SAFETY EFFECTS OF CROSS-SECTION DESIGN FOR TWO-LANE ROADS

Research, Development, and Technology
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, Virginia 22101-2296

U.S. Department of Transportation
Federal Highway Administration

Vol. II: Appendixes

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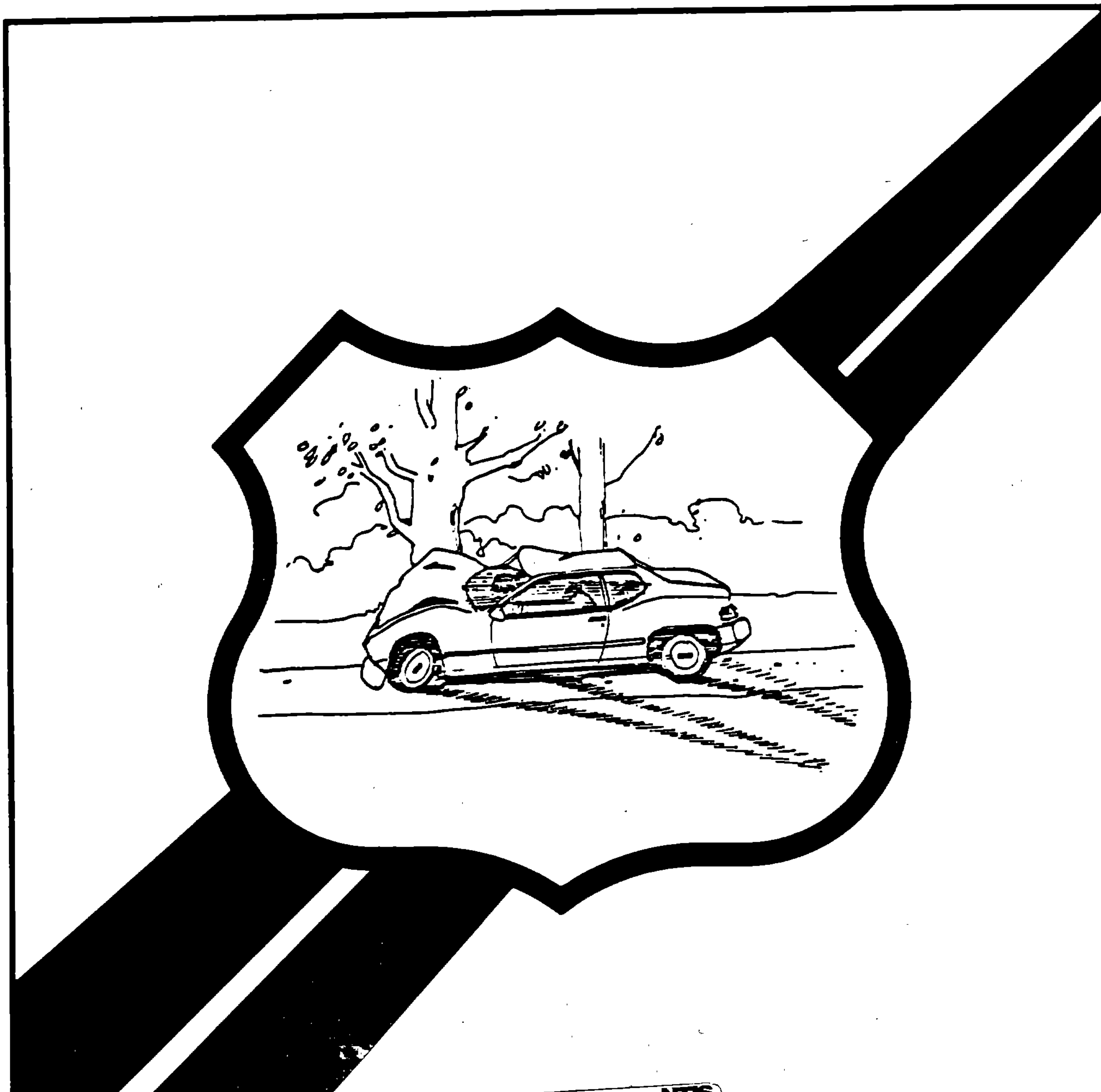

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16. Abstract

This study was intended to quantify the benefits and costs resulting from lane widening, shoulder widening, shoulder surfacing, sideslope flattening, and roadside improvements. Detailed traffic, accident, and roadway data were collected on 4,951 miles of two-lane roads in seven States. An accident predictive model and statistical tests were used to determine expected accident reductions related to various geometric improvements. Factors found to be most related to reduced accidents were wider lanes and shoulders, improved roadside conditions, and flatter sideslopes. Paved shoulders were found to have a marginal safety benefit compared to unpaved shoulders.

Detailed accident analyses were also conducted for roadside features. Factors associated with increased fixed object accidents include higher traffic volumes, greater numbers of roadside objects, and closer distance of roadside objects to the road. Roadside objects associated with high accident severities include culverts, trees, utility and light poles, bridges, rocks, and earth embankments. Construction cost data from several States were used to develop a cost model for numerous types of roadway and roadside projects.

This volume contains appendixes to the final report. Appendixes are included on the development of the scale used to rate the roadside hazard, the statistical breakdown of key variables, the severity of different types of run-off-road accidents and the development of the cost estimates for cross-section improvements.

This volume is the second of a two volume final report. The other volume is:

FHWA No.	Vol. No.	Title
RD-87/008	I	Safety Effects of Cross-Section Design for Two-Lane Roads - Volume I - Final Report (The table of contents for Volume I is also contained in Volume II.)

17. Key Words

Sideslope, Roadside Features, Lane Width, Shoulder Width, Accident Predeiction Model, Accident Reduction Factors

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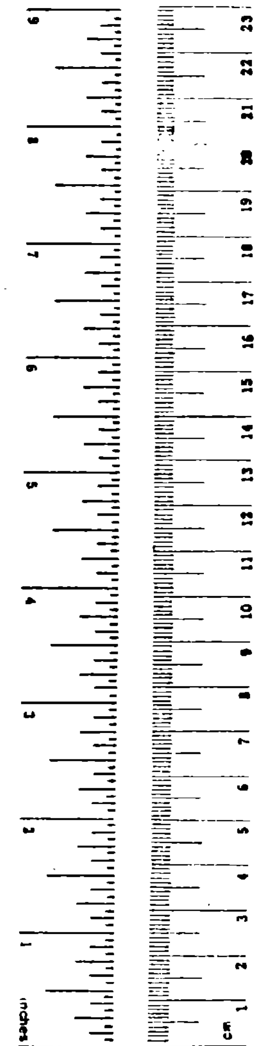
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

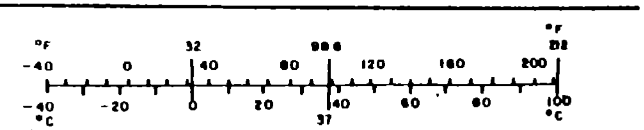
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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APPENDIX E - THE DEVELOPMENT OF THE ROADSIDE HAZARD SCALE

One of the original objectives of the research was to develop a rating system to quantify the hazard posed by a given section of highway roadside. Two alternative rating systems were given serious consideration: a hazard scale and frequency/severity system. To use the hazard scale, a judgment is made on the roadside according to the accident damage likely to be sustained by out-of-control vehicles on a scale from one (low likelihood of off-roadway collision or overturn) to seven (high likelihood of accidents resulting in fatality or severe injury). For the frequency/severity system, two judgments are made on the roadside of interest. First, the roadside is rated according to the frequency with which out-of-control vehicles are likely to become involved in off-roadway accidents (i.e., collide with fixed objects or overturn) on a scale from one (low likelihood of involvement) to seven (high likelihood of involvement). Second, the roadside is rated on the likely severity of off-roadway accidents on a scale from one (low likelihood of fatality or severe injury) to seven (high likelihood of fatality or severe injury). The hazard scale requires the person performing the rating to consider frequency and severity simultaneously, while in the frequency/severity system those elements must be considered separately.

It was not possible to judge the validity of the rating systems at the time they were developed because the true hazard posed by a given roadside was unknown. However, a consistent rating system was also desired and a test was conducted to evaluate the competing rating systems on the basis of consistency. A series of 141 photographs of roadsides in rural areas and 78 photographs of roadsides in urban areas were rated (rural and urban roadsides were rated on separate scales) by 13 transportation professionals using the hazard scale and the frequency and severity scales of the frequency/severity rating system. The range and the standard deviation of the ratings made by each of the 13 judges using each of the three scales (hazard, frequency and severity) was calculated for each roadside. If the ranges and standard deviations produced using the hazard scale were smaller than those produced using the frequency and severity scales, the hazard scale would be deemed the more consistent and, therefore, the preferred rating system. Conversely, if the hazard scale produced ranges and standard deviations of ratings which were larger than the frequency and severity scales, the frequency/severity rating system would be deemed the more consistent and preferred rating system.

The results of the test ratings given in table 1 for the 141 rural roadsides showed that the hazard scale produced much more consistent ratings than the severity scale and about the same consistency of ratings as the frequency scale. The hazard scale had the lowest standard deviations of rating 49 times, compared with 59 times for the frequency scale and 30 times for the severity scale (the totals will not add to 141 because there were roadsides with ties between two scales for the lowest standard deviation). The hazard scale had the highest standard deviation of rating for only 23 roadsides, compared with 54 roadsides for the frequency scale and 60 roadsides for the severity scale. The hazard scale had the smallest range of ratings for 21 roadsides, compared with 38 roadsides for the frequency scale and 18 roadsides for the severity scale. The hazard scale had the widest range of ratings for only 12 roadsides, compared with 29 roadsides for the frequency scale and 24 roadsides for the severity scale.

