Locating Slippery Highway Sites by Accident Analysis

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INTRODUCTION

It is generally agreed that a wet pavement surface presents less resistance to skidding than does the same surface in a dry condition. It is also well known that ice and snow are very slippery; but on the other hand, they are special conditions which do not reflect any skid characteristic of the pavement surface. It is, therefore, the wet surface condition that is critical relative to the minimum coefficient of friction that will be provided by a particular pavement surface.

In many instances, a surface which does not indicate any particular difficulty with respect to skidding when dry will become quite slippery when wet, and accidents as a consequence of slippery surfaces may result. The accident spot map of Indiana for 1958 is shown in Fig. 1. Figure 2 shows the dry surface accidents occurring in a portion of Grant County during 1958. It is rather typical of the location of accidents occurring on dry surfaces anywhere in the state. There is a concentration of accidents on SR 9 south and west of Marion; however, there is no particular grouping of skidding accidents.

Figure 3 shows the same area of Grant County but indicates wet surface accidents occurring in 1958. Here again there is a concentration of accidents on the heavily traveled portion of SR 9. However, a rather definite grouping of skidding accidents is now obvious at the junction of SR 9 and SR 15 as well as at the junction of SR 9 and SR 37. Although skidding was involved in several dry surface accidents throughout the shown portion of the county, there was no indication that any sites were experiencing difficulty with respect to skidding. In Fig. 3, however, it is noted that the wet surface accidents which involved skidding are clustered at those sites at which the drivers may have been required to make several difficult

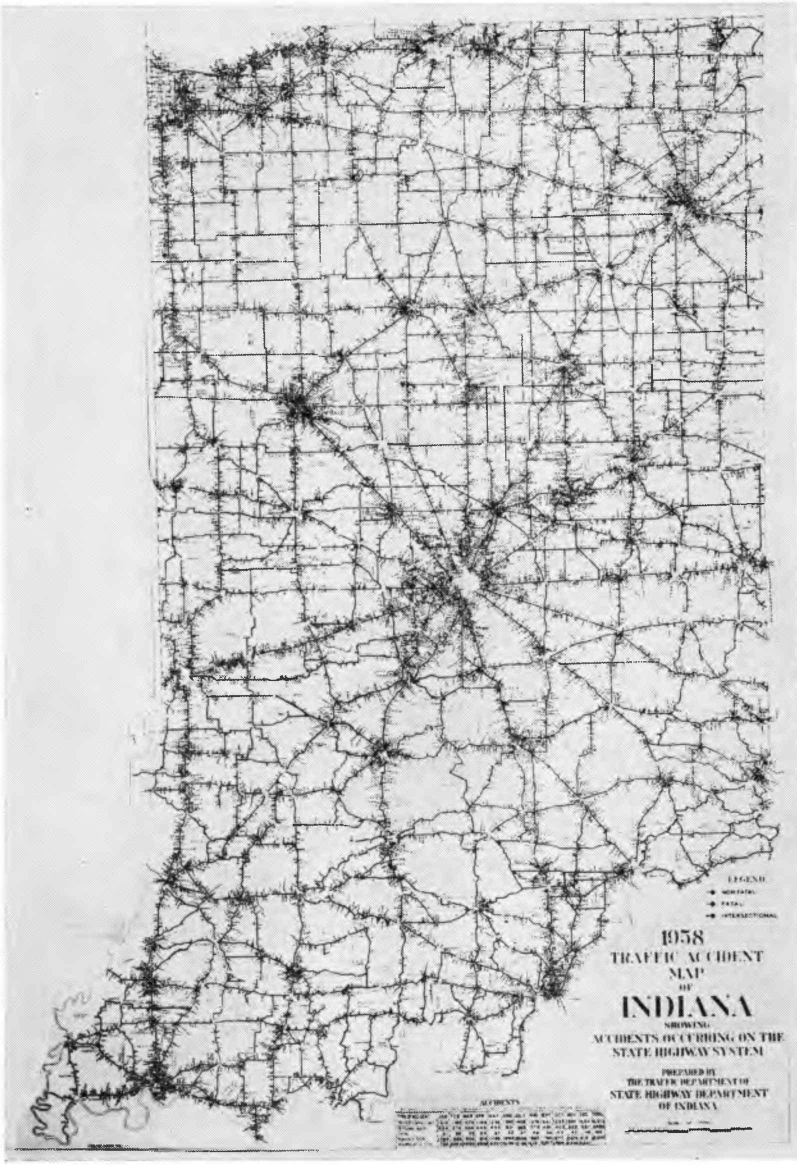
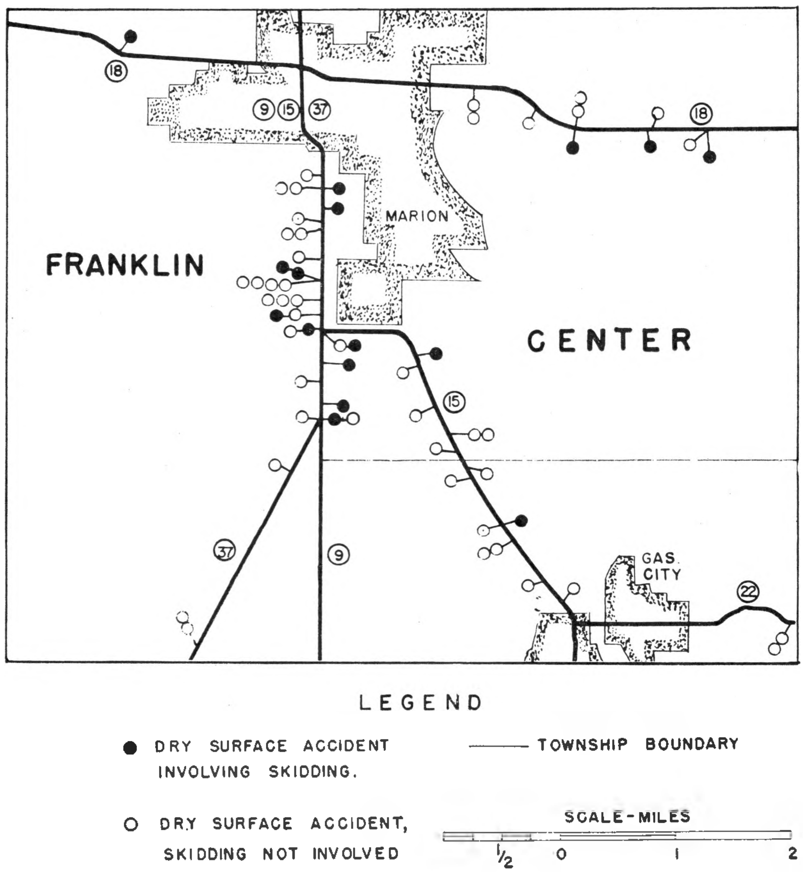


