Critique of Tentative Skid-Resistance Guidelines

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The selection of appropriate minimum skid number (SN) values for wet pavements remains a major issue in skid-resistance research. The purpose of the research presented in this paper was to critique several reported accident and driver behavior studies related to skid resistance in an attempt to determine the most reasonable tentative guidelines for use in Virginia. The review confirmed our belief that required SN_{40} values vary with roadway and traffic conditions and that much work remains to be done regarding the determination of required SN_{40} values for specific roadway and traffic characteristics. For these reasons we concluded that accident data should continue to be the primary basis in Virginia for identifying wet-pavement sites that have high accident rates. However, general SN_{40} guidelines were selected for the purpose of determining potentially hazardous wet-pavement accident sites, that is, sites with SN_{40} values below the guideline values. Sites selected in this manner will be included in the normal site review process of the program to reduce wet-pavement accidents and may or may not be treated, depending on the results of the review process. The tentative SN_{40} guidelines selected and stated in terms of Virginia's survey of locked-wheel-trailer values are 30 for Interstate and other divided highways and 40 for two-lane highways.

The selection of appropriate minimum skid number (SN) values for wet pavements remains a major issue in skid-resistance research and a practical problem for organizations responsible for the construction and maintenance of highways. For the purpose of this discussion, SN refers to the locked-wheel skid number obtained with a skid trailer meeting the requirements for ASTM designation E 274-70.

Several studies have been undertaken to define the minimum desirable wet-pavement, skid-resistance level. As recognized by Kummer and Meyer, these studies can be divided into three groups (1):

1. Studies relating total accidents, wet-pavement accidents, or wet-pavement skidding accidents to some measure of skid resistance for the pavements on which the accidents occurred;
2. Driver behavior studies that usually involve measuring accelerations (usually negative) and relating these accelerations to SN values [the friction demand determined in this way is labeled FN, where $FN = 100\ (a/g)$, a is the measured acceleration in meters per square second, and g is the gravitational constant $(32.2/s^2)$]; and
3. Studies based on vehicle and pavement design (requisite FN levels based on vehicle design and highway geometric design are obviously limited only by the design criteria and not by driver behavior, and thus FN levels defined in this way may not agree with levels required for normal driving behavior).

The method used in the first of these study categories has the advantage of directly relating SN values as normally obtained in skid survey testing to accident experience. However, comparisons of various research results are difficult because of the variabilities involved in testing, even when the same test method is employed, and because of differences in traffic and highway characteristics.

The FN values developed in the second and third study categories must be converted to corresponding SN values. Assumptions regarding the relationship of FN to SN, including the question of whether FN represents the critical slip value obtained prior to skidding (and thus a higher value) or the locked-wheel skid value, vary among researchers. Furthermore, several researchers have indicated that modifications, in which such things as tire tread depth, pavement texture, and water depth are considered, should be made to SN values obtained from FN values so that they represent SN values available under normal driving conditions. Therefore, even if researchers determine a need for like FN values, they may specify different SN values because of varying philosophies regarding the relationship of FN to SN.

PURPOSE AND SCOPE

The purpose of this paper is to critique reported studies concerning minimum skid resistance (SN_{40}) guidelines. The critique resulted from a review of several studies to determine the most reasonable tentative guidelines for Virginia. The guidelines that have been established are tentative because they are based on the currently available research results we reviewed. These guidelines will be modified as necessary by future research results and used as secondary input to Virginia's program to reduce wet-pavement accidents. Wet-pavement accident statistics will be the prime indicator of pavements most in need of improved skid resistance.

Accident and driver behavior studies have been used to establish and modify these tentative guidelines. Studies concerning the required skid resistance as determined on the basis of vehicle or pavement design were not considered because these studies relate to theoretical limits that may or may not be exceeded in practice.

The guideline SN values presented in this paper are stated in terms of Virginia's current skid-trailer measurements. An evaluation of the skid trailer was conducted June 16 to 24, 1975, at the Field Test and Evaluation Center for Eastern States (EFTC) in East Liberty, Ohio. The conclusion was that the unit performed well: it obtained SN_{40} values approximately three units above those for the EFTC reference tester (2).

