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16. Abstract

This study considers the relative benefit/cost for the provision of wide paved shoulders on rural two-lane highways. Cost elements considered were accidents, pavement edge maintenance, paved shoulder surface maintenance, and travel time.

It is concluded that wide paved shoulders (6-10 feet wide) are cost beneficial for AADT's above 1,500 vehicles per day. This value corresponds very well with the 2000 vehicles per day reported in the Transportation Research Board Special Report 214, 1987.

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GUIDELINES FOR USING WIDE PAVED SHOULDERS ON LOW-VOLUME TWO-LANE RURAL HIGHWAYS BASED ON BENEFIT/COST ANALYSIS

BY

Donald L. Woods
Professor of Civil
Engineering and
Research Engineer

John B. Rollins
Associate
Research Economist

Laurence M. Crane
Research Associate

TEXAS TRANSPORTATION INSTITUTE
TEXAS A&M UNIVERSITY

Based on

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May, 1989

METRIC (SI*) CONVERSION FACTORS

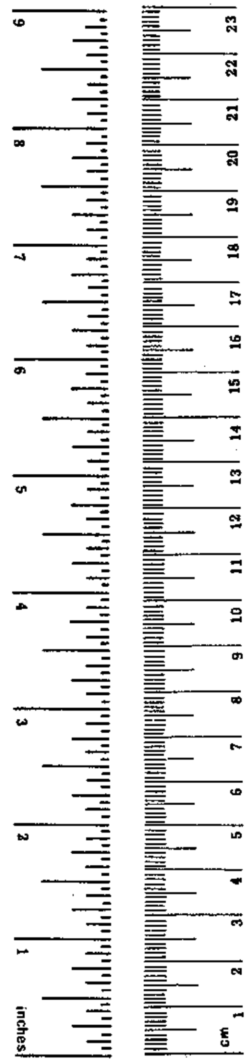
APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
in	inches	2.54	millimetres	mm
ft	feet	0.3048	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
	AREA			
in^2	square inches	645.2	millimetres squared	mm^2
ft^2	square feet	0.0929	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
mi^2	square miles	2.59	kilometres squared	km^2
ac	acres	0.395	hectares	ha
	MASS (weight)			
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
	VOLUME			
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft^3	cubic feet	0.0328	metres cubed	m^3
yd^3	cubic yards	0.0765	metres cubed	m^3

NOTE: Volumes greater than 1000 L shall be shown in m^3.

TEMPERATURE (exact)

°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
	AREA			
mm^2	millimetres squared	0.0016	square inches	in^2
m^2	metres squared	10.764	square feet	ft^2
km^2	kilometres squared	0.39	square miles	mi^2
ha	hectores (10 000 m^2)	2.53	acres	ac
	MASS (weight)			
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T
	VOLUME			
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3

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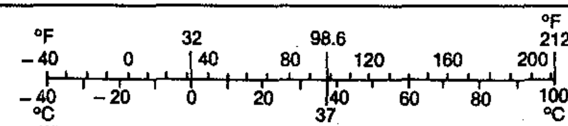

These factors conform to the requirement of FHWA Order 5190.1A.

* SI is the symbol for the International System of Measurements

PREFACE

In designing and operating low-volume, two-lane roadways, the choice of cross section elements for that roadway are always a concern. The impression that low-volume roadways do not warrant wide paved shoulders is widespread. Wide paved shoulders (i.e., those 6 ft. wide or wider) provide an additional travel lane for slow moving vehicles, increase average running speed thus saving time, facilitate passing maneuvers, accommodate emergency stops, provide primary recovery space for the errant vehicle, and reduce accidents. These benefits do not accrue equally to all two-lane highways due to variations in the traffic demand.

Wide paved shoulders reduce accidents and travel time while [1] increasing vehicle operating costs. They also reduce pavement edge damage and thus pavement edge maintenance cost. These benefits must be compared to the cost of providing and maintaining a wide paved shoulder. It is reasonable that at some level of traffic demand wide paved shoulders are cost beneficial on two-lane rural highways. The major objective of this research was to identify that level of demand for both existing roadways and for new construction where wide paved shoulders are cost beneficial.

A recent Transportation Research Board publication [2] recommends the combined lane and shoulder widths given below:

RECOMMENDED PAVEMENT WIDTHS FOR RURAL TWO-LANE ROADWAYS

		10 Percent or More Trucks		Less Than 10 Percent Trucks	
Design Year Volume (AADT)	Running Speed (MPH)	Lane Width	Combined Lane and Shoulder Width	Lane Width	Combined Lane and Shoulder Width
1-750	Under 50	10	12	9	11
	50 and over	11	12	10	12
751-2,000	Under 50	11	13	10	12
	50 and over	12	15	11	14
Over 2,000	All	12	18	11	17

It is clear that wide paved shoulders are not considered to be a major concern for traffic demands below 2,000 vehicles per day. Clearly, research to evaluate the relative trade-off of wide paved shoulders on low-volume rural highways was needed.

ABSTRACT

This study considers the relative benefit/cost for the provision of wide paved shoulders on rural two-lane highways. Cost elements considered were accidents, pavement edge maintenance, paved shoulder surface maintenance, and travel time.

It is concluded that wide paved shoulders (6-10 feet wide) are cost beneficial for AADT's above 1,500 vehicles per day. This value corresponds very well with the 2000 vehicles per day reported in the Transportation Research Board Special Report 214, 1987.

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Statement of Problem

The benefits provided to motorists by wide paved shoulders on rural two-lane highways are many and varied. Wide paved shoulders provide additional travel space, accommodate emergency stops, provide temporary lanes during reconstruction or maintenance, and reduce the run-off-road accident potential. This study has examined the benefits to society, as well as installation and maintenance costs to the highway agency of adding wide paved shoulders on low-volume, two-lane highways.

Literature Review

The majority of past studies of the relationship between shoulder width and accident experience have revealed a consistent trend in reduced accident experience with increasing shoulder width (3,4,5,6). The safety benefits of paved shoulders is clearly demonstrated in the literature.

Several economic analyses, based on accident data from various states, have attempted to evaluate the cost-effectiveness of paved shoulder widening. Heimbach [7] conducted a cost-effectiveness analysis of using three- and four-foot wide paved shoulder on two-lane highways. The results suggest that shoulders of this width are cost-effective for average annual daily traffic (AADT) in excess of 2000 vehicles per day. Shannon and Stanley [8], based on accident data from Idaho and Nevada, recommended a range of shoulder widths for AADT up to 3000 vehicles per day. Davis [9] estimated the optimum shoulder as a function of AADT and operating speed. Zegeer [10], in a Kentucky study, concluded that a roadway section with six or more shoulder related accidents per mile per year warranted installation of paved shoulders on two-lane highways.

Fambro [1] clearly identified the effects of adding paved shoulders on two-lane highways in Texas based on an examination of two-lane rural roads with and without paved shoulders. Accident rates were determined by a before-and-after accident study. Significant differences in accident experience on roads with paved shoulders and without paved shoulders were identified. A benefit/cost analysis was not conducted as a part of Fambro's research. The findings were therefore necessarily limited.

Study Objectives

The objectives of this study were: 1) To perform benefit/cost analysis of adding wide (8 to 10 foot) paved shoulders on two-lane rural roads. The basis of comparison were roadways having wide paved shoulders (8 to 10 feet), those having narrow paved shoulder and sod or stabilized aggregate shoulders); and, 2) To develop guidelines for adding wide paved shoulders to new and existing rural two-lane highways.

ACCIDENT DATA FOR LOW-VOLUME TWO-LANE HIGHWAYS

Selection of Study Sites

Three primary criteria were used in the selection of the study sites: (1) AADT Group, 2) pavement width, and 3) paved shoulder width. The ranges of each of the factors were as follows:

Pavement Width	Paved Shoulder Width	AADT Level's
	< 2 feet	
18 feet	2-5 feet	251-750
20 feet	6-8 feet	751-1,500
22 feet	8-10 feet	1,501-3,000
24 feet	> 10 feet	

All data were extracted from the automated data file and distributed to district personnel for verification. Many adjustments in the automated data file values were made using this quality control step. Sites were selected across the entire state, but not necessarily uniformly. Many sections of highway in one area have low volumes and paved shoulders while most low-volume roadways in another area do not. Thus the second area is over-represented in the zero shoulder width classification, while the first area tended to be overrepresented in the paved shoulder groups.

Every attempt was made to select sites which were homogeneous from a geometric and traffic perspective. As many sites as practical were included in test matrix cells. Due to the lack of availability of site selection criteria in the field sites, a minimum target frequency for each cell was established at six. Some cells could not be filled. For example, higher volume (750-1000 VPD) roadways in the 18 ft. pavement width with an 8-10 ft. paved shoulder were very rare.

A minimum length of section was established at 2.0 miles. Previous experience suggested that at least two miles was necessary to have any opportunity of having a measurable accident rate. Adjacent sections were aggregated to meet the two-mile length goal. Often, successive Control and Sections did not have the same AADT estimate. In such cases, the AADT was not allowed to vary more than one AADT Group from the target group. The predominate AADT in the resulting aggregated section had to conform to the target group range. The weighted average AADT of the entire section was used as the AADT for the site when two or more sections were aggregated.

Accident data were extracted for each study site for the years 1984, 1985, and 1986. The results of the statistical analysis are presented below. Pavement edge maintenance costs could not be obtained by Control and Section. This necessitated selection of maintenance cost sites to meet the needs of the project.

Accident Types

Table 1 contains a summary of the accidents by type and severity for the selected study sites. The dominate accident type is the single vehicle run-off-the-road (R-O-R) accident. R-O-R accidents comprise 57 percent of

TABLE 1. LOW-VOLUME, TWO-LANE HIGHWAY ACCIDENT BY TYPE AND SEVERITY FOR THE STUDY SITES

ACCIDENT TYPE	ACCIDENT SEVERITY PDO	A	B	C	K	TOTAL
R-O-R	26(.25)	4(.04)	17(.17)	11(.11)	0	58(.57)
RT. ANGLE	1(.01)	0(.00)	2(.02)	0(.00)	0	3(.03)
LT. TURN	3(.03)	1(.01)	0(.00)	0(.00)	0	4(.04)
ANIMAL	14(.14)	2(.02)	1(.01)	1(.01)	0	18(.18)
HEAD ON	2(.02)	3(.03)	0(.00)	0(.00)	0	5(.05)
REAR END	8(.08)	1(.01)	1(.01)	0(.00)	0	10(.10)
SIDESWIPE	0(.00)	1(.01)	0(.00)	0(.00)	0	1(.01)
UNKNOWN	2(.02)	0(.00)	0(.00)	0(.00)	0	2(.02)
TOTALS	56(.55)	12(.12)	21(.21)	12(.12)	0	101(1.0)

all accidents observed. Collisions with animals (18 percent), and rear-end collisions (10 percent) are the other significant accident types. Neither of these latter two accident types can reasonably be associated with the presence or absence of a wide paved shoulder. The remainder of the accident types have a few accidents but no pattern of any consequence. The large percentage of R-O-R accidents is logically related to the lack of a paved shoulder.

