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ABSTRACT

Thirty-six highway control sections were analyzed for the effectiveness of renewal of surface friction. After elimination of sections serving as links for incompleted interstate routes and of sections requiring upgrading, 23 sections remained. A criterion was developed to estimate a normal number of wet road accidents and hence the potential accident reduction by friction renewal. Neither the ratio of wet weather accident rates to total accident rates nor surface friction (SN_{40}) are adequate to define a section that will benefit from treatment. The cost per lane mile of wet weather accidents along with the above indices identifies sections warranting detailed study. Several control sections received seal coats in 1972, and the 1973 wet weather accident reductions proved the cost effectiveness of the treatment and tended to confirm the estimating criterion. In some cases the entire cost of treatment was recovered in accident savings in the first year. It is recommended that benefit/cost analyses be used to assist in defining priorities for treatment of wet weather accident prone sections.

Key Words: highways, pavements, accidents, wet roads, road friction, accident costs.

IMPLEMENTATION

Priority in treating slippery road sections is difficult to determine because of differing section lengths, traffic volumes and accident rates. Some part of the highway budget may be directed specifically at reducing the economic loss from wet road accidents. A benefit/cost analysis of treatment of sections identified as problem sections should be a useful tool to assist in determining priorities. The findings of this study can be implemented by:

1. Revising the computer program for annual summary and printout of accident data to include the cost per lane mile of wet road accidents.
2. Using a combination of the ratio of wet to overall accident rate and the cost per lane mile of wet road accidents to identify control sections as critical wet weather sections.

SUMMARY

Thirty-six non-interstate rural highway control sections previously identified and named "worst case" sections were studied. Four of these were sections serving as links for incomplete sections of interstate and nine others were identified as requiring capital geometric or structural upgrading. The remaining twenty-three sections were analyzed for benefits in accident reduction from renewal of surface friction. A criterion was developed for predicting the number of wet road accidents to be expected in sections with adequate geometric design and acceptable wet road friction. It was found that a number of the study sections did not exhibit a wet road accident problem; the high number of wet road accidents was a reflection of long section length and high traffic volumes. While only eleven of twenty-three sections would produce annual accident savings sufficient to meet annual costs of friction renewal, several sections produced high benefit/cost ratios. In some cases the accident cost savings in one year were sufficient to pay the cost of a seal coat surface. All of the sections judged inadequate are currently being rebuilt. A number of sections was seal-coated in 1972, and the results in 1973 tend to confirm the criterion for estimating the effects. It is recommended that wet road accident costs be programmed as part of the computerized annual accident summary printouts and that benefit/cost analyses be used in determining priorities for surface friction treatments.

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CHAPTER I

INTRODUCTION

Wet weather accidents have been recognized as a problem on Texas highways and an effort is being made to reduce the loss from this cause. A fairly rapid identification of road sections experiencing a wet road problem can be made from accident records by establishing a statewide ratio of wet to dry road accidents and determing those sections with above average ratios. Criteria are needed to identify those sections of roadway which would benefit from resurfacing, the primary remedial treatment applied by the State Department of Highways and Public Transportation.

Selecting those sections with high wet-road to dry-road accident ratios does not necessarily identify sections which can benefit from resurfacing. A given section of highway might be excellent in all respects and have very few accidents. By pure chance the wet/dry ratio might be high while the total number of accidents is at a practically irreducible minimum.

It is concluded that the best method of determing how the available resurfacing funds can be spent is to apply benefit/cost analyses after a more sophisticated screening of the problem sections has been accomplished. For the purposes of this study, control sections previously selected by Huchingson (1) were used as the study sample.

Case Study Sections

Huchingson (1) applied multiple criteria to 1970 and 1971 Texas accident data to select thirty-six "worst case" wet road accident control sections. Huchingson used as separate criteria ratio of wet road accident rate to total rate, wet road accident probability, multiple fatal accidents, a combination of the above three criteria, wet road fatal accidents and wet road injury accidents. He then used a cross comparison of section rankings by the different criteria to make a final selection of "worst case" sections. His thirty-six "worst case" sections were subjected to more detailed analyses in this study.

Some patterns can be discerned from a rapid examination of the 36 control sections. First, several sections of highway serving incomplete links of Interstate highways are included. Second, nearly all the sections lie east of a line from Harlingen to San Antonio to Dallas. The part of the state east of this line is that part having the highest rainfall. In addition the most easterly part of the state is rolling topography and has a shortage of natural non-polishing aggregate with higher traffic volumes than the western part. Thus, the preponderance of critical sections are found where one might predict that the factors would combine to create the worst wet road conditions.

Almost every non-interstate arterial highway in the eastern part of the state has at least one control section in Huchingson's 36 "worst case" control sections. This suggests that these major routes should be monitored carefully to determine needs for upgrading, anti-skid surfacing, removal of roadside hazards or other treatment in order to prevent accident rates from rising in other control sections.

CHAPTER II

ACCIDENT COSTS AND PRIORITIES

In this chapter, accident costs are estimated for wet weather accidents and for total accidents on the study control sections. Accident costs per mile of highway are also calculated and then are used to develop a general priority ranking of the control sections. It is assumed that wet weather accident costs, including both direct and indirect costs, are the best indicators of priorities for improvement. The cost of all accidents are also calculated since this cost could have use in the determination of other priorities; and, indeed, most of the percentage reductions in accidents from safety improvements that have been reported in previous studies are reductions in total accidents - not only wet weather accidents, even when wet weather and skidding accident reductions were the goal of the safety improvements. Since these study sections were chosen because of wet weather accident problems, the cost per mile of wet weather accidents is used in this chapter to rank the sections.

Table 1 lists the length and daily vehicle miles traveled on the 36 control sections identified by Huchingson (1). Table 2 summarizes both the wet weather accidents and total accidents for the study sections.

Using information on Texas accident costs from a study by Burke, (2) it is possible to estimate the annual accident costs for each of the control sections. Burke estimated that the average cost of a rural property-damage-only (PDO) accident is $515. He also estimated that the average cost of a rural accident involving a fatality or injury is $3,300

TABLE 1.

Characteristics of Study Sections

Section Designation	Length in Miles	Daily Vehicle Miles
US A-1*	6.89	31,474
US B-1	11.35	115,974
US C-1	34.58	349,051
US C-2	5.94	256,679
SH A-2	16.52	62,925
US D-1	12.17	29,987
US D-2	17.50	11,988
US E-1	10.29	38,227
US E-2	10.48	39,090
FM E-3	11.49	50,717
FM E-4	3.70	26,718
SH E-5	5.95	28,667
US E-6	12.84	62,890
FM C-3	28.11	31,933
SH F-1	8.93	14,172
US F-2	19.16	68,842
US G-1	17.53	47,015
SH D-3	8.94	30,611
US H-1	8.75	136,150
US H-2	5.59	59,908
SH H-3	13.14	32,206
US I-1	9.59	77,554
FM J-1	13.25	9,434
SH I-2	15.77	24,380
US I-3	7.14	32,851
SH I-4	4.36	19,040
FM I-5	11.54	24,499
US D-4	16.43	57,439
US K-1	12.69	191,987
US K-2	5.77	32,877
US L-1	15.81	10,719
US M-1	12.17	75,052
US N-1	10.00	14,420
FM P-1	5.23	14,576
US P-2	6.78	40,314
SH P-3	5.69	15,323

*The section designation gives the type of highway, a letter key to the SDHPT District number and a numeric key to the actual section within the District.

TABLE 2.

Reported Wet Weather and Total Accidents on Study Sections, by Accident Severity, 1971

Section Designation	Reported Accidents in 1971			
	Wet Weather		Total	
	F & I	PDO	F & I	PDO
US A-1	6	2	8	4
US B-1	8	25	21	65
US C-1	10	5	71	109
US C-2	4	15	48	161
SH A-2	7	2	22	20
US D-1	6	13	11	33
US D-2	3	3	14	24
US E-1	7	8	13	23
US E-2	6	3	16	18
FM E-3	9	4	19	34
FM E-4	5	10	13	28
SH E-5	6	7	9	22
US E-6	2	5	15	22
FM C-3	2	8	10	18
SH F-1	5	3	24	14
US F-2	4	1	10	21
US G-1	6	4	20	29
SH D-3	5	11	10	26
US H-1	10	55	44	163
US H-2	7	9	11	35
SH H-3	5	3	13	18
US I-1	12	32	43	100
FM J-1	2	1	4	10
SH I-2	5	2	13	14
US I-3	4	7	13	30
SH I-4	5	11	17	48
FM I-5	7	23	22	52
US D-4	2	7	9	22
US K-1	3	25	33	99
US K-2	3	3	9	5
US L-1	2	0	2	8
US M-1	6	5	10	14
US N-1	5	11	8	20
FM P-1	8	16	13	22
US P-2	7	14	12	28
SH P-3	7	4	10	9

if only direct costs are included. If both direct and indirect costs are included, the average rural accident involving a fatality or injury costs $9,100. Direct costs include the cost of property damage and medical and hospital costs, whereas indirect costs include the loss of future earnings less consumption expenditures. It should perhaps be noted that some methods of calculating the cost of accidents include consumption expenditures in costs of fatalities and derive much higher costs than those used here.

Multiplying the numbers of accidents by type from Table 2 by Burke's average accident costs gives the annual accident cost for each control section, and these are shown in Table 3. Annual accident costs including and excluding indirect costs are shown for both wet weather and total accidents. These costs give a general indication of the overall cost of accidents on a control section. However, they are not a full indication of overall costs since unreported accidents are not included. Also, there has been considerable inflation since Burke's accident cost study was completed in 1969; since there is no price index for accidents, it is difficult to estimate the amount that costs have increased since 1969. In 1975 dollars, however, the costs undoubtedly would be at least 20% higher and might be as much as 50% higher since there have been large percentage increases in medical and hospital expenses. Also, these accident costs do not include any dollar value for pain and suffering, and thus are estimates only of "economic" losses to society. Nevertheless, these estimates give a conservative (i.e., low) estimate of the annual dollar savings that would result from eliminating all accidents on these sections.

Dividing the annual control section costs in Table 3 by the length (in miles) of each control section gives the accident cost per mile, which is shown in Table 4.

TABLE 3.

Cost of Wet Weather and Total Accidents, Per Study Section, Including and Excluding Indirect Costs, for the Year 1971

Section Designation	Accident Cost Per Control Section			
	Wet Weather		Total	
	Direct Only	Direct & Indirect	Direct Only	Direct & Indirect
US A-1	$ 20,830	$ 55,630	$ 28,460	$ 74,860
US B-1	39,275	85,675	102,775	224,575
US C-1	35,575	93,575	290,435	702,235
US C-2	20,925	44,125	241,315	519,715
SH A-2	24,130	64,730	82,900	210,500
US D-1	26,495	61,295	53,295	117,095
US D-2	9,900	28,845	58,560	139,760
US E-1	27,220	67,820	54,745	130,145
US E-2	21,345	56,145	62,070	154,870
FM E-3	31,760	83,960	80,210	190,410
FM E-4	21,650	50,650	57,320	132,720
SH E-5	23,405	58,205	41,030	93,230
US E-6	9,175	20,775	49,500	147,830
FM C-3	10,720	22,320	42,270	100,270
SH F-1	18,045	47,045	86,410	225,610
US F-2	13,715	36,915	43,815	101,815
US G-1	21,860	56,660	80,935	196,935
SH D-3	22,165	51,165	46,390	104,390
US H-1	61,325	119,325	229,145	484,345
US H-2	27,735	68,335	54,325	118,125
SH H-3	18,045	47,045	52,170	127,570
US I-1	39,600	125,680	193,400	442,800
FM J-1	7,115	18,715	18,350	41,550
SH I-2	17,530	46,530	50,110	125,510
US I-3	16,805	40,005	58,350	133,750
SH I-4	22,165	51,165	80,820	179,420
FM I-5	34,945	75,545	99,380	226,980
US D-4	10,205	21,805	41,030	93,230
US K-1	22,775	40,175	159,885	351,285
US K-2	11,445	28,845	32,275	84,475
US L-1	6,600	18,200	10,720	22,320
US M-1	22,375	57,175	40,210	98,210
US N-1	22,165	51,165	36,700	83,100
FM P-1	34,640	81,040	54,230	129,630
US P-2	30,310	70,910	54,020	123,620
SH P-3	25,160	65,760	37,635	95,635

TABLE 4.

