Table 3. Roadside hazard ratings.

Side Slope	Coverage Factor	Roadside Hazard Ratings by Lateral Clear Width (ft)						
		30	25	20	15	10	5	0
6:1 or flatter	90	24	28	32	34	42	46	47
	60	24	27	29	30	35	38	39
	40	24	27	27	27	32	34	34
	10	24	24	24	24	25	26	26
4:1	90	35	37	39	41	44	48	49
	60	35	36	38	39	40	43	44
	40	35	36	37	37	39	41	41
	10	35	35	35	35	36	37	37
3:1	90	41	42	42	43	44	48	49
	60	41	42	42	42	43	45	46
	40	41	42	42	41	41	44	45
	10	41	42	42	41	41	42	42
2:1 or steeper	90	53	53	53	53	45	49	50
	60	53	53	53	53	46	49	50
	40	53	53	53	53	48	50	50
	10	53	53	53	53	50	50	50

rate requires some clarification. The raw regression coefficients reported in the paper express the relation between the covariate and dependent variable for the entire data base. Because these coefficients do not reflect interactions between variables, they must be viewed with caution. In the case of curve length, the negative coefficient appears illogical unless one considers the strong correlation between curve length and degree of curve. In any event, as was discussed in the paper, the actual effect of this coefficient is negligible given the practical range of curve length.

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Abridgment

Some Partial Consequences of Reduced Traffic Lane Widths on Urban Arterials

CLINTON L. HEIMBACH, PAUL D. CRIBBINS, AND MYUNG-SOON CHANG

When four-lane, urban, undivided arterials are newly built or reconstructed in place, traffic lane width becomes one of the major determinants of total right-of-way width. A particularly difficult problem arises when the urban corridor permits the construction of 10- or 11-ft-wide lanes, but not 12-ft-wide lanes. There are no guidelines for the roadway designer to indicate the trade-offs in traffic safety and operations as the width of a traffic lane is reduced below the 12-ft standard. The relationship of operating speed and accidents to a series of independent variables that characterize roadway design features and traffic volumes is investigated. It is concluded that both peak and off-peak operating speeds, as well as traffic accidents, are significantly related to traffic lane width on urban arterials. Specifically, operating speeds decrease and accidents increase as traffic lane width decreases. Operating speeds are also influenced by the posted speed limit, traffic volume, and total traffic lane width. Also, the number of accidents per year is related to the number of intersections per mile, the number of access trips to and from commercial driveways, average daily traffic, total traffic lane width, and changes in horizontal and vertical alignment. An example of the cost trade-offs between changes in traffic lane width and accidents and operating speeds is presented.

Traffic lane width is a key design element for the roadway; it influences right-of-way width, land costs, construction costs, levels of service, and traffic operational characteristics. In the past highway designers and traffic engineers have generally disregarded any lane width other than 12 ft, but because of current reductions in funding for improvements, there is increased interest in the feasibility and desirability of narrower traffic lanes.

The issue of lane width arises with restricted right-of-way width in urban corridors for new construction or reconstruction. It also arises with transportation system management (TSM) types of improvements in urban locations, where additional traffic lanes can be obtained by decreasing individual lane widths. Reducing lane widths, however, presents a dilemma. Although reduction in traffic lane width may result in reduced capital improvement cost, which may be the only way to accomplish the roadway improvement, such reduction does not meet most design standards and may result in permanent lowering of the roadway level of service.

It is clear that there are significant trade-offs involved when traffic lane widths are reduced to less than 12 ft. It is important that the decision maker know what these trade-offs are in order to evaluate the impact of a proposed reduction in lane width. Neither the technical research literature nor the design manuals provide guidelines to the decision maker for determining these trade-offs. This question of trade-offs is addressed in this paper. The scope of the investigation was limited to four-lane, undivided, urban arterial highways. Finally, it should be emphasized that no departure from current roadway standards for traffic lane widths is suggested in this paper.

