a left-turn lane to be $6 per square foot of additional pavement required. This unit cost included construction cost items of earthwork, asphaltic-concrete pavement, and drainage, and maintenance cost items of pavement markings and snow removal over the life of the project. Thus, the construction and maintenance costs of a left-turn lane were computed by multiplying the additional square feet of pavement area required by the left-turn lane times the unit cost of $6 per square foot. The construction and maintenance costs were then annualized by multiplying them by the capital recovery factor (0.11746) for a 10 percent interest rate, 20-year service life, and zero salvage value. The dimensions of the left-turn lane configuration used to compute the additional pavement area required were determined as a function of approach speed and left-turn volume in accordance with Nebraska design standards (26).

CONCLUSIONS

On the basis of the results of the benefit-cost evaluation conducted in this research, the following conclusions were reached in regard to the provision of left-turns on the uncontrolled approaches of four-leg intersections of rural two-lane highways in Nebraska:

1. The approach volumes at which left-turn lanes were warranted were dependent on the prevailing approach conditions, in particular the left-turn percentage, opposing volume, approach speed, and shoulder condition.
2. The approach volumes required to warrant left-turn lanes were considerably higher on approaches with, rather than without, paved shoulders, because of the lower rear-end accident rates and the reduced effectiveness of left-turn lanes in reducing rear-end accidents on such approaches.
3. Under no circumstances on approaches without paved shoulders were left-turn lanes warranted at an approach annual average daily traffic (AADT) of less than 2,500 vehicles per day (vpd). On approaches with paved shoulders, left-turn lanes were never warranted at approach AADTs of less than 4,500 vpd.

It must be remembered that the benefit-cost evaluation conducted in this research was based on accident experience, traffic conditions, road-user unit costs, and left-turn lane costs that were intended to be representative of intersections on rural two-lane highways in Nebraska during 1983. Consequently, on approaches with higher than average accident rates or truck percentages or both, left-turn lanes may be warranted at volumes lower than the warranting volumes found in this study. In addition, the use of different unit road-user costs and left-turn lane costs would also alter the findings of this study. Higher unit road-user costs and lower left-turn lane costs would reduce the warranting volumes. Conversely, lower unit road-user costs and higher left-turn lane costs would increase the warranting volumes.

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Abridgment

Superelevation and Roadway Geometry: Deficiency at Crash Sites and on Grades

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ABSTRACT

Survey data on roadway superelevation, curvature, and grade collected at the sites of fatal rollover accidents and at comparison sites in New Mexico and Georgia were analyzed to determine the effect of grade on superelevation after adjustment for curvature. These adjusted data were then used to determine the effect of superelevation on accidents. After adjustment for curvature, it was found that in comparison with flat roadway sections (grade +2.5 to -2.5 percent) sections with grade (greater than +2.5 or less than -2.5 percent) had less superelevation. After adjustments for both curvature and grade, fatal rollover accident sections were found to have less superelevation than comparison sections. Inadequate superelevation presents a risk that should be eliminated from the roadway system.