The results of the test ratings of the 78 urban roadside photographs given in table 2 show that the hazard scale produced much more consistent results than the frequency scale but less consistent results than the severity scale. The hazard scale had the lowest standard deviation of rating for 23 roadsides, compared to 35 roadsides for the severity scale and 14 roadsides for the frequency scale. The hazard scale had the highest standard deviation of rating for 23 roadsides, compared with only 12 roadsides for the severity scale and 37 roadsides for the frequency scale. The hazard scale had the smallest range of ratings for five roadsides, compared with 15 roadsides for the severity scale and eight roadsides for the frequency scale. The hazard scale had the widest range of ratings for ten roadsides, while the severity scale had the widest range for only two roadsides and the frequency scale had the widest range for 23 roadsides.

The test results were re-examined to gain insight into different issues. First, the 44 rural roadsides and 21 urban roadsides which had the highest standard deviations of ratings were eliminated and results

Table 1. Results from tests for consistency of roadside rating systems using 141 rural roadsides.

	Hazard Scale	Frequency Scale	Severity Scale
Number of roadsides* with lowest standard deviation of ratings	49	59	30
Number of roadsides* with highest standard deviation of ratings	23	54	60
Number of roadsides* with smallest range of ratings	21	38	18
Number of roadsides* with largest range of ratings	12	29	24

* The row totals do not equal 141 (the number of roadsides rated) because there were some ties between two scales which are not reported in this table.

Table 2. Results from tests for consistency of roadside rating systems using 78 urban roadsides.

	Hazard Scale	Frequency Scale	Severity Scale
Number of roadsides* with lowest standard deviation of ratings	23	35	14
Number of roadsides* with highest standard deviation of ratings	23	37	12
Number of roadsides* with smallest range of ratings	5	8	15
Number of roadsides* with largest range of ratings	10	23	2

* The row totals do not equal 78 (the number of roadsides rated) because there were some ties between two scales which are not reported in this table.

were produced with the remaining roadsides. No major changes were seen in the relative merits of the scales due to the elimination of those roadsides. Second, the ratings of two relatively inexperienced judges were omitted and the results were tabulated for the other 11 judges. Again, the overall results of the test were not affected by the omissions. This latter result suggests that relatively inexperienced persons can use the rating scales reasonably well.

Based on the test results, the hazard scale was chosen as a better roadside rating system than the frequency/severity system. The hazard scale was more consistent than the severity scale for rural roadsides and more consistent than the frequency scale for urban roadsides. In addition, the hazard scale was simpler to use and analyze then a two-dimensional frequency/severity scale. Thus, the hazard scale was used during the research. The relationships between the rates of some types of accidents and the roadside hazard rating were shown during later stages of the research to be strong, helping show the validity of the roadside hazard scale.

Table .3. Descriptive statistics for the total seven State data base - ADT.

Measure	Grand Total or Mean	ADT							
		1-250	251-400	401-750	751-1,000	1,001-2,000	2,001-4,000	4,001-7,500	7,501 and Higher
Number of Sections	1,944	52	86	151	124	378	530	403	220
Total Mileage	4,951	156	277	507	380	1,089	1,307	853	383
Total Accs/100 MVM	266	387	227	240	253	238	259	287	308
Total Accs/Mile/Year	3.69	0.23	0.28	0.51	0.82	1.29	2.77	5.75	12.10
Single Vehicle Accs/100 MVM	95	252	131	134	136	106	78	74	54
Single Vehicle Accs/Mile/Year	.936	.142	.160	.283	.443	.565	.843	1.453	2.050
Proportion Inj. & Fatal	.360	.245	.361	.364	.412	.373	.345	.355	.372

Table 4. Descriptive statistics for the total seven State data base - terrain.

Measure	Grand Total or Mean	Terrain		
		Flat	Rolling	Mountainous
Number of Sections	1,944	780	805	359
Total Mileage	4,951	1,947	2,134	870
Total Accs/ 100 MVM	266	244	250	351
Total Accs/ Mile/Year	3.69	3.50	3.57	4.38
Single Vehicle Accs/100 MVM	95	69	90	161
Single Vehicle Accs/Mile/Year	.936	.809	.868	1.363
Proportion Inj. & Fatal	.360	.324	.358	.329

Table 5. Descriptive statistics for the total seven State data base - speed limit.

Measure	Grand Total or Mean	Speed Limit						
		25	30	35	40	45	50	55
Number of Sections	1,944	18	21	105	55	160	102	1,483
Total Mileage	4,951	25	30	144	89	276	242	4,146
Total Accs/ 100 MVM	266	640	728	460	477	383	277	220
Total Accs/ Mile/Year	3.69	9.74	12.10	10.51	9.71	8.96	4.95	2.14
Single Vehicle Accs/100 MVM	95	165	123	89	131	83	86	94
Single Vehicle Accs/Mile/Year	.936	1.933	2.020	1.762	2.055	1.488	1.268	.726
Proportion Inj. & Fatal	.360	.338	.244	.299	.334	.357	.376	.366

Table 6. Descriptive statistics for the total seven State data base - lane width.

Measure	Grand Total or Mean	Lane Width (ft)						
		8	9	10	11	12	13	14
Number of Sections	1,944	9	278	373	567	601	110	6
Total Mileage	4,951	28	722	937	1,483	1,463	310	8
Total Accs/ 100 MVM	266	369	300	307	251	251	186	493
Total Accs/ Mile/Year	3.69	1.19	2.23	3.91	4.26	3.98	2.15	7.55
Single Vehicle Accs/100 MVM	95	174	127	126	75	78	92	114
Single Vehicle Accs/Mile/Year	.936	.489	.691	1.104	.973	.943	.747	1.644
Proportion Inj. & Fatal	.360	.530	.370	.381	.350	.343	.388	.368

Table 7. Descriptive statistics for the total seven State data base - shoulder width.

Measure	Grand Total or Mean	Shoulder Width (ft)												
		0	1	2	3	4	5	6	7	8	9	10	11	12 and Greater
Number of Sections	1,944	158	74	116	205	202	365	178	84	219	55	258	13	17
Total Mileage	4,951	450	204	299	495	494	882	428	224	565	155	673	35	50
Total Accs/ 100 MVM	266	376	290	319	357	272	268	206	215	211	197	218	225	173
Total Accs/ Mile/Year	3.69	4.70	2.49	4.00	4.02	3.55	3.94	3.44	3.41	3.58	2.29	3.55	3.58	1.99
Single Vehicle Accs/100 MVM	95	149	149	146	137	105	89	69	73	59	56	58	40	57
Single Vehicle Accs/Mile/Year	.936	.948	.948	1.316	1.211	.997	.877	.843	.970	.829	.564	.829	.587	.634
Proportion Inj. & Fatal	.360	.354	.400	.382	.389	.406	.367	.340	.377	.337	.305	.314	.318	.312

Table 8. Descriptive statistics for the total seven State data base - shoulder type.

Measure	Grand Total or Mean	Shoulder Type				
		Paved Only	Gravel Only	Earth Only	Other	No Shoulder
Number of Sections	1,944	447	641	499	199	158
Total Mileage	4,951	1,217	1,441	1,356	487	450
Total Accs/ 100 MVM	266	218	318	215	252	376
Total Accs/ Mile/Year	3.69	2.88	4.66	2.75	3.93	4.70
Single Vehicle Accs/100 MVM	95	85	103	79	88	149
Single Vehicle Accs/Mile/Year	.936	.903	1.100	.687	1.094	.948
Proportion Inj. & Fatal	.360	.383	.358	.355	.326	.354

Table 9. Descriptive statistics for the total seven State data base - average recovery distance.

Measure	Grand Total or Mean	Average Recovery Distance (ft)					
		0-5	6-10	11-15	16-20	21-25	26-30
Number of Sections	1,944	203	533	521	405	237	45
Total Mileage	4,951	495	1,279	1,309	1,105	640	123
Total Accs/ 100 MVM	266	387	328	262	195	177	147
Total Accs/ Mile/Year	3.69	5.92	4.89	3.58	2.38	2.03	1.32
Single Vehicle Accs/100 MVM	95	170	120	93	57	49	53
Single Vehicle Accs/Mile/Year	.936	1.772	1.297	.874	.511	.374	.367
Proportion Inj. & Fatal	.360	.398	.405	.350	.316	.320	.362

Table 10. Descriptive statistics for the total seven State data base - driveways per mile.

Measure	Grand Total or Mean	Driveways/Mile				
		0-5	5-10	10-20	20-40	40-90
Number of Sections	1,944	567	439	518	297	123
Total Mileage	4,951	1,662	1,248	1,345	548	149
Total Accs/ 100 MVM	266	181	227	267	362	565
Total Accs/ Mile/Year	3.69	1.25	2.07	3.25	7.67	12.99
Single Vehicle Accs/100 MVM	95	87	101	108	80	88
Single Vehicle Accs/Mile/Year	.936	.516	.708	1.016	1.485	2.016
Proportion Inj. & Fatal	.360	.372	.358	.364	.350	.311
Multiple Veh. Accs/100 MVM	21.5	13.2	18.1	25.4	28.9	37.6
Multiple Veh. Accs/Mile/Year	.297	.113	.170	.305	.612	.803
Angle Accs/ 100 MVM	56.3	16.1	35.2	48.9	115.4	205.4
Angle Accs/ Mile/Year	1.02	0.16	0.43	0.74	2.46	4.73

Table 11. Descriptive statistics for the rural seven State data base - median roadside rating.

Measure	Grand Total or Mean	Median Roadside Rating - Rural				
		1 & 2	3	4	5	6 & 7
Number of Sections	1,801	48	476	819	413	45
Total Mileage	4,785	154	1,315	2,127	1,043	147
Total Accs/ 100 MVM	240	126	188	241	297	351
Total Accs/ Mile/Year	2.91	1.33	2.29	3.26	3.21	2.10
Single Vehicle Accs/100 MVM	96	50	58	90	143	238
Single Vehicle Accs/Mile/Year	.862	.401	.539	.884	1.208	1.176
Proportion Inj. & Fatal	.364	.385	.324	.353	.423	.405

Table 12. Descriptive statistics for the rural seven State data base - horizontal curvature.

