

PREDICTING WET WEATHER ACCIDENTS†

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Abstract—The development of a wet weather safety index, WWSI_w, is presented. WWSI_w is an empirical formulation based on prediction equations for wet accident rates. These equations were derived by multiple regression techniques from a survey of 68 highway segments in Texas. These segments covered a range of wet accident rates from zero to 40 accidents per year per mile. In general, much higher values of wet accident rates are observed in urban areas than in rural areas. Also, the sensitivity to pavement skid resistance is much higher in urban than in rural areas. The findings and developments reported warrant a restructuring of many state programs to reduce wet weather accidents. The Wet Weather Safety Index and associated equations represent a practical method of predicting wet accident rates as a function of traffic, road geometric, and pavements surface characteristics. These predictive equations may be cautiously used to determine accident reduction due to specific remedial measures. These new developments can be integrated into a comprehensive plan to reduce wet weather accidents, a plan which should greatly increase the effectiveness of those resources devoted to this objective.

INTRODUCTION

The major objective of this work was to develop an efficient way of using traffic and highway characteristics to accurately define those segments of highway having a high potential for wet weather accidents and to develop a priority rating scheme to determine where maintenance funds should be spent to maximize accident reduction. The traditional way of determining the need for resurfacing based on the value of skid number (SN) or other measures of the frictional properties of a pavement surface cannot be justified on a benefit/cost basis because the influence of skid number on accidents is highly site-specific. At one site, increasing SN values from 25 to 50 might eliminate all wet weather accidents. On another site it might have no effect at all.

The position taken here is that perhaps there is not, but more importantly need not be, a unique answer to the question of an appropriate level of skid resistance in order for skid number determinations to be used in the optimum way for the public good.

If specific levels of skid resistance are set as standards for required maintenance, no matter how scientifically or arbitrarily, there will be many exceptions to the defined levels; that is, sections of roadway where achievement of the set levels does not have the results anticipated. There are and will be discovered areas where the SN values are under 30 where there is no wet weather accident hazard and other sites where wet weather accident rates are and will be critical with SN values greater than 40. The reason, of course, is that skid resistance is only one of many factors influencing the propensity toward accidents and, indeed, even toward skidding. Specific levels of skid resistance should not be arbitrarily required, as such compliance will in many cases be a waste of public funds, funds that are becoming increasingly scarce for sorely needed maintenance activities.

The approach taken here was an effort to place SNs in the proper perspective with regard to their influence on wet road safety. Although a thesis has been advanced opposing the use of minimum skid resistance levels as the criterion dictating resurfacing, minimum levels are considered appropriate as a way of controlling surface friction characteristics when resurfacing

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is undertaken or on new construction. Methods of achieving higher levels of skid resistance over extended periods of time by setting minimum standards for aggregate resistance to polishing are also considered appropriate for resurfacing or new construction. These standards should not be arbitrarily reduced based on the apparent insensitivity of rural wet accident rates to skid resistance.

The efforts of highway departments to provide higher levels of available friction to the public have in general been productive. The application of principles presented here should make these efforts even more productive.

RELATIONSHIPS BETWEEN WET WEATHER ACCIDENTS AND HIGHWAY AND TRAFFIC CHARACTERISTICS

General

The classic approach to determining the influence of various highway and traffic characteristics on wet weather accidents has been to survey various elements of the roadway to determine the accident history of the elements and to attempt to develop single variable correlations between specific factors and accident statistics. The independent variable usually chosen is skid number, other characteristics often accounted for by road type and traffic volume stratification.

Tire-pavement friction

One of the problems associated with comparing the many studies of the influence of tire-pavement friction on accident statistics is the fact that almost no two studies use the same method of determining tire-pavement friction. The methods vary from the ASTM standard of SN_{40} , the skid number at 40 mph through skid numbers at other speeds, and to peak braking force coefficients and cornering slip numbers. Most of the cornering slip numbers or cornering force coefficients are taken at a large enough angle to get close to the maximum friction developable by the tire in the cornering mode, but different tires and different pavement wetting methods are used in different studies.

To achieve the proper perspective, Figs. 1 and 2 should be considered, figures showing plots of unstratified data pairs of accidents and skid numbers. These figures, based on studies in Texas [McCullough, Hankins, 1966] and Kentucky [Rizenbergs, Burchett and Warren, 1976a], show the high degree of variability from site to site and illustrate either that a great deal of stratification needs to take place before a reasonable trend is apparent or that the influence of tire-pavement friction on wet weather accidents is so subtle as to be practically undetectable. The truth of the matter probably lies in between these extremes. In general, there is an influence of available friction on wet accident rates, which has been shown in a number of

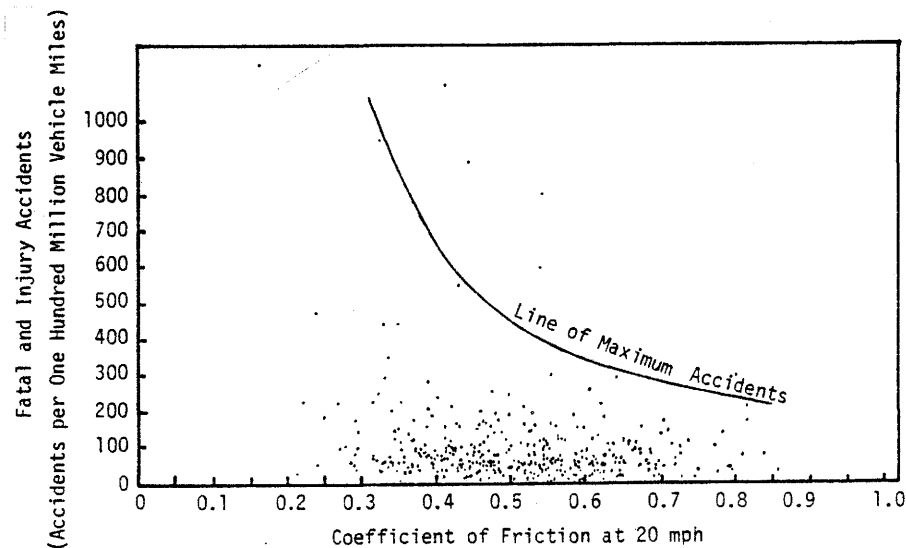


Fig. 1. Comparison of accidents and coefficient of friction. [McCullough, Hankins, 1966].