LITERATURE REVIEW

The research literature on traffic lane width indicates that investigators have concentrated their efforts on rural, two-lane highways (1-5). When the effect of traffic lane width relative to highway speeds has been studied, the results have been inconsistent (6,7). When total traffic lane width was investigated relative to accident rates, the results were also inconsistent (1,8,9). Because traffic lane width should be investigated as a part of the total roadway system, it is appropriate to note the research results for certain other roadway design elements relative to measures of accident exposure. Investigators have reported that, as the number of urban intersections, access points, commercial

Table 1. Traffic lane width relative to pavement width for four-lane, undivided, urban arterials.

Total Pavement Width[a] (ft)	Center Traffic Lane Width (ft)	Curb Traffic Lane Width (ft)
40	9	11
44	10	12
44	11	11
46	11	12
48	11	13
50	12	13
52	11	15
52	12	14
54	13	14
56	14	14

[a]The pavement width is symmetrical with respect to the roadway centerline.

driveways, and commercial units increases, accidents also increase (8-10). A similar increase in accidents has been reported when the grade on vertical tangents increases (11,12).

In summary, it appears that neither the research literature nor the standard design manuals (13-15) offer the designer or decision maker any definitive guidelines on the consequences of reducing traffic lane widths to less than 12 ft.

METHODOLOGY

Study Observation Unit

The highway sections in urban locations that were studied were classified into the intersection proper, its approach, and the roadway between. The intersection approach was assumed to be 500 ft, subject to confirmation in the field. Because the research focused on the effect of traffic lane width, the impact of traffic signals on accidents and traffic flow had to be eliminated from the data collected in the field. Thus the study observation unit consisted of that portion of an urban, four-lane, undivided arterial between two approach legs of a signalized intersection, and excluded the intersection proper and the 500-ft-long approaches on both ends. All minor street intersections within the study observation unit were controlled with stop signs.

Data Base

Roadway traffic and accident data were collected for 108 four-lane, undivided, urban highway sections that had signalized intersections more than 2,000 ft apart in 8 urbanized areas in North Carolina. Site selection was limited to urban highways that had no access control, an asphalt surface, a curb and gutter, no parking on either side, a posted speed limit no more than 45 mph, and a minimum of 1 yr of accident experience without any change of roadway characteristics. Fifty-seven sites, which had a balance between total pavement width, traffic volume, and access density, were selected for investigation.

Roadway data included information on roadway section length, lane width, posted speed limit, horizontal and vertical alignment, intersections, private driveways, commercial driveways, and abutting land use. Traffic data included peak- and off-peak-hour traffic volumes and speeds, traffic composition, average daily traffic (ADT), and access trips to and from private driveways, commercial driveways, and intersecting streets. Accident data included a 100 percent sample of 1,936 accidents on all 57 sections over a 6-yr period.

Pavement and Traffic Lane Width Data

An analysis of the symmetrically balanced pavement width sections indicated the pattern of traffic lane widths given in Table 1. Because of symmetry with respect to traffic lane widths about the roadway centerline, the analysis used total pavement width to characterize the four individual lane widths, thereby reducing the number of variables.

Models Used in Analysis

Two general models were formulated for study: (a) measures of highway speed were related to traffic volume and roadway characteristics, and (b) measures of accident exposure were related to combinations of traffic volume and roadway characteristics. (Guidelines for model formulation were found in the work of other investigators reported in the reference list.) A total of 31 dependent variables and 36 independent variables were analyzed. Logarithmic and square root transforms of dependent accident variables were utilized by using stepwise multiple linear regression.

ANALYSIS

Off-Peak-Hour Traffic-Flow Model

For off-peak-hour conditions, the best traffic-flow model developed was one that related off-peak-hour speed (OPOS) on the urban arterials to posted speed (PS), off-peak-hour volume (OPHV), and total traffic lane width (LW), as follows:

$$OPOS = 9.057 + (0.644)PS - (0.003)OPHV + (0.143)LW \quad (1)$$

The coefficient of multiple determination (R^2) is 57 percent. The regression coefficients for the independent variables are all significantly different from zero at the 10 percent level of significance.

Peak-Hour Traffic-Flow Model

For peak-hour conditions, the best traffic-flow model found was one that related peak-hour operating speed (POS) to posted speed (PS) and total traffic lane width (LW), as follows:

$$POS = 6.315 + (0.533)PS + (0.258)LW \quad (2)$$

The coefficient of multiple determination (R^2) is 53 percent. The regression coefficients for the independent variables are significantly different from zero at the 1 percent level.