Table 2 contains a breakdown of the run-off-the-road accidents for those accidents where a specific roadside object was involved. Object struck and injury severity are provided. Only trees, fences and culverts had sufficient data to have any trend at all. For these three object classes, a remarkable similarity exists across all severity categories. This suggests that no single roadside object dominates either in frequency or severity in the run-off-the-road fixed object accidents.

Run-off-the-road accidents are the most frequent accident type with 57 percent of the total. To keep this statistic in perspective, this represents an accident rate of about 0.11 accidents per mile per year. Additionally, 45 percent of these do not create any personal injury. The injury accident rate is 0.06 accidents per mile per year. Safety does not appear to be a serious problem on the low-volume, two-lane highway system.

TABLE 2. SINGLE VEHICLE RUN-OFF-THE-ROAD ACCIDENT SEVERITY BY OBJECT STRUCK

OBJECT	PDO	A	B	C	K	TOTAL
TREE	4(.10)	1(.025)	1(.025)	3(.075)	0	9(.225)
FENCE	4(.10)	1(.025)	4(.100)	2(.050)	0	11(.275)
CULVERT	2(.05)	1(.025)	2(.050)	2(.050)	0	7(.175)
OTHER	4(.10)	1(.025)	6(.150)	2(.050)	0	13(.325)
TOTALS	14(.35)	4(.100)	13(.325)	9(.225)	0	40(1.00)

Statistical Methodology

A two-factor analysis of variance (ANOVA) model was run on the accident rate stratified into AADT groupings. Accident rate is expressed as accidents per million vehicle-miles traveled. The AADT groupings, and two factors used were shoulder type (driveable or non-driveable) and surface width. The interaction effect of these two factors was also included in the ANOVA model. The design was unbalanced in nature (i.e., unequal numbers of roadway sections in each of the factor level combinations) with missing cells. The unbalanced nature of the design was an artifact of the sampling procedure which reflected the true proportion of these roadway sections for the entire population. For this reason, a weighted hypothesis of means giving more weight to those cells which represented the largest number of road sections. This is the Type I sum of squares in SAS PROC GLM. The log transformation of accident rates was used as the dependent variable. This was based on the results of normality tests applied to the log transformation which was necessary to satisfy the ANOVA assumption of normally distributed errors. To accommodate missing cells, a constant factor of 0.5 was added to all accident rates.

Statistical Results

All of the ANOVA results followed a consistent pattern of: no significant surface width by shoulder type interaction; no significant difference in the accident rates among the four surface width categories; a significant difference in accident rates for driveable and non-driveable shoulders were present. All tests were conducted at the 5 percent level of significance. These results were consistent for total, fatal, injury and for all AADT levels with the exception of instances where sample size were too small to accurately test the relevant hypothesis. In all cases, the accident rate for non-driveable shoulder sections were significantly higher than for driveable shoulder sections within similar AADT groupings.

Accident Costs

The procedure outlined by Rollins and McFarland (11), was followed to express accident rates and changes in dollar measurements for use in the benefit/cost analysis. This approach was necessary to be able to express accident costs in a form that could be directly used with the state accident data. Costs are expressed on a per vehicle and per victim basis rather than on a per accident basis. They are in terms of the Maximum Abbreviated Injury Scale (MAIS). The MAIS scale is: 0, no injury; 1 to 5, least to most severe nonfatal injury; and 6, fatality. Accident data on injuries consists of injury severities coded by the A-B-C scale; A, incapacitating injury; B, non-incapacitating injury; and C, possible injury.

State's accident records typically use the A-B-C scale for coding the severities of nonfatal injuries. The MAIS scale cannot be used directly with state accident data in benefit/cost analysis. The method devised by Rollins and McFarland was used for relating the percentage distribution of MAIS severities to that of A-B-C severities. Direct and indirect costs per victim by MAIS category are summarized in Table 3. Direct costs include property damage, medical, legal, and funeral costs. Indirect costs include administrative costs, human capital costs (lost productivity) for injuries, and for a fatality, human capital costs adjusted for the individuals' willingness-to-pay to reduce their risk of death or injury. These 1980 costs are adjusted by the Consumer Price Index (CPI) and the Index of Average Hourly Earnings (IAHE) to obtain 1987 MAIS costs.

TABLE 3. UPDATING MAIS COSTS FROM 1980 TO 1987

CPI, all items (1980 => 246.8, 1987I => 334.5; 1967 = 100)
IAHE (1980 => 127.3, 1987I => 171.3; 1977 = 100)

ACCIDENT	MAIS	DIRECT (CPI)		INDIRECT (IAHE)		TOTAL COST
		1980	1987I	1980	1987I	1987
	0	$716	$970	$132	$178	$1,148
	1	1,601	2,170	690	928	3,098
	2	3,442	4,665	1,165	1,568	6,233
	3	8,089	10,963	2,217	2,983	13,946
	4	18,467	25,028	32,564	43,819	68,847
	5	138,684	187,958	122,897	165,375	353,333
	6	18,294	24,794	724,227	974,549	999,343

The accident data used to estimate accident costs included the number of vehicles per accident, accident frequencies and proportions by severity. This included data on the number of injuries in nonfatal injury accidents, the number of injuries per fatal accident, property damage only accidents, and the percentage distribution of A-B-C severities in fatal and nonfatal injury accidents.

The accident cost savings per year due to having driveable shoulders is calculated as follows. The savings per MVM for each ADT category equals the difference between the average accident cost multiplied by the annualized accident rates for driveable shoulders, and the average accident cost multiplied by the annualized accident rates for non-driveable shoulders. The appendix section of this technical report contains the specifics of the accident cost calculations, and offers examples of these calculations for the interested reader. Table 4 is a summary of these calculations of annual accident cost savings that result from having driveable shoulders.

TABLE 4. CALCULATION OF ANNUAL ACCIDENT COST SAVINGS DUE TO HAVING DRIVEABLE SHOULDERS, BY AADT LEVEL

	Average Cost Per Accident		Accident Rate/MVM		Accident Cost
ADT	Driveable	Non-Driveable	Driveable	Non-Driveable	Savings Per MVM
0-250	NA	52,532	NA	0.7979	NA
251-750	35,463	49,609	0.7961	1.1542	$29,027
751-1500	80,147	51,278	0.6424	1.0858	4,190
1501-3000	70,764	62,991	0.5081	0.8831	19,672

PAVEMENT EDGE AND SHOULDER MAINTENANCE COSTS

Introduction

Pavement edge maintenance costs should be reduced by having a wide paved shoulder on low-volume, two-lane highways by protecting the pavement edge from water infiltration. The magnitude of the pavement edge cost reduction varies with the volume of heavy trucks using the facility in question. In order to estimate the reduction in pavement edge maintenance cost, an average cost had to be obtained for each pavement width, shoulder width and AADT group used in the study.

The cost data would desirably have been matched to study sites selected on a one-to-one basis. The state's automated maintenance cost file is not recorded by Control and Section descriptors. Rather, the data are stored by Highway Number and County. Thus, cost data sites had to be selected which were comparable to the selected accident sites across the entire county with respect to AADT, pavement width, and shoulder width characteristics.

Cost Site Selection

The pavement edge and shoulder maintenance cost sites were selected to obtain a minimum of six (6) sites in each cell of the final experimental matrices. The selected sites identified from the State Department of Highways and Public Transportation (SDHPT) section data were reviewed to insure that desired characteristics were more or less uniform across the entire county. Two primary criteria were used to select sites in addition to a constant cross section throughout the county: 1) the AADT values had to be in the target group, and 2) none could be more than one group away from the target group. Weighted average AADT was used as the basis for estimating the AADT of the entire roadway section in the county. This is expressed as:

$$W = \frac{\sum_{\text{Section} = 1}^{n} \text{AADT x Section Length}}{\sum_{\text{Section} = 1}^{n} \text{Section Length}}$$

The weighted average AADT was then used along with the section length to normalize the cost data to an annual cost per mile value.

Maintenance Management Function Codes

The annual cost data in 1986 for the applicable maintenance management codes were obtained for each cost study site. These cost sites were scattered throughout the state. The average costs should reflect the statewide average cost when sufficient observations are available in the cell.

Data on maintenance costs for some 500 sections of roadway were obtained from the automated data file. The 1986 cost for each maintenance cost code was divided by the mileage of roadway involved to make the cost data directly comparable. The resulting units are 1986 dollars per mile.

Correlation of Pavement Edge Maintenance Cost and Pavement Width

The cost data, by function code, were subjected to detailed statistical analysis. Briefly summarized, no measurable correlations between the pavement width, shoulder width or other variables and the cost data were found. The resulting multiple coefficient of determination (R^2) was always less than 0.2 and generally less than 0.1. Less than 20 percent of the observed variation can be explained by the variables included in the models. Literally, the average value of the cost for each function code was a better estimate of the data set trends than were the models tested. For this reason, the cost data were summarized by three shoulder width categories: 1) zero feet; 2) less than 6 feet; and 3) 6 feet or more in width. The resulting average values are presented in Table 5.

TABLE 5. EDGE AND SHOULDER MAINTENANCE COST SUMMARY

TOTAL COSTS OF EDGE CODES 270, 451, 452 AND 460

SUM OF ALL

SHD. WIDTH	AVERAGE COSTS ($/MILE) ACTUAL	OVERALL*
0	$1907	$1392
<6	$1749	$1276
=>6	$ 330	$ 330

AVERAGE EDGE MAINTENANCE COST
FOR AN UNPAVED SHOULDER-$1392/MILE/YEAR

COST SAVINGS AT 15% REDUCTION=$208/MILE/YR

COST SAVINGS AT 40% REDUCTION=$557/MILE/YR

COST SAVINGS AT 70% REDUCTION=$974/MILE/YR

*The overall average includes all sections within the shoulder width group, including those site sections that had zero reported maintenance costs in 1986.