Cost of Wet Weather and Total Accidents, Per Mile of Highway, Including and Excluding Indirect Costs, for the Year 1971, by Study Section

Section Designation	Accident Cost Per Mile of Highway			
	Wet Weather		Total	
	Direct Only	Direct & Indirect	Direct Only	Direct & Indirect
US A-1	$ 3,023	$ 8,074	$ 4,131	$ 10,865
US B-1	3,460	7,548	9,055	19,785
US C-1	1,029	2,706	8,399	20,308
US C-2	3,522	7,428	40,625	87,494
SH A-2	1,461	3,918	5,018	12,742
US D-1	2,184	5,336	4,394	9,653
US D-2	566	1,648	3,346	7,986
US E-1	2,645	6,590	5,320	12,678
US E-2	2,037	5,357	5,923	14,778
FM E-2	2,764	7,307	6,981	16,572
FM E-4	5,851	13,689	15,491	35,870
SH E-5	3,934	9,782	6,896	15,669
US E-6	714	1,618	3,855	11,513
FM C-3	381	794	1,504	3,567
SH F-1	2,021	5,268	9,676	25,264
US F-2	716	1,927	2,287	5,314
US G-1	1,247	3,232	4,617	11,234
SH D-3	2,479	5,723	5,189	11,676
US H-1	7,009	13,637	26,188	55,354
US H-2	4,962	12,225	9,718	21,131
SH H-3	1,373	3,580	3,970	9,708
US I-1	4,129	13,105	20,167	46,173
FM J-1	537	1,412	1,385	3,136
SH I-2	1,112	2,951	3,178	7,959
US I-3	2,353	5,603	8,172	18,732
SH I-4	5,083	11,735	18,537	41,151
FM I-5	3,028	6,546	8,612	19,669
US D-4	621	1,327	2,497	5,674
US K-1	1,795	3,166	12,599	27,682
US K-2	1,984	4,999	5,594	14,640
US L-1	417	1,151	678	1,412
US M-1	1,839	4,698	3,304	8,070
US N-1	2,217	5,117	3,670	8,310
FM P-1	6,623	15,495	10,369	24,786
US P-2	4,471	10,459	7,968	18,233
SH P-3	4,422	11,557	6,614	16,808

The accident costs per mile from Table 4 give a better indication of priority rankings for improvements than the section costs in Table 3, since the cost of a safety improvement would tend to be a function of the length of the study section. Since both direct and indirect accident costs probably should be considered in benefit/cost studies of safety improvements, Columns 3 and 5 (including direct and indirect costs) of Table 4 are of special interest. Since this study is concerned with wet weather accidents, priorities for safety improvements should be based primarily on wet weather accident costs as given by Column 3 of Table 4, though this in no way implies that safety efforts are or should be confined to the wet weather problem. Using this basis for ranking study sections, the highest priority section is FM P-1, with an annual cost of $15,495 per miles, followed by FM E-4, with an annual cost of $13,689 per mile, etc. down to the lowest priority section which is FM C-3, with an annual cost of $794 per mile. The priority ranking based on wet weather accident cost per mile is given in Table 5, which also shows the ranking using total accident costs.

TABLE 5.

Ranking of Study Sections, In Descending Order of Costs, Using Cost of Wet Weather and Total Accidents, Per Mile of Highway, Including Indirect Costs, for the Year 1971, by Study Sections

Section Designation	Ranking and Accident Cost Per Mile of Highway			
	Wet Weather		Total	
	Rank	Cost/Mile	Rank	Cost/Mile
FM P-1	1	$15,495	8	$24,786
FM E-4	2	13,689	5	35,870
US H-1	3	13,637	2	55,354
US I-1	4	13,105	3	46,173
US H-2	5	12,225	9	21,131
SH I-4	6	11,735	4	41,151
SH P-3	7	11,557	15	16,808
US P-2	8	10,459	14	18,233
SH E-5	9	9,782	17	15,669
US A-1	10	8,074	25	10,865
US B-1	11	7,548	11	19,785
US C-2	12	7,428	1	87,494
FM E-3	13	7,307	16	16,572
US E-1	14	6,590	21	12,678
FM I-5	15	6,546	12	19,669
SH D-3	16	5,723	22	11,676
US I-3	17	5,603	13	18,732
US E-2	18	5,357	18	14,778
US D-1	19	5,336	27	9,653
SH F-1	20	5,268	7	25,264
US N-1	21	5,117	28	8,310
US K-2	22	4,999	19	14,640
US M-1	23	4,698	29	8,070
SH A-2	24	3,918	20	12,742
SH H-3	25	3,580	26	9,708
US G-1	26	3,232	24	11,234
US K-1	27	3,166	6	27,682
SH I-2	28	2,951	31	7,959
US C-1	29	2,706	10	20,308
US F-2	30	1,927	33	5,314
US D-2	31	1,648	30	7,986
US E-6	32	1,618	23	11,513
FM J-1	33	1,412	35	3,136
US D-4	34	1,327	32	5,674
US L-1	35	1,151	36	1,412
FM C-3	36	794	34	3,567

CHAPTER III

REVIEW OF PREVIOUS WORK

A recent report, NCHRP 14 (3), provided a review of studies that attempted to relate accident frequencies to friction and skid resistance. One study (4), covering 150 miles of rural highway in Great Britain, found that the percentage of wet road accidents in which skidding was reported decreased linearly with increasing sideway friction factor (See Figure 1). German studies (5) showed that the percentage of accidents on wet pavements decreased with increase in locked wheel friction factor up to a factor of 0.4, but remained constant with further increases (See Figure 2). The NCHRP report also cited the study by McCullough and Hankins (6) as showing that it makes little difference whether all accidents, wet road accidents, or skidding accidents were used in making correlations. The report concludes, however, "that accident rates for specific sites in conjunction with skid resistance data can be a useful means for determining whether or not low skid resistance is a major contributory cause" (3, p. 6). It is interesting that the German studies indicate a required wet road friction in general agreement with American studies (6, 7, 8).

A recent publication by Rizenbergs, et al., (9) interprets accident data in such a way that the wet road accident rates appear to approach uniform values for skid numbers (SN_{40}) above forty or forty-five (see Figure 3).

In 1966, Roy Jorgenson and Associates and Westat Research Analysts prepared estimates of the effects of numerous safety improvements on accident rates (10). The report states (p. IV) "that substantial accident reductions can be brought about in specific situations by identifying locations and sections of highway that meet a predetermined definition of 'hazardous', and then by directing improvements toward these situations."

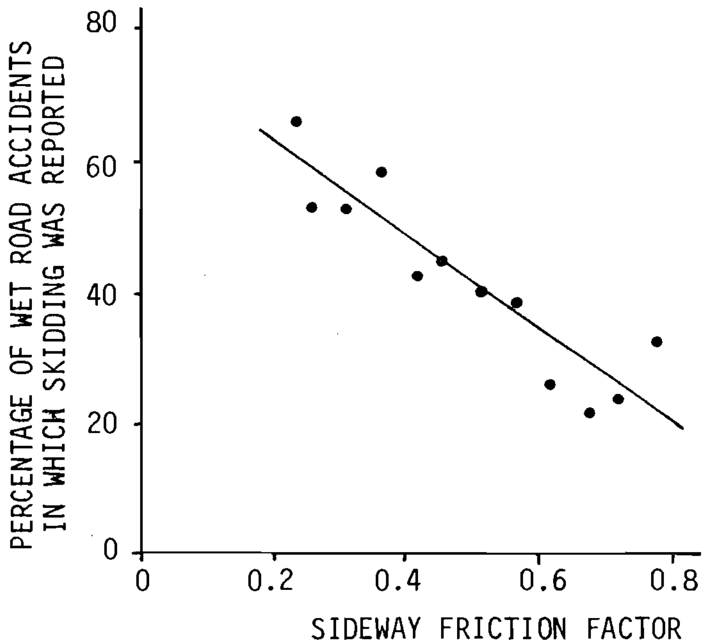

FIGURE 1. DECREASE OF WET-SKIDDING ACCIDENTS WITH IMPROVED FRICTION FAC

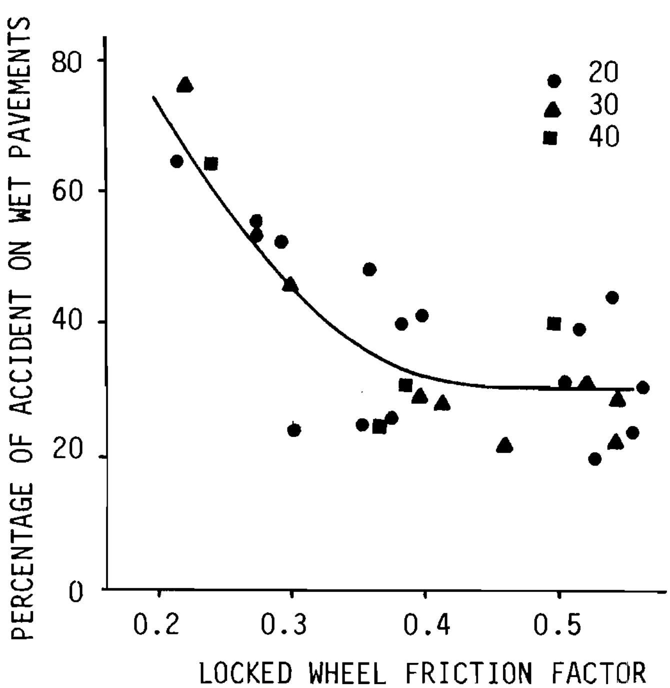

FIGURE 2. WET-PAVEMENT ACCIDENT RATE AS A FUNCTION OF FRICTION FACTOR.