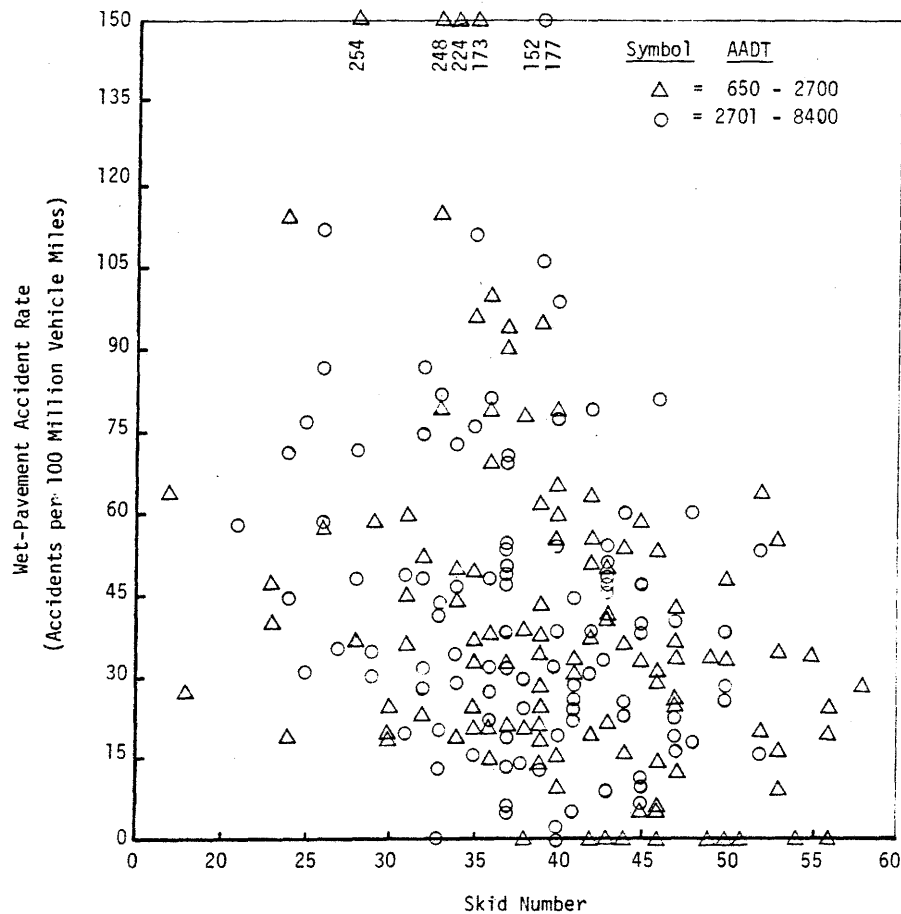


Fig. 2. Wet pavement accidents rates vs. skid numbers. [Rizenbergs, et al., 1976].

studies. What has rarely been shown is the influence, on a site-specific basis, of friction on accident rates. The probable cause is that on one site the influence is negligible or sometimes even the reverse of the trend normally assumed, while on another the influence is profound. What comes out of statistical studies is the average influence of friction on a great number of sites. The danger in applying this average influence to any specific site is obvious. Funds will be spent on sites where no value will be received, and funds will be limited to improve sites where a great value would be received.

Many efforts have been devoted to quantifying the influence of friction on wet weather accidents. Giles [1957], Schulze [1975], Schlosser [1977], Rizenbergs *et al.* [1973, 1976a, 1976b], and Blackburn *et al.* [1977] have all achieved some success, but the variety of friction measurement methods and roadway types represented in these studies make consistent interpretation difficult. A detailed discussion of these studies has been presented by Ivey *et al.* [1977].

There is no doubt that an overall influence of friction on wet accident rates exists, and the literature indicates that it is fairly significant. The major problem is to develop a means to determine the highways where it is most significant so that maintenance funds can be allocated reasonably.

EMPIRICAL PREDICTION OF WET ACCIDENT RATES

General

On the premise that wet weather accident rates are the most direct measure of relative degrees of safety, a field study of sixty highway segments in Texas was undertaken. Data so acquired were used to derive equations capable of predicting wet accident rates. This predictive capacity is a necessary step in the formulation of an empirical Wet Weather Safety Index.

Site selection procedures

The selection of the 22 highway control sections used in this study was made as follows:

(a) First a magnetic tape was created containing all 1975 Texas accidents, identified as to location by mile point, which occurred in the state-maintained highway system.

(b) Each accident was weighted according to the severity of the accident. Fatal accidents received a weight of 50; "A" level injury accidents received a weight of 20; "B" level accidents received a weight of 10; "C" level accidents received a weight of 5; and property damage only (PDO) accidents received a weight of 1.