Table 5 reports total costs: 1) the actual average cost in the year 1986; and 2) the overall average cost across all sites in the AADT and shoulder width group including those sites with no reported maintenance in the year 1986. While both are subject to experimental and small sample errors, if these data are used to estimate maintenance costs, care must be used in selecting the most appropriate average cost value. Overall average costs should be used when estimating the maintenance cost on the entire low-volume, two-lane highway system. The best estimate for a particular highway section on which maintenance is to be performed, however, is the actual average cost in 1986 excluding those sites which did not have maintenance in the year 1986. The entered and generated variables were subjected to detailed statistical analysis. The normalized cost for each maintenance code was used as the dependent variable and the weighted annual average daily traffic; weighted annual average traffic divided by the pavement width; half pavement width plus shoulder width; and weighted annual average traffic squared were used as the independent variables. A second analysis included the log of the pavement width as a transformed variable after the work of Griffin and Mak [12].

A correlation analysis of the independent variables revealed a substantial degree of variable interaction; however, the interaction was not deemed to be so large as to negate the potential value of an Analysis of Variance (ANOVA) or Regression analysis of the data. An ANOVA analysis identified too few observations in certain cells for this analysis to be successfully carried out.

Statistical Analysis Of Cost Data

Multiple linear regression analysis for each maintenance function code resulted in coefficients of determination (R^2) that were extremely low. The largest R^2 value for any maintenance code was 0.09, which indicates a nearly random pattern of maintenance costs per mile.

The overall average cost per mile for each maintenance cost code is the best estimate of the maintenance cost, given that no correlation exists with the independent variables tested. The sum across all maintenance function codes is the best estimate of the annual shoulder maintenance cost.

BENEFIT/COST ANALYSIS

Introduction

The central focus of this research is the benefit/cost of adding wide paved shoulders to low-volume, two-lane roadways. The assumptions on which the benefit/cost analysis is based as well as the results of the analysis are presented below. The assumptions made are, in the opinion of the authors, reasonable. However, the reader must test these assumptions against experience to ultimately determine the meaningfulness of these analyses.

Benefit/Cost Analysis Of Adding Shoulders On Two-Lane Highways

Two-lane rural highways with driveable shoulders allow motorists to drive faster and with a greater degree of comfort than would otherwise be the case. While the small increment of time saved for each driver is of little economic value, real benefits include motorist comfort and convenience including reduced level of concentration required and reduced driver fatigue. Travel time savings, therefore, represent not only the benefits of time savings but also other benefits that are not readily quantifiable. The travel time savings reported herein are surrogate measures of benefits that the motorist receives from the addition or widening of shoulder on two-lane, rural highways.

The procedure for estimating the change in operating speed and the resulting travel time savings is based on a 1984 NCHRP Report [2]. In general, this procedure was as follows. The hours per vehicle-mile traveled (VHT/VMT) were calculated as a function of AADT, lane width, shoulder width, and the operational level-of-service of the roadway for two-way operation. Eleven ft. driving lanes were assumed and paved shoulders 6 or more ft. wide were considered to be driveable and those less than 6 ft. in width were considered to be non-driveable. The hours of travel per roadway section per year was equal to the product of the hours of travel per year in the particular roadway, shoulder width, and AADT group and the number of vehicle-miles traveled in that group. The difference in travel times for each AADT and pavement width group, the time saved by the motorist due to the presence of driveable shoulders, are presented in Table 6.

TABLE 6. TRAVEL TIME ESTIMATE FOR DRIVEABLE AND NON-DRIVEABLE SHOULDERS

AADT RANGE	AVERAGE AADT	VEHICLE MILES (millions)	HOURS OF TRAVEL TIME (Per Section/Year) NON-DRIVEABLE	DRIVEABLE	ND-D
0-250	158	0.231316	3,995.6	3,993.4	2.2
251-750	450	0.624567	10,825.8	10,808.9	17.0
751-1500	1,063	1.398372	24,414.2	24,323.6	90.6
1501-3000	2,129	2.689822	47,556.3	47,203.1	353.2

Time was valued at $7.50 per hour [10]. This amount is considered to be a conservative estimate of the value of time because it does not specifically account for vehicle occupancy rates. Operating costs increase as a result of the speed increase due to having a driveable shoulder. Assuming a 5 mph increase in speed over the range from 40 to 60 miles per hour, the total running costs increase by about $2 per 1000 vehicle-miles driven [1]. The annual net user cost savings that result from time savings are summarized in Table 7 by AADT level.

TABLE 7. ANNUAL TRAVEL TIME SAVINGS AND NET USER COST ESTIMATES

AADT	HOURS* SAVED	TIME SAVINGS ($7.50/HR.)	INCREASED OPERATING EXPENSES	NET USER SAVINGS ($ PER SECTION/YEAR)
0-250	2.2	17	9	8
251-750	17.0	128	69	59
751-1500	90.6	680	350	330
1501-3000	353.2	2650	1,398	1,252

* Based on the total vehicle-miles of travel in each AADT group.

Shoulder Installation Costs

A 6-foot wide paved shoulder provided as a part of new construction would cost about $8.50 per square yard or approximately $58,840 per mile. A 6-foot paved shoulder added to an existing roadway using maintenance forces is estimated to cost about $6.00 per square yard or approximately $42,240 per mile. These estimates were obtained from operating agency personnel and are believed to reflect the average costs.

Shoulder Maintenance Costs

The maintenance cost for the benefit/cost ratio computation is the difference between maintaining shoulders that are driveable and those that are non-driveable. The increased cost of maintaining the surface of driveable shoulders is partially offset by the decreased cost of maintaining the pavement edge. Table 8 contains a summary of the estimated net difference in costs to the road user for assumed 15 percent, 40 percent and 70 percent reductions in annual pavement edge maintenance costs. Great variability was observed in the maintenance costs, and sample sizes were small and unequal. Based on the values in Table 8, the net increase in maintenance costs is assumed to be $550 per mile per year for the purposes of the benefit/cost analysis of adding shoulders to two-lane highways.

TABLE 8. MAINTENANCE COST DIFFERENCES OF DRIVEABLE AND NON-DRIVEABLE SHOULDERS

PAVED SHOULDER WIDTH (FEET)	PERCENT REDUCTION IN EDGE MAINTENANCE	ESTIMATED EDGE MAINTENANCE COST SAVINGS ($/MILE/YEAR)	ESTIMATED PAVED SHOULDER MAINTENANCE COSTS ($/MILE/YEAR)	NET EXPECTED COSTS ($/MILE/YEAR)
<6	15%	$208	$1160	-$952
	40%	$557	$1160	-$603
	70%	$974	$1160	-$186
>=6	15%	$208	$1039	-$831
	40%	$557	$1039	-$482
	70%	$974	$1039	-$65

<u>Benefit/Cost Calculations</u>

The benefit/cost ratios due to having driveable shoulders are calculated as follows. The benefit of having driveable shoulders is the sum of annual accident cost savings and travel time savings, minus increased vehicle operating costs due to higher speeds on roads with driveable shoulders. Benefit/cost ratios are calculated per mile of highway for each AADT group using the average AADT for non-driveable shoulders to calculate benefits. Accident savings per mile per year, given in Table 9, are calculated by multiplying the accident savings per million vehicle-miles from Table 4 by the millions of vehicle miles in each AADT group. The annual accident savings are added to net user cost savings per mile and maintenance costs per mile to obtain annual cost savings per mile, as shown in Table 10. The net user cost savings per mile are in column 3 of Table 10 and are derived by dividing the per section savings values in Table 7 by the average section length in each AADT group.

TABLE 9. ANNUAL ACCIDENT COST SAVINGS CALCULATION

AADT GROUP	AVERAGE AADT	ACCIDENT SAVINGS/MVM	MVM PER MILE	SAVINGS PER MILE
0-250	157.7	NA	0.0576	NA
251-750	450.5	29,027	0.1644	4,772
751-1500	1,062.8	4,190	0.3879	1,625
1501-3000	2,129.2	19,672	0.7772	15,289

Assuming a 20-year life and a 5 percent interest rate, life cycle benefits per mile are calculated by multiplying annual cost savings per mile by 12.4622, the uniform series present worth factor. These benefit estimates are shown in the last column of Table 10. Benefit/cost ratios are calculated for new construction and existing roads and are given in Table 11.

TABLE 10. CALCULATION OF ANNUAL COST SAVINGS AND TWENTY YEAR BENEFITS

	ANNUAL COST SAVINGS PER MILE				ANNUAL TOTAL
AADT GROUP	ACCIDENTS SAVINGS	NET USER COST SAVINGS	MAINTENANCE COSTS	TOTAL	BENEFITS TIMES 12.4622
0-250	NA	2	-550	NA	NA
251-750	4,772	16	-550	4,238	52,814
751-1500	1,624	92	-550	1,166	14,531
1501-3000	15,289	362	-550	15,101	188,192

The data in Table 11 indicate that driveable shoulders are clearly cost-beneficial within the AADT levels of 1501-3000. For AADT levels lower than 1500, the accident and time savings are positive; however, the shoulder construction and annual maintenance costs dominate except for existing roads at an AADT level of 251 to 750.

TABLE 11. BENEFIT/COST RATIOS FOR DRIVEABLE SHOULDERS ON TWO-LANE HIGHWAYS

	BENEFIT/COST RATIO	
DRIVEABLE SHOULDER COST/MILE	NEW CONSTRUCTION $59,840	EXISTING ROADS $42,240
AADT GROUP		
0-250	NA	NA
251-750	0.88	1.25
751-1500	0.24	0.34
1501-3000	3.14	4.46

It is recommended that a driveable shoulder be added to two-lane highways with a 1500 or more AADT. Operational flexibility for maintenance and slow moving vehicle operations make driveable shoulders highly desirable on all two-lane highway facilities.

SUMMARY OF FINDING

Finding

The material discussed above lead to the following finding:

* Wide paved shoulders are cost-beneficial on two-lane rural highways for AADT levels above 1,500 vehicles per day.

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APPENDIX

Accident Cost Data

Accurate estimation of motor vehicle accident costs is of central importance in benefit/cost evaluations of alternative uses of safety funds. The following procedure is used to estimate the change in accident costs due to having driveable shoulders. This procedure, outlined by Rollins and McFarland [11], is followed to express accident rates and changes in dollar measurements for use in the benefit/cost analysis. This approach is necessary to be able to express accident costs in a form that can be directly used with the state accident data. Costs are expressed on a per vehicle and per victim basis rather than on a per accident basis, and are in terms of the Maximum Abbreviated Injury Scale (MAIS). The MAIS scale is: 0, no injury; 1 to 5, least to most severe nonfatal injury; and 6, fatality. Accident data on injuries consists of injury severities coded by the A-B-C scale; A, incapacitating injury; B, non-incapacitating injury; and C, possible injury.