Source: Reference 3

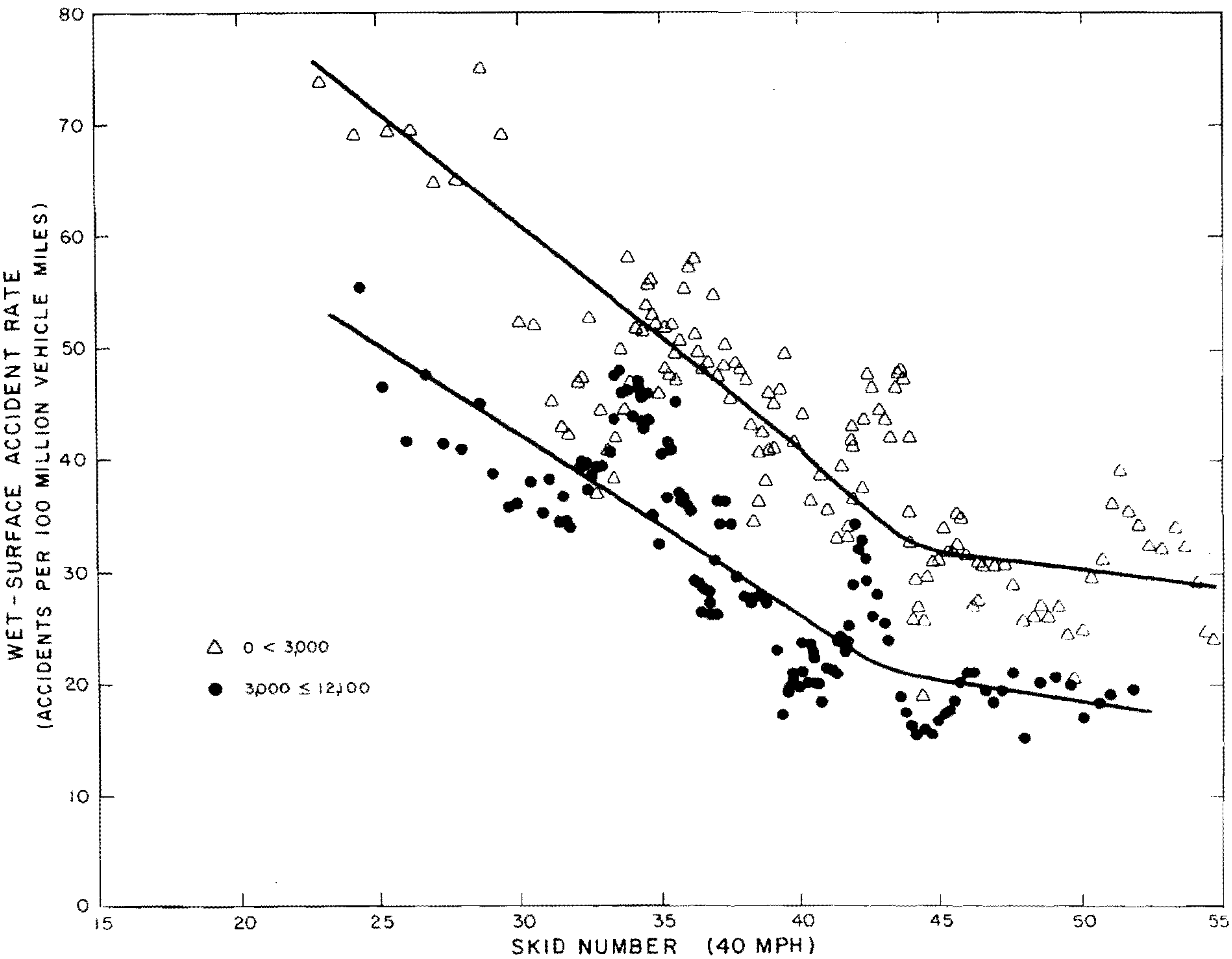

FIGURE 3. SKID NUMBER VERSUS ACCIDENT RATE.

Source: Reference 10

Of particular interest is the fact that the report reviewed data on the effects of resurfacing on accident rates. Jorgenson-Westat concluded that only Ohio performed resurfacing as a safety improvement and only Ohio data show consistent accident reductions. Ohio had established three criteria for safety resurfacing: four or more accidents per mile per annum, a minimum rate of 2.4 accidents per million vehicle miles, and a minimum percent of wet road accidents varying with the total number of accidents per mile as shown in Table 6. The first two criteria indicate accident involvement above the Ohio average while the third indicates a slick pavement and might be supplemented by or replaced by skid trailer measurements of wet road friction.

Jorgenson-Westat also point out that resurfacing does not tend to reduce accidents unless it serves to deslick slippery sections and indeed that resurfacing roads of low geometric standards which are not experiencing skidding accidents may actually increase accidents. Tanner (11) attributes this increase to smoother ride and higher speeds. There is little doubt that surface renewal can reduce wet road accidents if the wet road coefficient is increased. Giles and Sabey (12) found reductions of 45 percent in total accidents and 90 percent for wet road skidding accidents.

Jorgenson-Westat provide values for estimating the benefits of treatments other than resurfacing. The other treatments would generally be spot treatments and would be applicable to this study only if the accidents in a study section were clustered rather than distributed throughout the section.

TABLE 6.

Minimum Percent Wet Pavement
Accidents Versus Total
Accidents Per Mile (Ohio)

Total Accidents Per Mile	Wet Pavement Accidents Percent of Total	Minimum Number of Wet Pavement Accidents Per Mile
20 or more	27%	5.4
14-19.9	28	3.9
10-13.9	30	3.0
9- 9.9	33	3.0
8- 8.9	35	2.8
7- 7.9	37	2.6
6- 6.9	40	2.4
5- 5.9	43	2.2
4- 4.9	50	2.4

Source: Reference 10, p. 183

CHAPTER IV

ALTERNATIVE SAFETY IMPROVEMENTS

In Chapter II a ranking of the study sections was developed in terms of accident cost per mile. There remains the task of determining appropriate remedial measures, the estimated accident reductions and the cost effectiveness in each case.

Before examining the study sections in detail, one must consider in broad terms the alternatives that are available to reduce the wet road accident frequency. The alternatives may be divided broadly into two classes. The first might be called legislative and administrative and the second physical improvements.

Legislative or administrative action would be aimed primarily at reducing the demand made by the motorist on the driver-vehicle-road system. For instance, legislation might be changed so that, instead of having statewide speed limits, the highest speed limits might be applied only to freeways, somewhat lower speed limits to those roads serving a feeder function. All of the arguments for or against such a system will not be pursued, but the approach should be valid in that it attempts to match the motorist's behavior to the standard of road economically justified for the traffic amount and type. Further, it is not unduly restrictive because the lower speed limits are applied to short haul trips where less is to be gained by higher speeds.

The recent response to the "energy crisis" resulted in reduced speed limits, a reduction which removed the practicality of applying the above system. However, recognizing that voluntary obedience to the reduced speed limits is inconsistent, more use might be made of speed zoning and speed advisory warnings than would be needed if graded speed limits were used.

A second administrative action would be to adjust priorities. For instance, roadways serving as links in the incompleted interstate highway system show up frequently as problem sites. Because traffic will ultimately be removed from the existing links it is not economically sound to invest heavily in them. Therefore, accelerating the removal of the gaps in the interstate freeways by continuing to give them priority in the capital investment program is certainly appropriate, and might even be considered a valid argument against delays brought on by environmentalist groups.

Improving the wet road friction is one of the most effective ways of reducing wet road accidents if the present surfaces are providing a poor level of friction. Among many ways it may be done by seal coating, then layers of open-graded hot mix, standard hot mix resurfacing, or by grooving of PCC surfaces. The treatments, except for grooving, are listed in ascending order of cost which also happens to be the order of life expectancy. Therefore, one would ordinarily make a selection on the basis of least annual cost. However, other factors must be considered. For instance, seal coating is not appropriate for intersection areas with heavy braking and acceleration forces because the aggregate would be removed (13). At the other extreme, heavy resurfacing should not be applied to a road with design deficiences because it will improve the riding quality, encourage higher speeds and may increase the accident rate even if the friction is improved (11).

The upper limit of physical change would be complete rebuilding of the roadway. Such action usually could not be justified solely on the basis of wet road accidents. However, a severe problem of wet road accidents could be a factor in determining priorities in capital programming and, if the present facilities are overloaded, rebuilding and expansion of the facility may be the only solution.

A third group of treatments involve little physical change and might be classed as palliatives. These include edge markings, delineators, signs and warnings. Some studies have indicated that these can be quite effective. Of course, one would not expect significant improvement if the present level of delineation, marking and signing is good.

A number of further treatments are available such as improved shoulders, site improvement where accidents are grouped, intersection treatments and spot illumination. These do not fall into general classes and would require individual analyses.

The treatments discussed above fall generally into two classes, improving the roadway to meet the motorist's demands or aiding the motorist in adjusting to conditions. In general, the former would be expected to be more effective than the latter.

The best treatments probably should not be expected to reduce wet road accident rates to dry road rates. Not only is it impossible to provide the same levels of friction on wet roads as on dry but other factors come into play. Visibility may be reduced by rainfall, road splash, unclean windshields or other factors so that the driver has reduced warning of imminent danger (18). Further, it is well known from traffic studies that drivers adjust speed, but not by appropriate amounts for deteriorated conditions. This applies to wet roads, short sight distances, darkness, fog or whatever; and must be considered in assessing the effectiveness of treatments.

A word of caution is in order here. For a given section of roadway, the accident statistics may vary widely from year to year. Therefore, most before-and-after accident studies based on data of one year or shorter duration must be looked upon as indicators rather than accurate measures. Similarly, any assessments of accident cost savings based on short-term statistics must be viewed as guides only. The benefits might vary widely from year to year for a given section.

Finally, it should be pointed out that there is a scarcity of definitive data on the effectiveness of many treatments. Furthermore, since most studies of effectiveness have been of short duration, there is often conflict in the reported results. Therefore, a substantial measure of engineering judgement must be applied in estimating benefits until such time as more accurate indices are developed. The benefit estimates should account for the fact that certain treatments may reduce dry road as well as wet road crashes (14).

Figure 4 is a flow chart of a step-by-step procedure to evaluate the appropriate treatment for a given section once it has been identified as one having a wet weather accident problem. Basically this chart divides roads into those that are geometrically adequate (alignment, grade, cross-section and number, and width of lanes) from those needing upgrading. Of the latter group, those not scheduled for immediate rebuilding may need short life surface improvement to reduce wet road accidents until rebuilding is done.

Those sections that are geometrically adequate may be structurally sound or not. If a section needs structural reinforcing as well as improvement of surface friction, the whole cost of this treatment cannot be charged