(c) All weighted accidents within a control section were then summed to produce a *Severity Index* (SI) for each control section. For example, assume that a given control section sustained two fatal accidents, 10 "A" level accidents, 100 "B" level accidents, 300 "C" level accidents and 1000 PDO accidents. (See the National Safety Council's injury scale for definitions of A, B and C level injuries.) The severity index for this particular control section would be 3800.

$$(2 \times \text{Fatal}) + (10 \times A) + (100 \times B) + (300 \times C) + (1000 \times \text{PDO}) = \text{SI}$$

or

$$(2 \times 50) + (10 \times 20) + (100 \times 10) + (300 \times 5) + (1000 \times 1) = 3800.$$

(d) Next, SI's were calculated for all control sections in Texas based upon accidents which occurred on wet roads. That is to say, all accidents sustained on a given control section which occurred on wet roads were weighted and summed to produce a wet road severity index for that control section. The control sections were then arrayed in descending order according to the size of their wet road severity indexes. The first 100 control sections were selected for further consideration.

(e) Each of the 100 control sections with high wet road severity indexes was then compared to the total severity index for that control section. If 25% (or more) of the overall severity index for a control section derived from wet road accidents, that control section was saved for final consideration. For example, assume that a given control section had a wet road severity index of 580 and an overall severity index of 2500. Obviously, 29% of the overall severity index derived from accidents which occurred on wet roads. Therefore, this control section would have been saved for final consideration as a field study site.

(f) Following the procedures outlined above, 25 control sections in the state of Texas were defined to be candidates for final consideration for field sites. Of these 25 candidate sites, three were made up wholly of interstate highways. These three control sections were eliminated as being inappropriate sites to be used with the WWSI model which was under development. This decision was made when it was found that most of these accidents occurred at service road intersections. The remaining 22 control sections were surveyed.

Any criteria used to select control sections for this study are necessarily arbitrary. There is no right or wrong selection process for choosing those control sections which are "most hazardous" during wet weather. While the procedure which was used is arbitrary, it is submitted that the procedure was at the same time reasonable. In deriving the procedure described above two objectives were considered:

(1) Not all accidents should be considered equally hazardous. Some allowance should be made for accidents resulting in injury and death to be considered more important than PDO accidents. Without this proviso, wet weather commuter accidents of the PDO variety might overshadow all calculations of wet weather hazard.

(2) There is strong correlation between wet weather accidents and total accidents along control sections. This phenomenon results from the fact that both wet weather accidents and total accidents correlate with traffic volume. Control sections with low traffic volumes have relatively few total accidents and relatively few wet weather accidents, and vice versa.

Thus, in determining which control sections were overrepresented in wet weather accidents, wet weather severity indexes were normalized by total severity indexes to produce a measure of relative wet weather hazard. Only those control sections with 25% or more of the overall severity index attributable to wet roads were considered for use in this study.

Survey procedures

General. During the preliminary reconnaissance trip, the proposed survey sites were documented by color slide photography. To achieve this, color slides were taken which were representative of the particular individual conditions encountered within the limits of the control section and of any special features observed within the section.

Specific properties. Many items must be determined or estimated for each highway site. Table 1 gives items which were found to be available from files at the State Department of Highways and Public Transportation of Texas. Where data were not available they were collected in the field by the survey crew. Table 2 gives those items which were to be determined in the field.

Detailed methods of measuring the properties specified in Tables 1 and 2 are available from a Texas report by Ivey *et al.* [1977]. The method of arriving at an estimate of access to the highway sections is illustrated by Figs. 3 and 4.

A set of photographs was prepared as a standard for rating access. Separate ratings were given for two-lane, two-way roads; four-lane undivided roads; and four-lane divided roads. The least access is rated as "1" and the heaviest access as a "5". All standard photographs are given in the report by Ivey *et al.* [1977].

Results of field surveys and accident data analysis

Selected data from the field studies and from analysis of accident and road inventory records are given in Table 3. Thirty-two high-speed and 36 low-speed sites were surveyed. The

Table 1. Survey information available from Texas road inventory files

Length and degree of all curves
Centerline grade
Lane widths
Paved shoulder width
Study site limits and lengths
Skid number (when available)

Table 2. Survey information determined in the field

Surface texture
Surface slopes
Surface rutting
Sight distance
Vehicle speed profile
Curve superelevation
Traffic count (used to predict ADT)
Skid number

Table 3. Representative data

High-speed roads (rural); posted speed 55 mph, mean speeds 47-61 mph						
Site No.	WAR ^a	ADT	No. Lanes	ACC ^b	SN ^c	TW ^d
5	6.56	7900	4	3	16	0.081
10	0	6200	4	3	21	0.077
12	5.52	8800	4	2	48	0.077
16	1.86	1300	4	2	35	0.084
19	3.53	26300	4	3	23	0.057
23	0.29	1600	2	1	58	0.082
29	1.23	5800	2	2	18	0.062
32	0.58	4600	2	1	18	0.053
Low speed roads (Urban); posted speed 30-50 mph, mean speeds 32-50 mph						
Site No.	War ^a	ADT	No. Lanes	ACC ^b	SN ^c	TW ^d
1	2.22	19800	4	3	55	0.055
10	0.34	13900	4	1	29	0.055
14	0	6100	4	2	17	0.053
15	7.57	6000	4	2	9	0.053
19	26.9	12900	4	3	23	0.077
24	40.4	29800	4	5	38	0.055
28	1.17	1800	2	3	33	0.091
36	33.2	15900	6	5	21	0.053

^aWAR—Wet accident rate per year per mile.