ACCIDENT STUDIES

Virginia Study

In a previous study we researched the relationship between skid resistance and percentage of wet-pavement accidents on 502.1 km (312 miles) of the Interstate highway system in Virginia. Based on our judgment, we separated the sites into the following four categories:

1. Open roadway—level and tangent noninterchange areas;
2. Nonopen roadway—vertical and horizontal curves at noninterchange areas;
3. Open interchange—level and tangent interchange areas; and
4. Nonopen interchange—vertical and horizontal curves at interchange areas.

Sight distance was considered highly important in the classification of sites; therefore, areas with gentle horizontal and vertical curves affording good sight distances were classified as open roadway. Estimated speeds for the sites studied were between 104.6 and 112.7 km/h (65 and 70 mph). Skid resistance was measured with the research council's locked-wheel trailer at 64.4 km/h (40 mph) but converted by correlation to predicted 64.4-km/h (40-mph) stopping distance skid numbers ($PSDN_{40}$) for comparison with the accident data.

We concluded that the percentage of wet-pavement accidents increased significantly below an SDN_{40} of 42; there was little difference among the categories. In terms of Virginia's current survey skid trailer, the SDN_{40} value of 42 would be equivalent to an SN_{40} of 29 based on the latest available correlation between the survey trailer and the stopping-distance method (4).

Texas Study

McCullough and Hankins studied the relationship of accidents per 161 million vehicles·km (100 million vehicle-miles) and skid resistance on 517 rural road sections that represented a random sample of Texas highways (5). Skid resistance was measured with a locked-wheel trailer at 32.2 and 80.5 km/h (20 and 50 mph), and the results of the study indicated that accidents increased at SN values below approximately 45 at 32.2 km/h (20 mph) and 35 and 80.5 km/h (50 mph). A straight-line extrapolation indicates an SN_{40} value of approximately 38.

A direct comparison of the results of the Virginia and Texas studies is difficult because we do not know how the sections studied in each case compared relative to roadway characteristics or mean traffic speeds, nor is there any way to relate the skid trailers involved. McCullough and Hankins recommend, based on the accident data and design practice, minimum SN values of 40 at 32.2 km/h (20 mph) and 30 at 80.5 km/h (50 mph) as a guide for surface improvements, which indicates a minimum desirable SN_{40} value of 33.

Tennessee Study

Moore and Humphreys studied 75 high accident sites in Tennessee to relate percentages of wet-pavement accidents to SN_{40} values obtained with a locked-wheel trailer (6). They concluded that the percentage of wet-pavement accidents increased significantly below an SN_{40} value of 40. The same difficulties discussed above are encountered in trying to relate those results directly to the Virginia results.

Kentucky Studies

Rizenbergs, Burchett, and Napier studied the relationship of pavement friction and wet-pavement accident experience on rural Interstate and parkway roads in Kentucky (7). Both SN and PSN were measured with a skid trailer at 112.7 km/h (70 mph). Several methods of relating wet-pavement accident data to SN_{40} and PSN_{70} were tried; the result was that wet-pavement accidents per 1.6 million vehicle·km (1 million vehicle-miles) correlated best. They concluded that the minimum desirable values were an SN_{70} of 27 and PSN_{70} of 57. Their reported correlations between SN_{70} and SN_{40} for bituminous and portland cement concrete pavements permit the determination of the minimum desirable SN_{40} value, which is approximately 40.

Because the data in the Kentucky and Virginia studies were for similar types of highways, the results would be expected to be fairly close, but, in fact, Kentucky results seem to indicate almost a 40 percent higher minimum desirable SN_{40} (40 versus 29). A comparison of the performance of the Kentucky and Virginia trailers at the Ohio test center indicated that the two units perform about the same.

In a second Kentucky study, Rizenbergs, Burchett, and Warren studied the relationship of wet-pavement accidents and skid resistance on rural, two-lane roads (8). In this study the test speed was 64.4 km/h (40 mph). For the roads studied, the ratio of wet- to dry-pavement accidents correlated best with pavement friction, and increases in SN_{40} above 40 resulted in only a slight reduction in the ratio. The authors also concluded that a low SN_{40} value does not necessarily imply an accident problem, and the general guidelines in the table below were suggested for assessing pavement skid resistance.