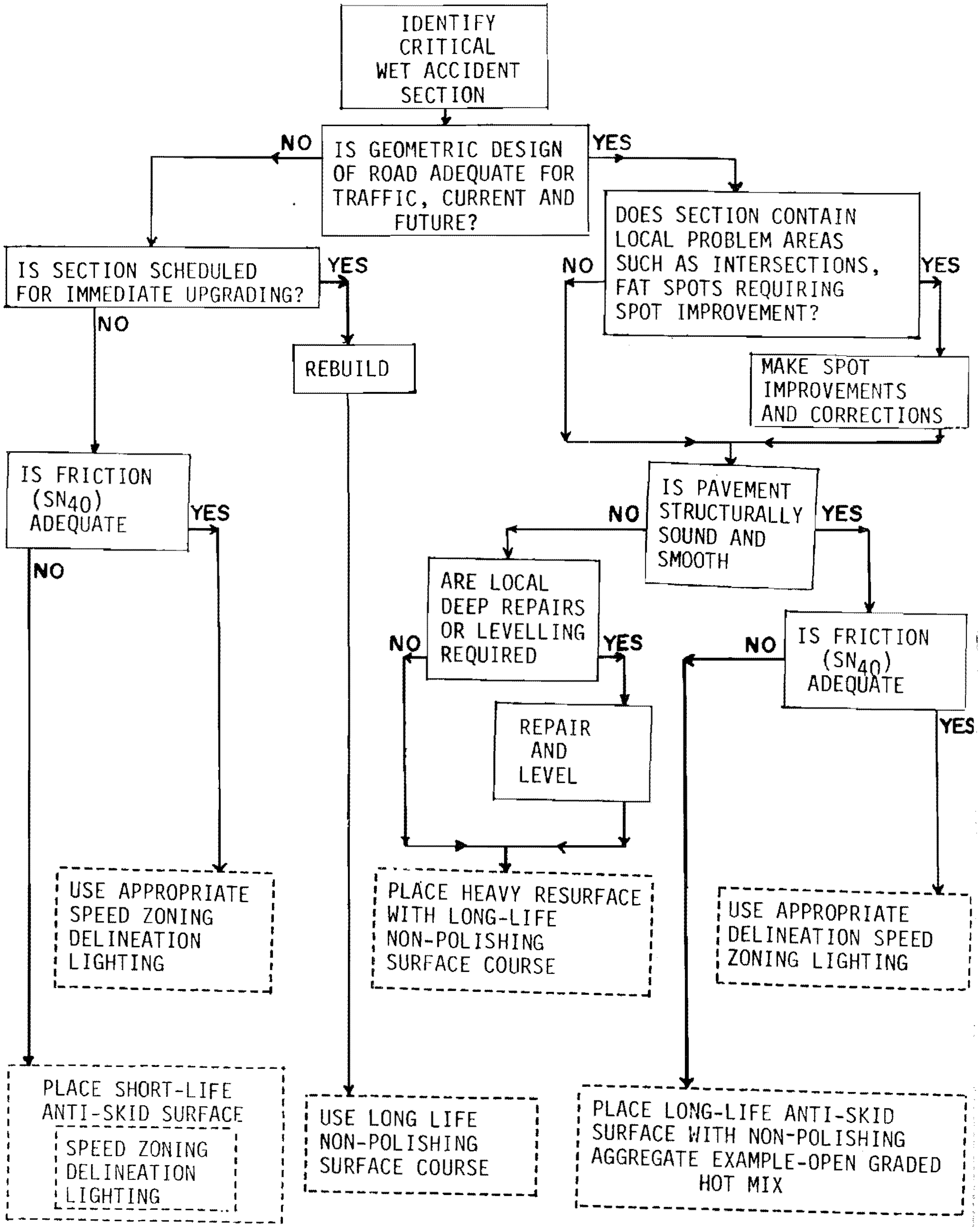

FIGURE 4. FLOW CHART FOR SELECTING TREATMENT FOR CRITICAL WET ACCIDENT SECTIONS

against accident reduction but only that incremental part, say for non-polishing aggregate in the surface course, specifically aimed at producing and maintaining a high wet road friction.

Sections both geometrically adequate and structurally sound probably have high wet weather accidents because of poor friction. These sections can readily be corrected by application of a high friction surface. Since these sections are free of other defects, the benefits from improved friction may be spectacular. If the road is only marginally adequate, improving friction may not reduce the wet weather accidents to the same extent.

An example of treatment and benefit/cost analysis from the study sections is considered here. Section US P-2 had 21 wet weather accidents in 1971 on a 6.78 mile section and an estimated wet weather accident cost of $10,459 per mile. A seal coat was applied in September 1972 and the resulting wet weather accident totals were 11 in 1972 and 3 in 1973. The benefit/cost analysis is made below:

1. Assuming all accident reduction is accounted for by the treatment -

   Accident cost saving = 18/21 x $10,459 = $8,965 per mile
   (18 = no. of accidents eliminated out of 21 total accidents)

   $$\text{Estimated treatment cost} = \frac{25\text{ ft (width)} \times 5280\text{ ft/mile}}{9\text{ ft}^2/\text{yd}^2}\ (\$0.35/\text{yd}^2)$$

   $$= \$5,133 \text{ per mile}$$

   Annual treatment cost (5 yr. life, 8% interest) = $1,286 per mile

   Benefit/cost ratio = 6.97

2. Allowing for statistical variation in accident data -

   Before treatment - measured number = 21
   - probable variation = ± 6

   After treatment - measured number = 3
   - probable variation = ± 3

Least probable savings [(21-6) - (3+3)] = 9

Accident cost savings =(9/21) x $10,459. = $4,482. per mile

Benefit/cost ratio = 3.49

The estimated statistical variation for the accident data in the above analyses are taken from Tamburri and Smith for 85 percent confidence limits (15). This particular section returned a high benefit/cost ratio even when the most unfavorable case of statistical variation in accident occurrence is assumed. When a less pessimistic view is taken, it is seen that the capital cost of the treatment is recovered in savings of accident costs in the first year. Thus, even if the treatment becomes less effective toward the end of its assumed life, it is still very cost effective.

No data are available for the above section for the wet friction (SN_{40}) values before or after treatment. One can assume, since the anti-skid treatment was applied, that the section was recognized, without formal measurement, as being slippery and in need of treatment. Presumably, since the road design was adequate for the traffic volume, slipperiness was the prime factor in the wet road accidents.

The question may be raised whether the fuel crisis was a factor in the accident reduction. However, records show that only minor traffic effects were measurable late in 1973. Only later in the first quarter of 1974 did travel volumes, vehicle speeds and accidents substantially drop (16,17). Traffic volumes for the control section analyzed were essentially constant.

If one applies the analytic method to various control sections, it becomes obvious that two types of sections will return a high benefit/cost ratio. First, those sections with very high numbers of total accidents and moderate wet weather to total rates will produce a positive return because of the large number of accidents eliminated. Second, there are those sections with low overall accident rates but very high ratios of wet weather to total rates. These latter sections are usually associated with slick surfaces and the potential for reducing wet weather accidents is still great.

A third group may be identified. This group is made up of low traffic volume sections having high wet weather accident rates and low measured wet friction. Because of the low volumes, the potential accident savings will not pay for surface improvements. Perhaps speed zoning could be used so that the driver is aware of the hazard. The proposed method of analysis at least exposes the facts for decision making.

In general there is good agreement between those sections showing a positive benefit/cost ratio and those meeting the Ohio criteria (10). Some sections having very high wet-to-overall rates not meeting the Ohio criteria return a positive benefit on analysis.

All thirty-six sections were examined to estimate the potential returns from anti-skid treatments. Those sections having apparently adequate geometrics for the traffic volumes were first tested for long-life anti-skid treatment (open-graded hot mix with nonpolishing aggregate) and, if necessary, for a lower annual cost treatment. Sections that were considered, from a study of inventory data and traffic volume, to require upgrading in the near future were tested only for less expensive short-life treatments.

For the purpose of evaluation, if the road were geometrically adequate but had low wet friction, it was assumed that an anti-skid surface would reduce the number of wet road accidents to one quarter of the number of dry road accidents for the particular section. This figure was developed by considering overall ratios for the state. When the 1971 data were analyzed, it was found that wet road accidents amounted to 21 percent of the dry accidents (Appendix B). By district, the percentages ranged from 7 to 35. When data for only those districts containing at least one of the study sections were used, wet road accidents were 23 percent of the dry accidents and the range by district was greatly reduced. Consideration was also given to the fact that the average time that roads are wet in Texas is slightly less than ten percent. Thus, the average post-treatment wet road rate is about two and one-half times the dry rate, even after treatment. A few of the sections studied were treated in 1972 and the 1973 results, in some cases, were better than indicated by the above criterion. However, the hazard of placing great confidence in the data when the numbers are small has been noted. Therefore until data are developed to produce a better estimate, it is concluded that one should not use such optimistic estimates that the potential benefits may be overestimated.

The question might be raised whether the above criterion is valid for estimates of benefits of short term treatments for sections known to have low friction but also needing upgrading by widening, shouldering or other geometric improvements. It may be argued that the wet road accident record results from the sum of all the deficiencies, that there is no way of estimating those attributable to poor friction and no way of estimating benefits. This argument neglects to consider that the expected benefits are calculated only on reducing the wet accidents to a fixed ratio of the dry accidents. General improvements should reduce both wet and dry accidents whereas anti-skid treatments can reduce a disproportionate number of wet accidents. One might even argue that this class of section merits treatment when the benefit/cost ratio is barely unity on the basis that this class of section produces a disproportionate number of fatal accidents because the lack of maneuver room obviates any mitigating pre-crash action by the driver and that loss of life cannot be evaluated truly in economic terms.

The interest rate used to calculate annual costs was 8 percent. This rate was chosen as a realistic rate for governmental work. Very little added effort is required to calculate the annual costs for other interest rates.

For those sections having high wet road accident rates but apparently adequate friction, no simple estimates of treatments, costs and benefits can be made. Detailed field study along with detailed study of the location and type of each accident would be required. Then, appropriate treatments such as delineation, intersection improvements, speed zoning, advisory speed warnings, beacons, signalization, or illumination must be selected and the cost and the expected benefits calculated. Tamburri and Smith (15), and Jorgenson-Westat(10), present valuable data for estimating the accident reductions for various spot treatments. Most of the treatments would be expected to affect wet and dry rates equally. The exception might be curve advisory speed signing which could produce greater results for wet than for dry road conditions. This is so because the available friction when the road is dry will usually far exceed the comfortable passenger accelerations whereas it may not when the road surface is wet.

Benefit/cost analyses were performed for all the study control sections and are contained in Appendix A. The prices used in making the analyses are the estimated prices for future work taking into account the higher costs of asphalt and of production and delivery of non-polishing aggregates.

For sections where treatments have been made since the selection of the study sections, actual costs and results are used for comparative purposes. In fact, the prices may vary considerably even within a small area depending upon the availability of materials at the particular date. Hence, general prices for benefit/cost analyses reflect all the accuracy that is justified.

It is not a simple matter to decide whether a road surface has adequate friction. A road with capacity well above the traffic volume and with few access points may operate at low friction values and have few wet road crashes because the number of incidents of high friction demand is small. On the other hand, a road carrying traffic volumes at or above its rated capacity will experience many emergency maneuvers and require a high wet road friction. Thus, a range, rather than a critical number of friction values, must be used to evaluate whether a road section will benefit from friction improvement.

It was found during the analysis that in some cases the accident histories were inconsistent with what one might conclude from inventory data of road geometrics, skid number and traffic volume. More detailed information on many sections was obtained by conferring with highway district personnel and/or inspection of the road sections. The additional information usually served to explain what was otherwise considered anomalous data.

CHAPTER V

DISCUSSION

A number of points become apparent when the analyses of the thirty-six study sections are considered. Possibly the most startling of these is that wet road accident rates are not very well correlated with wet road friction. Tangent alignment in flat topography with none or few access points tends to produce few accidents even on relatively slippery surfaces. Presumably, this is because the traffic stream is non-turbulent and maneuvers demanding high friction are few. Truck speeds may be uniform and in the same range as passenger vehicle speeds so that involuntary queues do not form and high torque acceleration for passing occurs rarely. Photos 1 and 2 are general and close-up views of a surface that has a low skid number because of traffic polishing; but on which the wet road accident rate is low. On the other hand, in rolling topography the wet to dry ratio of accidents will increase sharply when friction values fall only moderately. This seems to be so even when the traffic volumes are well below the rated capacity. Of course, access points create turbulence, therefore affecting the required friction.

Many sections identified as having a wet road accident problem are deficient in geometric standards and will be taken care of in due course by road reconstruction. In the meantime, these sections demand a high coefficient of friction because of conflicts. If reconstruction is not scheduled for the immediate future, one might apply a high friction surface even though existing friction values are not particularly low. A benefit/cose analysis can assist in evaluating whether the temporary treatment is justified.

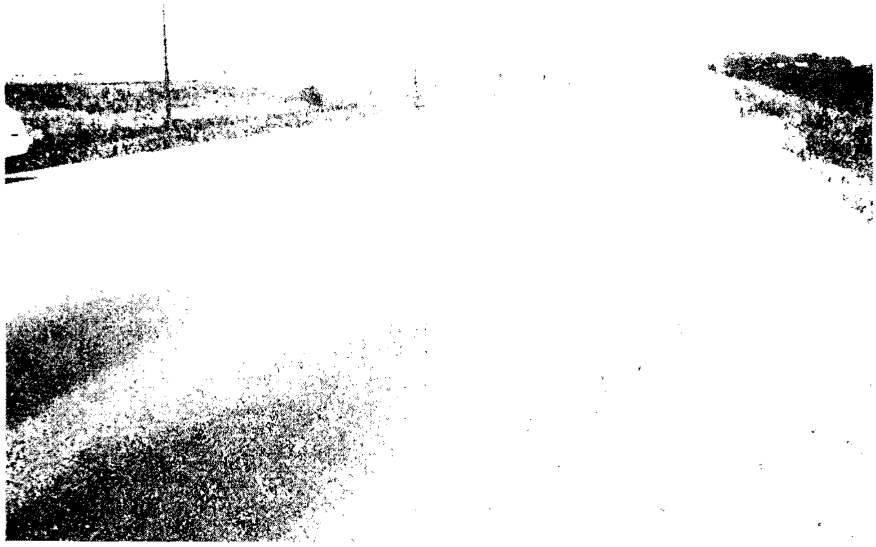

PHOTO 1. EXCELLENT GEOMETRICS OF THIS ROAD KEEP ACCIDENTS LOW DESPITE SLIPPERINESS FROM BLEEDING IN WHEEL PATHS.