^bACC—Access code; see Figs. 3 and 4.

^cSN—Skid number at 40 mph, wet pavement.

^dTW—Time road is wet as a decimal portion of all time.

These sites are eight of the thirty-two used in analysis of high-speed roads.

These sites are eight of the thirty-six used in analysis of low-speed roads.



TWO-LANE
ROADWAY

MULTILANE
ROADWAY
NOT DIVIDED



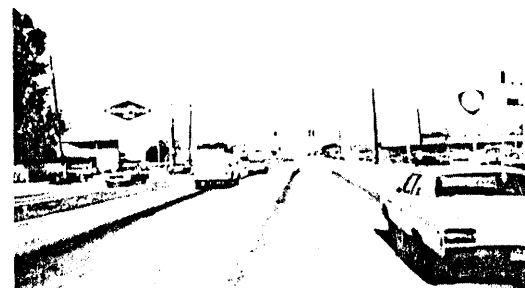
MULTILANE
ROADWAY
DIVIDED

Fig. 3. Access classification No. 1.



TWO-LANE
ROADWAY

MULTILANE
ROADWAY
NOT DIVIDED



MULTILANE
ROADWAY
DIVIDED

Fig. 4. Access classification No. 5.

16 sites documented in Table 3 were chosen to show the range of the main characteristics used in the analysis.

SAS regression

The most direct method of developing predictive equations was taken by using simple linear models in a Statistical Analysis System (SAS) regression. The models were of the form

$$y = a_1x_1 + a_2x_2 + \cdots a_nx_n + c$$

$$y = b_1x_1 + b_2x_2 + \cdots b_nx_n + c$$

Independent variables considered were (1) ADT; (2) SN; (3) ACC, Access code; (4) Mean traffic speed; (5) Variation in traffic speed; (6) Number of traffic lanes; (7) Proportion of time road is wet; (8) Curvature; and (9) Surface texture. Not all of these factors were found to aid in the correlations. The independent variable, wet accident rate (WAR), was calculated in terms of wet accidents per year per mile. The data developed in the field were stratified between those sections with a 55 mph speed limit and those where the speed limit was less than 55 mph. This corresponds roughly to rural and urban sections.

The equations developed in this way are:

Low Speed (Urban) [Speed Limit < 55 mph]

$$\text{WAR}_{\text{LS}} = -21.7 + 0.0009 \text{ ADT} + 2.34 \text{ ACC} - 0.40 \text{ SN} + 286 \text{ TW} + 1.32 \text{ LN} \quad R^2 = 58\% \quad (1)$$

and

High Speed (Rural) [Speed Limit = 55 mph]

$$\text{WAR}_{\text{HS}} = -0.75 + 0.0001 \text{ ADT} - 0.053 \text{ VM} + 0.54 \Delta V + 0.69 \text{ ACC} - 0.025 \text{ SN} \quad R^2 = 46\% \quad (2)$$

The variables are:

ADT average daily traffic

ACC Access code

SN Skid number at 40 mph

TW Proportion of time wet

VM Mean traffic speed

ΔV Variation in traffic speed (one standard deviation from the mean)

LN Lanes of traffic

The two equations (1 and 2) each contain five independent variables, although not necessarily the same variables. ADT, ACC and SN are common to both; but the urban eqn (1) contains TW and LN, while the rural equation contains ΔV and VM. Of interest is the fact that neither pavement mixture nor curvature entered into these equations. Eqn (1) accounts for 58% of the variation in urban wet accident rate; eqn (2) accounts for 46% of the variation in rural accident rate. *F*-tests on the regression coefficients yielded the probabilities shown in Table 4. For eqn (1) ADT, SN and TW are significant at the traditional α of 0.05. For eqn (2) ADT and ΔV are also significant at the 0.05 level. While not quite meeting the 0.05 significance test, ACC in both eqns (1) and (2) should also be considered significant.

Figures 5-11 illustrate the sensitivity of these two equations to the independent variables involved.

A graphical demonstration of the relative precision of these equations is shown by Fig. 12. This figure shows observed wet accident rate as a function of the wet accident rate predicted by eqns (1) and (2). While at first glance the correlation may not appear spectacular, comparison with Fig. 2 (wet accident rate vs SN) will illustrate the improvement that has been made in predicting accident rates.

Table 4. Probability levels for independent variables

Urban data (eqn 1)		Rural data (eqn 2)	
Independent variables	Probability level	Independent variables	Probability level
ADT	0.0011	ADT	0.0133
ACC	0.0522	ΔV	0.0355
SN	0.0126	ACC	0.0554
TW	0.0168	SN	0.3576
LN	0.2899	VM	0.5283