Fig. 1. Accident spot map of Indiana for 1958.

maneuvers and where the wet surface presented a reduced resistance to skidding below that necessary to complete the maneuvers safely. Skid tests conducted on SR 9 just north of its junction with SR 15 indicated an average distance to stop of 98 feet from 30 mph. A vehicle traveling at the average speed for this section of highway (40 mph) would require about 200 feet to stop.

It is not intended to convey the impression that the road is the only part of the driver-vehicle-road system that contributes to skidding. It is, however, the only component over which the highway engineer



PORTION OF GRANT COUNTY, INDIANA

Fig. 2. Dry surface accidents in portion of Grant County.

has direct and substantial control. Moreover, by applying sound engineering practices to the highway, it may be possible to minimize the deficiencies of the driver and the vehicle. The efficient and effective use of nonslippery highway surfaces for the purpose of reducing the number of accidents involving skidding requires that slippery sites at which accidents are occurring be identified and evaluated at the earliest possible date.

The commonly employed field testing procedures (such as the stopping-distance method), effectively evaluated on a relative basis, the skid resistance of the surfaces upon which the tests are conducted.

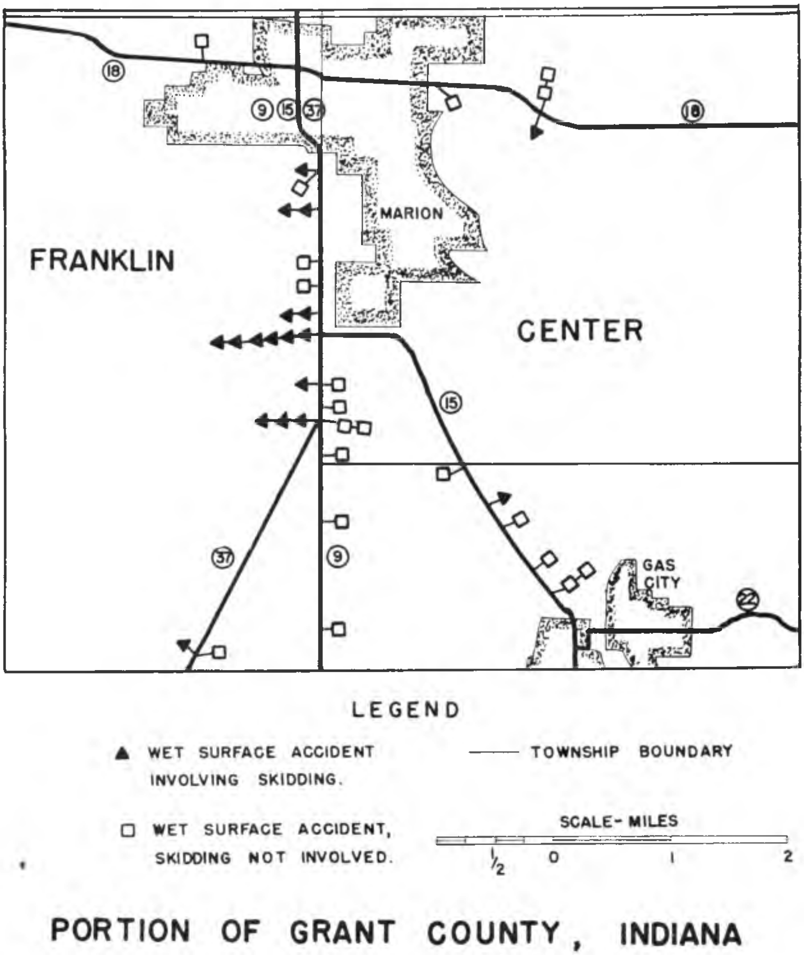


Fig. 3. Wet surface accidents in portion of Grant County.