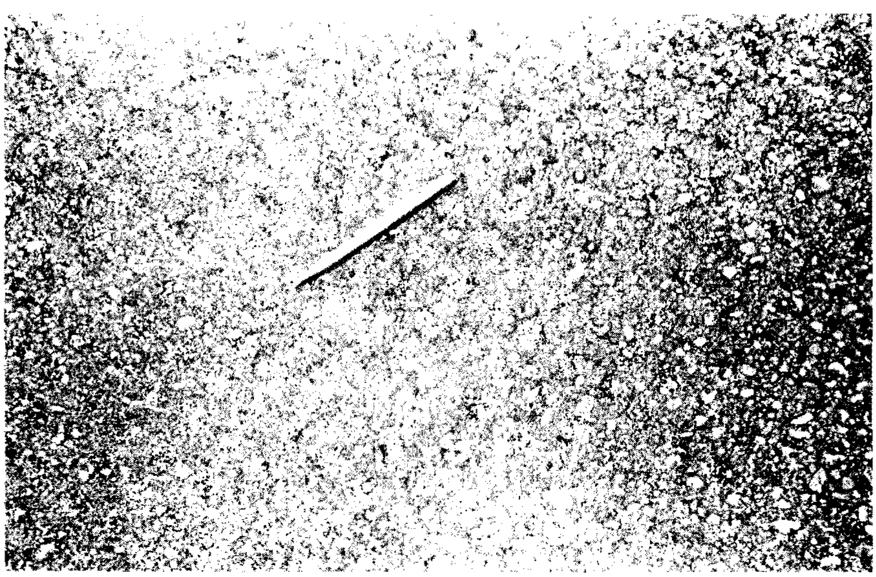

PHOTO 2. CLOSE-UP VIEW OF WHEEL PATH SURFACE FROM PHOTO 1. NOTE LACK OF RUGOSITY OF SURFACE.

On analysis, many of the study sections did not show a positive benefit/cost ratio. This indicates some deficiencies in the original criteria for identification of problem sections. The problem sections were identified, to some extent, by numbers of accidents and more particularly by the occurrence of fatal accidents. Both the length and traffic volumes for sections cover a wide range and therefore rates rather than numbers must be considered in order to identify a problem section. The accident rate severity will be accounted for in the per mile cost of the accidents.

The sections returning the highest benefit/cost ratios (both in estimated benefits using the criterion developed in this study and in actual cases where treatment has been done) were 2-lane sections of good geometric design where the pretreatment wet to dry ratio was high and the number of dry road accidents low. Wider sections, whether multi-lane or dual, should prove more difficult to justify resurfacing in that the numbers of accidents may be significant, but the increased width doubles the per mile cost of the remedial treatment and reduces the benefit/cost ratio.

There are some problems inherent in the benefit/cost analyses that tend to show up in marginal cases. If the section is short the numbers may be small and one must then be concerned about their statistical validity. On the other hand, if the section is long the traffic volume and the road surface may vary widely within the section. In this latter case the accident records should be examined in detail to determine whether the accidents are concentrated in particular areas so that treatment of a part of the section or spot treatment of identifiable hazardous areas can be done at a high benefit/cost ratio.

A number of the control sections forming the study sections received anti-skid surfaces in 1972. The 1973 and, in some cases, the 1974 accident data are now available. Considering the year-to-year variation that may be expected, the results are equal to or slightly better than was used for benefit/cost calculations. Photos 3 and 4 illustrate the general view and close-up of an excellent seal coat on a 2-lane road in rolling terrain employing slag aggregate. Photos 5 and 6 are general and close-up views of a similar surface to photos 3 and 4 on a dual highway in rolling terrain.

Photos 7, 8, 9 and 10 illustrate general and close-up views of effective seal coats employing lightweight manufactured aggregate. Photo 11 illustrates the texture of a new open-graded hot mix surface made with non-polishing aggregate.

Of the 36 control sections studied, three have been unloaded by completion of interstate highway links and one more will be. Nine more sections were considered to be in need of upgrading. Eight of these sections are in fact either rebuilt or currently under construction. Table 7 is a summary table of the analysis of all the control sections with pertinent remarks. All sections showing high benefit/cost ratios for frictional renewal have been treated. For sections treated in 1972 the 1973 accident data confirm the high economic returns.

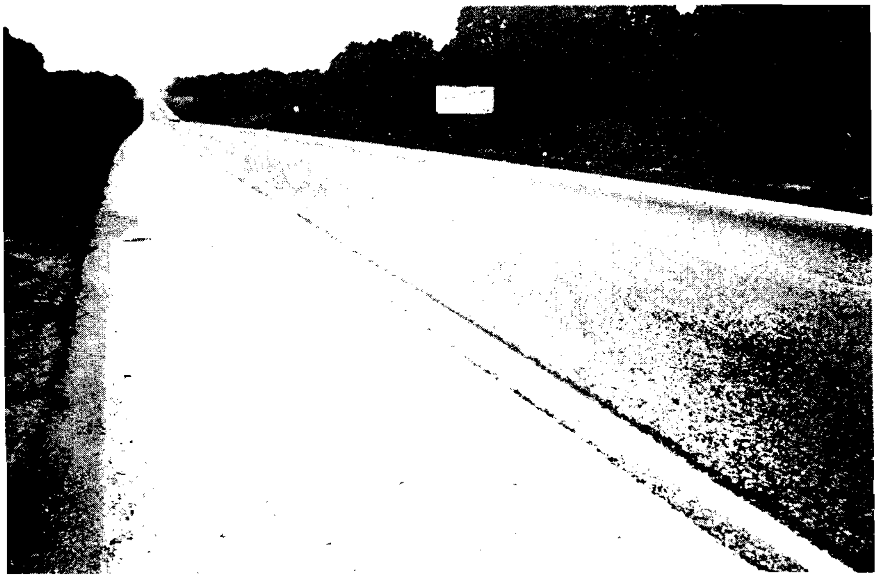

PHOTO 3. SEAL COAT OF SLAG COVER STONE ON 2-LANE ROAD IN ROLLING TERRAIN THAT HAD EXPERIENCED A WET WEATHER ACCIDENT PROBLEM.

PHOTO 4. CLOSE-UP VIEW OF SURFACE IN PHOTO 3. NOTE THE VESICULAR NATURE OF THE AGGREGATE PARTICLES.

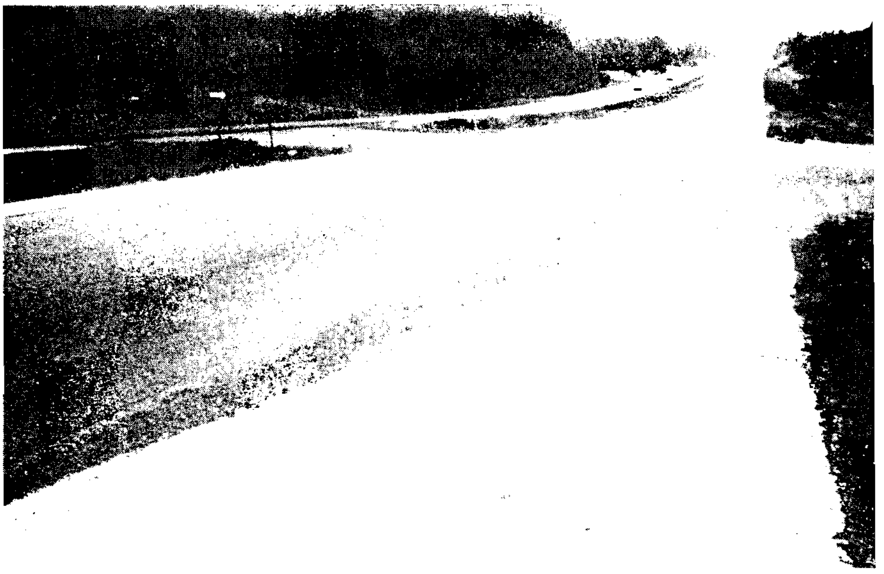

PHOTO 5. A SEAL COAT OF SLAG ON A DUAL HIGHWAY WITH CONTRASTING PAVED SHOULDERS.

PHOTO 6. A CLOSE-UP OF THE SURFACE FROM PHOTO 5. THOUGH THE SURFACE IS 3 YEARS OLD THE INDIVIDUAL PARTICLES MAINTAIN THEIR SURFACE ROUGHNESS.

PHOTO 7. SEAL COAT ON DUAL HIGHWAY WITH LIGHTWEIGHT AGGREGATE COVERSTONE.

PHOTO 8. CLOSE-UP OF SURFACE IN PHOTO 7. ALTHOUGH SOME DEFECTS OF UNDERLYING SURFACE ARE APPARENT IN PHOTO 7, A GOOD ANTI-SKID TEXTURE IS MAINTAINED.

PHOTO 9. A 2-LANE HIGHWAY OF EXCELLENT SECTION AND MODEST TRAFFIC VOLUME SEAL COATED BECAUSE OF WET-WEATHER ACCIDENTS.

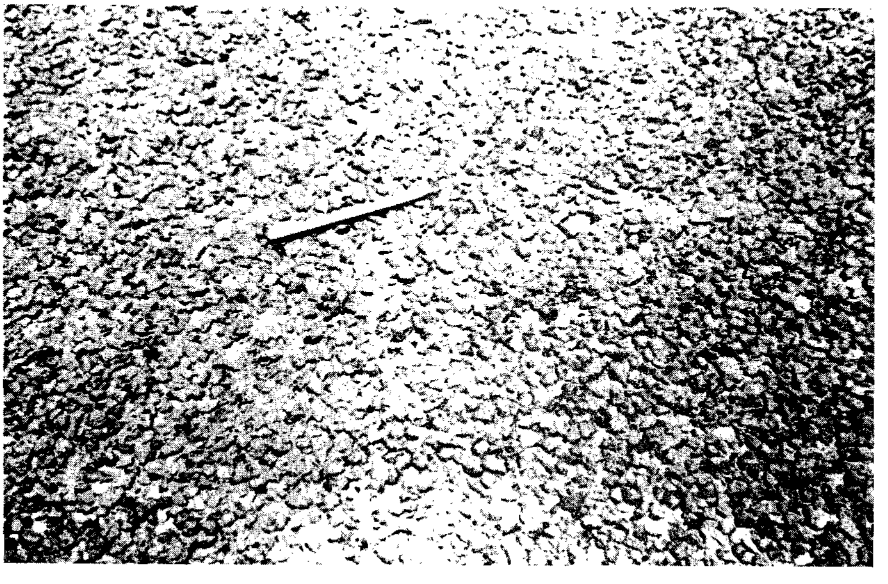

PHOTO 10. CLOSE-UP OF SURFACE IN PHOTO 9 SHOWING EXCELLENT TEXTURE WITH LIGHTWEIGHT COVERSTONE.