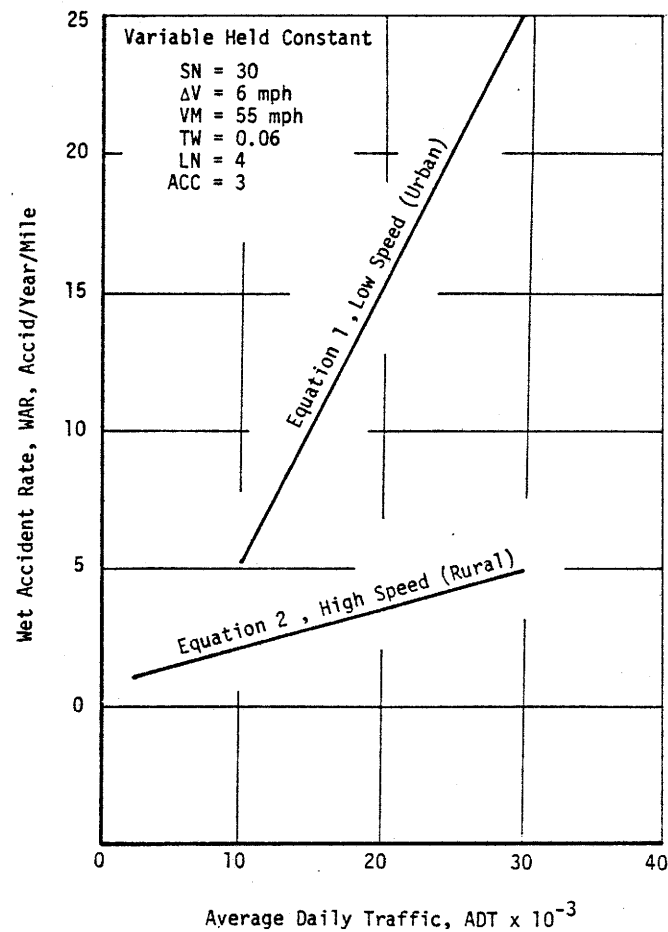


Fig. 5. Sensitivity of equations 1 & 2 to ADT.

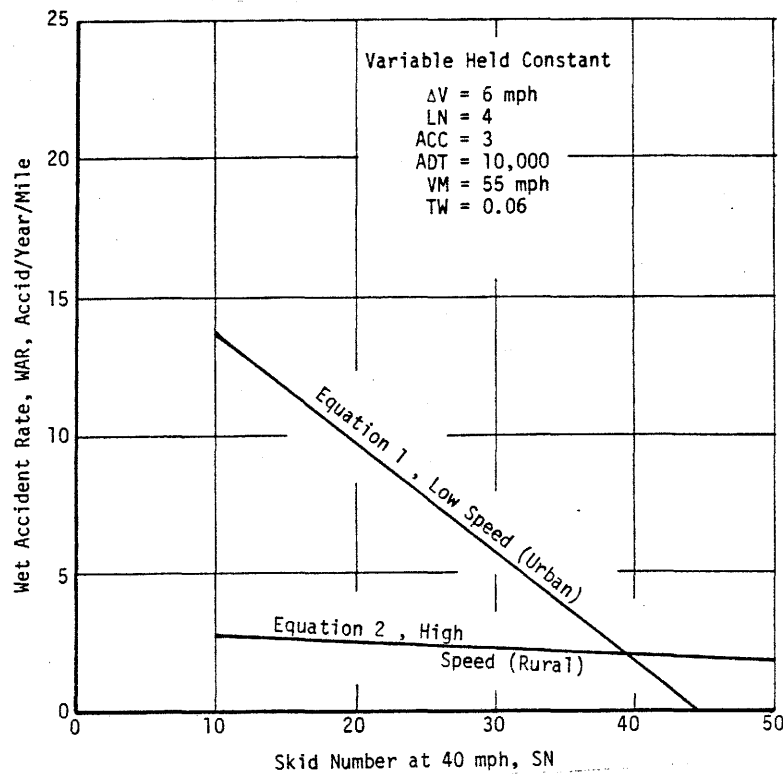


Fig. 6. Sensitivity of equations 1 & 2 to skid number.

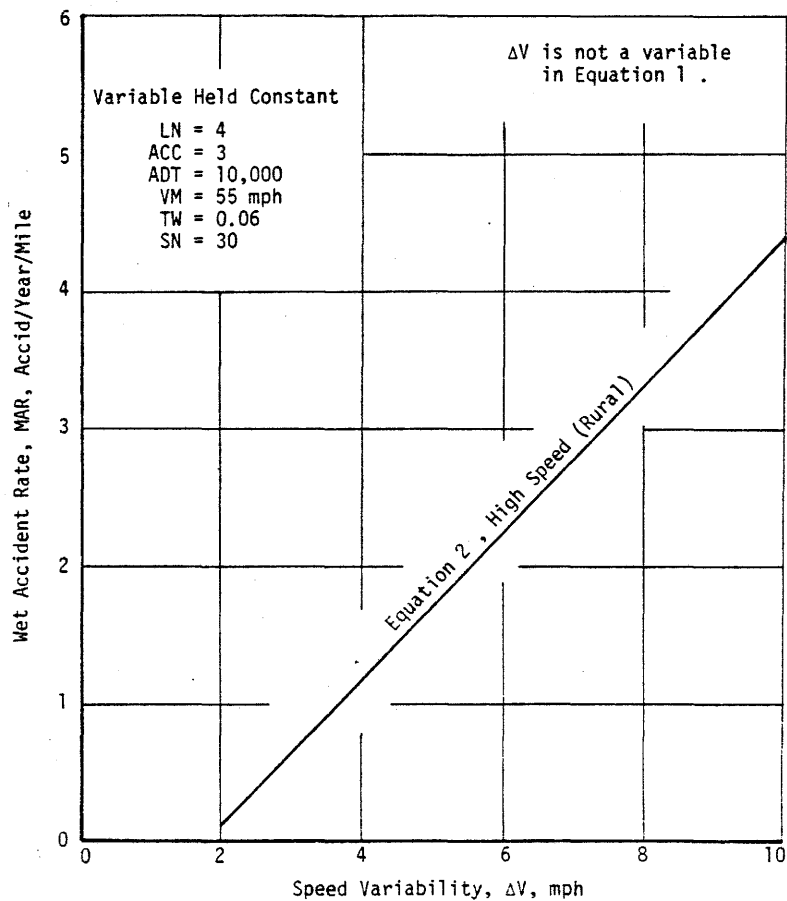


Fig. 7. Sensitivity of equations 1 & 2 to speed variability.