Direct and indirect costs per victim by MAIS category are summarized in Table A-1. Direct costs include property damage, medical, legal, and funeral costs. Indirect costs include administrative costs, human capital costs (lost productivity) for injuries, and for a fatality, human capital costs adjusted for the individuals' willingness-to-pay to reduce their risk of death or injury. These 1980 costs are adjusted by the Consumer Price Index (CPI) and the Index of Average Hourly Earnings (IAHE) to obtain 1987 MAIS costs.

The accident data used to estimate costs included the number of vehicles per accident in Table A-2, and accident frequencies and proportions by severity in Table A-3. Also included is the information on the number of injuries in nonfatal injury accidents in Table A-4, and the number of injuries per fatal accident in Table A-5.

TABLE A-1

UPDATING MAIS COSTS FROM 1980 TO 1987

CPI, all items (1980 => 246.8, 1987I => 334.5; 1967 = 100)

IAHE (1980 => 127.3, 1987I => 171.3; 1977 = 100)

MAIS	DIRECT (CPI)		INDIRECT (IAHE)		TOTAL
	1980	1987I	1980	1987I	1987
0	$716	$970	$132	$178	$1,145
1	1,601	2,170	690	928	3,099
2	3,442	4,665	1,165	1,568	6,233
3	8,089	10,963	2,217	2,983	13,946
4	18,467	25,029	32,564	43,819	68,848
5	138,684	187,965	122,897	165,375	353,340
6	18,294	24,795	724,227	974,549	999,344

TABLE A-2
VEHICLES PER ACCIDENT (RURAL)

AADT Level		Accident Severity Fatal	Injury	PDO
0 to 250				
D	freq.	0	7	12
	veh./acc.	0.0000	1.0000	1.0000
ND	freq.	21	210	269
	veh./acc.	1.0000	1.1143	1.1004
251 to 750				
D	freq.	5	72	110
	veh./acc.	1.4000	1.0556	1.0364
ND	freq.	97	1064	1307
	veh./acc.	1.1031	1.1128	1.1285
751 to 1500				
D	freq.	32	259	286
	veh./acc.	1.3438	1.1274	1.0909
ND	freq.	89	967	1062
	veh./acc.	1.2022	1.1655	1.1742
1501 to 3000				
D	freq.	37	288	464
	veh./acc.	1.4865	1.2257	1.1961
ND	freq.	58	586	677
	veh./acc.	1.4310	1.2270	1.2408

NOTE: D - Driveable Shoulder (6 ft. paved or wider)
ND = Non-Driveable Shoulder (less than 6 ft. paved)

TABLE A-3
ACCIDENT FREQUENCIES AND PROPORTIONS

AADT Level		Accident Severity Fatal	Injury	PDO	Total
0 to 250					
D	freq	0	7	12	19
	prop	0.0000	0.3684	0.6316	1.0000
ND	freq	21	210	269	500
	prop	0.0420	0.4200	0.5380	1.0000
251 to 750					
D	freq	5	72	110	187
	prop	0.0267	0.3850	0.5883	1.0000
ND	freq	97	1064	1307	2468
	prop	0.0393	0.4311	0.5296	1.0000
751 to 1500					
D	freq	32	259	286	577
	prop	0.0555	0.4489	0.4956	1.0000
ND	freq	89	967	1062	2118
	prop	0.0420	0.4566	0.5014	1.0000
1501 to 3000					
D	freq	37	288	464	789
	prop	0.0469	0.3650	0.5881	1.0000
ND	freq	58	586	677	1321
	prop	0.0439	0.4436	0.5125	1.0000

TABLE A-4

INJURIES PER INJURY ACCIDENT

NOTE: The fractions indicate the number of each injury category given a reported injury accident. The fractions do not add to one since more than one injury can occur in an injury accident.

AADT Level	Injury Accident Frequency	Per Injury Accident A	B	C
0 to 250				
D	7	0.4286	0.2857	0.4286
ND	210	0.3381	0.7095	0.3714
251 to 750				
D	72	0.4167	0.8333	0.3472
ND	1064	0.3675	0.6353	0.3863
751 to 1500				
D	259	0.3822	0.6988	0.3745
ND	967	0.3454	0.6753	0.4302
1501 to 3000				
D	288	0.3299	0.7500	0.4583
ND	586	0.4147	0.6655	0.4164

TABLE A-5

INJURIES PER FATAL ACCIDENT

NOTE: The fractions represent the expected number of fatalities and injuries for each injury category given a reported fatal accident. The fractions do not add to one since more than one fatality can occur in a single reported fatal accident.

AADT Level	Fatal Accident Frequency	Per Fatal Accident K	A	B	C
0 to 250					
D	0	0.0000	0.0000	0.0000	0.0000
ND	21	1.0952	0.4286	0.0952	0.0476
251 to 750					
D	5	1.4000	0.2000	0.0000	0.0000
ND	97	1.0928	0.3196	0.2784	0.1649
751 to 1500					
D	32	1.3125	0.0625	0.2500	0.3750
ND	89	1.0499	0.3034	0.2921	0.1011
1501 to 3000					
D	37	1.3514	0.5405	0.4054	0.2162
ND	58	1.2586	0.4483	0.2931	0.2241

Cost Per Property-Damage-Only Accident

The cost per property-damage-only (PDO) accident can be calculated from the costs per vehicle involvement in Table A-1 and the average number of involvements per PDO accident in Table A-2. Total costs per PDO accident by shoulder type are shown in Table A-6 and are calculated as follows: Total Cost = (direct cost per involvement x involvements per accident) + (indirect costs per involvement x involvements per accident) As an example, the PDO costs for a driveable shoulder and AADT level of 1501 to 3000 are:

Total PDO Costs = (\$970 x 1.1961) + (178 x 1.1961) = \$1373.

TABLE A-6

COST PER PDO ACCIDENT (RURAL ONLY)

AADT Level	Acc. Freq.	Driveable	Acc. Freq.	Not Driveable
0 to 250	12	\$1148	269	\$1,263
251 to 750	110	\$1190	1307	\$1,296
751 to 1500	286	\$1252	1062	\$1,348
1501 to 3000	464	\$1373	677	\$1,424

Costs Per A-B-C Injury

Because state accident records typically use the A-B-C scale for coding the severities of nonfatal injuries, the MAIS scale cannot be used directly with state accident data in benefit/cost analysis. Therefore, the method devised by Rollins and McFarland was used for relating the percentage distribution of MAIS severities to that of A-B-C severities. Figure 1 shows the cumulative percent of injuries by MAIS versus cumulative percent by A-B-C for injuries in fatal accidents. The injuries in nonfatal injury accidents are plotted in like fashion in Figure 2. Percentages by MAIS severities can be read from Figures 1 and 2 for any cumulative percentages by A-B-C severities from accident data, establishing weights to apply to the costs of MAIS injuries and thereby producing the costs of A, B, and C injuries. The data for the percentage distributions of A, B, and C injuries in nonfatal injury accidents are presented in Table A-7, and the distributions of A, B, and C injuries in fatal accidents is shown in Table A-8.

TABLE A-7

PERCENTAGE DISTRIBUTION OF A-B-C SEVERITIES IN NONFATAL INJURY ACCIDENTS

NOTE: The numbers in Table A-7 represent the expected distribution of A-B-C Injuries given the frequency of reported nonfatal accidents. These are values extended from Table A-4.

AADT Level	Injury Acc. Freq.	Per Injury Accident A	B	C
0 to 250				
D	7	37.50	25.00	37.50
ND	210	23.83	50.00	26.17
251 to 750				
D	72	26.09	52.17	21.74
ND	1064	26.46	45.73	27.81
751 to 1500				
D	259	26.26	48.01	25.73
ND	967	23.81	46.54	29.65
1501 to 3000				
D	288	21.45	48.76	29.79
ND	586	27.71	44.47	27.82

TABLE A-8

PERCENTAGE DISTRIBUTION OF A-B-C SEVERITIES IN FATAL ACCIDENTS

NOTE: The values in Table A-8 are the expected number of fatalities and injuries by A-B-C category, given a reported fatal accident.

AADT Level	Injury Acc. Freq.	Per Injury Accident A	B	C
0 to 250				
D	0	- %	- %	- %
ND	21	75.01	16.66	8.33
251 to 750				
D	5	100.00	0.00	0.00
ND	97	41.90	36.49	21.61
751 to 1500				
D	32	9.09	36.36	54.55
ND	89	43.56	41.93	14.51
1501 to 3000				
D	37	46.51	34.89	18.60
ND	58	46.43	30.36	23.21

NOTE: D= Driveable Shoulder (6 ft. wide or wider paved shoulder)
ND= Non-driveable shoulder (less than 6 ft. wide paved shoulder)