Measure	Grand Total or Mean	Percent with Horizontal Curvature 2.5 Degrees or Greater					
		0-10	11-20	21-30	31-40	41-50	51-100
Number of Sections	1,188	596	181	123	99	52	137
Total Mileage	3,477	1,772	561	394	263	135	353
Total Accs/ 100 MVM	227	185	204	232	297	332	346
Total Accs/ Mile/Year	2.07	1.96	2.11	1.98	2.89	2.16	1.95
Single Vehicle Accs/100 MVM	107	73	98	123	145	183	198
Single Vehicle Accs/Mile/Year	.796	.615	.902	.840	1.262	1.110	.949
Proportion Inj. & Fatal	.377	.343	.400	.376	.426	.428	.435

Table 13. Descriptive statistics for the rural seven State data base - vertical curvature

Measure	Grand Total or Mean	Percent of sections with Vertical Curvature 2.5 Percent or Greater						
		0-10	11-20	21-30	31-40	41-50	51-75	76-100
Number of Sections	1,174	680	149	112	84	41	71	37
Total Mileage	3,421	1,887	491	368	260	102	213	100
Total Accs/ 100 MVM	231	223	229	229	206	291	277	305
Total Accs/ Mile/Year	2.10	2.27	1.88	2.01	1.42	2.86	1.50	2.19
Single Vehicle Accs/100 MVM	109	96	110	121	106	158	151	164
Single Vehicle Accs/Mile/Year	.813	.798	.806	.928	.548	1.371	.744	.882
Proportion Inj. & Fatal	.378	.359	.376	.434	.394	.474	.404	.375

Table 14. Descriptive statistics for the urban seven State data base - median roadside rating.

Measure	Grand Total or Mean	Median Roadside Rating - Urban				
		1 & 2	3	4	5	6 & 7
Number of Sections	143	15	43	38	42	5
Total Mileage	166	25	50	40	47	4
Total Accs/ 100 MVM	603	268	668	434	805	633
Total Accs/ Mile/Year	13.5	5.7	12.7	12.6	17.6	16.2
Single Vehicle Accs/100 MVM	80	38	66	72	109	128
Single Vehicle Accs/Mile/Year	1.869	.668	1.216	1.704	2.939	3.354
Proportion Inj. & Fatal	.308	.378	.298	.319	.280	.343

Table 15. Descriptive statistics - area type by lane width.

Lane Width (ft)	Rural			Urban			Total		
	No. Sections	Miles	Avg. Mi/ Section	No. Sections	Miles	Avg. Mi/ Section	No. Sections	Miles	Avg. Mi/ Section
8	9	28.47	3.16	0	0	-	9	28.47	3.16
9	265	710.52	2.68	13	11.72	0.90	278	722.24	2.60
10	346	907.09	2.62	27	29.64	1.10	373	936.73	2.51
11	524	1,437.90	2.74	43	45.38	1.06	567	1,483.28	2.62
12	555	1,406.27	2.53	46	56.65	1.23	601	1,462.92	2.43
13	101	293.65	2.91	9	16.46	1.83	110	310.11	2.82
14	1	1.24	1.24	5	6.29	1.26	6	7.53	1.26
Total	1,801	4,785.14	2.66	143	166.14	1.16	1,944	4,951.28	2.55

Table 16. Descriptive statistics for the total data base - State by average recovery distance.

Number of sections, with total mileage in parentheses.							
	Average Recovery Distance (ft)						
State	0-5	6-10	11-15	16-20	21-25	26-30	Total
Ala.	1 (3.9)	27 (49.5)	97 (201.5)	150 (362.0)	138 (355.8)	24 (60.3)	437 (1,032.9)
Mich.	8 (27.5)	44 (118.2)	113 (262.1)	89 (223.8)	27 (63.7)	1 (3.7)	282 (699.1)
Mont.	1 (0.5)	24 (73.3)	46 (143.8)	53 (196.3)	34 (108.4)	10 (24.4)	168 (546.6)
N.C.	25 (77.9)	92 (215.6)	121 (348.1)	35 (100.5)	2 (3.5)	0 -	275 (745.6)
Utah	16 (40.3)	39 (85.4)	61 (158.3)	53 (137.2)	27 (82.3)	7 (21.4)	203 (524.9)
Wash.	69 (218.2)	96 (296.7)	37 (113.9)	19 (70.7)	7 (24.0)	3 (13.2)	231 (736.8)
W.V.	83 (126.4)	211 (440.3)	47 (83.8)	6 (14.3)	1 (0.6)	0 -	348 (665.4)
Total	203 (494.8)	533 (1,279.0)	522 (1,311.6)	405 (1,104.7)	236 (638.3)	45 (123.0)	1,944 (4,951.3)

Table 17. Descriptive statistics for the total data base - State by lane width.

Number of sections, with total mileage in parentheses.							
	Lane Width (ft)						
State	8	9	10	11	12	13-14	Total
Ala.	0 -	114 (275.0)	90 (213.4)	140 (333.0)	93 (211.5)	0 -	437 (1,032.9)
Mich.	0 -	5 (9.0)	37 (102.6)	115 (316.2)	125 (271.3)	0 -	282 (699.1)
Mont.	0 -	8 (26.2)	26 (83.4)	20 (70.8)	96 (306.2)	18 (60.0)	168 (546.6)
N.C.	0 -	58 (197.1)	68 (193.3)	81 (199.6)	67 (154.8)	1 (0.8)	275 (745.6)
Utah	0 -	0 -	7 (11.3)	27 (77.3)	77 (190.1)	92 (246.2)	203 (524.9)
Wash.	1 (5.0)	7 (21.2)	40 (125.7)	112 (359.1)	69 (217.8)	2 (8.0)	231 (736.8)
W.V.	8 (23.5)	86 (193.9)	105 (207.1)	72 (127.2)	74 (111.1)	3 (2.6)	348 (665.4)
Total	9 (28.5)	278 (722.2)	373 (936.7)	567 (1,483.3)	601 (1,462.9)	116 (317.6)	1,944 (4,951.3)

Table 18. Descriptive statistics for the total data base - State by ADT.

Number of Sections, with Total Mileage in Parentheses								
	State							
ADT	Ala.	Mich.	Mont.	N.C.	Utah	Wash.	W.V.	Total
1-250	4 (12.8)	3 (11.3)	9 (31.5)	0 -	29 (72.2)	7 (28.4)	0 -	52 (156.2)
251-400	17 (48.9)	2 (5.8)	16 (67.9)	8 (27.1)	32 (92.3)	7 (23.9)	3 (9.6)	85 (275.6)
401-750	48 (154.0)	14 (59.9)	27 (93.4)	12 (45.4)	24 (72.1)	17 (59.0)	9 (22.8)	151 (506.6)
751-1,000	31 (81.4)	8 (19.8)	21 (74.5)	13 (55.6)	11 (29.0)	14 (53.1)	26 (66.8)	124 (308.2)
1,001-2,000	87 (229.8)	49 (147.3)	56 (173.4)	48 (164.4)	24 (65.1)	38 (127.3)	75 (177.9)	377 (1,085.2)
2,001-4,000	134 (285.0)	107 (253.5)	25 (71.2)	72 (188.5)	38 (99.3)	72 (251.2)	82 (157.8)	530 (1,306.7)
4,001-7,500	94 (188.7)	70 (146.8)	12 (32.2)	66 (151.8)	33 (70.7)	48 (128.3)	80 (134.5)	403 (853.1)
7,501 and Greater	22 (32.2)	29 (54.6)	2 (2.5)	56 (112.7)	12 (24.2)	28 (65.5)	73 (96.0)	222 (387.7)
Total	437 (1,032.9)	282 (699.1)	168 (546.6)	275 (745.6)	203 (524.9)	231 (736.8)	348 (665.4)	1,944 (4,951.3)

APPENDIX G - EXAMINATION OF KEY VARIABLES

Table 19. One-way analysis of covariance results for lane width using the rural data base.*

Flat Terrain

Lane Width (ft)	8-9	10	11	12-14	Total or Mean
Adjusted Mean of SVA/100 MVM**	100	80	61	67	70
Number of Sections	58	101	228	314	701

Rolling Terrain

Lane Width (ft)	8-9	10	11	12-14	Total or Mean
Adjusted Mean of SVA/100 MVM**	104	96	87	81	90
Number of Sections	119	159	229	247	754

Mountainous Terrain

Lane Width (ft)	8-9	10	11	12-14	Total or Mean
Adjusted Mean of SVA/100 MVM**	148	209	127	162	163
Number of Sections	97	86	67	96	346

* - Control variables used in this analysis were shoulder width, ADT, average roadside recovery distance and median sideslope ratio.

** - "SVA/100 MVM" means single vehicle accidents per 100 million vehicle miles.

Table 20. One-way analysis of covariance results for shoulder width using the rural data base.*

Flat Terrain

Shoulder Width (ft)	0-1	2-3	4-5	6-13	Total or Mean
Adjusted Mean of SVA/100 MVM**	111	69	73	63	70
Number of Sections	66	61	150	424	701

Rolling Terrain

Shoulder Width (ft)	0-1	2-3	4-5	6-13	Total or Mean
Adjusted Mean of SVA/100 MVM**	145	97	88	74	90
Number of Sections	79	104	260	311	754

Mountainous Terrain

Shoulder Width (ft)	0-1	2-3	4-5	6-13	Total or Mean
Adjusted Mean of SVA/100 MVM**	217	192	124	136	163
Number of Sections	44	130	122	50	346

* - Control variables used in this analysis were lane width, ADT, average roadside recovery distance and median sideslope ratio.