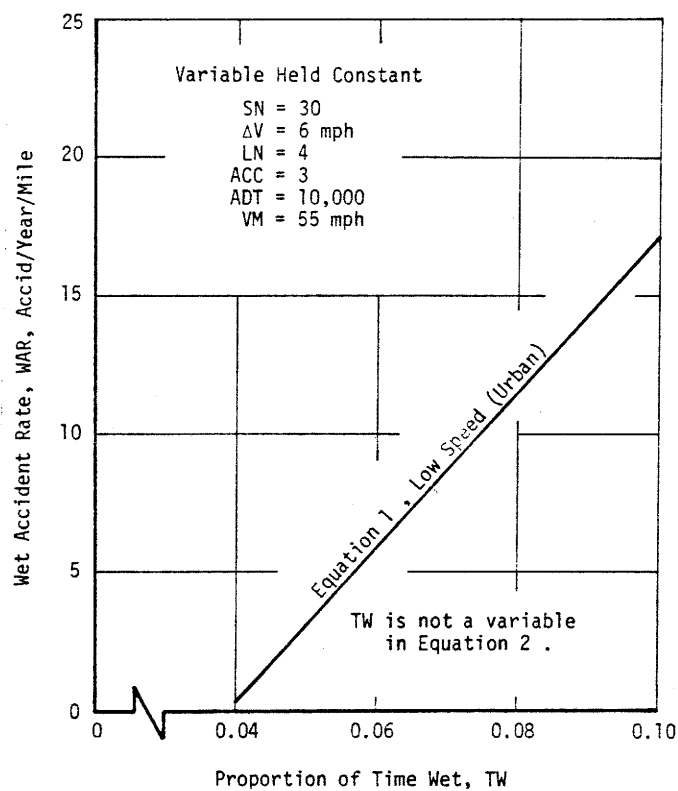


Fig. 8. Sensitivity of equations 1 & 2 to time wet.

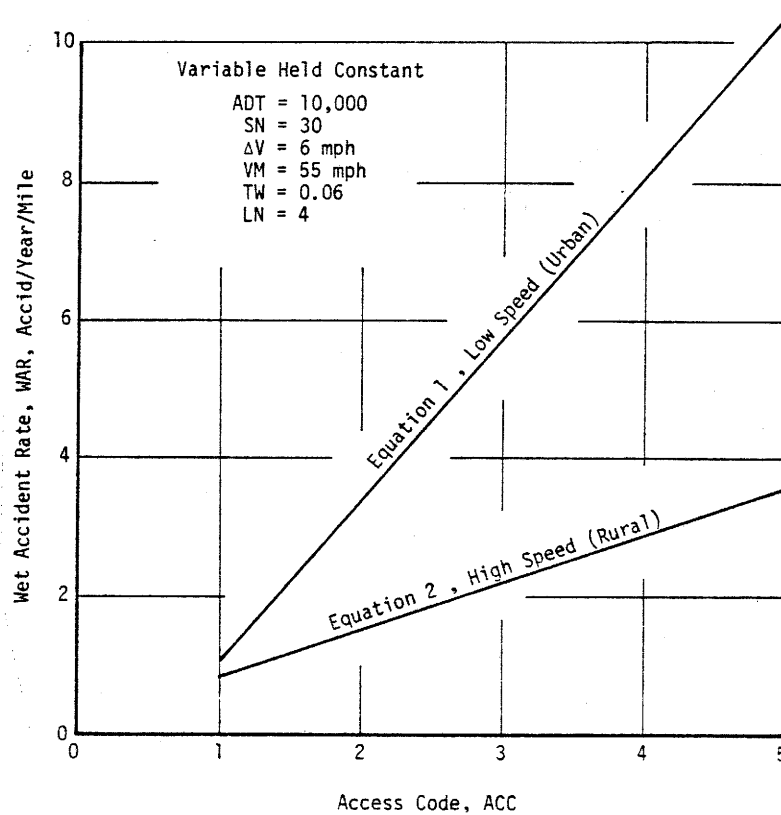


Fig. 9. Sensitivity of equations 1 & 2 to access.