PHOTO 11. A CLOSE-UP VIEW OF THE TEXTURE OF A RECENTLY PLACED OPEN GRADED HOT MIX SURFACE. THE AGGREGATE IS A NONPOLISHING SANDSTONE.

SECTION	INTERSTATE LINK	NEEDS REBUILD	B/C RATIO LONG LIFE	B/C RATIO SHORT LIFE	OHIO CRITERIA	SN_{40}	REMARKS
FM P-1				4.0	+ve	40(1975)	Sealcoat 1973-B/C 4.0 actual
FM E-4		X			+ve		Urban industrial overloaded
US H-1		X	1.2		+ve	27	Being rebuilt on new location
US I-1	Yes Unloaded				nd		Seal coated
US H-2		X		4.6	+ve	28	Being rebuilt
SH I-4			1.2	4.0	-ve	Unk	Seal coated-No full year accident red.avail
SH P-3				3.5	nd	31(1975)	Seal coated-Capital recovery first yr.
US P-2				6.9	+ve		Seal coated-Results better than prediction
SH E-5		X			±ve		Non-homogeneous section being rebuilt
US A-1			1.4	3.36	nd	55(1975)	N. bound seal 1972 S. bound seal 1975
US B-1			0.9	2.2	+ve	27(Orig)	Seal coated-No post-treatment data
US C-2				0	-ve		Low rates. Needs full freeway for volume.
FM E-3		Done		1.3	-ve		Road expanded High traffic growth
US E-1		Done			nd		Upgraded to dual
FM I-5				4.0	+ve	59(1975)	Seal coated-results as predicted
SH D-3		X			-ve		Non-homogeneous, being rebuilt
US I-3				<1	-ve	39	Speed zone short section
US E-2		X		1.7	-ve	28	Rebuild 1975

TABLE 7.

SECTION	INTERSTATE LINK	NEEDS REBUILD	B/C RATIO LONG LIFE	B/C RATIO SHORT LIFE	OHIO CRITERIA	SN_{40}	REMARKS
US D-1			1.4		nd	28	
SH F-1				<1	-ve	Unk	Intersection and fog
US N-1				3.4	nd	Unk	Critical section rebuilt
US K-2	Yes Unloaded				nd		
US M-1		X			-ve		Upgraded to dual
SH A-2			1.8		nd		Seal coated
SH H-3				0.7	nd	28(Orig)	Seal coated
US G-1				0	nd		Resurfaced-structural
US K-1	Yes			0.1	-ve		No justification for temporary surface
SH I-2				0.5	nd	37	not critical
US C-1				0	-ve	Unk	Rates low - Volume high
US F-2				0	nd	Unk	Bleeding
US D-2	Yes Unloaded			0	nd		
US E-6				0	nd	32	Seal coat 1975
FM J-1				0	nd	Unk	Rates low
US D-4				0.2	nd	45	Rebuild short section 1975 - Rates low
US L-1				0	nd	Unk	No problem
FM C-3				0.4	nd	Unk	Low Rates - fog

+ve - Meets Ohio criteria -ve - Does not meet Ohio criteria nd - Not defined in Ohio criteria-accidents/mile too low

TABLE 7 (continued).

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

1. A method has been developed for estimating the benefit/cost ratio of treatments to reduce wet road accidents.

2. The method has been developed fully only for those road sections with adequate geometric design where low pavement friction is the identifiable problem.

3. A step-by-step procedure was developed in Chapter IV to allow the selection of appropriate treatment whether or not a road section is adequate. A benefit/cost study may be made at various stages, as appropriate, within the step-by-step procedure.

4. It is concluded that no single value of surface friction (SN_{40}) can be selected as critical. Alignment, topography, access points, and ratio of capacity to volume have been identified as affecting the friction value at which wet road accidents become disproportionate to dry road accidents.

5. For study sections in East Texas it was estimated that the number of wet road accidents should not be greater than one quarter the number of dry road accidents if the wet road friction is adequate. The basis for this criterion was developed in Chapter IV, pages 23 and 24. The results achieved in a number of sections that had surfaces renewed tend to confirm this criterion. For areas with significantly different climate, a different estimating factor would need to be developed. This could readily be done considering regional data. For instance, for some areas of West Texas the number of wet accidents should normally not exceed one-eighth the number of dry road accidents.

6. Very high benefit/cost ratios may be realized when good two-lane roads with adequate capacity have their surface friction renewed. Wider roads, costing more to surface, may not yield such high benefit ratios.

7. There is no particular advantage in using accident severity in determining whether a road section is critical. Rather, it is better to deal only with accident rates and to introduce severity only at the stage of determining the economic cost of the accidents.
8. The benefit/cost relationship can be a powerful tool in identifying appropriate treatments and setting priorities for dealing with sections identified as having a wet road accident problem.
9. There is general agreement with the Ohio criteria for resurfacing. However, sections with too few accidents to meet the Ohio criteria will return a positive benefit/cost ratio if the wet-to-dry accident ratio is high.
10. All of the sections determined to be inadequate or showing a high benefit/cost ratio for surface renewal have been or are currently being treated, indicating that the present Texas priority programming is effective.
11. The cost per lane mile of wet road accidents is a logical index for automatic calculation in annual accident summaries. It provides a value for rapid comparison with the annual cost per lane mile of a standard remedial treatment.

Recommendations

1. The following steps are recommended as the procedure to identify road sections with wet road accident problems to be analyzed for action:
    a. Select sections with high ratios of wet road to overall accident rate.
    b. Eliminate from the selection those sections whose accident rates per hundred million vehicle miles are low.
    c. Eliminate from the selection those low volume sections having very small numbers of accidents that are statistically unreliable. The number of accidents per mile may be used as a guide.

d. For the remaining sections develop wet road accident costs and costs/mile, or alternatively proceed directly from step "a" to calculation of wet road accident cost per lane mile.

2. Use the flow chart developed in Chapter IV, Figure 4, to select appropriate treatments and perform benefit/cost analyses at appropriate stages.

3. Only nonpolishing aggregates should be used for surface courses. The necessary polish resistance can be related to the volume of traffic using the particular roadway. In the case of hot mix pavements a sprinkle treatment may be used to minimize the required quantity of nonpolishing aggregate.

4. Seal coats should not be placed routinely over existing seal coats or surface treatments. Excessive embedment of the cover aggregate and/or bleeding may result, rendering the treatment ineffective. Only if it is determined that these problems are unlikely for a given section should a seal coat be used. Photos 12 and 13 are a general view and a close-up view of a surface only two years old, illustrating excessive embedment. The effective life of the treatment is being reduced.

5. Seal coats should not be used as treatments at such sites as signalized intersections where the high shear of braking and acceleration will remove coverstone leaving a slick surface (13).

6. Seal coats are not recommended over nonuniform surfaces where the binder demand will be different from place to place. Further, any surfaces requiring repair work before seal coating should have this work done well in advance of the date for seal coating.

PHOTO 12. GENERAL VIEW OF SEAL COAT SURFACE PLACED OVER A SEAL COAT SHOWING STREAKING IN WHEEL PATHS.

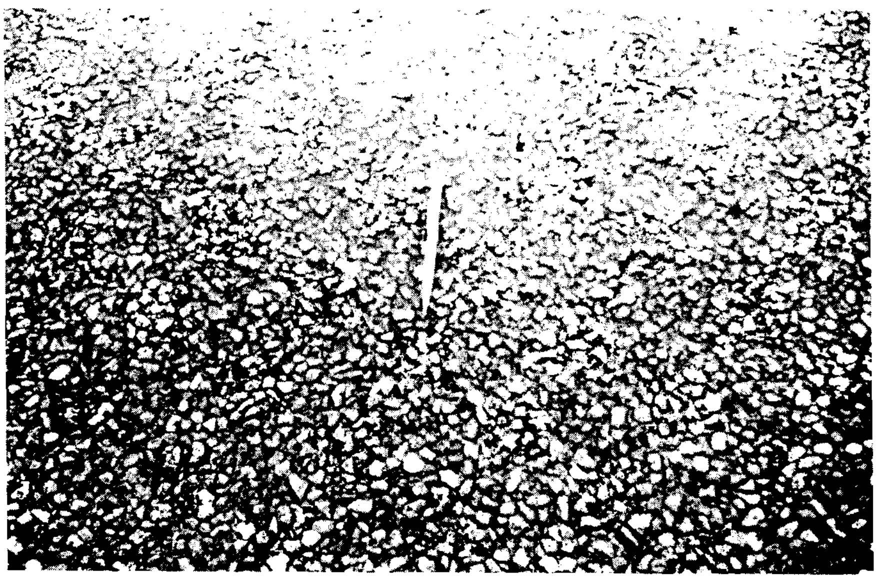

PHOTO 13. CLOSE-UP OF TEXTURE SHOWN IN PHOTO 12. EXCESSIVE EMBEDMENT LEAVES FEW PARTICLES IN BOLD POSITION SUBJECT TO EARLY POLISHING.

7. Sections identified as having high wet road accident rates but having good friction values require detailed engineering study to identify problems, potential treatments, and probable benefits.
8. A special accident data system should be set up to record the effectiveness of surface friction renewal so that the criterion used in this study of one wet road accident to four dry road accidents may be confirmed or modified.
9. The SDHPT computer program for calculating annual tabulations and rates of accidents should be modified to calculate and print out automatically the wet road accident costs per lane mile for each control section. This would provide an index for very rapid identification of critical study sections and an input for benefit/cost analyses.
10. Burke's accident cost values should be updated. A simple method of updating would be to use an inflation modifier. For instance, if we assume that inflation from 1969 (the date of the data used by Burke) has been at an 8% annual rate, the inflation factor to year 1975 would be $1(1+.08)^6 =$ 1.59. An adjustment of this magnitude would affect the benefit/cost ratios significantly, unless a corresponding increase in resurfacing costs occurred.
11. Consideration should be given to renewing surfaces of study sections with benefit/cost ratios less than unity if the friction values are very low. The cost figures used in analysis measure only direct economic costs and not indirect costs or total societal costs of crippling injuries and fatalities.
12. When a control section is identified as being a critical wet road accident section, the details of the accidents should be examined. For instance, one study section over seven miles long with adequate friction values had eight of eleven wet road accidents at one intersection and the

adjacent half-mile of developed roadside. Speed zoning with enforcement in this short section should return a high benefit/cost ratio. Another section had accidents clustered at an intersection and occurring in fog. Flashing beacons at the intersection should be effective in providing advance warning to drivers.

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APPENDIX A

BENEFIT/COST ANALYSES OF CONTROL SECTIONS

Each of the study sections was analysed for benefit from improvement of the wet road friction. The sections were considered in order of their rank by accident cost per mile. Notes regarding the sections were added where pertinent. In cases where the information clearly indicated that low pavement friction was not the problem, no analysis of benefit from surfacing was made. Rather, an identification of the problem was attempted.

1. FM P-1 5.23 miles

1971 Accidents - 24 wet, 11 dry

Wet accident cost/mile	$15,495	
SN_{40} - 1971 mean value	20	
ADT	2900	
Surface - 2 lanes	22'	

Calculations

Expected wet accidents	3	
Annual benefit 21/24 x 15,495	$13,558	per mile
Cost - Long life at $1.50/yd^2	19,360	per mile
Annual cost (15 yr)	2,262	
Short life at 0.35/yd^2	4,517	per mile
Annual cost (5 yr)	1,132	per mile

Benefit/Cost Ratio -	Long Life	6.0
	Short Life	12.0

Note: In 1971 an armed service base adjacent to the section closed, changing the nature of the traffic and turning movements so that wet road accidents dropped to 9 in 1972. In 1973 a high friction seal coat was placed, increasing the SN_{40} mean value to 40. The 1973 and 1974 wet weather accidents were 2 and 1, respectively. The traffic volume had increased slightly and the dry road accidents increased to 15 in 1974.