Skid Number	Skid-Resistance Assessment
>39	Skid resistant
33 to 39	Marginal
26 to 32	Slippery
<26	Very slippery

Arizona Study

Burns and Peters, as part of a general skid-resistance study of Arizona highways, determined a Mu-meter reading of 40 to be the desirable minimum value when one considers wet-pavement accident data (9). Based on a correlation contained in their paper, the Mu-meter value of 40 is equivalent to an SDN_{40} of 42 and thus an SN_{40} value of 29 for the Virginia survey trailer.

British Studies

Giles, Sabey, and Cardew correlated British portable tester (BPT) results with the risk of being in a skidding accident by measuring skid resistance at known high skidding-accident sites and several randomly selected sites. They developed the curve shown in Figure 1 (10) and, based on this curve, suggested minimum guidelines for the British portable tester as given in Table 1 (10). Similarly, minimum sideway friction coefficient (SFC) standards were suggested based on work by Giles (11). These suggested standards are given in the following table (1 km/h = 0.6 mph). Site categories are given in Table 1.

	Skidding Resistance	
Site Category	Test Speed (km/h)	Sideway Force Coefficient
A	50	0.55
B	50	0.50
	80	0.45
	50	0.50
C	50	0.40

For the above standards to be meaningful to this study, the relationship of SFC_{30} values (as measured by the British portable tester) to locked-wheel skid trailer values (SN_{40}) must be known.

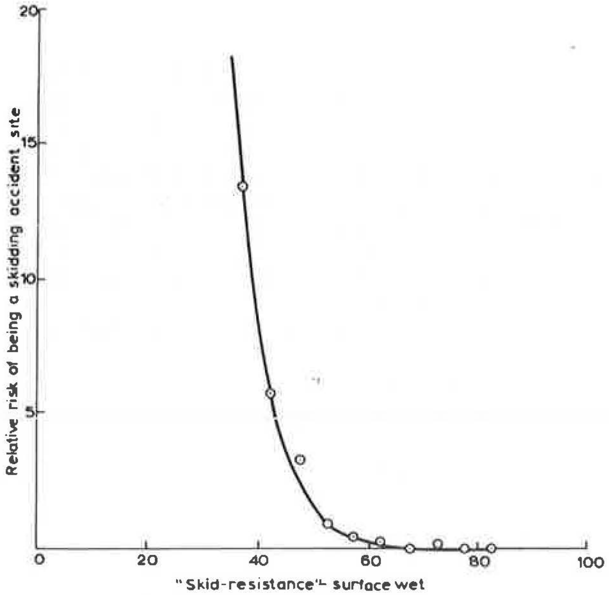
Giles developed the relationship shown in Figure 2 (10) between BPT values and locked-wheel retardation values at 48.3 km/h (30 mph) for a vehicle equipped with treaded tires. Dillard and Mahone reported on two studies relating the BPT and stopping distance skid values; the results are shown in Figure 3 (12). The 1960 and 1962 data shown in Figure 3 indicate quite different relationships between the two devices. There were several possible reasons for the differences as explained by Dillard and Mahone. One reason is that the 1960 data were collected on in-service road surfaces; the 1962 data, however, were obtained on specially prepared test surfaces.

In a discussion of the Dillard and Mahone paper, Enrick offered several possible explanations for the different results; his evidence indicates that several of the 1962 test sites produced misleading results. Also, the 1960 data by Giles and a Purdue study cited by Enrick produced similar results though nearly 170 varied road surfaces in Great Britain and America were employed in the latter. Further, the use of the 1960 results as opposed to the 1962 results only serves to indicate a higher, and thus more conservative, SDN_{40} as the desirable minimum.

The following table gives SN_{40} values corresponding to the minimum BPT values given in Table 1. Set 1 values were determined by estimating required SDN_{40} values based on Figure 3 and converting them to SN_{40} values based on latest Virginia correlation results. Set 2 values are based on Figure 2 assuming retardation at 48.28 km/h (30 mph) is equal to SN_{30} and assuming a gradient of 0.5 SN. The two sets of SN_{40} values closely agree.

Category	BPT	Set 1	Set 2
A	65	51	51
B	55	39	39
C	45	26	28

Figure 1. Relative risk of a surface being a skidding-accident site for different values of skid resistance.



Desirable minimum SN_{40} values as derived from the various sources are summarized in the following table.