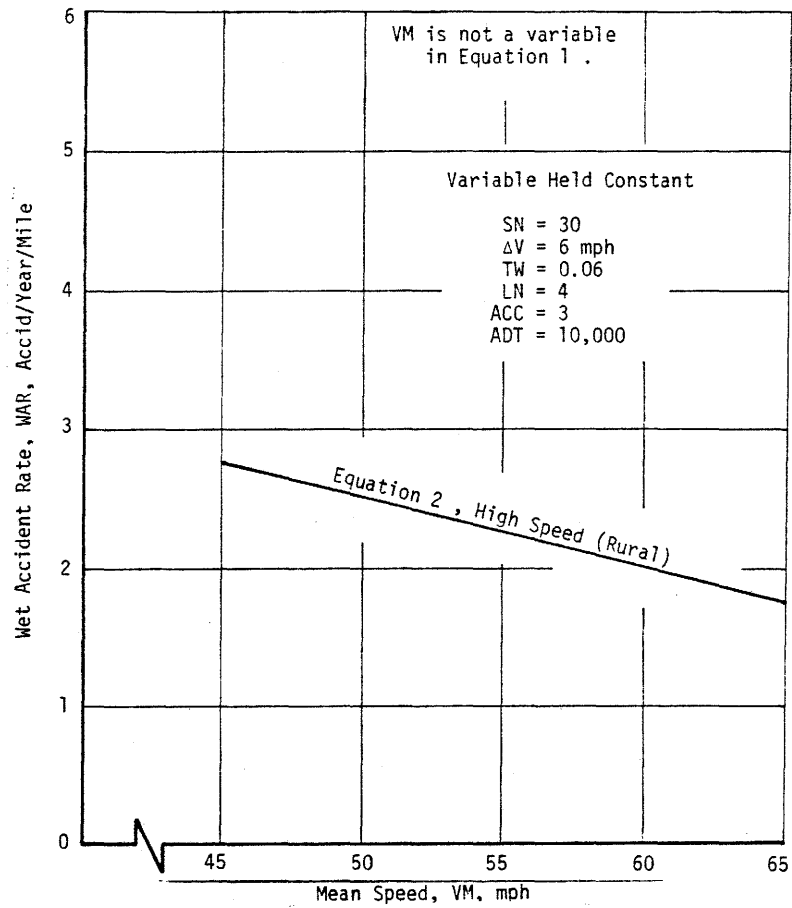


Fig. 10. Sensitivity of Equations 1 & 2 to mean speed.

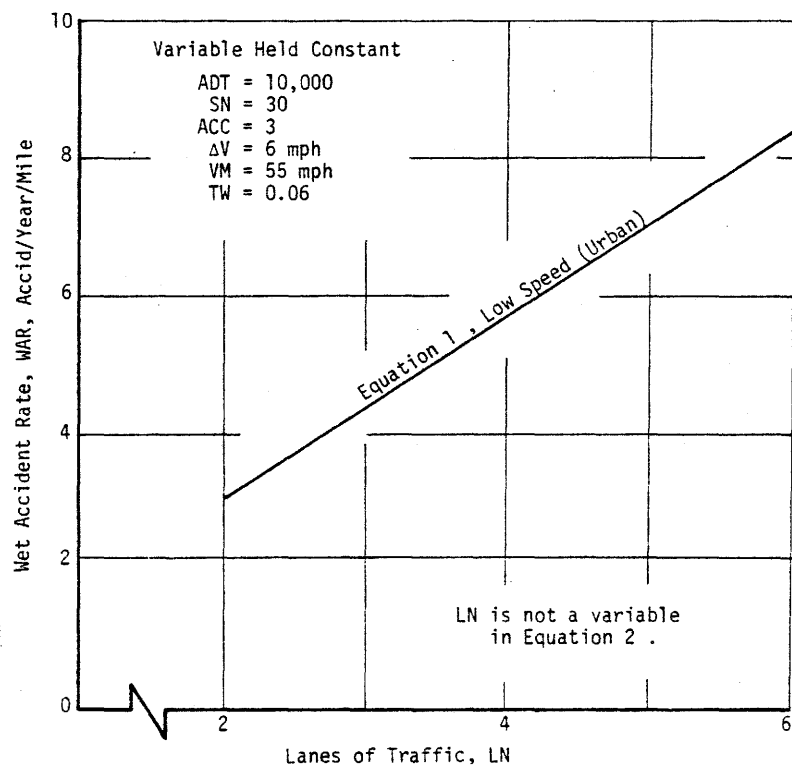


Fig. 11. Sensitivity of Equations 1 & 2 to lanes of traffic.

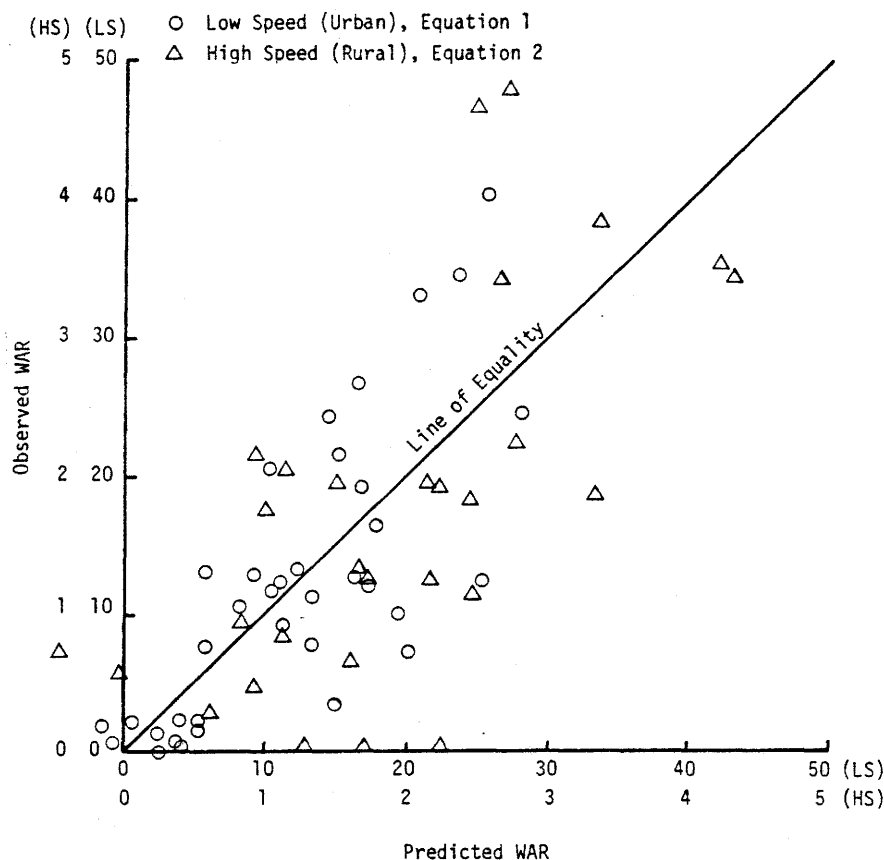


Fig. 12. Observed WAR vs. Predicted WAR. (Predicted values from equations 1 and 2).