** - "SVA/100 MVM" means single vehicle accidents per 100 million vehicle miles.

Table 21. One-way analysis of covariance results for ADT using the rural data base.*

Flat Terrain

ADT	50-1000	1001-2000	2001-4000	4001-7500	7501 and Greater	Total or Mean
Adjusted Mean of SVA/100 MVM**	101	83	65	59	38	70
Number of Sections	120	119	222	172	68	701

Rolling Terrain

ADT	50-1000	1001-2000	2001-4000	4001-7500	7501 and Greater	Total or Mean
Adjusted Mean of SVA/100 MVM**	121	100	79	66	40	90
Number of Sections	198	166	211	114	65	754

Moutainous Terrain

ADT	50-1000	1001-2000	2001-4000	4001-7500	7501 and Greater	Total or Mean
Adjusted Mean of SVA/100 MVM**	242	150	152	120	81	163
Number of Sections	94	85	68	64	35	346

* - Control variables used in this analysis were lane width, shoulder width, average roadside recovery distance and median sideslope ratio.

** - "SVA/100 MVM" means single vehicle accidents per 100 million vehicle miles.

Table 22. One-way analysis of covariance results for median roadside hazard rating using the rural data base.*

Flat Terrain

Median Roadside Hazard Rating	1-3	4	5-7	Total or Mean
Adjusted Mean of SVA/100 MVM**	57	78	112	70
Number of Sections	353	295	53	701

Rolling Terrain

Median Roadside Hazard Rating	1-3	4	5-7	Total or Mean
Adjusted Mean of SVA/100 MVM**	57	87	130	90
Number of Sections	166	426	162	754

Mountainous Terrain

Median Roadside Hazard Rating	1-3	4	5-7	Total or Mean
Adjusted Mean of SVA/100 MVM**	113	179	157	163
Number of Sections	5	98	243	346

* - Control variables used in this analysis were lane width, shoulder width, ADT and median sideslope ratio.

** - "SVA/100 MVM" means single vehicle accidents per 100 million vehicle miles.

Table 23. One-way analysis of covariance results for average roadside recovery distance using the rural data base.*

Flat Terrain

Average Roadside Recovery Distance (ft)	0-8	9-16	17 and Greater	Total or Mean
Adjusted Mean of SVA/100 MVM**	114	75	53	70
Number of Sections	74	336	291	701

Rolling Terrain

Average Roadside Recovery Distance (ft)	0-8	9-16	17 and Greater	Total or Mean
Adjusted Mean of SVA/100 MVM**	139	98	48	90
Number of Sections	171	313	270	754

Mountainous Terrain

Average Roadside Recovery Distance (ft)	0-8	9-16	17 and Greater	Total or Mean
Adjusted Mean of SVA/100 MVM**	158	179	93	163
Number of Sections	241	99	6	346

* - Control variables used in this analysis were lane width, shoulder width, ADT and median sideslope ratio.

** - "SVA/100 MVM" means single vehicle accidents per 100 million vehicle miles.

Table 24. One-way analysis of covariance results for median sideslope ratio using the rural data base.*

Flat Terrain

Sideslope Ratio	2:1 or Steeper	3:1	4:1 or 5:1	6:1 or 7:1	8:1 or Flatter	Total or Mean
Adjusted Mean of Roll./100 MVM**	21.5	18.0	21.9	14.3	21.2	18.2
Number of Sections	26	56	250	288	49	669

Rolling Terrain

Sideslope Ratio	2:1 or Steeper	3:1	4:1 or 5:1	6:1 or 7:1	8:1 or Flatter	Total or Mean
Adjusted Mean of Roll./100 MVM**	19.1	27.0	22.9	25.7	43.2	25.6
Number of Sections	54	112	239	282	47	734

Mountainous Terrain

Sideslope Ratio	2:1 or Steeper	3:1	4:1 or 5:1	6:1 or 7:1	8:1 or Flatter	Total or Mean
Adjusted Mean of Roll./100 MVM**	41.6	50.3	45.5	36.9	52.2	42.8
Number of Sections	35	58	114	126	6	339

* - Control variables used in this analysis were lane width, shoulder width, ADT and average roadside recovery distance.

** - "Roll./100 MVM" means rollover accidents per 100 million vehicle miles.

Table 25. One-way analysis of covariance results for terrain conditions using the rural data base.*

All Terrain Conditions

Terrain	Flat	Rolling	Mountainous	Totals or Means
Adjusted Mean of SVA/100 MVM**	89	90	125	96
Number of Sections	701	754	346	1,801

* - Control variables used in this analysis were lane width, shoulder width, ADT, average roadside recovery distance and median sideslope ratio.

** - "SVA/100 MVM" means single vehicle accidents per 100 million vehicle miles.

APPENDIX H - DETAILED ACCIDENT SEVERITY DATA

Table 26. Accident severity by accident type and obstacle struck for Michigan data base.*

Severity by Accident Type

TOTAL ACCIDENTS		NUMBER OF ACCIDENTS				NUMBER OF PERSONS						
		Total	Fatal	Injury	P.D.	Total Occupants	Killed	Injured	Not Injured	Injured A	Injured B	Injured C
	1. Overturned	7711	88	4460	3163	12184	94	6111	5979	1433	2457	2221
	2. Other Non-collision	1222	13	371	838	2274	14	400	1860	131	159	110
Collision with:	3. Pedestrian	936	111	806	19	2455	112	892	1451	355	325	212
Collision with:	4. M.V. In Transport	55554	291	18076	37187	183863	355	31587	151921	5320	9463	16804
Collision with:	5. M.V.–Other Roadway	26	5	13	8	93	6	42	45	13	10	19
Collision with:	6. Parked M.V.	4505	8	532	3965	6379	8	714	5657	146	290	278
Collision with:	7. Railroad Train	126	14	58	54	195	21	82	92	36	32	14
Collision with:	8. Pedalcyclist	1113	33	963	117	2879	33	1067	1779	301	479	287
Collision with:	9. Animal	20771	1	578	20192	34828	1	692	34135	77	271	344
Collision with:	10. Fixed Object	29339	233	10225	18881	44548	252	13291	31005	2774	5645	4872
Collision with:	11. Other Object	588	2	100	486	1012	2	141	869	24	61	56
	Totals	121891	799	36182	84910	290710	898	55019	234793	10610	19192	25217

MANNER OF TWO MOTOR VEHICLE COLLISION	Total	Fatal	Injury	P.D.
1. Head on	4722	127	1922	2673
2. Rear end	8184	27	2228	5929
3. Sideswipe-meeting	126	3	27	96
4. Sideswipe-passing	322	5	42	275
5. Angle	6869	78	3145	3646
6. Backed into	1278	3	88	1187
7. All others	38570	60	11164	27346
8. Not stated	14	1	5	8
Totals	60085	304	18621	41160

Severity by Obstacle Struck

Object Hit By Vehicle	% of Total Objects Hit	Total Objects Hit	Fatal Accid.	Personal Injury Accid.	Property Damage Accid.	Rural Accid.	Urban Accid.
Guard rail or post	7.4	3,971	28	1,392	2,551	2,581	1,390
Highway sign	10.3	5,513	22	1,397	4,094	3,041	2,472
Street light, utility pole	14.1	7,531	58	3,385	4,088	2,734	4,797
Culvert	1.0	510	17	250	243	467	43
Ditch, embankment, stream	17.1	9,127	30	3,386	5,711	7,588	1,539
Bridge pier or abutment	0.5	260	17	134	109	124	136
Bridge rail or deck	0.8	430	3	178	249	279	151
Tree	17.5	9,332	171	4,419	4,742	6,847	2,485
Highway or railroad signal	0.6	327	0	111	216	116	211
Building	2.9	1,545	15	616	914	337	1,208
Mailbox	7.7	4,100	14	859	3,227	3,414	686
Fence	5.7	3,063	7	851	2,205	1,588	1,475
Traffic isle or curb	2.1	1,146	16	281	849	304	842
Concrete barrier in median	2.7	1,469	1	744	724	229	1,240
Other on-trafficway object	5.9	3,158	10	786	2,362	1,603	1,555
Other off-trafficway object	3.1	1,668	39	518	1,111	956	712
Overhead fixed object	0.5	251	0	22	229	105	146
Not known	0.1	66	7	35	24	19	47
TOTALS	100.0	53,467	455	19,364	33,648	32,332	21,135
PERCENT TOTALS		100.0	0.9	36.2	62.9	60.5	39.5

Note: Summary of severity by obstacle struck includes accidents in which an obstacle was struck as primary object hit or as the secondary object hit (rebound).

* The Michigan data base contained all accidents in rural areas in 1983.[1]

Table 27. Accident severity by obstacle struck for Washington data base.*

Obstacle Struck	Number of Accidents and Percent of Row Total										
	Fatal		A-Type		B-Type		C-Type		PDO		Total
	No.	%	No.	%	No.	%	No.	%	No.	%	No.
Tree	64	3.4	284	15.2	491	26.3	209	11.2	816	43.8	1,864
Sign	25	1.4	148	8.5	348	20.0	204	11.7	1,016	58.4	1,741
Utility/Light Pole	75	1.6	581	12.0	1,140	23.6	561	11.6	2,476	51.2	4,833
Mailbox	0	0.0	24	7.3	68	20.8	40	12.2	195	59.6	327
Culvert	9	2.1	82	19.0	139	32.3	56	13.0	145	33.6	431
Bridge Column	6	6.1	15	15.2	23	23.2	15	15.2	40	40.4	99
Bridge End	7	5.2	13	9.6	37	27.4	22	16.3	56	41.5	135
Fire Hydrant	1	0.7	11	7.4	17	11.5	16	10.8	103	69.6	148
Railroad Signal	0	0.0	0	0.0	5	18.5	2	7.4	20	74.1	27
Guardrail	144	1.7	724	8.7	1,708	20.5	971	11.7	4,774	57.4	8,321
Bridge Rail	42	1.6	197	7.7	536	21.0	327	12.8	1,455	56.9	2,557
Rock	21	1.1	207	11.3	431	23.5	253	13.8	925	50.4	1,837
Barrier Wall	10	0.5	143	6.5	450	20.4	315	14.3	1,292	58.5	2,210
Fence	26	1.7	156	10.4	270	18.0	168	11.2	876	58.6	1,496
Earth Embankment	55	1.6	427	12.6	921	27.0	445	13.1	1,541	45.5	3,389
Totals	485		3,012		6,584		3,604		15,730		29,415

* - The Washington data base consisted of all accidents reported during a five-year period.