Source	Category A	Category B	Category C
Mahone and Runkle			29
McCullough and Hankins		38	
Moore and Humphreys		40	
Rizenbergs and others		40	40
Burns and Peters		29	
Giles, Sabey, and Cardew	51	39	27
Suggested composite	50	40	30

The values are grouped in accordance with those categories given in Table 1 although we felt that none of the accident studies would pertain in general terms to category A. Results of studies pertaining to roads like Interstate highways are given in category C; however, those pertaining to a cross section of rural highways are given in category B. The SN_{40} values equivalent to the BPT values for each category as determined by Giles are also given. Suggested composite SN_{40} values for all categories are indicated, based on the individual SN_{40} values given.

There is not total agreement on the SN_{40} values given, and no explanation can be offered as to why some of the differences exist. However, one could conclude that, in general, an SN_{40} value of 30 is the minimum desirable and probably is sufficient only on highways with good geometric conditions and moderate to low traffic congestion within normal traffic speeds. Higher SN_{40} values obviously are required in other cases, and in general terms an SN_{40} of 40 appears to be the desirable minimum for many two-lane rural highways. At severe curves, some interchange ramps, and some intersections, values as high as 50 may be required, as is suggested by the British guidelines.

DRIVER BEHAVIOR STUDIES

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Probably the most referred to research in this country regarding minimum SN values is the report by Kummer and Meyer (1). Although results of some accident studies and vehicle and highway design criteria were evaluated by the study, the basis of the recommended minimum SN values was the maximum deceleration patterns of three drivers in local traffic and on long-distance trips. Data were obtained by a device mounted in the vehicle and with the knowledge of the driver. The minimum values recommended are intended to allow for normal driving maneuvers, including cornering and braking, by the majority of drivers under usual traffic conditions.

Table 1. Suggested values of skid resistance for use with portable tester.

Category	Type of Site	Skid Resistance on Wet Surface	Standard of Skidding Resistance Represented
A	Most difficult Roundabouts Bends with radius less than 150 m on derestricted roads Gradients, 1 in 20 or steeper, longer than 90 m Approach to traffic lights on derestricted roads	Above 65	Good (fulfilling the requirements even of fast traffic and making it unlikely that the road will be the scene of repeated skidding accidents)
B[a]	Roads and conditions not covered by categories A and C	Above 55	Generally satisfactory (meeting all but the most difficult conditions encountered on the roads)
C[a]	Easy Straight roads Easy gradients and curves No junctions Free from mixed traffic and emergency-creating conditions	Above 45	Satisfactory only in favorable circumstances
D	All sites	Below 45	Potentially slippery

Note: 1 m = 3.3 ft.

[a] On smooth-looking or fine-textured roads, in these categories, vehicles having smooth tires may not find the skid resistance adequate. For such roads, accident studies should also be made to ensure that there are no indications of difficulties due to skidding under wet conditions.

Figure 2. Comparison of measurements made with portable tester and locked-wheel braking method on all textures of road surface.

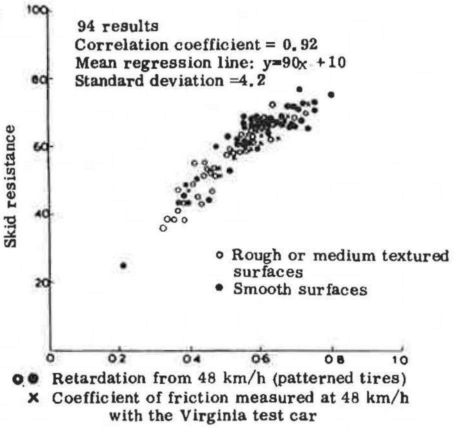
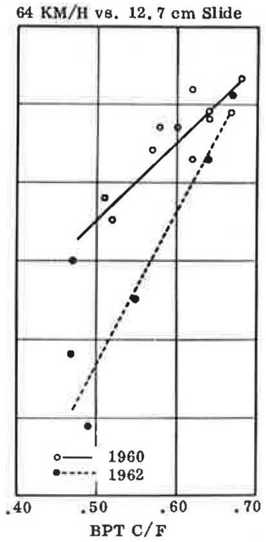


Figure 3. Relations between SDN_{40} and BPT.



Emergency maneuvers that might be the result of unforeseen traffic changes, driver misjudgment, or recklessness are not accounted for.