They are, however, expensive and time consuming. Furthermore, some other method must be utilized to determine the locations that are suspected of being slippery and at which the field tests should be conducted. A procedure which would systematically evaluate the skid resistance of segments of the entire highway system and which would indicate those sites which are slippery would be of considerable value. In the interest of economy, it would be desirable if such a method would minimize the number of field tests required and would necessitate a minimum of labor.

The accident report files contain a wealth of information, and it was this source that this study used. Previous investigations conducted in Great Britain (1, 2)** developed and utilized statistical methods for the analysis of highway sites having a low frequency of skidding accidents. After studies conducted at sites that had been so located and then de-slicked, indicated a substantial reduction in skidding accidents as well as in total accidents (3).

SKIDDING IN REPORTED ACCIDENTS

The overall problem of skidding in accidents occurring in 1958, as determined from the reported accidents on the state highways in ten counties of Indiana, is summarized in Table 1.

In order to compare the number of accidents by surface condition, it is necessary to consider the amount of traffic which traversed these highways while the surfaces were dry, wet, or icy; i.e., covered with ice or snow. The number of vehicle-miles traveled under the different surface conditions is unknown and is impossible to obtain. However, there must be a relationship between the total number of accidents occurring while the surfaces were dry, or icy, and the proportion of the time the surfaces were in each of these conditions as well as the amount of traffic using these facilities while these conditions prevailed. Therefore, if the total number of accidents occurring while the

Table 1

SKIDDING AS A FACTOR IN REPORTED ACCIDENTS

1958 Data, Ten Counties in Indiana

Condition of Road Surface	Total Number of Accidents	Number of Accidents in which Skidding was Involved	Skidding* Rate
Dry	1776	713	41
Wet	779	469	60
Icy (covered with ice or snow)	275	199	72
Total	2830	1381	49

* The number of accidents involving skidding as a percentage of the total number of accidents.

** Numbers in parentheses refer to listings in the bibliography.

surface was dry, wet, or icy is used as a measure of the exposure, a measure of the relative risk of skidding can be obtained by comparing the skidding rate; i.e., the percentage of accidents involving skidding.

The rather high skidding rate on dry surfaces is not surprising since most vehicles have braking systems of sufficient capacity to lock the wheels (4). Such locking is especially true when the driver perceives an accident as being imminent and attempts a panic stop and/or when the brakes are improperly adjusted. The skidding rate on wet surfaces, however, is considerably higher than on dry surfaces and it is still higher when the surface is icy.

EVALUATION OF LOW FREQUENCY ACCIDENT SITES

The skidding rate is a useful method of indicating the relative risk of skidding on dry, wet, and icy surfaces, because a large number of accidents have occurred. The accident frequency of the vast majority of specific sites is quite small, however, and some other method is necessary to consider the effect of chance occurrence and to determine when the frequency of skidding accidents is excessive. Such a method must also enable the highway engineer to determine when the frequency of skidding accidents is greater than some acceptable standard on some other length of highway. Statistical methods provide the solution of problems of this nature.

The statistical analysis used in this study is based on the binomial distribution, a statistical distribution of occurrences exhibiting a particular characteristic which might be classified as either a success or a failure. With respect to skidding accidents, this characteristic is skidding. An accident which did not involve skidding can be classified as a success, and an accident in which skidding was involved can be classified as a failure. The minimum percentage of accidents in which skidding was, in all probability, involved can be calculated; this value will be referred to as the significant skidding rate or the SSR. In other words, the long term value of the skidding rate is, in all probability, at least as large as the calculated SSR.

As an example of the necessity for utilizing this procedure for comparing low accident frequencies, consider two sites, both of which have the same skidding rate. Such a situation is illustrated in Fig. 4: n is the total number of accidents which occurred when the surface was wet, an X is the number of these accidents in which skidding occurred.