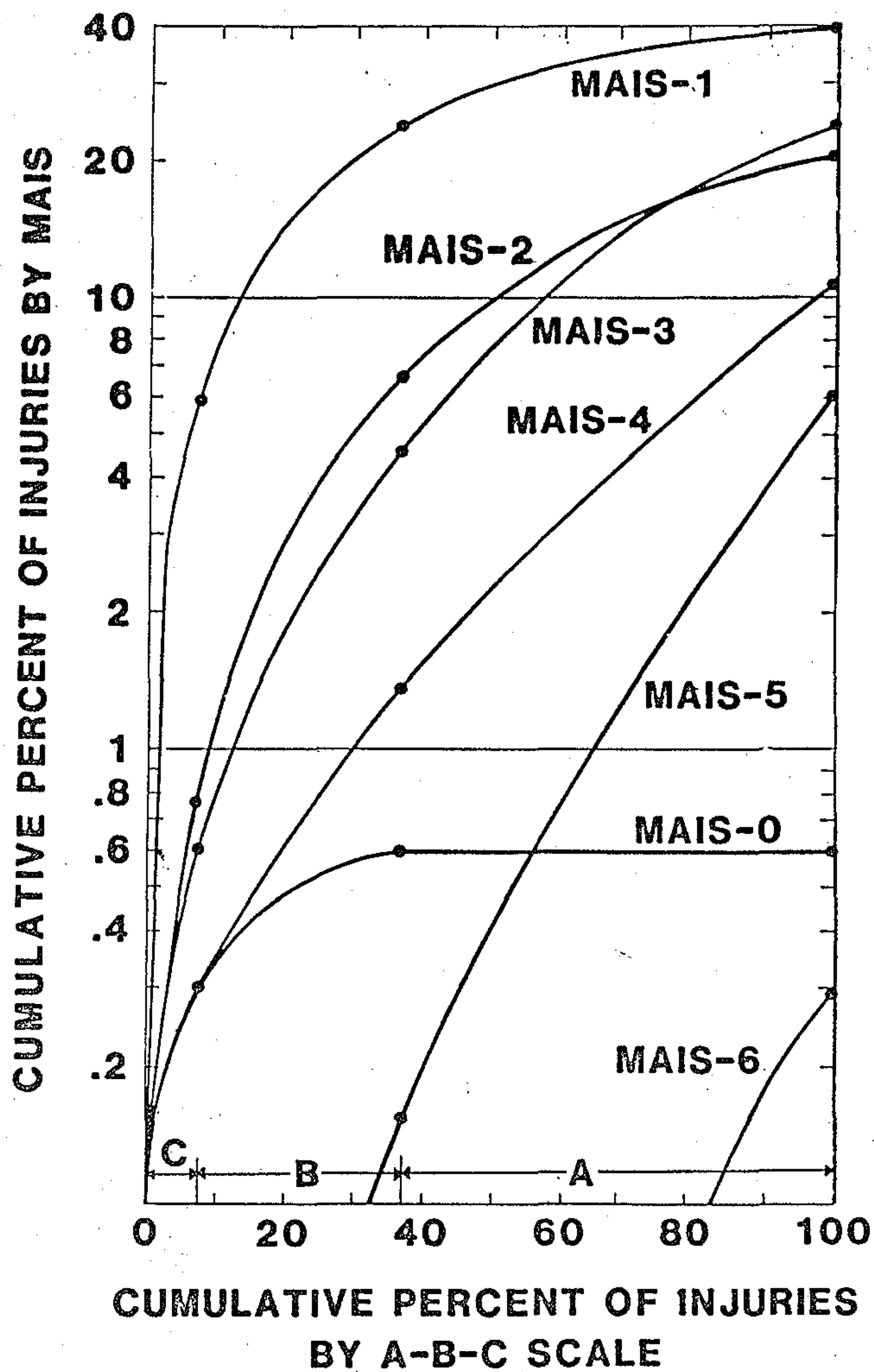

Figure 1. Cumulative percent of injuries by MAIS versus cumulative percent by A-B-C scale, injuries in fatal accidents, NCSS sample.

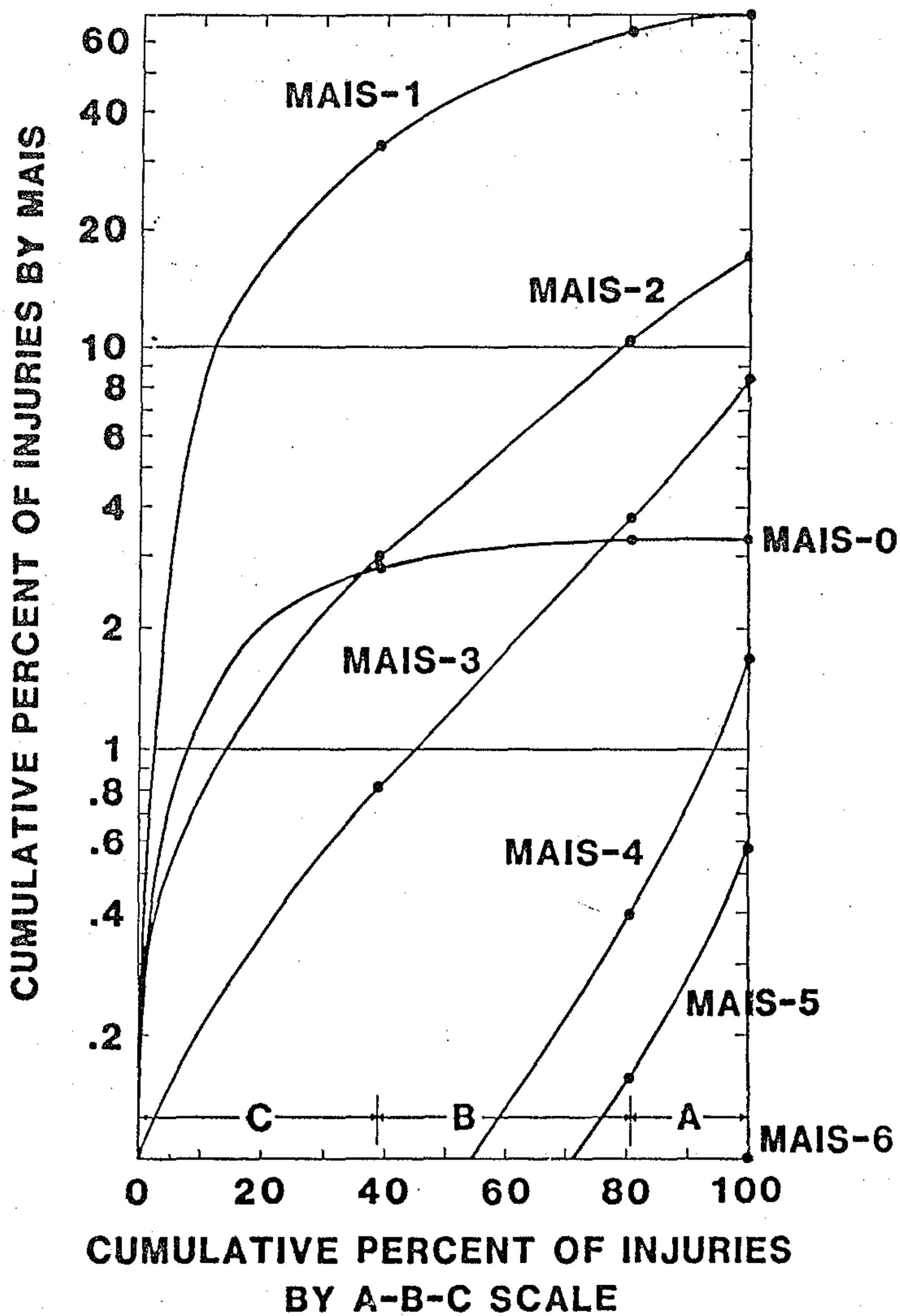

Figure 2. Cumulative percent of injuries by MAIS versus cumulative percent by A-B-C scale, injuries in injury accidents, NASS sample.

The procedure for estimating the costs of A, B, and C injuries in injury accidents is as follows. For example, from Table A-7 the percentage distribution on injury severities by A-B-C scale for driveable shoulders and an AADT level of 1501 TO 3000 are 21.45, 48.76 and 29.79 for A, B, C severities respectively. Using Figure 2, these A-B-C percentages are appropriately separated into MAIS severities. The resulting distributions are presented in Table A-9.

TABLE A-9

PERCENTAGE DISTRIBUTION OF INJURIES IN INJURY ACCIDENTS BY A-B-C AND MAIS SEVERITIES, BY ACCIDENT SEVERITY

Driveable	0	1	2	3	4	5	6	TOTAL
C	2.53	24.57	2.13	0.56	0.00	0.00	0.00	29.79
B+C	3.34	61.63	9.75	3.40	0.36	0.07	0.00	78.55
A+B+C	3.37	68.91	17.00	8.46	1.65	0.58	0.03	100.00

For each MAIS category the percentages of A and B severities are obtained by subtracting off first C+B from the total to get the A percentage, and then A+C from the total to get the B percentage. These percentages for A, B, and C severities are given in Table A-10 and are the weights for the MAIS costs in Table A-1 used to generate A, B, and C costs per injury in injury accidents and per injury in fatal accidents.

TABLE A-10

WEIGHTS FOR CONVERTING MAIS COSTS TO A-B-C COSTS PER INJURY IN INJURY ACCIDENTS

Driveable	0	1	2	3	4	5	6	TOTAL
A	0.03	7.28	7.25	5.06	1.29	0.51	0.03	21.45
B	0.81	37.06	7.62	2.84	0.36	0.07	0.00	48.76
C	2.53	24.57	2.13	0.56	0.00	0.00	0.00	29.79

The MAIS direct costs per victim in Table A-1 include a property damage component expressed as the average amount of property damage per victim. However, estimating the amount of property damage per accident necessitates the calculation of property damage on a per-accident basis because the average accident includes more than one injury per accident and, in the case of fatal accidents, some injuries as well as fatalities (see Table A-5).

Thus, to avoid double-counting of property damage, the direct cost of each nonfatal injury (MAIS-1 to MAIS-5) and fatality (MAIS-6) in Table A-1 is adjusted as follows. The average amount of property damage per victim [11] is deleted from each direct cost total in Table A-1 to give a net direct cost per MAIS injury.

The direct cost (net of property damage) and the indirect cost per A-B-C injury can be calculated by using these net direct costs for MAIS-1 to

MAIS-6 and the indirect costs in Table A-1 along with the weights in Table A-10. This process is shown in Table A-11, where the direct and indirect costs of an A injury in an injury accident on a driveable shoulder at the 1501 to 3000 vehicles per day AADT level is listed by MAIS accident scale. For those MAIS-0 that were coded as injuries on the A-B-C scale, direct and indirect costs of zero are used. (A cost of zero is used for MAIS-0, because no empirical information is available on direct or indirect costs associated with accidents, coded as injury accidents but that turn out to be MAIS-0, that is, PDO accidents. Although there may be some costs associated with such accidents, so that positive values should be used with the MAIS-0 weight in Table A-10, precisely what values would be appropriate is unclear. In any event, the costs of A, B, and C injuries are not significantly affected by using a zero cost instead of some positive values.) Multiplying the weights by the MAIS costs and dividing the sum of the products by the sum of the weights (expressed as a proportion rather than as a percentage) produces direct and indirect costs of A, B, and C injuries.

TABLE A-11

DIRECT AND INDIRECT COSTS OF AN "A" INJURY BY MAIS SCALE
AT 1501-3000 AADT ON A DRIVEABLE SHOULDER

MAIS	Wt.	Net Direct Cost	Direct Product	Indirect Cost	Indirect Product
0	0.0003	$ 0	$ 0	$ 0	$ 0
1	0.0728	1,071	78	928	68
2	0.0725	2,830	205	1,568	114
3	0.0506	8,090	409	2,983	151
4	0.0129	21,147	273	43,819	565
5	0.0051	184,117	939	165,375	843
6	0.0003	20,179	6	974,549	292
TOTAL	0.2145		$1,910		$2,033

The procedure can be illustrated by calculating the net costs of an A injury in an injury accident on a driveable shoulder and an AADT level of 1501 to 3000.