Table 28. Accident severity by obstacle struck for Utah data base*.

Obstacle Struck	Number of Accidents and Percent of Row Total										
	Fatal		A-Type		B-Type		C-Type		PDO		Total
	No.	%	No.	%	No.	%	No.	%	No.	%	No.
Guardrail	13	4.2	54	17.4	54	17.4	22	7.1	167	53.9	310
Utility Pole	5	1.2	68	16.2	60	14.3	35	8.4	251	59.9	419
Sign	4	1.3	41	13.3	21	6.8	12	3.9	231	74.8	309
Fence	4	1.0	59	15.1	43	11.0	37	9.4	249	63.5	392
Other or Unknown	20	2.4	127	15.2	121	14.5	73	8.7	496	59.3	837
Totals	46	2.0	349	15.4	299	13.2	179	7.9	1,394	61.5	2,267

* - The Utah data base consisted of accidents reported in five years on routes which had portions chosen as sections for the seven-state data base.

Table 29. Severity by accident type for Washington data base.*

Accident Type	Number of Accidents and Percent of Row Total										
	Fatal		A-Type		B-Type		C-Type		PDO		Total
	No.	%	No.	%	No.	%	No.	%	No.	%	No.
Fixed Object	532	1.5	3,555	9.9	8,183	22.7	4,164	11.5	19,646	54.5	36,080
Rollover	245	2.1	1,690	14.6	3,259	28.1	1,539	13.3	4,863	41.9	11,596
Run-off-Road - Other	1	1.2	3	3.6	14	16.7	9	10.7	57	67.9	84
Head-On	272	20.4	420	31.5	270	20.3	113	8.5	257	19.3	1,332
Sideswipe - Opp. Dir.	54	2.0	332	12.2	474	17.4	312	11.5	1,550	56.9	2,722
Sideswipe - Same Dir.	20	0.2	248	2.4	741	7.1	1,023	9.8	8,452	80.6	10,484
Rear-End	96	0.2	1,856	3.7	7,225	14.5	12,158	24.4	28,570	57.2	49,905
Backing or Parking	32	0.8	268	6.4	627	15.1	359	8.6	2,876	69.1	4,162
Ped., Bike, Moped	218	9.8	755	33.8	854	38.3	398	17.8	6	0.3	2,231
Angle	174	0.5	2,400	6.7	5,453	15.3	5,419	15.2	22,211	62.3	35,657
Train	2	4.3	4	8.5	12	25.5	5	10.6	24	51.1	47
Animal	6	0.2	56	1.8	213	6.9	123	4.0	2,682	87.1	3,080
Other	127	2.7	547	11.7	807	17.2	567	12.1	2,639	56.3	4,687
Totals	1,779	1.1	12,134	7.5	28,132	17.4	26,189	16.2	93,833	57.9	162,067

* - The Washington data base consisted of all accidents reported during a five-year period.

Table 30. Severity by accident type for Utah data base.*

Accident Type	Number of Accidents and Percent of Row Total										
	Fatal		A-Type		B-Type		C-Type		PDO		Total
	No.	%	No.	%	No.	%	No.	%	No.	%	No.
Fixed Object	46	2.0	349	15.4	299	13.2	179	7.9	1,394	61.5	2,267
Rollover	63	3.2	412	21.0	478	24.4	186	9.5	822	41.9	1,961
Run-off-Road - Other	26	1.7	253	16.7	244	16.1	138	9.1	858	56.5	1,519
Head-On	56	11.9	142	30.1	69	14.6	26	5.5	178	37.8	471
Sideswipe - Opp. Dir.	10	1.9	64	12.0	54	10.1	44	8.2	363	67.9	535
Sideswipe - Same Dir.	2	0.2	23	2.8	37	4.5	27	3.3	732	89.2	821
Rear-End	11	0.2	368	5.2	543	7.7	1,409	20.1	4,687	66.8	7,018
Backing or Parking	0	0.0	4	1.4	8	2.7	10	3.4	272	92.5	294
Ped., Bike, Moped	61	7.8	251	32.1	304	38.8	99	12.6	68	8.7	783
Angle	55	0.6	918	10.4	916	10.4	934	10.6	5,985	67.9	8,808
Train	1	9.1	3	27.3	1	9.1	0	0.0	6	54.5	11
Animal	2	0.1	65	2.6	68	2.7	53	2.1	2,330	92.5	2,518
Other or Unknown	9	0.9	80	7.8	86	8.4	57	5.6	788	7.7	1,020
Totals	342	1.2	2,932	10.5	3,107	11.1	3,162	11.3	18,483	65.9	28,026

* - The Utah data base consisted of all accidents reported in five years on routes which had portions chosen as sections for the seven-state data base.

APPENDIX I - LITERATURE REVIEW OF COSTS OF ROADSIDE IMPROVEMENTS

A literature search was conducted to find the highway agency costs of various roadside improvements. Several sources for cost data were found, but the costs for particular improvements often varied widely between sources. In addition, many types of common improvements were not covered by any of the literature sources.

Published independent estimates of the implementation cost of a type of roadside improvement are relatively rare. There is no comprehensive source of construction cost data available to the engineer. Construction cost estimates for a particular improvement are often made on a nationwide or statewide basis.[2] Cost estimates also appear often in a contract bid line item form rather than in the per project form needed for a project cost-effectiveness analysis.[3]

A set of implementation cost estimates for roadside improvements was published by Glennon for an evaluation of freeway roadside improvements. [4] Table 31 shows a summary of those estimated costs. Estimates were gathered from up to nine States per improvement and were averaged and adjusted by Glennon to arrive at the estimate shown on table 31. The States provided estimates based either on a summary of contract bid prices or on the opinion of a highway engineer. The assumptions made to arrive at the estimates in table 31 (i.e., whether the freeway was rural or urban in character, whether the improvement was part of a larger construction project, etc.) were not given. Glennon stressed that the estimates were to be used in a comparative program "insensitive to moderate absolute errors" which required only that the costs be fairly precise in relation to each other.

Extensive cost estimates were made in 1978 for a roadside hazard correction program on all types of roads in North Carolina and are shown in table 32.[6] The estimates were made from cost data supplied by State highway departments, research organizations and manufacturers of safety equipment, tempered by a comparison with North Carolina costs. The extent of the data supplied by the States and research organizations (i.e. the number of States responding for each improvement) was not provided. The assumptions made to arrive at the cost estimates were more complete

Table 31. Cost estimates for various roadside improvements from Glennon.[4]

Improvement	Unit	Unit Cost (1985 $)
Remove trees:		
2-4 inches	each	27
5-7 inches	each	71
8-10 inches	each	110
11-12 inches	each	140
12 inches and greater	each	270
Remove luminaire support	pole	310
Remove 8-10 inch utility pole	pole	360
Remove curb	L.F.	1.30
Remove guardrail	L.F.	2.70
Remove signs	sign	110
Remove bridge rail	foot	9
Remove culvert headwall, extend to 30 ft. and grade:		
4-foot lateral placement	project	3600
12-foot lateral placement	project	2600
20-foot lateral placement	project	1900
25-foot lateral placement	project	1300
Install guardrail	L.F.	8
Reconstruct raised drop inlet to level inlet	project	350
Move steel post signs	post	180
Move wood post signs	post	45
Make steel post signs breakaway	post	320
Make wood post signs breakaway	post	9
Make luminaire supports breakaway	pole	290
Install gore attenuation system	each	1400
Bridge deck widening:		
0-90-foot length	S.F.	21
100-foot and greater length	S.F.	32
Install bridge rail	L.F.	21
Anchor guardrail to bridge rail or abutment	each	180
Flatten sideslope	C.Y.	1.60

Note: Costs updated from 1974 to 1985 dollars by use of FHWA composite index.[5]

L.F.= Linear Foot
S.F.= Square Foot
C.Y.= Cubic Yard

Table 32. Cost estimates for various roadside improvements from North Carolina.[6]

Improvement	Unit	Unit Cost (1985 $)
Remove trees	each	86
Make utility poles breakaway	pole	52
Relocate utility poles 30 ft. from edge of pavement	pole	540
Improve substandard bridge rail (to three beam)	L.F.	36
Install impact attenuators:		
water-filled	site	35,000
sand-filled cell	site	14,000
steel barrels	site	25,000
Make sign or support breakaway	sign	140
Relocate large metal support behind guardrail	sign	180
Install guardrail ends:		
breakaway cable terminal	end	500
turned-down Texas terminal	end	430

Note: Costs updated from 1978 to 1985 dollars by use of FHWA composite index.[5]

L.F.= Linear Foot

than those made explicit for the estimates by Glennon but the assumptions about the agency performing the construction and the topography of the site were not given.[4]

Implementation cost estimates were prepared for a few roadside improvements during a 1979 hazard reduction program and are found on table 33.[7] Cost data from various contract work with the California Department of Transportation over a three-year period and the opinion of experts in California were used as the bases for the estimates. The extent of the cost data base for this study was thus much more limited than the other studies cited in this section. The improvements were to be made to nonfreeway State highways but the urban extent of this system was not given. The assumptions made to arrive at the estimates in table 33 were well documented. For instance, it was articulated that for moving utility poles, the poles would be spaced at 250-foot intervals on one side of the road, there would be joint usage of a single pole, and the purchase cost of small strips of right-of-way was included.

Cost estimates for implementing roadside improvements on two-lane rural roads were included among the cost estimates for a variety of safety projects made in 1980 by Smith, et al. and detailed on table 34.[8] Sources for the estimates on table 34 include the construction bid tabulations of the Interstate Reports Branch, Federal Aid Division, Office of Engineering, FHWA; the Safety Improvement Project file maintained by the Office of Highway Safety, FHWA; and a published nationwide construction cost guide.[3] Estimates were made for "typical projects" in a "moderately rolling" terrain, but few other details of the assumptions made to arrive at the estimates were revealed. For instance, a cost of $12,000 is listed in table 34 per project for a modification of bridge rails. The type of modification (the type of existing rail and the type of new rail) and the extent of the project (the number of rails, the length of the bridge) were not given, rendering that particular cost estimate useless for comparison to other estimates without further assumptions. Smith, et al., admitted the imprecision of their cost estimates, stating that some roadside improvements are "variable in terms of cost," but gave no indication of the extent of variation for particular improvements.