In the case of site A, two out of two wet surface accidents involved skidding; therefore, the skidding rate is 100 per cent. However, the two out of two may be due to chance; and we can only say, at the five per cent significant level, that 95 per cent of the time, 19 times out of 20 we would expect the true long term skidding rate at this location to be at least 15 per cent. It might be as high as 100 per cent, but the chances are small, one chance in 20, that it is less than 15 per cent. In the case of site B four out of four wet surface accidents involved skidding; thus, the skidding rate for this site is also 100 per cent. However, since the frequency is higher; i.e.,

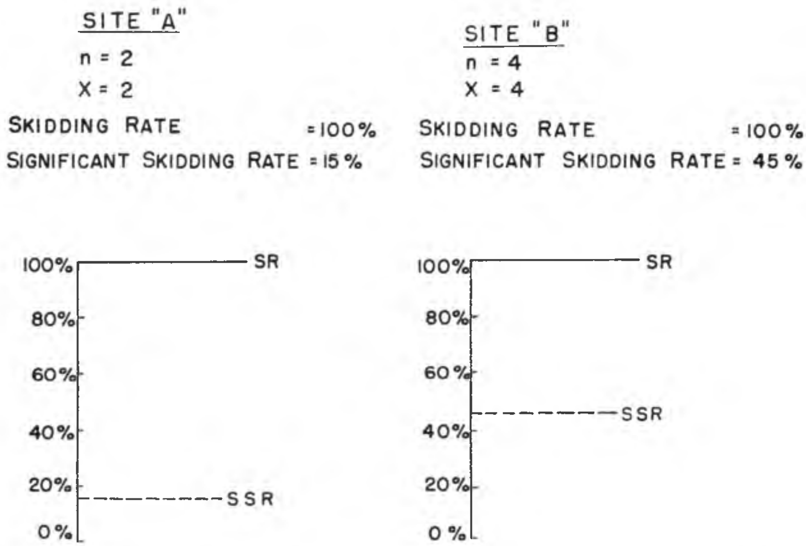


Fig. 4. The significance of low accident frequencies graphically represented.

there are more accidents involved, we can determine the minimum value that the long-term skidding rate will have within narrower limits, that is, the effect of chance occurrence is less. The SSR for this site is 45 per cent. Here again, the true skidding rate might be as high as 100 per cent but the chances are only one in 20 that it is less than 45 per cent. Thus, we see that the SSR is dependent upon the accident frequency, and is in reality, the lower confidence limit for the skidding rate.

As an aid in determining the SSR, Table 2 has been prepared for a wide range of accident frequencies. Tables of the cumulative binomial probability distribution (5) were used to calculate values indicated in the table and are for the five per cent significance level. The table is most easily used by entering the table with the number of wet-surface accidents involving skidding (column X), then reading horizontally to the column farthest to the right which has a number larger than the total number of wet surface accidents which occurred. The SSR is then given at the top of this column. For example, if a total of seven wet surface accidents occurred and four of these involved skidding, one enters column X with four and reads horizontally to the last column containing a number larger than seven, which in this case is eight; the number at the top of this column gives the SSR as being 20 per cent. This means that 19 times out of 20 the true long term percentage of wet surface accidents at this location which involve skidding is at least 20 per cent.

Table 2

TABLE FOR THE DETERMINATION OF THE SIGNIFICANT SKIDDING RATE

The skidding rate* is significantly greater than the percentage given at the top of the column if the total number of wet surface accidents is less than that given in the body of the table.

Number of Wet Surface Accidents in Which Skidding Occurred X	2%	4%	6%	8%	10%	12%	14%	15%	20%	25%	30%	35%	40%	45%	50%	Number of Wet Surface Accidents in Which Skidding Occurred X
2	19	10	7	5	4	4	3	3	......	......	......	......	......	......	......	2
3	42	22	15	11	9	8	7	7	5	4	4	4	......	......	......	3
4	69	35	24	18	15	13	11	10	8	7	6	5	5	5	......	4
5	100	51	34	26	21	18	16	15	11	10	8	7	7	6	6	5
6	132	67	45	34	28	24	20	19	15	12	11	9	9	8	7	6
7	166	84	57	43	35	29	25	24	18	15	13	11	10	10	9	7
8	201	101	68	52	42	35	31	29	22	18	15	14	12	11	10	8
9	236	119	80	61	49	41	36	34	26	21	18	16	14	13	12	9
10	273	138	93	70	57	48	41	39	30	24	21	18	16	15	14	10
11	310	157	105	80	64	54	47	44	33	27	23	20	18	17	15	11
12	348	175	118	89	72	60	52	49	37	30	26	23	20	18	17	12
13	387	194	131	99	80	67	57	53	41	34	29	25	22	20	19	13
14	426	214	144	109	87	73	63	59	45	37	31	27	24	22	20	14
15	465	234	157	119	95	80	69	65	49	40	34	30	26	24	22	15
16	504	252	170	128	103	87	75	70	53	43	37	32	29	26	24	16
17	543	272	183	138	112	93	81	75	57	47	40	34	31	28	25	17
18	582	293	197	148	120	100	86	81	61	50	42	37	33	30	27	18
19	623	313	209	159	128	106	92	86	65	53	45	39	35	31	29	19
20	664	334	224	169	135	113	98	92	70	57	48	42	37	33	31	20
21	706	354	237	179	144	121	103	97	74	60	51	44	39	35	32	21
22	748	375	251	190	152	125	110	102	78	63	54	47	41	37	34	22
23	788	396	265	200	161	134	115	103	82	67	56	49	43	39	36	23
24	829	417	279	209	169	142	122	113	87	70	59	51	46	41	38	24
25	871	438	292	221	171	148	128	120	91	73	62	54	48	43	39	25

* At the 0.05 level of significance (i.e., there is only one chance in twenty that the true skidding rate is less than that indicated).