Net direct cost = (sum of products)/(sum of weights)=($1910/.2145) = $8904

Indirect costs = (sum of products)/(sum of weights)=($2033/.2145) = $9478

Total costs = Direct cost + Indirect costs = $8904 + $9478 = $18,382

The net total costs per injury in injury accidents and per injury in fatal accidents are summarized by AADT level and shoulder type in Tables 14 and 15 for A-B-C severities.

TABLE A-12

NET TOTAL COST PER INJURY IN INJURY ACCIDENTS

AADT Level and Shoulder Type	Per Injury Accident A	B	C
0 to 250			
D	$ -	$ -	$ -
ND	17,025	3,488	2,155
251 to 750			
D	16,577	3,214	2,130
ND	16,425	3,304	2,165
751 to 1500			
D	16,519	3,264	2,153
ND	17,434	3,573	2,172
1501 to 3000			
D	18,382	3,835	2,169
ND	15,958	3,227	2,168

TABLE A-13

NET TOTAL COST PER INJURY IN FATAL ACCIDENTS

AADT Level and Shoulder Type	A	B	C
0 to 250			
D	$ -	$ -	$ -
ND	45,046	5,228	5,294
251 to 750			
D	-	-	-
ND	67,445	15,706	5,150
751 to 1500			
D	117,470	51,821	10,607
ND	66,412	12,957	5,086
1501 to 3000			
D	63,500	13,265	7,586
ND	63,608	14,374	5,170

Cost Per Nonfatal Injury Accident

The total cost per nonfatal injury accident for AADT level and by shoulder type is estimated as follows. From Table A-12 the net total costs of A, B, and C injuries (C_A, C_B, and C_C) are multiplied times the numbers of A, B, and C injuries per accident (A, B, C) in Table A-4. For injury accidents on driveable shoulders and an AADT level of 1501 to 3000 the net total costs per accident are:

Net total cost = $(C_A \times A) + (C_B \times B) + (C_C \times C)$

Net total cost = ($18,382 x .3299) + ($3,835 x .7500) + ($2,169 x

Net total cost = $6,064 + $2,876 + $994 = $9,935

The amount of property damage per accident is then added to the net total cost per accident to determine the total cost per nonfatal injury accident. The property damage per accident is the average property damage per vehicle involved in injury accidents ($2,212 in 1987 dollars) [11] times the average number of vehicles involved per injury accident as reported in Table A-2.

Property damage cost = cost per vehicle x vehicles per injury accident.

For driveable shoulder and a 1501 to 3000 AADT level, property damage would equal: $2,212 x 1.2257 = $2,711.

Total cost per injury in an injury accident equals the net total cost plus property damage. For our example: $9,935 + $2,711 = $12,646.

These values are summarized in Table A-14 for injury accidents and Table A-15 for fatal accidents.

TABLE A-14
TOTAL COST PER INJURY ACCIDENT

AADT Level and Shoulder Type	Net Total Cost	Property Damage	Total Cost
0 to 250			
D	-	-	-
ND	$9,031	$2,465	$11,496
251 to 750			
D	10,325	2,335	12,660
ND	8,972	2,462	11,434
751 to 1500			
D	9,401	2,494	11,895
ND	9,369	2,578	11,947
1501 to 3000			
D	9,935	2,711	12,646
ND	9,668	2,714	12,382

TABLE A-15
TOTAL COST PER FATAL ACCIDENT

AADT Level and Shoulder Type	Fatality	ABC	Property Damage	Total Cost Per Accident
0 to 250				
D	$ -	$ -	$ -	$ -
ND	1,089,426	25,098	5,096	1,119,620
251 to 750				
D	-	-	-	1,119,437*
ND	1,087,039	26,777	5,621	1,119,437
751 to 1500				
D	1,305,581	24,275	6,848	1,336,704
ND	1,044,365	24,448	6,126	1,074,939
1501 to 3000				
D	1,344,275	41,339	7,575	1,393,189
ND	1,251,965	33,887	7,292	1,293,144

*Due to small sample size problems, the same total cost for driveable shoulders was assumed as was calculated for non-driveable shoulders.

Cost Per Fatal Accident

The total cost per fatal accident in Table A-15 is calculated the same way as the cost per nonfatal accident, but with the cost per fatality added. The total cost per fatal accident is equal to the sum of the indirect and direct costs. The indirect cost per fatal accident is readily obtained by multiplying the indirect cost per fatality in Table A-1 and the indirect costs of A, B, and C injuries per fatal accident in Table A-5.

The direct cost per fatal accident is estimated as follows. As with the net direct cost per injury, the direct cost per fatality of $24,795 in Table A-1 is adjusted by deleting the average amount of property damage per victim, estimated to be $4,616 in 1987 dollars [11], to give a net direct cost per fatality of $20,179. The direct cost per fatal accident, net of property damage, is then estimated as the sum of the net direct costs per fatality and per A, B, and C injury (NDC_F, NDC_A, NDC_B, and NDC_C, respectively) times the corresponding average numbers of fatalities and A, B, and C injuries per fatal accident (K, A, B, and C, respectively). The total cost per fatal accident is equal to the sum of the direct and indirect costs.

Alternatively, the total cost per fatal accident can be estimated as follows:

$$TC_F = NTC_F + NTC_I + PD_F$$

Total cost of Fatal Accident (TC_F) = Net total cost of the fatalities (NTC_F) + Net total cost of the injuries in the fatal accident (NTC_I)+ Property damage sustained in the fatal accident (PD_F).

Total cost per fatal accident on driveable shoulders with an AADT level of 1501 to 3000 is:

NTC_F = (Indirect cost of fatality + Net direct cost of fatality) x (Number of fatalities per accident).

$$NTC_F = (IC_F + NDC_F) \times (K)$$

$$\$1,344,275 = (\$974,549 + \$20,179) \times (1.3514)$$

NTC_I = Net total costs of A, B, and C injuries in a fatal accident from Table A-13 ($NTCA_F$, $NTCB_F$, and $NTCC_F$) times the average numbers of A, B, and C injuries per fatal accident (A_F, B_F, and C_F) from Table A-5.

$$NTC_I = (NTCA_F \times A_F) + (NTCB_F \times B_F) + (NTCC_F \times C_F)$$

$$NTC_I = (\$63,500)(.5405) + (\$13,265)(.4054) + (\$7,586)(.2162)$$

$$NTC_I = \$34,322 + \$5,378 + \$1,640 = \$41,339$$

The property damage per fatal accident (PD_F) equals the property damage per vehicle (PD_V) times the number of vehicles per fatal accident (V/FA) from Table A-2.

$$PD_F = PD_V \text{ X (Vehicles/F Accidents)} = \$5,096 \times 1.4865 = \$7,575$$

As previously stated, the total cost of a fatal accident is given by:

$$TC_F = NTC_F + NTC_I + PD_F$$

$$TC_F = \$1,344,275 + \$41,339 + \$7,575 = \$1,393,189$$

Total cost per fatal accident on driveable shoulders with an AADT level of 1501 to 3000 is $1,393,189.

The total cost per accident by shoulder type and AADT level is summarized in Table A-16. The average cost of an accident is calculated by multiplying the total cost per category (fatal, injury, and PDO) by the respective accident proportions from Table A-3. Again using AADT level of 1501 to 3000 and driveable shoulders, the average cost is:

$$C_{AVG.} = C_F + C_I I + C_P P$$

$$= (\$1,393,189)(.0469) + (\$12,646)(.3650) + (\$1,373)(.5881)$$

$$= \$70,764$$

<u>Accident Cost Savings Per Year</u>

The accident cost savings per year due to having driveable shoulders is calculated as follows. The savings per MVM for each ADT category equals the difference between the average accident cost multiplied by the annualized accident rates for driveable shoulders, and the average accident cost multiplied by the annualized accident rates for non-driveable shoulders. For example, the savings at the 1501-3000 ADT level is calculated as follows:

(Non-driveable Accident Cost x Non-driveable Accident Rate) -
(Driveable Accident Cost x Driveable Accident Rate) = Savings

($62,991 x 0.8831) - ($70,764 x 0.5081) = $19,672

These results are summarized in Table A-18.

TABLE A-16
TOTAL COST PER ACCIDENT BY AADT AND SHOULDER TYPE

AADT Level and Shoulder Type	Cost Per Accident Fatal	Injury	PDO	Average
0 to 250				
D	$ -	$ -	$1,148	$ -
ND	1,119,620	11,496	1,263	52,532
251 to 750				
D	1,119,437	12,660	1,190	35,463
ND	1,119,437	11,434	1,296	49,609
751 to 1500				
D	1,336,704	11,895	1,252	80,147
ND	1,074,939	11,947	1,348	51,278
1501 to 3000				
D	1,393,189	12,646	1,373	70,764
ND	1,293,144	12,382	1,424	62,991

TABLE A-17
TOTAL ACCIDENT RATES PER MILLION VEHICLE MILES AND
MEAN ANNUAL MILLIONS OF VEHICLE MILES PER ROADWAY SECTION

AADT Level	Shoulder Type Driveable	Not Driveable
0 - 250		
Rate	-	0.7979
MVM	0.42925136	0.23131560
251 - 750		
Rate	0.7961	1.1542
MVM	1.05661836	0.62456716
751 - 1500		
Rate	0.6424	1.0858
MVM	1.94110900	1.39837165
1501 - 3000		
Rate	0.5081	0.8831
MVM	3.30322041	2.68982192

TABLE A-18
CALCULATION OF ANNUAL ACCIDENT COST SAVINGS DUE TO HAVING
DRIVEABLE SHOULDERS, BY AADT LEVEL

ADT	Average Cost Per Accident Driveable	Non-Driveable	Accident Rate/MVM Driveable	Non-Driveable	Accident Cost Savings Per MVM
0-250	--	52,532	--	0.7979	NA
251-750	35,463	49,609	0.7961	1.1542	$29,027
751-1500	80,147	51,278	0.6424	1.0858	4,190
1501-3000	70,764	62,991	0.5081	0.8831	19,672

Statistical Analysis Of Accident Rate Data

Method

A two-factor analysis of variance model was run on the accident rate (defined as the number of accidents per million vehicle-miles traveled) stratified into AADT groupings (0-250, 251-750, 751-1500, and 1501-3000). The two factors were shoulder type (driveable or non-driveable) and surface width (<18 ft., 18 ft.-20 ft., 20 ft.-22 ft., 22 ft.-24 ft., and >24 ft.). The interaction effect of these two factors was also included in the ANOVA model. The design was unbalanced in nature (i.e., unequal numbers of roadway sections in each of the factor level combinations), and in some cases there were missing cells. The unbalanced nature of the design was an artifact of the sampling procedure which reflected the true proportion of these roadway sections for the entire population. For this reason, a weighted hypothesis of means was desirable in order to give more weight to those cells which represented the largest number of road sections. This corresponds to the Type I sum of squares in SAS PROC GLM. The log transformation of accident rates was used as the dependent variable. This was based on the results of normality tests applied to the log transformation which was necessary to satisfy the ANOVA assumption of normally distributed errors. To accommodate missing cells, a constant factor of 0.5 was added to all accident rates.