Then, assuming that the 1972 costs were (9/24) x 15,495 or $5,810 per mile and the savings were 7/9 of this or $4,519 per mile as a result of the seal coat, the B/C ratio for the actual treatment was 4519.1132 = 4. Note that the benefit was sufficient to recover the capital cost in the first year.

2. FM E-4 3.70 miles

1971 Accidents - 15 wet, 26 dry

Wet accident cost/mile	$13,689
SN_{40} - Variable, worst section mean value	31
ADT	6,000-8,400
Surface - 2 lanes	

B/C ratio for antiskid treatment was not calculated. This section is basically urban industrial with high turning movements and high truck traffic. A short life (seal coat) treatment would probably not stand up to the type of traffic while a long life treatment is not appropriate because the section requires additional lanes. The problem is evaluated as capacity rather than friction, and friction improvement would yield only minor benefits. This tentative evaluation regarding capacity was made on the basis of total volume, high truck percentage, large number of access points, and high turning movements.

3. US H-1 8.75 miles

1971 Accidents - 65 wet, 142 dry

Wet accident cost/mile	\$13,637
SN_{40} - mean values	26 & 27
ADT	22,000
Surface - 4 lanes 4 lanes divided	48'

Calculations

Expected wet accidents	36
Annual benefit (29/65) x 13,637	\$6,084 per mile
Cost - Long life at \$1.50/yd^2	\$42,240 per mile
Annual cost (15 years)	\$4,935 per mile
B/C ratio	1.2

On calculation this section shows a positive benefit from friction improvement. It also meets the Ohio criteria for resurfacing. However, the section has a number of heavily used entrances to a military base at one end with the remainder being continuous urban development with innumerabale conflicts between through and local traffic. Therefore, the benefits from friction improvement are probably overstated and, in any case, the dry-road accident rate is undesirably high. Only a relocation of the route to separate the functionally different traffic is an adequate treatment and such a treatment is in progress.

4. US I-1 9.59 miles

1971 Accidents - 44 wet, 99 dry

Wet accident cost/mile	\$13,105
SN_{40}	Unknown

ADT	8,000
Surface - 2 lanes, earth shoulders	26'

Note: No B/C calculations were made. This section was serving as a link for an incompleted section of interstate highway and loaded beyond capacity. Following completion of the interstate, the section was seal-coated in 1972 and produced a satisfactory wet road accident rate in 1973.

5. US H-2 5.59 miles

1971 Accidents - 16 wet, 30 dry

Wet accident cost/mile	\$12,225
SN_{40} - 1973 mean value	28
ADT	11,000
Surface - 2 lanes, with 9' paved shoulders	26'

Calculations

Expected wet accidents	8
Annual benefit (8/16) x \$12,225	\$6,112 per mile
Cost - short life at 0.35/yd^2	\$5,340 per mile
Annual cost (5 yr)	\$1,337 per mile
Annual cost (3 yr)	\$2,072 per mile
B/C ratio (5 yr)	4.6
B/C ratio (3 yr)	2.9

Note: Meets Ohio criterion for resurfacing. The road is obviously loaded beyond rated capacity. Calculations were made for the hypothetical case of delayed major upgrading and probably overestimate the benefits for an overloaded facility.

In the real case, major reconstruction is in progress. The hypothetical case illustrates the potential benefit of short term temporary expedient.

6. SH I-4 4.36 miles

1971 Accidents - 16 wet, 49 dry

Wet accident cost/mile	$11,735
SN_{40}	Unknown
ADT	4,400

Surface - 2 lane, 24' with 10' paved shoulder

Calculations

Expected wet accidents	12
Annual benefit - (4/16) x $11,735	$2,934 per mile
Cost - long life at 1.50/yd^2	$21,120 per mile
Annual cost (15 yr)	$2,467 per mile
B/C ratio	1.2

Note: Because the cross section is adequate to accommodate some traffic growth, the economics for long life treatment were calculated. A seal coat effective for five years would yield a B/C ratio of 2.4. In the actual case, a seal coat was placed in midyear 1973 reducing 1973 wet accidents to 12. The year 1973 was one of the heaviest rainfalls on record, and no other improvements were undertaken. Thus, our criteria may be underestimating benefits when a road with spare capacity is involved.

7. SR P-3 5.69 miles

1971 Accidents - 11 wet, 8 dry

Wet accident cost/mile	$11,557
SN_{40}	Unknown
ADT	2,800

Surface - 2 lanes, 26' with 9' paved shoulders

Calculations

Expected wet accidents	2
Annual benefit - (9/11) x $11,557	$9,456 per mile
Cost - long life at 1.50/yd^2	$22,880 per mile
Annual cost (15 yr)	$2,673 per mile
B/C ratio	3.5

Note: Because the section is adequate to accommodate traffic growth, the benefits of a long life treatment were calculated. In the actual case a seal coat was applied in midyear 1972 - the result being 3 in 1972, 6 in 1973 and 4 in 1974. Although this is a significant accident reduction, the wet accidents are not reduced to the expected extent and one might ask why. Three reasons may be postulated. First the seal coat was placed over an existing seal coat and the degree of aggregate imbedment was greater than optimum so that the wet road friction did not remain as high as desirable. Second, the number of private entrances along the route is sufficient to create above-normal conflicts. Third, the rainfall in the district in 1973 and 1974 was abnormally high.

The actual cost of the treatment was $3,575 per mile while the accident benefits in 1973, the worst year following treatment, were $4,298. Thus, the treatment has been very cost effective even though the wet road accidents are above our expected number.

The section did not meet the Ohio criterion for resurfacing.

8. US P-2 6.78 miles

This section was used in Chapter IV to illustrate the benefit/cost analysis.

Later information became available that the actual treatment included shoulders at a total cost of $5,011 per mile and that the 1974 wet road accidents were only one. The very high benefit/cost ratio is confirmed.

9. SH E-5 5.95 miles

This section was not analyzed because the cross section, the surface, the friction values and the traffic are widely variable. The deficient section in which a large proportion of all the accidents occur is currently under construction for major upgrading.

10. US A-1 6.89 miles

1971 Accidents - 8 wet, 4 dry

Wet accident cost/mile	$8,074
SN_{40}	Unknown
ADT	$4,500

Surface - dual 24' pavements, 10' paved shoulders.

Calculations

Expected wet accidents	1
Annual benefit (7/8) x $8,074	$7,065 per mile
Cost - long life at $1.50/yd	$42,240 per mile
Annual cost (15 yr)	$4,935 per mile
B/C ratio	1.4

Note: This section does not meet the Ohio criteria for resurfacing. However, the very high ratio of wet-to-dry accident rates indicates a friction problem. The analysis shows a positive benefit/cost ratio for long life treatment which was used in calculations because of the adequate geometrics. Because of the small numbers of accidents, the year-to-year variation may be large.

In fact, the northbound roadway was given a high-friction seal coat in 1972 with good results. The southbound roadway requiring leveling and structural improvement was treated in early 1975.

11. US B-1 11.35 miles

1971 Accidents - 33 wet, 53 dry

Wet accident cost/mile	$7,548
SN_{40} - mean value	27
ADT	13,000

Surface - 4 lanes, divided, paved shoulders

Calculations

Expected wet accidents	13
Annual benefit (20/33) x 7,548	$4,575 per mile

Cost - long life at $\$1.50/yd^2$ — $42,240 per mile

Annual cost (15 yr) — $4,935 per mile

B/C ratio — 0.92

Note: For short life treatment at $35¢/yd^2$, the benefit/cost ratio is 2.2. In the actual case, a high friction seal coat has been applied at a cost of $26¢/yd^2$ which should yield a good return on investment. This section meets the Ohio criteria for resurfacing.

12. US C-2 5.94 miles

1971 Accidents - 19 wet, 190 dry

Wet accident cost/mile	$7,428
SN_{40}	Unknown
ADT	$43,000

Surface - dual roadways, 4 lanes

Calculations

No calculations were performed. The wet road accident rate is very nearly the same as the dry rate indicating no wet road problem. The section ranks number 1 in total accident costs per mile. The accidents probably cannot be reduced except by converting the road to full freeway standards.

13. FM E-3 11.94 miles

1971 Accidents - 13 wet, 40 dry

Wet accident cost/mile	$7,307
SN_{40} - 1971 values	Unknown
ADT	$4,400

Surface - 2 lanes 26', paved 8' shoulders

Calculations

Expected wet accidents	10
Annual benefit (3/13) x $7,307	$1,686 per mile
Cost - short life at 35¢/yd^2	$5,339 per mile
Annual cost (5 yr)	$1,337 per mile
B/C ratio	1.26

Note: The actual section had the paved shoulders added in 1971 and the surface renewed. Wet road accidents fell to 6 in 1972 and have now returned to the 1971 level. In the meantime, the traffic has grown very rapidly and the number of dry accidents more than doubled so that the ratio of wet to dry has remained good. This section did not meet the Ohio criteria for resurfacing.

14. US E-1 10.29 miles

1971 Accidents - 15 wet, 21 dry

Wet accident cost/mile	$6,590
SN_{40} - 1971 values	Unknown
ADT	4,000-7,500
Surface - dual, 4 lanes	

Calculations

Expected wet accidents	5

Note: In 1971 this section was being upgraded and new pavements placed as required. The wet road accidents have since remained in the expected range. This section did not meet the Ohio criteria for resurfacing.

15. FM I-5 11.54 miles

1971 Accidents - 30 wet, 44 dry

Wet accident cost/mile $6,546

SN_{40} - 1971 values Unknown

ADT 1,330 - 4,200

Surface - 2 lane 20' and 4 lane 48'

Calculations

Expected wet accidents 11

Annual benefit (19/30) x $6,546 = $4,146 per mile

Cost - short life (20' wide) at 35¢/yd^2 = $4,106 per mile

Note: Logical calculations for the non-homogeneous section are not straight forward. In the actual case, the 6.5 mile section 20' wide was seal coated in 1972 reducing 1973 wet accidents to 11. This work has returned a very high benefit/cost ratio. The section met the Ohio criteria for resurfacing.

16. SH D-3 8.94 miles

1971 Accidents - 16 wet, 20 dry

Wet accident cost/mile $5,723

SN_{40}- variable by sections - generally low

ADT 4,140

Surface - variable - 2 lanes 22', earth shoulders to dual

Calculations: No calculations were made for this non-homogeneous section, some parts of which , below the desirable standard for the traffic, are currently being upgraded. The high ratio of wet to dry accidents indicates that surface renewal should be included for the entire section.

17. US I-3 7.12 miles

1971 Accidents - 11 wet, 32 dry

Wet accident cost/mile	$5,603
SN_{40} - mean values	38 and 39
ADT	4,600
Surface - 4 lanes, 44'	

Calculations

Expected wet accidents	8

Note: The number of wet-road accidents is only slightly above the expected value and the SN_{40} values are not critical. A study of detailed data indicates that nearly all accidents occur at one intersection and an adjacent half mile of developed roadside. Speed zoning of the critical area is recommended along with driveway controls in the area of developed roadside.

18. US E-2 10.48 miles

1971 Accidents - 9 wet, 25 dry

Wet accident cost/mile	$5,357
SN_{40} - mean value 1971	Unknown
ADT	3,800
Surface - 2 lanes, 20', unpaved shoulders	

Calculations

Expected wet accidents	6
Annual benefit (3/9) x $5,376 =	$1,786 per mile
Cost - short life at 35¢/yd^2 =	$4,106 per mile
Annual cost (5 yr) =	$1,029 per mile
Annual cost (3 yr) =	$1,593 per mile

Note: The calculations indicate that a temporary friction course would be cost effective even for such a short period as 3 years. However, the section warrants upgrading and will be widened to 26' pavement with paved shoulders in 1975. Both wet road and total accident experience should improve.