Table 33. Cost estimates for various roadside improvements from California.[7]

Improvement	Unit	Unit Cost (1985 $)
Protect end of bridge railing with guardrail	end	1400
Move utility pole 30-feet from edge of pavement	pole	1800
Move sign posts 30-feet from edge of pavement	post	600
Make sign posts breakaway	post	150
Drill wood sign post	post	12
Remove trees:		
0-100 Ornamental	each	480
0-100 Marketable	each	120
100 or more Ornamental	each	60
100 or more Marketable	each	12
Install guardrail	L.F.	12

Note: 1979 costs updated to 1985 by use of FHWA composite index.[5]

L.F. = Linear Foot

Table 34. Cost estimates for various roadside improvements from Smith et al.[8]

Improvement	Unit	Unit Cost (1985 $)
Remove isolated trees	each	270
Removed fixed objects -- clear roadside from 2 to 10 feet	mile	82,000
Relocate utility poles	pole	1,600
Install guardrail (both sides of road)	0.1 mile	11,000
Install guardrail at bridge ends	project	5,500
Modify bridge rail	project	12,000
Flatten side or backslope	0.1 mile	44,000

Note: 1981 costs converted to 1985 by use of FHWA composite index.[5]

Zegeer and Parker provided implementation cost estimates based on a literature review and a survey for several projects on various types of roads involving utility poles.[9] Their estimates are given in tables 35 and 36 for undergrounding utility lines and relocating utility poles. Estimates were gathered from four to six published sources per improvement (including several of the literature sources cited earlier). The literature sources, however, rarely specified the assumptions or provided detail about the projects, and comparison between the widely varying estimates from the literature was difficult. As a result, Zegeer and Parker surveyed utility companies about utility pole costs and obtained 31 responses from electric companies in 20 States and 12 responses from telephone companies in 21 States. Since assumptions regarding the cost estimates had been made explicit in the survey, the responses were readily compared. Assumptions made for undergrounding electric lines included, for instance, the size and type of power lines, the method of burial and the size of the utility line. Size and type of power line and pole material type were assumed for relocating electric lines. Rural and urban construction costs were summarized separately. The authors observed a wide variance in costs obtained from utility companies for a particular type of improvement and compensated for that variance by reporting both average costs and the ranges of costs. The reader could then judge the size of the variance and make adjustments while using the estimates.

Tables 31 through 36 reveal wide differences among the various published cost estimates for particular types of improvements. Besides the admitted or implicit imprecision of the estimates, there are several reasons for divergent estimates for a particular improvement. The assumptions about a "typical" project may differ between estimators and, since these assumptions are rarely spelled out in the literature, there is no way to adjust the reported price to reflect the differences. Inflation may have had uneven effects on certain projects through time, making the comparison of estimates adjusted with an overall composite index difficult. Many other factors including the number and the geographical distribution of the States providing data to the estimator vary between estimates.

Cost estimates were not found in the literature for several of the roadside improvement projects of interest in this study. Only one cost

Table 35. Summary of costs for undergrounding utility lines based on data from utility companies.[9]

Type of Utility Line	Range of Installation Costs (Dollars per Mile)		Average Installation Cost (Dollars per Mile)	
	Rural	Urban	Rural	Urban
Telephone Lines	$4,450-$30,817	$10,500-$85,000	$18,000	$36,000
Electric Distribution Lines <69 KV, Direct Bury, One Phase	$17,000-$29,000	$30,000-$45,000	$24,000	$38,000
Electric Distribution Lines <69 KV, Direct Bury, Three Phase	$29,000-$220,000	$45,000-$225,000	$105,000	$161,000
Electric Distribution Lines <69 KV, Conduit	$200,000-$650,000	$400,000-$1,050,000	$430,000	$650,000
Electric Tramsmission Lines ≥69 KV	$728,000-$1,728,000	$728,000-$1,728,000	$1,228,000	$1,228,000

Table 36. Summary of costs for relocating utility poles based on data from utility companies.[9]

Type of Utility Poles or Lines	Range of Installation Costs (Dollars per Pole)		Average Installation Cost (Dollars per Pole)	
	Rural	Urban	Rural	Urban
Wood Telephone Poles	$160-$600	$160-$754	$345	$425
Wood Power Poles Carrying <69 KV Lines	$150-$4,000	$150-$4,000	$1,270	$1,440
Non-Wood Poles (Metal, Concrete or Other)	$630-$3,250	$630-3,370	$1,740	$1,810
Heavy Wood Distribution and Wood Transmission Poles	$580-$5,500	$500-$7,100	$2,270	$2,940
Steel Transmission Poles	$10,000-$30,000	$20,000-$40,000	$20,000	$30,000

estimate was found in the literature for each of the following improvement projects: the installation of impact attenuators, the installation of guardrail ends, the removal of guardrails, and the removal of bridgerails. No estimates were found for improvement projects involving large mail-boxes, culvert headwalls, fire hydrants, railroad crossbucks or signals, continuous trees, cable guardrails, rock or dirt embankments, concrete barrier walls or fences.

APPENDIX J - METHODS OF ESTIMATING COSTS OF ROADSIDE AND CROSS-SECTION IMPROVEMENTS

In order to evaluate the cost-effectiveness of various roadside and cross-section improvements, the cost to the highway agency along with the accident and user cost savings must be estimated. Previously, estimates for a variety of roadside improvements were gathered from the literature and summarized in appendix I. It was found that the published cost estimates for a particular item vary widely and would not serve as the basis of costs for use in a cost-effectiveness procedure. Implementation costs of projects were thus estimated for this research by a summation of costs of individual line items of work which were obtained from State highway agency data.

Estimation of implementation costs of various cross-section and roadside improvements by a summation of individual line items of work proceeded in a manner similar to preparing an engineer's estimate for a construction project. First, the existing conditions at the improvement site were examined and summarized. Second, the conditions at the improvement site after the improvement was implemented were examined and summarized. Third, specific items of work necessary to achieve the "after" condition from the "before" condition were specified. Next, the quantities of each work item were estimated. Unit costs for each of these items were then estimated on the basis of data obtained from nine States. Finally, the unit cost was multiplied by the quantity needed for each line item and the costs for each item were summed to arrive at a final project cost.

The type of improvements for which the implementation costs were of interest included:

- Lane and/or shoulder widening.
- Shoulder surfacing.
- Sideslope improvements.
- Roadside obstacle countermeasures.

Assumptions

Several assumptions had to be made at each step of the summation of line items estimation method. In general, assumptions were made on the basis of available data with an aim toward a cost estimate which was the most representative of projects of a similar type across the country.

Assumptions for Existing Conditions

Before any quantity estimates could be made for the lane widening, shoulder widening, and shoulder surfacing improvements, the existing pavement design had to be assumed. Asphalt concrete was assumed as the pavement type due to its prevalence on rural U.S. roads. The depth of pavement in travel lanes was assumed as four inches, based on four different recommended minimum pavement depths from two to three inches for rural roads with "medium" traffic.[10] Since weather, traffic and other conditions vary widely between likely improvement sites, a pavement depth above the minimums recommended (and therefore more likely to be a representative value) was used. The aggregate base under travel lanes was assumed to be ten inches deep, for reasons similar to the above for pavement depth.[11] The depth of the shoulder surface course (whether gravel or asphalt concrete) was assumed as two inches to keep it less than the depth of pavement for travel lanes. The depth of the shoulder base was assumed to be eight inches. For simplicity and because they are not used everywhere, seal coats, binding courses, subbases, and other pavement design elements were not included in the assumed existing design.

Assumptions about existing sideslope conditions on rural roads were based on information gathered for the accident analysis part of this research project. Summarized in table 37 are field measurements of existing sideslope ratios and lengths from Alabama, Michigan, and Washington State which appear in the final rural data base for this research. Based on table 37, the most common deficient (i.e., steeper than 4 to 1 ratio or ten feet or less in length) sideslopes in need of flattening were:

- 1.5 to 1 ratio for five feet, (height of fill = 2.8 feet).
- 2 to 1 ratio for five feet, (height of fill = 2.2 feet).
- 2.5 to 1 ratio for five feet, (height of fill = 1.9 feet).
- 3 to 1 ratio for five feet, (height of fill = 1.6 feet).
- 3.5 to 1 ratio for five feet, (height of fill = 1.4 feet).
- 1.5 to 1 ratio for ten feet, (height of fill = 5.5 feet).

Table 37. Frequency of occurrence of existing sideslope conditions on a sample of rural roads in three States.

Median Sideslope Ratio	Median Sideslope Length, ft.						
	1-2	3-7	8-12	13-17	18-22	23-27	28 and above
1:1	1	3	1	0	0	0	0
2:1	2	59	10	4	0	0	0
3:1	0	58	50	15	2	0	0
4:1	0	22	68	19	4	2	0
5:1	0	14	52	15	8	8	1
6:1	0	11	40	14	14	9	8
7:1	0	5	11	6	5	5	3
8:1 and above	0	12	19	7	8	2	2

- 2 to 1 ratio for ten feet, (height of fill = 4.5 feet).
- 3 to 1 ratio for ten feet, (height of fill = 3.2 feet).
- 3.5 to 1 ratio for ten feet (height of fill = 2.7 feet).