Results

All of the ANOVA results followed a consistent pattern of: no significant surface width by shoulder type interaction; no significant difference in the accident rates among the four surface width categories (when averaged over shoulder type) but a significant difference in accident rates for driveable vs. non-driveable shoulders (when averaged over surface widths). All tests were conducted at the 5 percent level of significance. These results were consistent for total, fatal, injury and for all AADT levels (0-250, 251-750, 751-1500, 1501-3000, and greater than 3000) with the exception of certain instances where sample size (number of roadway sections) were too small to accurately test the relevant hypothesis. Table A-19 specifies the mean accident rates and sample sizes for the data. Where accuracy estimates were not available for driveable and non-driveable shoulders, shoulder types were combined and only one rate given. The p-values are the significant levels which would be needed to declare that the rates for driveable shoulders equal to that of non-driveable shoulders. Thus the p-value less than 0.05 is significant. In all cases, the accident rates for non-driveable shoulder sections were significantly higher than for driveable shoulder sections within similar AADT groupings.

TABLE A-19

ACCIDENT RATES AND p-VALUES FOR DRIVEABLE AND NON-DRIVEABLE SHOULDERS

ACCIDENT TYPE	AADT	DRIVEABLE RATE (n)	NON-DRIVEABLE RATE (n)	P-VALUE
TOTAL				
	0-250	-- (9)	2.39 (831)	--
	251-750	2.39	3.46	0.007
	751-1500	1.93	3.26	<0.0001
	1501-3000	1.52	2.65	<0.0001
FATAL				
	0-250	0.06		--
	251-750	0.10		--
	751-1500	0.11		--
	1501-3000	0.10		--
FATAL PLUS INJURY				
	0-250	-- (9)	0.89	--
	251-750	0.92	1.44	0.003
	751-1000	1.03	1.60	<0.001
	1001-3000	0.63	1.29	<0.001
INJURY				
	0-250	-- (9)	0.89	--
	251-750	0.86	1.28	0.009
	751-1500	0.93	1.45	<0.0001
	1501-3000	0.55	1.17	<0.0001
PROPERTY DAMAGE ONLY				
	0-250	-- (9)	0.89	--
	251-750	1.66		--
	751-1500	0.92	1.58	<0.0001
	1501-3000	0.91	1.30	<0.0001

Maintenance Management Function Codes Used

The annual cost data in 1985 and 1986 for the maintenance management codes described below were obtained for each cost study site. These cost sites were scattered throughout the state and several sites were located in each district. The average costs should, therefore, reflect the statewide average cost to a fair degree when sufficient observations are available in the cell.

Data on maintenance costs for some 500 sections of roadway were obtained from the SDHPT data file. During the process of obtaining these data, the project staff was informed that the 1985 cost data were highly suspect since that was the first year of data collection, and maintenance personnel were unfamiliar with the codes. Thus many errors in recording of cost data were suspected. Training and better descriptors of the situation included within each code substantially reduced these recording problems in the 1986 data set. For this reason, only the 1986 cost data were used in the cost analysis phase of this research.

TABLE A-20
MAINTENANCE MANAGEMENT FUNCTION
CODES FOR WHICH COST DATA
WERE OBTAINED

FUNCTION CODE	DESCRIPTION
270	EDGE REPAIR - Repair of raveled, low or damaged pavement edges.
431	SEAL COAT-SHOULDER; STRIP OR SPOT SEAL COAT - Application of a single layer of bituminous material followed by the application of a single layer of aggregate to the shoulder surface.
432	SEAL COAT-SHOULDERS; STRIP OR SPOT SEAL COAT - Repair cracked raveling or bleeding bituminous surfaces by the application of an aggregate seal coat over areas that are not full width of shoulder.
433	SEAL COAT-SHOULDER; FOG OR SKEET SEALING - Retain aggregate, enlivened surface and/or seal hairline cracks by the application of a thin layer of bituminous material to the shoulder.
434	SEAL COAT-SHOULDERS; SEAL CRACKS, SQUEEGEES - Seal crack in bituminous paved shoulders using squeegee.
440	POTHOLES AND EDGE REPAIR - The repair of bowl-shaped holes of various sizes in the shoulder, and repair of raveled, low or damaged shoulder edges of paved shoulders.
451	UNPAVED SHOULDERS; RECONDITION SOD SHOULDERS - Blading, dishing or other operations performed to maintain sod shoulders.
452	UNPAVED SHOULDERS; BLADE FLEXIBLE BASE SHOULDERS - Restore flexible base shoulders to original sections, prevent drop off at edge of pavement and correct edge spalling by blading.
460	BASE OR SUBGRADE REPAIRS - The repair of base and/or subgrade of distressed areas of shoulders.

Cost Data Normalization And Expected Trends

The 1986 cost for each maintenance cost code was divided by the mileage of roadway involved in order to make the cost data directly comparable. The resulting units are dollars per mile in 1986 for each function code.

The expected trend for each cost was expected to be as follows:

FUNCTION CODE	EXPECTED TREND IN COST
270	Decreasing with increased pavement width and increasing for increasing AADT.
431, 432, 433, 434, & 440	Increasing with increased shoulder width and AADT.
451, 452, & 460	Decreasing with increased pavement width and increasing with increased AADT.

Basic Variables For Each Function Code

The basic variables were:

1. Maintenance Cost in 1985 ($)
2. Maintenance Cost in 1986 ($)
3. Width of Pavement (Ft.)
4. Width of Each Shoulder (Ft.)
5. Annual Weighted Average Daily Traffic (VPD)
6. Length of Highway Section Involved (Miles)

Generated Variables For Each Function Code

Several variables were generated from the basic variables in order to test the correlation of maintenance cost with the expected trends discussed above. The generated variables were:

7. Normalized 1986 Maintenance Cost per Mile
8. Weighted AADT Divided by the Pavement Width
9. One-half the pavement width plus the shoulder width
10. The square of the weighted Annual Average Daily Traffic

It was expected that the generated variables would reflect the trends in costs associated with the interactions of the basic variables described above.

Correlation Of Pavement Edge Maintenance Cost Data And Pavement Width

The cost data included in Table A-21 were subjected to detailed statistical analysis using the entered and generated variables given previously in Table A-20. Briefly summarized, the findings of these analyses are that no measurable correlations between the pavement width, shoulder width or other variables and the cost data were found. The resulting multiple coefficient of determination (R^2) was always less than 0.2 and generally less than 0.1. This means that less than 20 percent of the observed variation in the cost data can be explained by the variables included in the model. More typically, the observed variability accounted for by the model was less than 10 percent of that observed. Literally, the average value of the cost for each maintenance function code was a better estimate of the data set trends than were the models tested. For this reason, the cost data were summarized by function code and three shoulder width categories: 1) zero feet; 2) less than 6 feet; and 3) 6 feet or more in width. The resulting average values are presented in Table A-22.

TABLE A-21

SUMMARY OF TWO-LANE PAVEMENT EDGE AND SHOULDER MAINTENANCE COSTS
1986 DOLLARS

MAINTENANCE FUNCTION CODE	PVT. WIDTH (FT.)	SHD. WIDTH (FT.)	AVERAGE COST PER MILE	STD. DEV OF COST PER MILE	STD. ERROR OF MEAN PER MILE	COEFF. OF VARIATION
270	18	0	159.50	236.796	50.485	148.458
270*	18	0	184.69	245.990	56.434	133.190
270	20	0	197.73	387.617	58.435	196.033
270*	20	0	290.00	441.692	80.642	152.306
270	22	0	130.33	138.012	41.612	105.895
270*	22	0	159.29	136.452	45.484	85.662
270	24	0	124.20	267.340	56.997	215.258
270*	24	0	151.79	289.571	68.253	190.765
270	18	<6	153.30	233.265	48.640	152.164
270*	18	<6	176.29	242.356	54.193	137.473
270	20	<6	188.82	366.903	51.887	194.310
270*	20	<6	269.75	414.164	70.001	153.538
270	22	<6	121.43	135.156	39.016	111.307
270*	22	<6	145.71	135.627	42.889	93.079
270	24	<6	124.20	267.344	56.998	215.259
270*	24	<6	151.79	289.571	68.253	190.765
270	22	>5.5	74.32	103.001	46.063	138.583
270*	22	>5.5	92.91	108.829	54.415	117.140
270*	24	>5.5	92.91	108.829	54.415	117.140
270	24	>5.5	78.38	156.867	26.144	200.137
270*	24	>5.5	104.67	174.063	33.498	166.619
431	20	0	7.43	10.975	4.908	147.750
431	24	0	277.68	327.708	123.862	118.016
431*	24	0	277.68	327.708	123.862	118.016
431	20	<6	7.43	10.975	4.908	147.750
431	24	<6	277.68	327.707	123.861	118.016
431*	24	<6	277.68	327.708	123.862	118.016
431	24	>5.5	1280.50	3575.450	842.742	279.223
431*	24	>5.5	338.94	414.904	114.904	122.234
432	24	0	152.89	304.982	152.491	199.481
432	24	<6	152.89	304.982	152.491	199.481

432	24	>5.5	119.93	223.657	51.311	186.488
432*	24	>5.5	227.87	269.660	85.274	118.340
432	20	0	67.85	33.224	23.493	48.967

TABLE A-21 (Cont.)