A summary of the deceleration data is given in Table 2 (1). In general, the higher decelerations occurred toward the end of a stop and thus were accompanied by low speeds. The six deceleration values above 40 on the 444.2-km (276-mile) trip all occurred at speeds below 32.2 km/h (20 mph). They concluded that FN values of 40 seemed to satisfy the normal needs of traffic, and higher values might be called for toward the end of a stop.

Table 3 (1) gives the selected FN values deemed desirable at different speeds based on the deceleration data (FN_0) and the conversion of these FN values to SN values. CSN indicates the additional FN value necessary to account for lateral decelerations during braking on a straight course as measured by Kummer and Meyer. $\Delta L/L$ represents the additional FN value necessary due to fluctuations in average wheel load. The values of $\overline{FN}$ and FN_d were computed as follows:

$$\overline{FN} = [(FN_0)^2 + (CSN)^2]^{1/2} \tag{1}$$

$$FN_d = [1/(1 \pm \Delta L/L)]\overline{FN} \tag{2}$$

In essence, then, the FN_d figures are the FN values recommended by Kummer and Meyer for the speeds shown.

The remaining conversions given in Table 3 are those required to change FN values to SN values. The K-factor is equivalent to FN/SN, assuming that FN represents critical braking and cornering slip numbers that occur prior to skidding and are normally larger than the locked-wheel SN values. SN_t and SN represent additions to the required SN necessary to compensate for fluctuations in measured SN values due to temperature changes and machine error. Table 3 thus gives the required SN values [SN(rounded)] at the speeds indicated, which account for each of the items as discussed above, and the recommended minimum SN_{40} values.

Table 2. Decelerations of three drivers in local traffic and on long-distance trips.

Deceleration FN		Combined Performance (Drivers A and B)				Combined Random and Square Courses				Driver C on 444.2-km Trip	
		Random Course		Square Course		Driver A		Driver B			
Range	Mean	No.	Percent	No.	Percent	No.	Percent	No.	Percent	No.	Percent
2.5 to 7.5	5	—	—	—	—	—	—	—	—	2	1.6
7.5 to 12.5	10	15	10.0	3	2.2	12	8.3	6	4.2	30	24.5
12.5 to 17.5	15	45	30.0	23	16.7	39	27.1	29	20.3	24	19.6
17.5 to 22.5	20	40	26.7	46	33.4	46	32.0	40	27.7	27	22.2
22.5 to 27.5	25	36	24.0	48	34.6	38	26.4	46	31.8	17	14.0
27.5 to 32.5	30	11	7.3	18	13.1	8	5.5	21	14.6	13	10.7
32.5 to 37.5	35	3	2.0	0	0	1	0.7	2	1.4	3	2.5
37.5 to 42.5	40	—	—	—	—	—	—	—	—	4	3.3
42.5 to 47.5	45	—	—	—	—	—	—	—	—	2	1.6
Total		150	100.0	138	100.0	144	100.0	144	100.0	122	100.0

Note: 1 km = 0.6 mile.

Table 3. Conversion of FN to corresponding SN.

	SN for Mean Traffic Speed								
Conversion Steps	0 km/h	16 km/h	32 km/h	48 km/h	64 km/h	81 km/h	97 km/h	113 km/h	129 km/h
FN_0	50	47.5	45	42.5	40	40	40	40	40
CSN	—	—	1.6	3.6	6.4	10.0	14.4	19.6	25.5
$\overline{FN}$	50	47.5	45	42.7	40.4	41.1	42.4	44.5	47.0
$\Delta L/L$(%)	—	—	2.5	5.0	7.5	10.0	12.5	15.0	18.5
FN_d	50	47.5	46.1	44.8	43.5	45.0	47.7	51.2	55.2
K-factor	1	1.3	1.6	1.8	2.0	2.2	2.4	2.6	2.8
SN_0	50	37.5	28.8	25	21.8	20.5	20	19.7	19.8
SN_t	56	43.5	34.8	31	27.8	26.5	26	25.7	25.8
SN	61	48.5	39.8	36	32.8	31.5	31	30.7	30.8
SN (rounded)	60	50	40	35	33	32	31	31	31
SN_{40}[a]	—	—	—	30	33	37	41	46	51

Note: 1 km/h = 0.6 mph.

[a] SN_{40} required based on SN (rounded) value (assuming a speed-SN gradient of 0.5).