Table 2—Continued

TABLE FOR THE DETERMINATION OF THE SIGNIFICANT SKIDDING RATE

The skidding rate* is significantly greater than the percentage given at the top of the column if the total number of wet surface accidents is less than that given in the body of the table.

Number of Wet Surface Accidents in Which Skidding Occurred X	2%	4%	6%	8%	10%	12%	14%	15%	20%	25%	30%	35%	40%	45%	50%	Number of Wet Surface Accidents in Which Skidding Occurred X
26	......	459	307	230	186	157	134	125	95	77	65	56	50	45	41	26
27	......	480	321	242	194	163	140	131	99	81	68	59	52	47	43	27
28	......	501	335	251	202	170	146	136	103	84	71	61	54	49	45	28
29	......	519	349	263	210	177	152	142	107	87	74	64	57	51	46	29
30	......	542	364	273	220	184	158	148	111	91	77	66	59	53	48	30
31	......	......	378	284	227	191	164	154	116	94	80	69	61	55	50	31
32	......	......	392	295	236	198	171	160	121	98	82	71	63	57	51	32
33	......	......	406	305	245	204	177	165	125	101	85	74	65	59	54	33
34	......	......	421	316	253	211	183	171	130	104	88	76	68	61	55	34
35	......	......	435	327	263	220	189	177	133	107	91	79	70	63	57	35
36	......	......	......	338	270	226	195	183	138	111	94	81	72	65	59	36
37	......	......	......	349	281	233	202	188	142	114	97	84	74	67	61	37
38	......	......	......	361	288	242	206	194	147	118	100	87	77	69	63	38
39	......	......	......	370	297	248	212	201	151	122	102	89	79	71	64	39
40	......	......	......	382	306	255	221	205	155	125	105	92	81	73	66	40
41	......	......	......	......	315	263	225	210	161	129	108	94	83	75	68	41
42	......	......	......	......	324	270	231	217	164	132	111	97	85	77	70	42
43	......	......	......	......	332	278	240	223	169	136	114	99	88	79	72	43
44	......	......	......	......	342	285	245	228	173	140	117	101	90	81	73	44
45	......	......	......	......	......	......	......	......	......	143	121	103	92	83	75	45
46	......	......	......	......	......	......	......	......	......	147	123	106	95	85	77	46
47	......	......	......	......	......	......	......	......	......	151	126	109	97	87	79	47
48	......	......	......	......	......	......	......	......	......	154	130	112	99	89	81	48
49	......	......	......	......	......	......	......	......	......	157	132	114	101	91	83	49
50	......	......	......	......	......	......	......	......	......	162	135	116	102	93	84	50

* At the 0.05 level of significance (i.e., there is only one chance in twenty that the true skidding rate is less than that indicated).

APPLICATION OF THE METHOD

This method of analysis was applied to all the State and US marked routes in 10 counties of Indiana, and county roads were not included, because many of them have gravel surfaces and were therefore outside the scope of the study. The SSR was determined for each accident cluster, a site where numerous accidents occurred; and for each road length, which was a numbered highway route throughout one township.

Table 3 shows the results of the road length analysis and indicates a few of the roads are causing the bulk of the skidding problem. Similar results were obtained for the accident cluster analysis.

Table 3

DISTRIBUTION OF ROAD LENGTHS ACCORDING TO THE SSR

Significant Skidding Rate	Number of Road Lengths
50	9
40	7
30	16
20	14
10	46
0	175
Total	267

In order to check the effectiveness and reliability of the SSR, as a measure of the slipperiness of the surface, field skid tests were conducted on a sample number of locations, selected by statistical means which insured the results obtained truly represented all of the road lengths (6).

The skid tests were conducted with the State Highway Department of Indiana skid vehicle (7), which has an electrically-activated, vacuum-breaking unit and thus eliminates driver variation in the application of brakes. It is also equipped to record the speed at which the vehicle was traveling when the brakes were applied and the distance required to stop. All tests were conducted on a thoroughly wet surface from 30 mph.