Accident Model

The models recommended for predicting the total number of vehicle accidents on four-lane, undivided urban arterials are

$$RVAPY = 1.32 + (0.091)NNINT + (0.045)ATCDW + (0.077)ADT + (0.070)HR - (0.051)LW + (0.081)VR \quad (3)$$

and

$$VAPY = -0.064 + 1.084(RVAPY)^2 \quad (4)$$

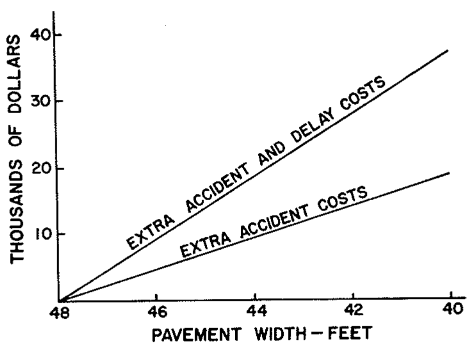
where

VAPY = total vehicle accidents per year,
RVAPY = square root transform of the total vehicle accidents per year,

Table 2. Illustrative problem.

Roadway Characteristics	Value
Highway section length (miles)	1.2
Pavement width (ft)	48
Individual traffic lane widths, curb to curb (ft)	13, 11, 11, 13
ADT (vehicles per day)	15,000
No. of minor street intersections	10
Posted speed limit (mph)	40
Peak hourly traffic volume (vehicles/hr)	1,350
Off-peak hourly traffic volume (vehicles/hr)	80
No. of access trips to and from commercial driveways per day	2,050
Cumulative sum of absolute value of changes in vertical elevation along arterial centerline (degrees)	100
Cost of opportunities foregone due to increases in vehicle travel time ($/hr)	5.00
Cost of equivalent property-damage-only accident ($)	760.00

Figure 1. Extra accident and delay costs for illustrative problem when total traffic lane width is reduced.



NNINT = number of side street intersections per mile of arterial roadway,
ATCDW = number of access trips to and from commercial driveways along the roadway section,
ADT = average daily traffic,
HR = square root of the cumulative sum of the absolute values of changes in horizontal direction (in degrees) along the arterial,
LW = total traffic lane width, and
VR = square root of the cumulative sum of the absolute values of changes in vertical elevation (in feet) along the arterial.

The coefficients for the independent variables in the regression model are significantly different from zero at the 10 percent level.

ILLUSTRATIVE APPLICATION OF RESEARCH RESULTS

The data assumed for a four-lane, undivided, urban arterial highway are given in Table 2. The research results are applied to these data in order to compute an estimate of the likely impact of reducing pavement and traffic lane widths from 48 to 40 ft. The arterial section is assumed to be 1.20 miles long between signalized intersections. Only the extra accident and delay costs are estimated in these calculations.

The numerical results are shown in Figure 1. The data in the figure indicate that the extra delay and accident costs associated with a reduction in pavement width from 48 to 40 ft will be approximately $37,229/mile/yr. If it is assumed that this annual cost prevails for 20 yr and that money is worth 8 percent, this annual cost is equivalent to a present worth of $365,300/mile at time year zero. The economic trade-off is obviously significant. For a complete analysis, estimates of the savings in construction and land costs as well as the extra costs due to accidents and time delays would have to be made.

CONCLUSIONS

The analysis and findings suggest that the traffic lane width on four-lane, undivided, urban arterials between signalized intersections (but not including the intersection proper or the approach leg) is significantly related to accidents and operating speeds.