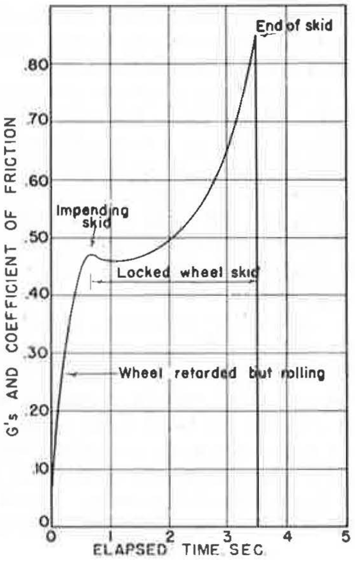


Figure 4. Typical change in coefficient of friction during skid.

Several observations are made regarding the conversion of FN to SN as given in Table 3. The equating of FN to critical brake or cornering slip resistance is not a procedure approved by all researchers; FN often is equated directly to SN (or locked-wheel deceleration). The critical slip values have often been shown to exceed the locked-wheel values, but the magnitude of the difference and the ability of an automobile braking on four wheels to achieve the difference in practice are somewhat uncertain.

Table 4 gives K-factors as determined from various sources. Those developed by Maycock were used by Kummer and Meyer in their conversion of FN values to SN values. Maycock's values were obtained by progressively braking the front wheels of an automobile to the locked condition and represent values obtained with treaded tires for water depths of 2.0 mm (0.8 in) or less [tests with bald tires were also run by Maycock (13), but the results were not used by Kummer and Meyer]. Dillard and Allen determined K-factors as part of a correlation study in Virginia during 1958 by comparing

Table 4. K-factors determined from various sources.

	16 km/h		32 km/h		64 km/h		80 km/h		88 km/h		97 km/h		113 km/h	
Sources	Avg	Range	Avg	Range	Avg	Range	Avg	Range	Avg	Range	Avg	Range	Avg	Range
Maycock			1.6	1.2 to 2.6	2.0	1.4 to 4.1					2.4	1.6 to 4.1		
Dillard	0.9	0.80 to 0.94			1.2	1.0 to 1.3			1.5	1.1 to 2.5				
Moyer			1.5	1.2 to 1.8	1.7	1.4 to 2.1					1.9	1.5 to 2.4		
Rizenbergs					1.8	1.5 to 2.2							2.0	1.4 to 2.6
Hartranft					1.8	1.5 to 3.8								
Lister			1.3	1.2 to 1.7										
Selected values	1.2		1.4		1.8		1.9				2.0		2.1	

Note: 1 km/h = 0.6 mph.

Table 5. Influence of K-factor on minimum SN_{40} values.

		Kummer and Meyer			Selected Avg Values			Selected Low Values		
Speed (km/h)	FN_d[a]	K[a]	SN	SN_{40}[b]	K[c]	SN	SN_{40}[b]	K[d]	SN	SN_{40}[b]
32	46	1.6	29	19	1.4	33	23	0.9	51	41
48	45	1.8	25	20	1.6	28	23	1.0	45	40
64	44	2.0	22	22	1.8	24	24	1.1	40	40
80	45	2.2	21	26	1.9	24	29	1.3	35	40
97	48	2.4	20	30	2.0	24	34	1.5	32	42
113	51	2.6	20	35	2.1	24	39	1.7	30	45

Note: 1 km/h = 0.6 mph.

[a] From Table 3.

[b] Gradient assumed to be 0.5 SN.

[c] From Table 4.

[d] Estimate based on values in the tabulation at the bottom of next page and general change with speed as indicated in Table 4.

Table 6. 95th percentiles, 99th percentiles, and maximum required skid resistance and associated speeds, decelerations, and distances for 12 sites.