Upon the completion of the field skid testing, the data were plotted as scatter diagrams. Visual inspection and some knowledge of the traffic conditions at the various locations indicated that speed and volume might be two additional factors which affect the SSR. Therefore, the overall speeds were obtained for the sample locations by the license plate method (8). Although the speed data were obtained under dry rather than wet pavement conditions, it is felt that little, if any, appreciable error is involved. Previous investigations (9) have revealed that even though speeds do drop when a rain-fall first begins, the drivers soon return to their former speed, provided the intensity of rain-fall is not sufficient to cause a reduction in visability. The traffic volumes were obtained from the 1958 traffic flow map and the speed and volume factors were evaluated. The resulting scatter diagrams of the relationship between the SSR and the stopping distance, average

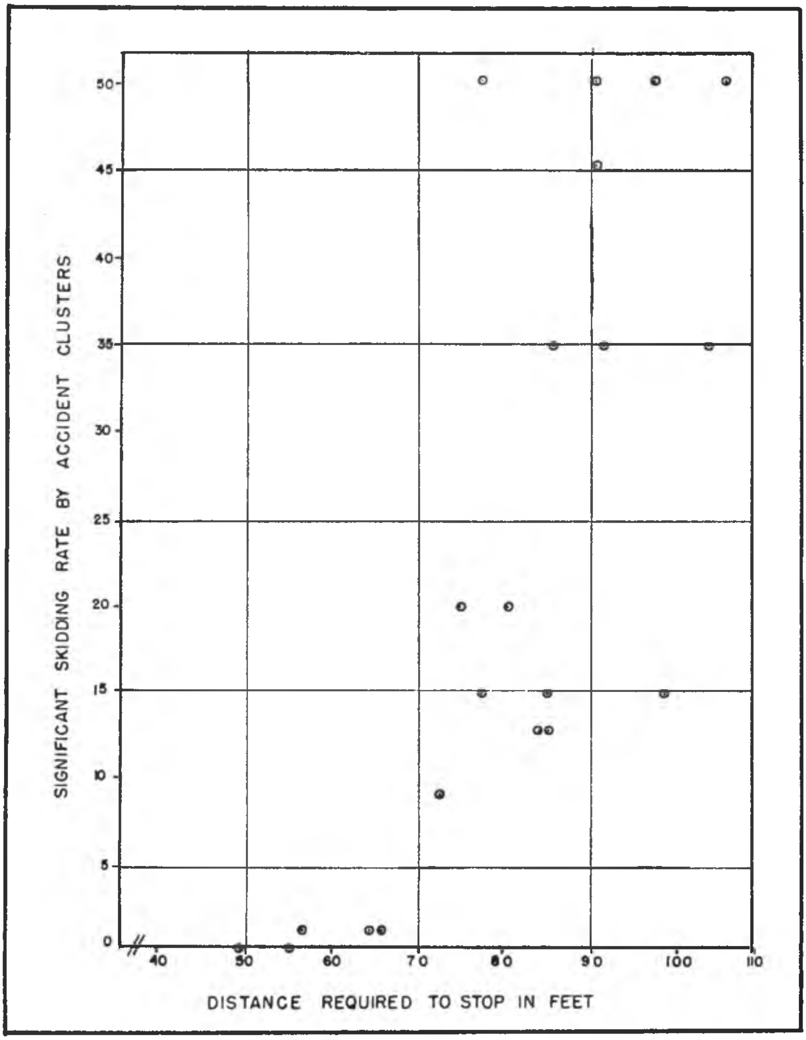


Fig. 5. Scatter diagram of the distance required to stop and the significant skidding rate by accident cluster.

speed and daily volume are shown in Figs. 5, 6 and 7, respectively, for the accident cluster analysis. Similar charts were obtained for the road length analysis.