19. US D-1 12.17 miles

1971 Accidents - 19 wet, 25 dry

Wet accident cost/mile	$5,336
SN_{40} - current - mean	≃ 20
ADT	2,500

Surface - 2 lanes, 26', 10' earth shoulders

Calculations

Expected wet accidents	6
Annual savings (13/19) x $5,336	= $3,650 per mile
Cost - long life at $\$1.50/yd^2$	= $22,880 per mile
Annual cost (15 yr)	= $2,673 per mile
B/C ratio	1.36

Note: Calculations were based on long-life treatment because the section can accommodate some traffic growth except for a very short section within the city which needs widening. A less costly surface with shoulder paving would probably also show a positive return. This section is a good example of a positive benefit when the wet/dry ratio is high. The section does not meet the Ohio criteria.

20. SH F-1 8.93 miles

1971 Accidents - 8 wet, 30 dry

Wet accident cost/mile $5,268

SN_{40} Unknown

ADT 1,600

Surface - 2 lanes, 24', 5' sod shoulders

Note: The wet-road accidents are in the expected range indicating that no great benefit can be expected by treating the section as a wet-friction problem. The section ranks much higher on total accident costs than on wet-road accident costs. Three of the five injury accidents occurring on wet roads were at one intersection and in fog. A flashing beacon at this intersection might prove beneficial.

21. US N-1 10.0 miles

1971 Accidents - 16 wet, 12 dry

Wet accident cost/mile $5,117

SN_{40} Unknown

ADT 1,600

Surface - 2 lanes, 20' , caliche shoulders 7'

- 2 lanes, 24' , paved shoulders 5'

Calculations

Expected wet accidents 3 or fewer

Annual benefit (13/16) x $5,117 = $4,158 per mile

Cost - short life at 35¢/yd^2 = $4,928 per mile (24' pvt)

Annual cost (5 yr) = $1,234 per mile

B/C ratio 3.4

Note: Only a short-life treatment was used in calculation because the section will be replaced by Interstate highway.

In the actual case, a complete reconstruction was done partly on a new location. Since most of the wet-road accidents occurred on one critical half-mile stretch, a resurfacing of that half-mile would have returned a very high benefit/cost ratio had it been necessary to delay the reconstruction.

Interestingly, in the same low-rainfall area, a section suddenly developed 9 wet-weather accidents in one month. It was resurfaced at a cost of $30,000 reducing the wet-weather accidents in the following year to only one for an accident benefit of over $21,000 in the single year.

22. US K-2 5.77 miles

1971 Accidents - 6 wet, 8 dry

Wet accident cost/mile	$4,999

Note: No analysis was made. In 1971 the section was under construction as a link in an Interstate highway and the accidents were increased. Since completion, only 1 wet-road accident per year has occurred.

23. US M-1 12.17 miles

1971 Accidents - 11 wet, 13 dry

Wet accident cost/mile	$4,698
SN_{40}	Unknown
ADT	6,200
Surface	Changed

Calculations: The road was re-built from a 2-lane to a dual highway and the wet-road accidents were reduced to 1 and 2 in succeeding years.

24. SH A-2 16.52 miles

1971 Accidents - 9 wet, 33 dry

Wet Accident cost/mile	\$3,918
SN_{40}	Unknown
ADT	3,800

Surface - 2-lane 26' - 9' paved shoulders

Calculations:

Expected wet accidents	8	

∴ No apparent benefit (section selected because of high fatality rate), but in 1972, wet accidents increased to 19.

Annual benefit 11/19 x 19/9 x 3,918	\$4,788 per mile	
Cost - Long life at \$1.50/yd	22,880 per mile	
Annual Cost (15 yr)	2,673 per mile	
B/C ratio		1.8

Note: While the cross section is excellent for the traffic volume the terrain is rolling which increases friction demand.

In the real case, a high friction seal coat was applied in 1973 at a cost of \$4,052 per mile yielding on the basis of the above calculations a B/C ratio for 5 year life of 4.7. The 1974 wet accidents were actually reduced to 5 so the true B/C ratio is very high. The section did not meet the Ohio criteria for resurfacing.

25. SH H-3 13.14 miles

1971 Accidents - 8 wet, 23 dry

Wet accident cost/mile	\$3,580
SN_{40} - mean value	28

ADT 2,720

Surface - 2 lanes, 26', 11' paved shoulders

Calculations

Expected wet accidents 6

Annual benefit (2/8) x \$3,580 = \$895 per mile

Cost - short life at 35¢/yd^2 = \$5,340 per mile

Annual cost (5 yr) = \$1,338 per mile

B/C ratio 0.67

Note: The section does not return a positive benefit. However, since the cross-section is very good in relation to the traffic volume and the wet time is low the results might be better than calculated. Further, at the low volume the treatment may last longer than 5 years. In the actual case, the section was given a high-friction seal coat in early 1975.

26. US G-1 17.53 miles

1971 Accidents - 10 wet, 39 dry

Wet accident cost/mile \$3,232

SN_{40} Unknown

ADT 3,200

Surface - dual 24' pavements, 10' & 6' shoulders

Calculations

Expected wet accidents 10

Annual benefit 0

Note: Because of the excellent cross-section for the low volume and the low rainfall in the area a lower wet accident rate might have been expected. In the actual case, the road was resurfaced in 1972. The 1973 wet accidents were only four in number. The saving of $1,940 per mile would pay the incremental cost of a high-friction aggregate.

27. US K-1 12.69 miles

1971 Accidents - 28 wet, 104 dry

Wet accident cost/mile	$3,166
SN_{40} - mean values	26 & 27
ADT	15,000 - 20,000

Surface - 4 lanes, 10' paved shoulders

Calculations

Expected wet accidents	26

Annual savings - (2/28) x $3,166 = $226 per mile

Note: Potential saving in wet-weather accidents is below the cost of the most economical temporary surface improvement.

The section is serving an uncompleted link of Interstate highway and while the number of accidents is high, the rates are low. Temporary treatment before completion of the Interstate highway does not appear to be justified.

28. SH I-2 15.77 miles

1971 Accidents - 7 wet, 20 dry

Wet accident cost/mile	$2,951
SN_{40} - mean value	37
ADT	1,460

Surface - 2 lanes, 30', gravel shoulders - 10'

Calculations

Expected wet accidents	5

Annual savings (2/7) x \$2,951 = \$843 per mile

Note: The accident rate is modest and the friction is not critical. The crashes are not concentrated in location. No remedial action is recommended.

29. US C-1 34.58 miles

1971 Accidents - 15 wet, 165 dry

Wet accident cost/mile	\$2,706
SN_{40}	Unknown
ADT	18,000

Surface - dual 24' with 10' & 6' shoulders

Note: This section is not a wet-road problem. The wet-to-total-rate ratio is about 1 and the total accident rate is modest. No treatment is required.

30. US F-2 19.16 miles

1971 Accidents - 5 wet, 26 dry

Wet accident cost/mile \$1,927

SN_{40} - Unknown

ADT 6,500

Surface - 2 lanes 24', shoulders 8' paved

Note: The number of wet road accidents is in the expected range. This section of road has a bleeding surface and the wet-road friction must be low. The section is very flat and straight without access points marking the friction demand low so the accident rate is low in spite of the apparently unsatisfactory surface. The accident severity is high because of high speeds.

31. US D-2 17.5 miles

1971 Accidents - 6 wet, 32 dry

Wet road accident cost/mile	$1,648
SN_{40} - Unknown	
ADT	700

Surface - 2 lane 24', 10' paved shoulders

Note: No analysis of this section was made as it is not basically a wet-friction problem. The section may have been selected on the basis of 1970 data. At that time, it was serving as a link in an incompleted interstate highway with long sections of freeway in either direction. Unsafe passing in the rolling terrain created a high accident and high severity rate at that time when the ADT was above 6500 vpd.

32. US E-6 12.84 miles

1971 Accidents - 7 wet, 30 dry

Wet accident cost/mile	$1,618
SN_{40} - mean value	32
ADT	5,000

Surface - 2 lane 26', shoulders 8' paved

Note: The number of wet accidents is in the expected range. Small amounts of money from maintenance funds have been spent judiciously to improve the surface in critical areas of high friction demand or where non-crash incidents have provided warning. For structural reasons, the entire section will be seal coated in 1975. Use of a high-friction aggregate may reduce the wet road accidents even further.

33. FM J-1 13.25 miles

1971 Accidents - 3 wet, 11 dry

Wet accident cost/mile $1,412

SN_{40} - Unknown

ADT 720

Surface - 2 lanes 20' and 18' - 2' shoulders

Note: Accident rates are low. Traffic volume is too low to polish the aggregate. Numbers are too small to be stable. Section was probably included because of two fatalities both of which occurred when vehicles left the roadway and struck private entrances. Any expenditures might best be applied on widening the section within the village.

34. US D-4 16.43 miles

1971 Accidents - 9 wet, 22 dry

Wet accident cost/mile $1,327

SN_{40} - mean value above 40

ADT - 3500 mean, 2300-4660 range

Surface - 2 lane 24' with 9' paved shoulders, dual 26' pavements with 9' paved shoulders

Note: Ratio of wet accident rate to dry is not very high and the rates are both low. The wet friction number is high except for a one-mile section within a village with a mean value in the mid-thirties. That section is currently being widened and upgraded. Fatal accidents probably influenced the inclusion of the section.

35. US 1-1 15.81 miles

1971 Accidents - 2 wet, 8 dry

Wet accident cost/mile	$1,151
SN_{40}	Unknown
ADT	1400

Surface - 2 lane 26', shoulders 8' paved

Note: Accident rates are low and numbers too small to be stable. The section was probably included because of fatalities but the 2 accidents and fatalities involved a single incident where one vehicle struck a previously crashed vehicle.

36. FM C-3 28.11 miles

1971 Accidents - 10 wet, 18 dry

Wet accident cost/mile	$ 794
SN_{40}	Unknown
ADT	1500

Surface - 2 lanes 24', earth shoulders

Note: While the ratio of wet-to-dry accidents is somewhat high, the rate is low as indicated by the low cost per miles. A number of the crashes occurred in fog. In 1972 and 1973 the wet road accidents dropped to 3 without any road alterations. This illustrates the instability of the numbers when the numbers are small or the number of crashes per mile is low.

APPENDIX B

1971 ACCIDENT TABULATION

DISTRICT	TOTAL	WET	DRY	WET % OF DRY	DRY	WET
1	2095	543	1552	35	1552	543
2	3013	598	2415	25	2415	598
3	1219	179	1040	17	1040	179
4	1572	151	1421	11		
5	2180	180	2000	9		
6	1215	141	1074	13	1074	141
7	1001	159	842	19		
8	1403	200	1203	17		
9	2877	589	2288	26	2288	589
10	2662	593	2069	29	2069	593
11	2180	420	1760	24	1760	420
12	7424	1217	6207	20	6207	1217
13	2169	389	1780	22	1780	389
14	3417	601	2816	21	2816	601
15	3110	566	2544	22		
16	2323	345	1978	17	1978	345
17	2270	404	1866	22	1866	404
18	2969	533	2436	22		
19	1718	363	1355	27		
20	3018	661	2357	28	2357	661
21	2003	311	1692	18	1692	311
22	614	69	545	13		
23	1373	245	1128	22	1128	245
24	696	47	649	7		
25	866	69	797	8		
	55,387	9573	45,814		32,022	7236
		21% of Dry				23% of Dry