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Effectiveness of Clear Recovery Zones

JERRY L. GRAHAM AND DOUGLAS W. HARWOOD

Clear recovery zones outside the highway shoulder provide an opportunity for vehicles that leave the roadway to come to a safe stop or to return to the roadway. The results of a research effort to determine the effectiveness of clear recovery zones in reducing the number and severity of run-off-the-road (ROR) accidents and to provide an approach for the cost-effective application of clear recovery zones are presented. Actual accident data were obtained and analyzed to compare three different roadside design policies: the 6:1 clear zone policy, the 4:1 clear zone policy, and the nonclear zone policy. Three highway types were also considered: two-lane highways, four-lane freeways, and four-lane divided nonfreeways. Road sections that had these highway types and roadside design policies were identified in Illinois, Minnesota, and Missouri. Analysis of the accident data for the study sections revealed that roadside design policy had a statistically significant relation to single-vehicle ROR accident rate for all of the highway types studied. The differences in the accident rate between roadside design policies were quantified for each highway type. An analysis of the severity of single-vehicle ROR accidents revealed that the severity distribution did not vary between the roadside design policies on any of the three highway types studied. Four design examples were developed in order to illustrate the cost-effectiveness implications of the safety effectiveness measures developed in the study. The examples compared the accident reduction benefits and typical construction costs for improving highways from one roadside design policy to another.

A clear recovery zone is a relatively flat roadside area that is free of unprotected fixed objects and other nontraversable hazards; it is intended to provide an opportunity for vehicles that leave the roadway to come to a safe stop or to return to the roadway. Since the late 1960s a highway cross section with 6:1 embankment slopes within a 30-ft clear recovery zone has been generally adopted for new construction and major reconstruction projects. However, many existing highways have clear recovery zones with 4:1 (steeper) embankment slopes or do not have a clear recovery zone at all. It has been suggested in recent design guidelines that there is a need for clear recovery areas wider than 30 ft when embankment slopes steeper than 6:1 are used.

Some of the major findings of NCHRP Project 17-5, which was conducted to help highway agencies with limited funds develop a rational basis for making cost-effective applications of clear recovery zones, are presented. The full study has been published in NCHRP Report 247 (1).

OBJECTIVES AND SCOPE

The objectives of the study were to determine the safety effectiveness of clear recovery zones of differing slopes and widths in reducing the number and severity of run-off-the-road (ROR) accidents and to describe a framework based on clear zone effectiveness that could be used in design practice to assure the cost-effective application of clear recovery zones. The study was not intended to consider criteria for the installation of guardrail at specific sites or blanket fixed-object removal programs. Rather, the study was intended to evaluate the safety effectiveness of providing clear recovery zones by flattening slopes or removing or treating fixed objects.

The project scope included the consideration of several types of highways in rural areas, including two-lane highways, four-lane freeways, and four-lane divided nonfreeways. Specifically excluded from consideration were intersections, interchange ramps, low-volume highways [average daily traffic (ADT) less than 750 vehicles/day], and highways with urban development.

RESEARCH APPROACH

The general research approach for NCHRP Project 17-5 was to determine the effectiveness of clear recovery zones from actual accident data for existing highway sections by comparing the accident experience of highway sections constructed under different roadside design policies. Three distinct roadside design policies have been used by U.S. highway agencies; they are called 6:1 clear zone, 4:1 clear zone, and nonclear zone in this study. The policies vary in both the embankment slopes used and the presence of unprotected fixed objects outside of the highway shoulder.

The average safety effects of the three roadside design policies, as applied by highway agencies to the actual terrain in the field, can be determined if the highway sections constructed under different policies have no major differences other than roadside design or if such differences that do exist can be identified and accounted for. Thus the objective of the analysis was not to determine the safety effects of an individual geometric feature (for example, shoulder width), but to assure that an effect of shoulder width was not mistaken for an effect of roadside design policy.

The primary measures of effectiveness (or dependent variables) for the study were the single-vehicle ROR accident rate for all levels of accident severity and the fatal and injury single-vehicle ROR accident rate. These measures of effectiveness were restricted to ROR accidents because it would be questionable to presume a relation between roadside design policy and accidents where no vehicle left the roadway. The measure of effectiveness was restricted to single-vehicle ROR accidents; multiple-vehicle ROR accidents were excluded because single-vehicle ROR accidents are more frequent on rural highways than multiple-vehicle ROR accidents and because the severity of single-vehicle ROR accidents can be attributed in large degree to roadside design. Single-vehicle ROR accidents that involve both the outside (right side) and the median (left side) of the roadway on divided highways were considered.

The independent variables for the analysis, be-