Earthwork would have to be performed on the sideslopes and backslopes to accomodate many widening projects. Based on table 37, common sideslopes to be used in computations of the earthwork cost portion of lane and shoulder widening projects were assumed to be a:

- 2 to 1 ratio for five feet, (height of fill = 2.2 feet).
- 4 to 1 ratio for five feet, (height of fill = 1.2 feet).
- 6 to 1 ratio for five feet, (height of fill = 0.8 feet).
- 2 to 1 ratio for ten feet, (height of fill = 4.5 feet).
- 4 to 1 ratio for ten feet, (height of fill = 2.4 feet).
- 6 to 1 ratio for ten feet, (height of fill = 1.7 feet).
- 4 to 1 ratio for twenty feet, (height of fill = 4.8 feet).
- 6 to 1 ratio for twenty feet, (height of fill = 3.3 feet).
- 4 to 1 ratio for thirty feet, (height of fill = 7.3 feet).

Samples of existing backslope ratio and length combinations were not available. Thus, assumptions about the existing backslopes were taken from Leisch and Newman.[12] They assumed, in the course of cost estimates of improvements to Minnesota rural roads and on the basis of samples of those roads, that there exist three basic cross-section types with the following characteristics:

- Low-type -- sideslope length three feet, sideslope ratio 2 to 1, backslope length five feet, and backslope ratio 2 to 1.

- Intermediate-type -- sideslope length six feet, sideslope ratio 3 to 1, backslope length eight feet, and backslope ratio 2 or 3 to 1.

- High-type -- sideslope length ten feet, sideslope ratio 4 to 1, backslope length twenty feet, and backslope ratio 3 to 1.

Existing sideslopes with a 1.5 or 2 to 1 ratio were assigned the corresponding backslope dimensions of 2 to 1. Likewise, sideslopes assumed as a 2.5, 3 or 3.5 to 1 ratio and a five or ten feet length were given an assumed backslope ratio of 3 to 1. All other existing sideslopes were given a backslope ratio of 3 to 1 and a length of 20 feet.

Assumptions for New Conditions

For lane widening, shoulder widening, and shoulder surfacing projects the depth of base and surface course for the new sections was assumed equal to that for the existing sections. Since overlays and pavement markings were assumed to be a common part of every 3R project, they were not considered in this procedure for estimating the costs of safety-related portions of projects.

For earthwork portions of lane and shoulder widening projects, the sideslope was assumed to be lengthened and flattened if the existing sideslope was deficient. Thus, figure 1 shows an example of an existing sideslope profile with the changes which would result from various widening alternatives. The existing 2 to 1 sideslope ratio was deficient, so during the widening projects the sideslope was to be flattened to a 4 to 1 ratio.

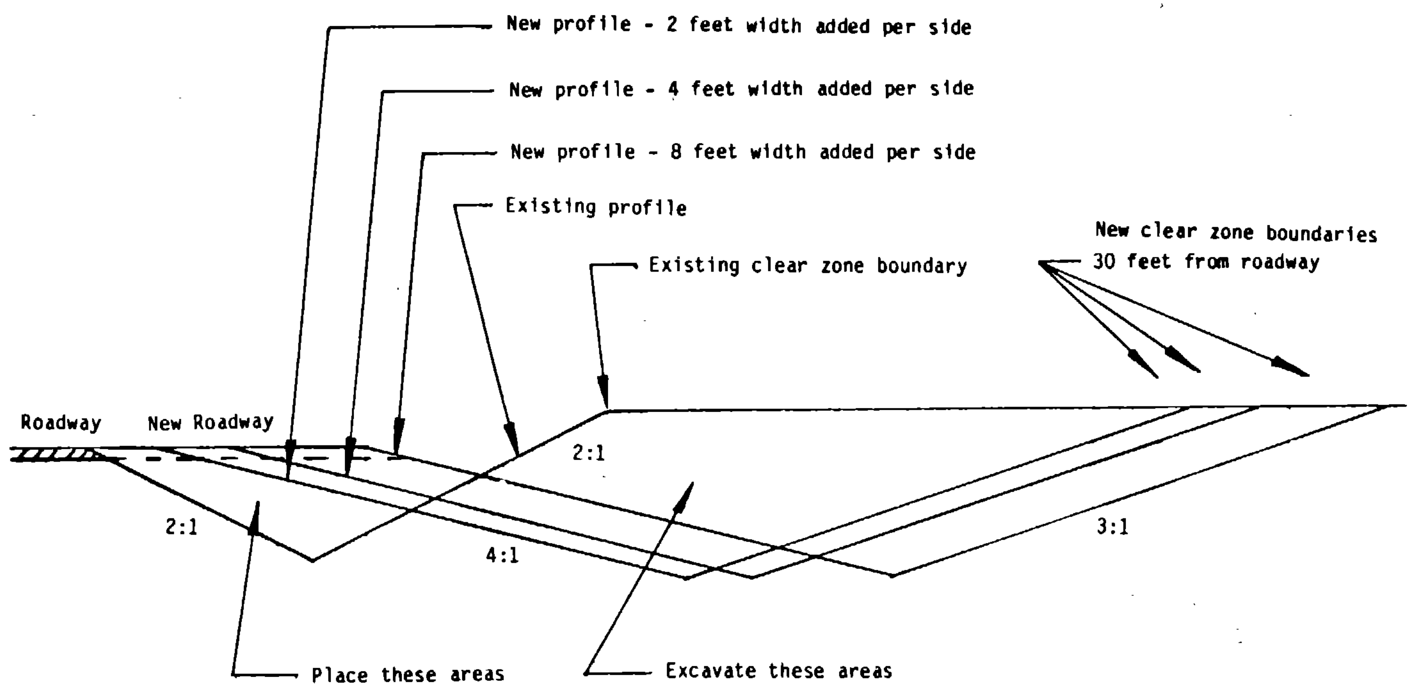
All new side and backslopes, whether resulting directly from sideslope improvement projects or from lane and shoulder widening projects, were assumed to have:

- Four to 1 or greater ratio sideslopes.
- Simple "vee" ditches where the side and backslopes intersect.
- Three to 1 ratio backslopes.
- A "clear zone" (i.e., the area between the shoulder edge and the return to the original grade level free of large fixed objects) of 30 feet.

These assumptions were made to assure that the new roadside profiles met current safety standards (i.e., for a driveable sideslope) and were representative of current practice. With these assumptions, sideslope improvement project profiles could be produced. From a series of drawings like figure 1 for widening projects and figure 2 for sideslope improvements, the quantities of earthwork necessary for implementation could be estimated. It should be mentioned that for many projects, it is not practical to provide sideslope flattening to a 4:1 ratio and clear zones of 30 feet. In such cases, other improvements may be made such as the installation of guardrail. The assumptions made above may be altered easily to allow the estimation of the costs of alternatives to sideslope flattening and providing clear zones.

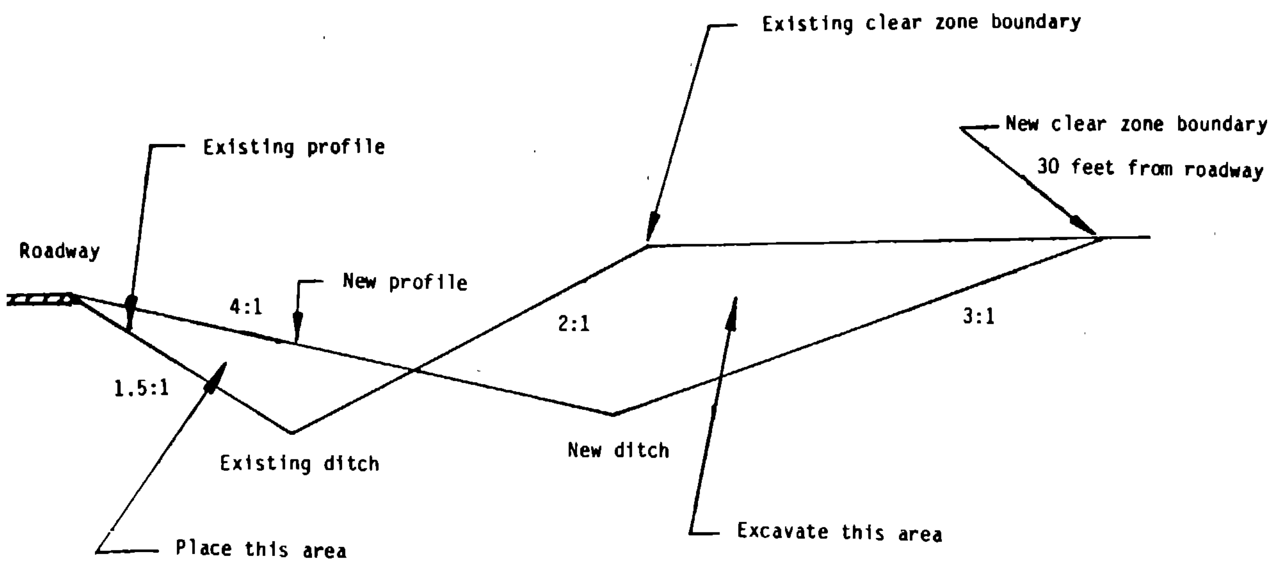
Assumptions for Work Line Items

The different line items of work necessary to implement each improvement category were assumed next. The major sources for assumptions about the lists of work items were actual project bid tabulations for different types of improvements from seven States. These sources were supplemented by lists of line items or work compiled by Leisch and Newman.[12]



Note: If amount to excavate is less than amount to place, borrow the difference

Figure 1. Example sideslope profile for computing quantity of excavation, borrow and place for slopework portion of lane and shoulder widening projects.



Note: If amount to excavate is less than amount to place, borrow the difference

Figure 2. Example of sideslope flattening profile for computing quantity of excavation, borrow and place.

The list of work items for widening projects was split into four portions:

- Lane widening.
- Shoulder widening.
- Slope work.
- Mobilization and traffic control.

This was done to increase the number of circumstances to which the costs calculated by this method would apply. The work items for the lane widening portion were assumed to be:

1. Excavating and disposing of the earth, existing base, gravel, or existing pavement.

2. Grading the top of the subgrade level.

3. Purchasing and placing the base.

4. Purchasing and placing the asphalt concrete.

The work items for the shoulder widening portion were assumed to be the same as for the lane widening portion with the addition of a work item for purchasing and placing gravel for the shoulder surface (if necessary). The work items assumed for the slope work portion were:

1. Relocating signs.
2. Relocating guardrail.
3. Clearing and grubbing areas of continuous trees.
4. Removing and replacing the topsoil.
5. Excavating and disposing earth (as necessary).
6. Borrowing and placing earth (as necessary).
7. Excavating and placing earth.
8. Reshaping the slopes and ditches.
9. Purchasing and placing seed.
10. Altering drainage structures.