	Site Characteristics			95th Percentile				99th Percentile				Maximum			
Site Number	Highway Type	Mean Initial Speed (km/h)	Mean Hourly Traffic Count	Deceleration (g)	Speed (km/h)	Required SN_{40}	Distance From Stop Line[a] (m)	Deceleration (g)	Speed (km/h)	Required SN_{40}	Distance From Stop Line[a] (m)	Deceleration (g)	Speed (km/h)	Required SN_{40}	Distance From Stop Line[a] (m)
1	4	36	450	0.35	40	33	20	0.38	50	41	34	0.41	53	47	34
2	1	36	412	0.25	60	27	58	0.46	34	46	15	0.47	55	56	34
3	5	40	426	0.34	56	38	58	0.38	63	47	58	0.46	84	64	79
4	1	36	104	0.24	66	28	58	0.39	37	37	11	0.43	63	54	68
5	2	38	448	0.31	69	39	58	0.44	50	50	34	0.48	58	59	34
6	4	30	116	0.29	35	22	20	0.38	31	33	11	0.51	72	68	117
7	6	39	94	0.36	47	37	34	0.46	42	50	26	0.44	68	57	49
8	6	40	112	0.29	58	32	49	0.49	21	43	6	0.52	77	71	58
9	3	41	282	0.30	77	39	91	0.38	87	53	68	0.49	82	68	58
10	2	37	406	0.30	53	31	41	0.38	71	49	68	0.47	64	61	49
11	5	40	592	0.35	58	40	41	0.46	60	57	34	0.62	70	84	41
12	3	35	370	0.21	66	23	79	0.28	61	32	79	0.43	64	55	117

Note: 1 km/h = 0.6 mph; 1 m = 3.3 ft.

[a] Distance of first switch of deceleration interval relative to stop line.

Table 7. Required SN_{40} values at intersections under varying assumptions.

Maximum Deceleration From Table 6 (g)	Kummer and Meyer K-Value	Runkle and Mahone K-Value	Low K-Value	Table 6 SN_{40} Values
0.41	19	22	38	47
0.47	22	26	44	56
0.46	27	30	41	64
0.43	17	19	39	54
0.48	23	25	44	59
0.51	27	31	45	68
0.44	23	25	39	57
0.52	28	31	46	71
0.49	28	31	43	68
0.47	24	26	43	61
0.62	33	33	55	84
0.43	22	24	39	55
Average for all intersections	24	27	43	62

results obtained by a National Aeronautics and Space Administration trailer measuring incipient friction and a General Motors trailer measuring locked-wheel skid resistance (14). These values may be low relative to the others given because two test vehicles were used rather than one as in the other cases. Moyer developed the K-factors based on tests on various pavements in California (15, 16). Rizenbergs and others developed the K-factor at 112.7 km/h (70 mph) in the Kentucky accident studies previously cited (8, 9). Hartranft developed the K-factor at 64.4 km/h (40 mph) as part of a Pennsylvania State University correlation study of locked-wheel, peak slip, and peak side friction (17). Lister developed the K-factor by braking the front wheels of an automobile (18).

In each of the above situations the K-factors represent something other than an automobile braking all four wheels. When the automobile is braked, all four wheels do not reach the incipient friction stage simultaneously; therefore, the resulting averaged incipient friction and K-factors are somewhat lower than those thus far discussed. Dillard and Allen, in the 1958 Virginia research mentioned previously (14), also studied deceleration patterns throughout skids by an automobile in locked-wheel tests from a speed of 64.4 km/h (40 mph). Typically, the data indicated trends as shown in Figure 4; the incipient values were slightly higher than the initial locked-wheel values.

SN_{40} values were determined by two locked-wheel trailers at the same sites at which the peak decelerations were determined for the automobile. Thus, locked-wheel trailer skid values can be compared to peak skid values for the automobile as given in the table below. The speed is the speed at which peak deceleration occurred. SN_{40} was measured at 64 km/h (40 mph) corrected to speed shown, based on a gradient of 0.5 SN.

Site	Deceleration (g)	Speed (km/h)	Trailer A		Trailer B	
			SN_{40}	K-Factor	SN_{40}	K-Factor
1	27	61	27	1.00	24	1.12
2	38	56	40	0.95	34	1.12
3	52	56	53	0.98	–	–
4	72	53	71	1.01	67	1.07

The K-factors determined by this means are about equal to 1 for speeds between approximately 48.3 and 64.4 km/h (30 and 40 mph) and thus are lower than the values given in Table 4. Although these conclusions are based on an extremely limited amount of data, the K-factors used by Kummer and Meyer appear to be somewhat high. More research is desirable to determine what peak decelerations can be attained by an automobile and how they relate to locked-wheel decelerations and SN_{40}.

Table 5 indicates the effects of various assumptions regarding K-factors on desirable minimum SN_{40} values; allowances were not made for temperature corrections or machine error. The SN_{40} values are 2 to 4 units higher for selected average K-factors than for the K-factors used by Kummer and Meyer; when selected low K-factors are used, the SN_{40} values are much higher (10 to 22 units).