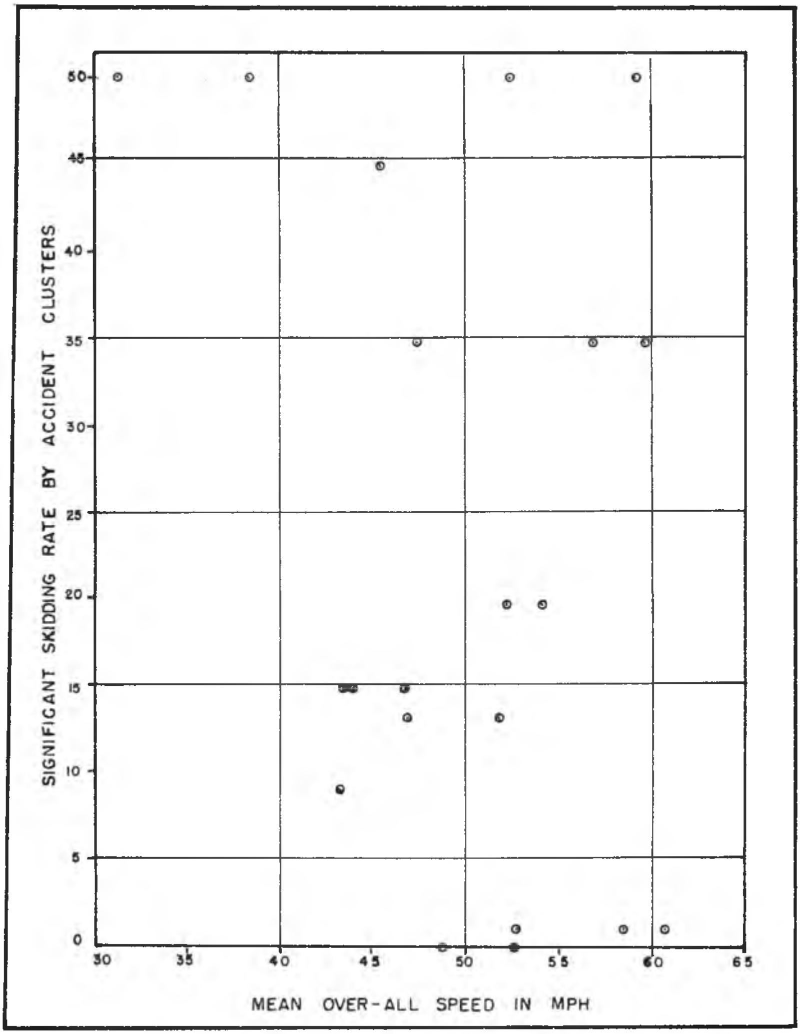


Fig. 6. Scatter diagram of the mean over-all speeds and the significant skidding rate by accident cluster.

The results of a correlation analysis for the accident cluster data is summarized in Table 4.

Table 4
SUMMARY OF THE CORRELATION ANALYSIS
FOR THE ACCIDENT CLUSTER DATA

Factors Correlated	Correlation Coefficient	Significant at the 0.05 Level
SSR—Slipperiness of the surface	$r_{y1} = 0.76$	yes
SSR—Mean over-all speed	$r_{y2} = 0.27$	no
SSR—ADT	$r_{y3} = 0.58$	yes
SSR—Slipperiness of the surface, mean over-all speed, and ADT	$R = 0.86$	yes

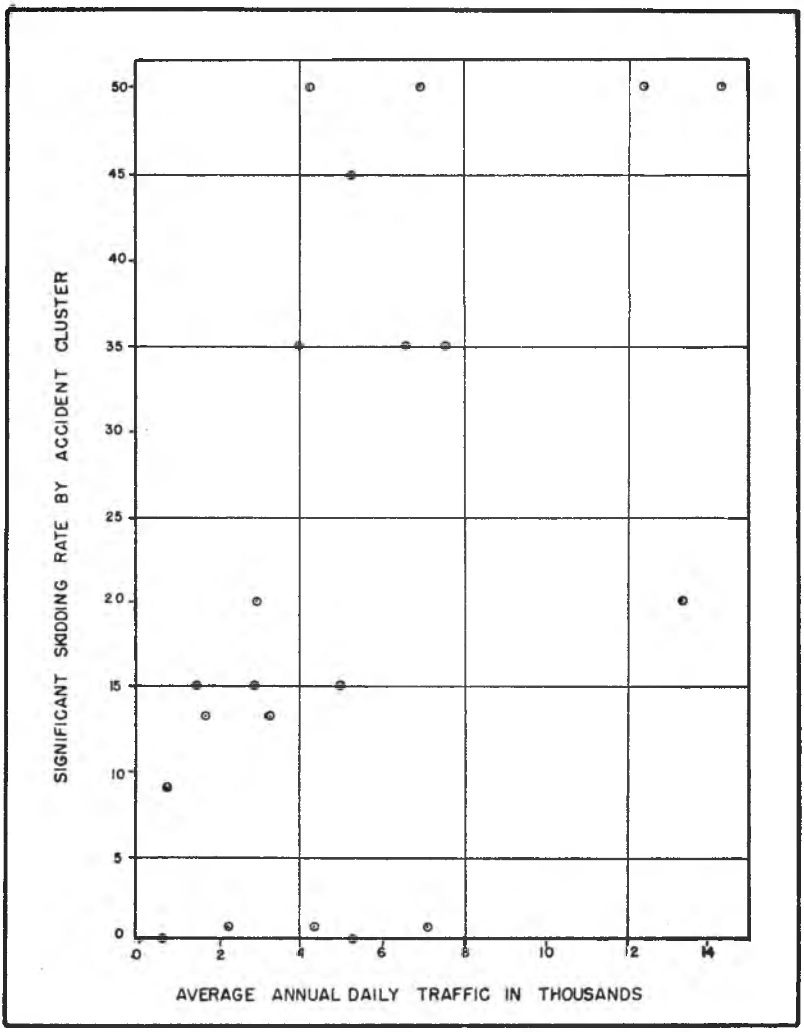


Fig. 7. Scatter diagram of the average annual daily traffic and the significant skidding rate by accident cluster.

Although the correlation between SSR and the mean over-all speed is not significant, visual inspection of the center portion of Fig. 6 indicates a relationship between these two factors at some speeds. Further analysis indicated significant positive correlation between these two factors for the values of the SSR between five and thirty-five.

In the examination of the simple correlation coefficients (the r_{yi} values) it must be remembered they are a measure of the dependence between the two factors under consideration and may include influence of other variables. The multiple correlation coefficient (R) is perhaps more valuable since it measures the degree of linear association between all the factors under consideration. The square of this coefficient is the portion of the total variation in the SSR (74 per cent) dependent upon the distance required to stop, the mean over-all speed, and the ADT.