Finally, the mobilization and traffic control portion was not split into smaller work items because this item commonly appeared in bid documents intact.

The work items for a shoulder surfacing project were assumed to be the same as for the lane widening portion of a widening job, with the addition of an item for mobilization and traffic control.

The work items for a sideslope flattening project were assumed to be the same as for the slope work portion of a widening job, with the addition of an item for mobilization and traffic control.

Individual types of roadside improvement projects were not split into smaller work items, because these items commonly appeared in bid documents intact.

The lists of work items for a particular project or portion of a project assumed above were simplified as much as possible without causing serious differences with real-world practices. Items such as the purchasing and placing of fertilizer and cover were not included due to their relatively low cost in relation to other cost items. Other items, such as the removal of structures, were not included because they appear sporadically in project bid documents. Still other items, such as the engineering effort expended by the implementing agency, were not included due to the difficulty of accounting for such costs with construction funding. In general, however, the lists of work items given above make up the bulk of the effort expended in a particular type of project.

Right-of-way costs were also excluded from the above lists of work items, for three reasons:

1. Right-of-way costs are extremely variable by location, time of purchase, etc.
2. Right-of-way costs do not apply for every project or to increments of each project.
3. Right-of-way costs are highly dependent on the number of parcels to be purchased, rather than the area to be purchased.

Thus, for cost calculations, it was assumed that the highway agency already owned the necessary right-of-way. If an agency wishing to use the line item method of cost estimation can reasonably estimate the cost of right-of-way, that item can easily be included in the summation.

Assumptions for Quantities of Each Item

Most of the quantitites of work items for a given project were calculated directly from the assumed project "before" and "after" conditions. For example, the quantity of asphalt concrete to be purchased and placed in a lane widening project per foot of total pavement widening can be calculated as 0.333 yards width X 0.111 yards depth X 1,760 yards length = 65 cubic yards, after the assumption of the depth of pavement is made.

This factor allows for computing the cost for pavement width increases of one foot or more, even though a two-foot increase in the total pavement width is considered a minimum in most cases. This factor per foot of widening is useful in cases where the total pavement is widened by an odd number of feet (i.e., 3, 5, 7 feet).

The following quantities of work items were calculated directly from scale drawings of the before and after slope and ditch profiles (as in figures 1 and 2):

- The area of clearing and grubbing of trees (assuming all surface area added to the clear zone must be cleared and grubbed).
- The volume of topsoil to be removed and replaced (assuming a three-inch depth, based on a Michigan DOT assumption).
- The volume of excavating and disposing.
- The volume of borrowing and placing.
- The volume of excavating and placing.
- The area of purchasing and placing seed.

Thus, only a few work items have quantities which cannot be calculated directly from the before and after conditions. The assumptions used for these quantities, and the basis of each assumption, are given in table 38.

<u>Assumptions for Unit Costs</u>

Cost data were gathered for each line item of work from sources (to be discussed later) in nine States. Three major assumptions were made in order to aggregate these data into unit costs which could be applied to each item of work. First, an adjustment for inflation was necessary to place cost data from different years on equal grounds. The FHWA indices presented in table 39 were used with the composite index used for all items not covered by the other two indices. Second, it was assumed that the items of work with similar names called for in documents from different States were similar and could be summarized without losing accuracy. Finally, the necessary assumptions were made to convert each item to standard units. In most cases, this meant using conversion factors such as the density of aggregate which were readily available from engineering practice.

Table 38. Assumed quanitites and sources of assumptions for various project work items.

Work Item	Unit	Assumed quantity per mile, both sides of road	Source for assumption
Relocate signs	each	21	Sample of rural roads in Washtenaw County, Michigan.
Relocate guard-rail	L.F.	600	Michigan State highway mean of 744 adjusted for use on non-Interstate routes.
Alter drainage structures	% of total slopework costs	7.5	Leisch and Newman [12] from Minnesota construction.
Mobilization and traffic control	% of total project costs	9.5	Sample widening and slope flattening projects from four states.

L.F. = Linear foot

Table 39. Price trends for federal-aid highway construction reported by FHWA.

Index	Year			
	1980	1983	1984	1985
Common excavation	157.2	149.6	163.6	192.3
Bituminous concrete	163.2	156.9	171.4	184.4
Composite	163.0	146.5	155.0	172.1

1977 prices = 100.0

Unit Costs

Unit costs for each line item of work assumed for each improvement were estimated based on unit costs reported in nine States. The sources of State cost data, as shown in table 40, were mostly unit bid price books. For each line item, these books show the average unit cost (total amount of money bid divided by total quantity bid) in the State for the particular time period, the total quantity bid and (sometimes) the number of projects in which the item appeared. Individual project bid tabulations from two States were also examined for line item unit costs. Where more than one bid was shown for a particular line item, only the awarded bid was used in computations.

Line item unit costs found in a unit bid price book or project bid tabulation were recorded on forms as shown in table 41. Often, States reported several lines for each line item. In such cases, only the most common three or four lines were recorded and used. A number of useful comparisons were made between costs found in different States, including comparisons of the item descriptions, units, numbers of projects, and quantities bid. Several unit bid price books listed average costs for each highway agency district as well as the entire State, so the high and low average district costs were also recorded and used to see the variation of costs for an item within a State.

Using all the information recorded on the form like table 41 for each item, overall high, median, and low unit costs were estimated. The highest and lowest State or district average unit costs were considered outliers, and were not considered in estimation of the high and low costs. Unit costs of the line items of work for widening, shoulder surfacing, and sideslope improvement projects are shown in table 42. The variation in unit costs between high and low costs of this table for a particular line item is wide as might be expected with the sampling techniques used and the assumptions made. The unit costs (i.e., overall project costs) for roadside obstacle countermeasures are presented in the final report.

Table 40. Sources of unit cost data.

Period of Data	State	Type of Source	Data Restrictions
CY 1980	Ohio	Unit bid price book	Construction
CY 1980	Ohio	Unit bid price book	Maintenance contract work
CY 1983	Montana	Unit bid price book	
CY 1983	W. Virginia	Unit bid price book	Interstate projects
CY 1983	W. Virginia	Unit bid price book	State and Federal-Aid Non-Interstate projects
CY 1984	California	Unit bid price book	
CY 1984	Montana	Unit bid price book	
July 1984 to June 1985	New York	Unit bid price book	
Dec. 1984 to Nov. 1985	Texas	Unit bid price book	
CY 1985	Missouri	Unit bid price book	Major and Interstate projects
CY 1985	Missouri	Unit bid price book	Supplementary projects
CY 1983	Utah	Project bid tabulations	
CY 1985	Michigan	Project bid tabulations	RRR projects

Table 41. Cost data from States for purchasing and installing guardrail end-anchors.

Source	Action (if different)	Description (if different)	Unit (if diff.)	Number of projects	Quantity	Cost ($)	Number of Dists.	Cost ($) High Dist.	Cost ($) Low Dist.
Mont. 1983				--	306	428			
Mont. 1983				--	8	450			
Mont. 1984				--	473	467			
W.Va. Int.		Breakaway Cable Terminal		14	178	582			
W.Va. Int.		Special Trailing End Terminal		9	67	465			
W.Va. Non-Int.		Breakaway Cable Terminal		64	349	604			
W.Va. Non-Int.		Special Trailing End Terminal		1	5	531			
Cal.		Cable Anchor Assembly		51	203	369	9	467	313
Cal.		Cable Anchor Assembly, Breakaway (Type A)		164	1,306	362	11	408	310
Cal.		Cable Anchor Assembly, Breakaway (Type B)		75	358	332	10	400	302
Mo. Int.		Terminal Section		--	689	497	12	557	439
Mo. Supp.		Terminal Section		--	135	490	11	610	453
N.Y.		Anchorage Units for Corrugated Beam Guide Rail		74	1,095	519	11	1,380	475
Tx.		Safety End Treatment (Type II 18 in.)		66	2,841	440			
Tx.		Safety End Treatment (Type III 24 in.)		72	1,219	565			
Mi.		Guardrail Anchorage Cable		1	85	700			
Mi.		Guardrail Anchorage Cable		1	18	800			

Table 42. Unit costs used in lane widening, shoulder widening, shoulder paving and sideslope flattening cost computations.

Action	Object	Number of States Reporting Costs	Unit	Unit Costs ($) High	Unit Costs ($) Median	Unit Costs ($) Low
Relocate	Signs	5	Each	440.00	200.00	70.00
Relocate	Guardrail	5	L.F.	19.00	8.00	6.00
Clear and Grub	Trees	6	Acre	8000.00	3500.00	1000.00
Remove and Replace	Topsoil	2	C.Y.	3.00	1.75	1.00
Excavate and Dispose	Earth	9	C.Y.	10.50	3.00	1.25
Grade	Subgrade	4	S.Y.	1.80	1.00	0.50
Purchase and Place	Base	7	C.Y.	47.00	18.00	8.00
Borrow and Place	Earth	6	C.Y.	22.00	5.00	1.90
Excavate and Place	Earth	7	C.Y.	14.00	3.50	1.60
Purchase and Place	Asphalt Concrete	5	C.Y.	110.00	64.00	49.00
Purchase and Place	Surface Aggregate	4	C.Y.	60.00	20.00	8.00
Reshape	Sideslopes & Ditches	3	Mile	32000.00	13000.00	3000.00
Purchase and Place	Seed	4	Acre	1700.00	1000.00	330.00
Purchase and Place	Center and Edgelines	6	Mile	3500.00	1500.00	500.00

L.F. = Linear Foot
C.Y. = Cubic Yard
S.Y. = Square Yard

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