The comparison of the SN_{40} values in Table 5 with the composite minimum SN_{40} values given in the tabulation on page 3, column 2, is interesting. Since the values as determined by Kummer and Meyer apply to main rural highways (not Interstate), it seems reasonable to compare their results with category B in the above table of desirable SN_{40} values, for which a minimum SN_{40} value of 40 is indicated. Because these roads are likely to have traffic speeds between 80.5 and 96.6 km/h (50 and 60 mph), the selected low K-factors appear to yield the most reasonable SN_{40} values of 40 and 42.

NCHRP Report 154

A second major study dealing with the establishment of minimum SN_{40} values based on driver behavior is the one described in NCHRP Report 154 (19). The intent of the study was to determine that level of lateral or longitudinal acceleration that accommodated a reasonable maximum demand in cornering or braking and to relate this level to an SN_{40} value, thus determining an appropriate K-factor. Acceleration data were obtained on dry pavements by using tape switches to sample from the normal traffic flow without the drivers' knowledge. Data were obtained at 12 intersection sites and 10 curve sites.

Table 6 (19) contains the data obtained at the 12 intersection sites. The SN_{40} values given were determined empirically by relating locked-wheel deceleration values as obtained with a 1970 Plymouth Fury and a 1971 Ford Mustang to SN_{40} values obtained with the National Bureau of Standards skid trailer. Conventional bias ply, belted bias ply, and radial tires were used on the Plymouth and belted bias tires on the Ford. The tests were conducted at the Texas Transportation Institute skid pad facility. The relationships determined are considered by the authors of this report to be generally applicable to U.S. automobiles that have tires in good condition. The relationships developed are based on the maximum decelerations from among the four vehicle and tire combinations and are thus conservative.

As with the Kummer and Meyer study, the required SN_{40} values for the 12 intersections studied by the authors of NCHRP Report 154 vary widely, depending on the K-values selected for the conversion of FN to SN. Table 7 shows SN_{40} values determined by using three sets of K-values—the ones developed by Kummer and Meyer, the average of selected values by the present authors, and the low values previously mentioned—and by using the SN_{40} values required as determined by the authors of NCHRP Report 154.

Unfortunately skid tests were not performed at the 12 intersections with an ASTM 274 trailer. We feel that it is quite unlikely that the average SN_{40} value for all intersections would approach the average SN_{40} value of 62 as computed from the required SN_{40} values given in NCHRP Report 154. Therefore, we believe it is more reasonable to assume that rolling incipient friction should be considered, and a set of the K-values as given in Table 7 would provide a means of calculating the needed friction. Since the surfaces are located at intersections, we prefer the low K-values. In addition, intersections would intuitively seem to need SN_{40} values in the range of 38 to 55.

SELECTION OF TENTATIVE SN_{40} GUIDELINES

Different SN_{40} values are required for varying roadway and traffic conditions. Also, much work remains to be done regarding the determination of required SN_{40} values for specific roadway and traffic characteristics, including the determination of the proper relationship between FN and SN. For these two reasons, it appears that accident data will continue for some time to provide the primary basis for identifying high accident sites on wet pavement; survey skid data will be used once sites are selected.

Nevertheless, selecting minimum SN_{40} guidelines is desirable for the purpose of identifying potentially hazardous sites for inclusion in the routine site review process in Virginia's program to reduce wet-pavement accidents. For this purpose, an SN_{40} value of 30 is considered to be the minimum guideline value for Interstate and other divided highways in Virginia, and an SN_{40} value of 40 is considered to be the minimum guideline value for two-lane highways. Sites with values below these guideline values will not automatically be scheduled for treatment, but will be included for evaluation with sites selected by use of accident data. Site treatments should be allocated on a priority basis to achieve the maximum reduction of wet-pavement accidents.

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Rehabilitation Decision Model

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A study was made of Utah's flexible pavement performance system to introduce new procedures and to alter existing procedures. The terminal serviceability concept was revised to consider functional class as well as average daily traffic. Highways with high average daily traffic were assigned a high terminal serviceability index to reduce user costs. A computerized pavement-rating system was developed to aid maintenance personnel in making the most appropriate pavement rehabilitation decision. The system can also be used by planning and programming personnel to