POSSIBLE PROCEDURES FOR A STATE-WIDE ROUTE SKID ANALYSIS

The question which now arises is: How might this procedure be utilized for the analysis of the paved streets and highways of a state? The first step necessary for locating slippery sites is to obtain the following information:

1. The total number of accidents which occurred when the pavement was wet.
2. The number of these accidents in which skidding was involved.
3. The locations at which these accidents occurred.

No differentiation should be made between skidding before and after breaking; that is, the number of accidents in which skidding was involved should be the total number of accidents in which skidding, before and after braking, occurred.

The accident spot map is the best method for recording skidding accident data. With appropriate identification, this information could be plotted on the accident map currently prepared in Indiana and in many other states. Visual inspection would then reveal those locations at which skidding accidents are grouping. A state-wide analysis could be performed as often as desired, and individual troublesome locations could be analyzed as they become apparent.

As noted in Fig. 1, this map is often somewhat crowded. Therefore, it may be advantageous to maintain a separate map for wet surface accidents. It would then be a very simple matter to differentiate between those accidents which involved skidding and those which did not. This would necessitate a minimum of information on any one map and would simplify initial visual inspection. The additional time required to plot the information necessary for a route skid-analysis would be quite nominal.

A separate location map for wet surface accidents might also be adopted to show the previous 12 months accidents rather than just those occurring since January 1 of any particular year. For example, this might be done by using pins with the numbers 1 through 12 on their heads to indicate the month in which the accident occurred. With such a system, the map could be studied to determine if any cluster existed at the end of each month and the pins representing the accidents which occurred during the earliest month of the preceding year would then be removed. Such a procedure would permit an analysis with a full twelve months accident history at the end of each month and at any time for a minimum of eleven months.

For most efficient results, accurate information on the location of the accident is required and care must be exercised when plotting the accident. For example, since the analysis should indicate which approach to an intersection is slippery, the location of each accident must be accurately reported and plotted to indicate the proper approach on which the accident occurred instead of simply indicating that an accident occurred at a given intersection. Similarly, indication should be made on the roadway on which each accident occurred on a multi-lane divided highway since one roadway may be slick while the other is not.

The greater the accuracy in reporting and plotting the more accurately a cluster can be determined; and therefore, the shorter the length of highway that needs to be de-slicked. Fig. 3 shows the wet surface accidents which occurred in a portion of Grant County. Although a considerable length of SR 9 is probably slippery, the de-slicking of the approaches to the intersections of SR 9 with SR 15 and SR 9 with SR 37 could substantially reduce the problem of skidding as well as the total number of accidents in this area.

When the resistance to skidding is increased at a previously slippery site, this fact should be clearly noted. Accidents occurring after the corrective measure has been completed would continue to be plotted and the effectiveness of the de-slicking should be evaluated. The same procedure should be followed when any portion of a highway has had its surface characteristics changed through resurfacing or reconstruction.

The most beneficial results for the smallest expenditure of funds can be realized by the proper de-slicking of rather limited lengths of highway which have been identified as being slippery and troublesome by this method of accident report analysis.

RESULTS, CONCLUSIONS AND RECOMMENDATIONS

Several interesting and valuable results were obtained from the investigation; the more important are as follows:

1. There is an extremely good correlation between the SSR and the slipperiness of the surface as measured by the stopping-distance method. Therefore, the SSR is a reliable measure of the relative slipperiness of the wet highway surfaces.

2. There is a significant correlation between the SSR and ADT. The importance of this relationship is that the SSR inherently involves a consideration of the traffic volume. Therefore, separate study of the traffic volumes on the various facilities is not necessary when determining the priority that a particular section should be given for the application of a de-slicking treatment. Priority should be given to those sites which have the highest significant skidding rate.

3. Regardless of speed, skidding occurs in an alarmingly high percentage of wet surface accidents when a wet surface provides a low resistance to skidding. Conversely, a very low percentage of wet surface accidents will involve skidding if a wet surface exhibits a uniformly high resistance to skidding. In the region between these two limiting conditions there is a relationship between speed and skidding.

4. The use of the accident cluster is superior to using the road length. Better correlation between the SSR and the various factors affecting skidding can be expected when accident clusters are used. Furthermore, an analysis using the accident cluster will facilitate greater economy because shorter and more specific sites will be indicated as being in need of de-slicking treatment.

5. A location map of wet surface accidents is recommended as the most practical, flexible, and simplest method of identifying wet surface accident clusters and for obtaining the information necessary for performing an analysis utilizing this method. The more accurately accidents are reported and plotted the more detailed the information obtained; and therefore, the greater the economy of the de-slicking operation.

6. It is recommended that slippery locations on the state highways of Indiana be determined at least once a year by the method just discussed and that high priority be given to proper de-slicking of these locations.

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