SUMMARY OF TWO-LANE PAVEMENT EDGE AND SHOULDER MAINTENANCE COSTS
1986 DOLLARS

MAINTENANCE FUNCTION CODE	PVT. WIDTH (FT.)	SHD. WIDTH (FT.)	AVERAGE COST PER MILE	STD. DEV OF COST PER MILE	STD. ERROR OF MEAN COST PER MILE	COEFF. OF VARIATION
433	20	0	104.10	169.218	75.677	162.567
433	24	0	3.06	6.110	3.054	200.000
433	20	<6	108.88	143.119	54.094	131.447
433*	20	<6	152.43	149.754	66.972	98.243
433	24	<6	3.06	6.110	3.054	200.000
433	24	>5.5	204.05	448.030	97.768	219.565
433*	24	>5.5	238.06	477.056	112.443	200.390
440	18	0	45.42	91.168	26.318	200.736
440*	18	0	77.85	110.869	41.904	142.411
440	20	0	50.79	68.200	16.075	134.289
440*	20	0	76.18	71.261	20.571	93.543
440*	22	0	195.20	58.484	29.242	29.961
440	24	0	113.75	290.737	72.684	255.600
440*	24	0	202.22	371.974	123.991	183.948
440	18	<6	43.86	87.466	24.259	199.407
440*	18	<6	71.27	104.319	36.882	146.271
440	20	<6	51.30	66.316	15.214	129.282
440*	20	<6	74.97	68.366	18.961	91.190
440	22	<6	156.99	99.328	44.421	63.271
440*	22	<6	156.99	99.327	44.420	63.270
440	24	<6	107.06	282.854	68.602	264.211
440*	24	<6	202.22	371.974	123.991	183.948
440	22	>5.5	215.05	189.792	84.878	88.256
440*	22	>5.5	268.81	169.583	84.792	63.087
440	24	>5.5	142.34	272.344	48.144	191.339
440*	24	>5.5	175.18	293.232	57.508	167.389
451	18	0	289.20	543.250	121.474	187.848
451*	18	0	361.49	588.164	147.041	162.705
451	20	0	62.21	87.093	13.771	139.994
451*	20	0	88.87	92.191	17.422	103.731
451	22	0	241.22	491.234	141.807	203.645
451*	22	0	413.52	599.398	226.551	144.950
451	24	0	66.08	108.904	27.226	164.804
451*	24	0	105.73	122.919	38.871	116.257
451	18	<6	278.47	531.769	116.041	190.958
451*	18	<6	344.00	574.038	139.225	166.874
451	20	<6	59.95	83.564	12.457	139.394
451*	20	<6	84.30	88.273	15.605	104.709
451	22	<6	225.71	473.634	131.362	209.842
451*	22	<6	366.78	570.466	201.690	155.534
451	24	<6	62.19	106.657	25.868	171.491
451*	24	<6	105.73	122.919	38.871	116.257

451	24	>5.5	106.27	300.430	52.298	282.711
451*	24	>5.5	140.27	339.664	67.933	242.145

TABLE A-21 (Cont.)

SUMMARY OF TWO-LANE PAVEMENT EDGE AND SHOULDER MAINTENANCE COSTS
1986 DOLLARS

MAINTENANCE FUNCTION CODE	PVT. WIDTH (FT.)	SHD. WIDTH (FT.)	AVERAGE COST PER MILE	STD. DEV OF COST PER MILE	STD. ERROR OF MEAN COST PER MILE	COEFF. OF VARIATION
452	18	0	190.36	204.726	61.727	107.548
452*	18	0	209.39	205.284	64.916	98.037
452	20	0	90.26	123.611	29.980	136.953
452*	20	0	127.87	130.303	37.615	101.907
452	22	0	102.56	112.317	45.452	109.518
452*	22	0	119.65	112.622	45.978	94.129
452	24	0	244.63	468.303	135.187	191.436
452*	24	0	242.92	375.857	118.857	154.725
452	18	<6	182.85	196.922	56.847	107.694
452*	18	<6	199.47	197.507	59.551	99.013
452	20	<6	114.22	136.791	29.850	119.760
452*	20	<6	149.92	138.712	34.678	92.527
452	22	<6	89.74	110.126	38.935	122.722
452*	22	<6	119.65	112.622	45.978	94.129
452	24	<6	244.63	468.303	135.187	191.436
452*	24	<6	242.92	375.858	118.858	154.725
452	24	>5.5	82.09	122.747	25.594	149.530
452*	24	>5.5	104.86	130.210	30.691	124.170
460	18	0	4.41	11.158	4.217	253.020
460	20	0	2.80	4.844	2.797	173.205
460	22	0	160.26	280.863	140.431	175.254
460	24	0	73.11	96.315	55.608	131.739
460	18	<6	4.41	11.158	4.217	253.020
460	20	<6	27.57	49.705	24.853	180.284
460	22	<6	160.26	280.863	140.431	175.254
460	24	<6	73.11	96.316	55.608	131.739
460	22	>5.5	60.74	85.900	60.741	141.421
460	24	>5.5	20.85	42.277	10.254	202.812
460*	24	>5.5	35.44	51.020	16.134	143.974

* - Actual Cost Data

In reviewing the data in Table A-22, several interesting trends are observable. Under Function Code 270, Pavement Edge Maintenance, the average cost increases with the existence of a narrow shoulder (non-driveable shoulder) but is reduced to about one-half the basic value for wide paved shoulders (driveable shoulders). For Function Code 440, Potholes and Edge Repair in the Shoulder, the cost increases as the shoulder width increases, as would be expected. On-the-other-hand, Function 451, Recondition Sod Shoulders, and Code 452, Flexible Base Repair, are essentially the same for shoulders up to six feet wide and is reduced to about one-half that observed for roadways with a narrow shoulder. The costs for Function Code 460, Base and Subgrade Repairs, are about $145 per mile per year for narrow shoulders (0-6 feet) and increases to an average of $237 per mile per year for wide paved shoulders. Maintenance costs for Function Codes 431, 432, and 433 had too few data elements available to average by shoulder width Groups, and the resulting overall values are reported in Table A-22.

The reader is cautioned that some data elements in Table A-22 are subject to serious limitations as noted. Notice also that Table A-22 reports to costs: 1) the actual average cost in the year 1986; and 2) the average cost across all sites in the AADT and shoulder width group, including those sites with no reported maintenance in the year 1986. While both are subject to experimental and small sample errors, if these data are used to estimate maintenance costs, care must be used in selecting the most appropriate average cost value. Overall average costs should be used when estimating the maintenance cost on the entire low-volume, two-lane highway system. The best estimate for a particular highway section on which maintenance is to be performed, however, is the actual average cost in 1986 excluding those sites which did not have maintenance in the year 1986. Table A-23 contains the average maintenance cost by Function Code and the associated 80^{th} percentile value. The 80^{th} percentile estimate would probably be the best to use in estimating the probable cost of the job.

The entered and generated variables were subjected to detailed statistical analysis. The normalized cost for each maintenance code was used as the dependent variable and the weighted annual average daily traffic; weighted annual average traffic divided by the pavement width; half pavement width plus shoulder width; and weighted annual average traffic squared were used as the independent variables. A second analysis included the log of the pavement width as a transformed variable after the work of Mak and Griffin [12].

A correlation analysis of the independent variables revealed a substantial degree of variable interaction, however, the interaction was not deemed to be so large as to negate the potential value of an Analysis of Variance (ANOVA) or Regression analysis of the data. An ANOVA analysis identified too few observations in certain cells for this analysis to be successfully carried out.

Statistical Analysis Of Cost Data

Multiple linear regression analysis for each maintenance function code resulted in coefficients of determination (R^2 that were extremely low. The largest R^2 value for any maintenance code was 0.09, which indicates a nearly random pattern of maintenance costs per mile.

The meaning of these findings can best be illustrated by the ratio of the standard deviation to the mean value. A highly variable data set has the mean and standard deviation about equal. The maintenance cost data sites were selected to insure a maximum of uniformity across the entire county. Only those sites which met all criteria discussed previously were included in the sample. The apparent lack of consistency in maintenance costs with logical changes in the pavement width, weighted average daily traffic, paved shoulder width and other variables is of concern. One possible explanation for these findings is lack of uniformity in the data recording procedures.

TABLE A-22

EDGE AND SHOULDER MAINTENANCE COST SUMMARY BY SDHPT COST FUNCTION CODE

FUNCTION CODE 270
EDGE REPAIR - ACC PVTS.

SHD. WIDTH	ACTUAL COST	AVERAGE COST
0	$260	$216
<6	$252	$203
≥6	$68	$48

FUNCTION CODE 452
RESTORE FLEXIBLE BASE

SHD. WIDTH	ACTUAL COST	AVERAGE COST
0	$1175	$825
<6	$1035	$742
≥6	$64	$45

ALL SHOULDER WIDTHS
SEAL COAT SHOULDERS

FUNCTION CODE	ACTUAL COST	AVERAGE COST
431	$1638	$655**
432	$333	$218
433	$203	$81

** RESULT DUE TO ONE LARGE COST SITE

FUNCTION CODE 460
BASE OR SUBGRADE REPAIR

SHD. WIDTH	ACTUAL COST	AVERAGE COST
0	$290	$222
<6	$290	$210
≥6	$67	$46

FUNCTION CODE 440
RECONSTRUCT SOD SHD.

SHD. WIDTH	ACTUAL COST	AVERAGE COST
0	$296	$213
<6	$293	$206
≥6	$105	$85

TOTAL COSTS OF EDGE MAINTENANCE
CODES 270, 451, 452 AND 460

SHD. SHD. WIDTH	SUM OF ALL COSTS ($/MILE) ACTUAL	AVERAGE
0	$1907	$1392
<6	$1749	$1276
>6	$330	$241

AVERAGE EDGE MAINTENANCE COST - NOT PAVED

FUNCTION CODE 451

SHD. WIDTH	ACTUAL COST	AVERAGE COST
0	$182	$129
<6	$172	$121
≥6	$131	$102

SHOULDER - $1392

COST SAVINGS AT 15% REDUCTION=$208/MILE/YR

COST SAVINGS AT 40% REDUCTION=$557/MILE/YR

COST SAVINGS AT 70% REDUCTION=$994/MILE/YR

TABLE A-23

CONFIDENCE INTERVAL ON THE AVERAGE ANNUAL MAINTENANCE COST PER MILE

MAINTENANCE FUNCTION CODE	SHD WIDTH (FT.)	AVERAGE COST PER MILE	STD. ERROR OF THE MEAN COST PER MILE	80 % CONFIDENCE INTERVAL LOW	HIGH
270	0	216	55.144	145	287
270	<6	203	51.292	137	269
270	≥6	47	16.972	25	69
431	ALL	655	462.661	63	1247
432	ALL	218	124.653	58	378
433	ALL	81	31.303	41	121
440	0	213	92.368	95	331
440	<6	206	85.647	96	315
440	≥6	85	24.113	54	116
451	0	129	34.457	85	173
451	<6	120	31.741	79	161
451	≥6	102	43.479	46	158
452	0	825	470.500	223	1427
452	<6	742	417.990	207	1277
452	≥6	45	13.154	28	62
460	0	222	116.885	72	372
460	<6	210	110.889	68	352
460	≥6	47	19.665	22	72

The overall average cost per mile for each maintenance cost code is the best estimate of the maintenance cost, given that no correlation exists with the independent variables tested.