Two-step constrained regression

The SAS regression efforts demonstrated some difficulties in analyzing a data set that is comparatively small with respect to the number of independent variables considered. The high variability in a single year's evaluation of wet accident rate also contributed to the problem. A technique that has proven useful in the past in situations like these is the "Two-Step constrained Regression". This technique is a versatile way of grouping many variables in logical patterns which usually results in models exhibiting considerably larger R -squared values. The procedure is described in detail by R. L. Lytton [Ivey *et al.* 1977]. The data were again stratified according to sites where the speed limit was 55 mph and sites where the speed limit was less than 55 mph. This stratification may again be considered to conform roughly to rural and urban sites.

The result of this effort was the two equations:

$$WAR'_{LS} = \frac{0.24[ADT + 3000]^{1.21}[TW + 0.01]^{1.78}[ACC + 0.5]^{0.60}}{[SN + 5.5]^{1.09}} - 4.0 \quad R^2 = 63\% \quad (3)$$

55 mph (Rural)

$$WAR'_{HS} = 6.37 \times 10^{-7} \frac{ADT^{1.1} \Delta V^{1.4} ACC^{0.37}}{TW^{0.95}} - \frac{1.66 \times 10^{-4} ADT^{0.9}}{TW^{0.44}} + \frac{11.8}{SN^{0.22}} - 4.8 \quad (4)$$

These equations seem reasonable with respect to most preconceived ideas on the subject and with respect to most of the literature. Table 5 gives probability levels for the individual independent variables.

Table 5. Probability levels for independent variables

Urban data(eqn 3)		Rural data(eqn 4)	
Independent variables	Probability level	Independent variables	Probability level
ADT	0.00001	ADT	0.00038
SN	0.00072	SN	0.63
ACC	0.010	ACC	0.25
TW	0.0015	TW	0.15
		ΔV	0.059

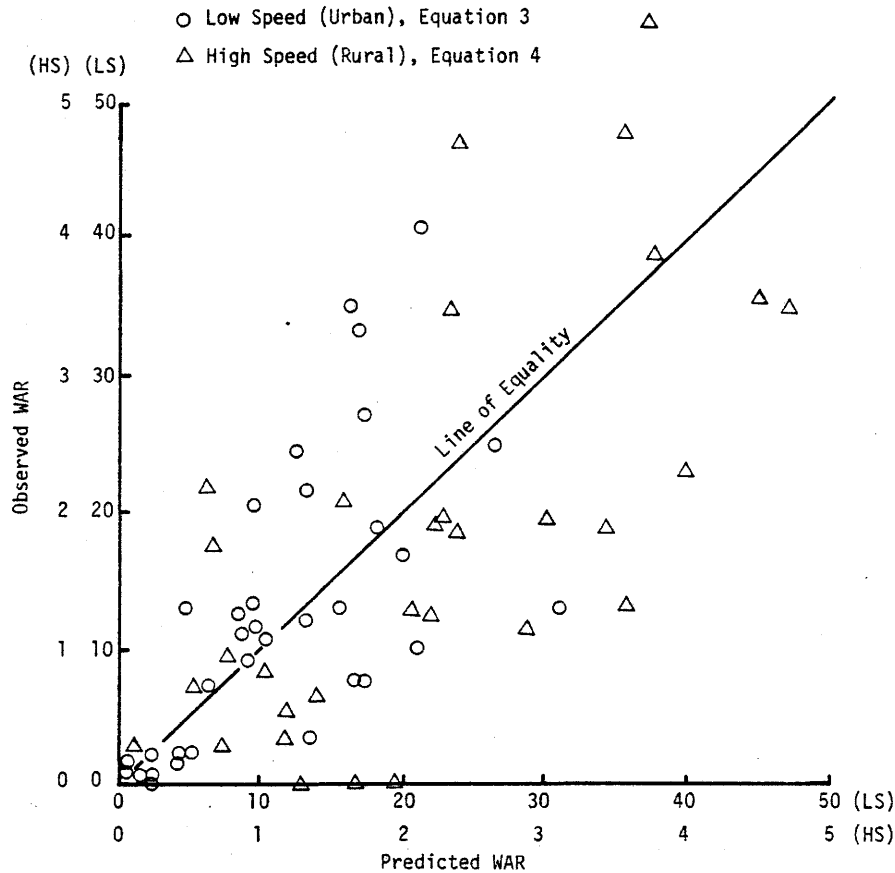
 $R^2 = 63\%$ $R^2 = 42\%$.

Fig. 13. Observed WAR vs. Predicted WAR. (predicted values from equations 3 and 4).

Figure 13 gives a comparison of observed values of WAR and predicted values. A perfect fit of the data would be indicated by all points falling on the line of equality. Although this certainly is not the case, the R^2 values achieved are considered good when the inherent variability of single-year accident data is recognized.

The sensitivity to SN_{40} shows the same basic trends in these equations as shown in the SAS equations (eqns 1 and 2). The SAS equations show a difference in sensitivity to SN_{40} of about 16 to 1 between urban and rural sites. A similar difference in sensitivity exists between eqns (3) and (4). Actual differences between the two sets of equations (i.e. 1 and 2, 3 and 4) will be illustrated in the next section.

AN EMPIRICAL WET WEATHER SAFETY INDEX

Based on the empirically derived equations for wet accident rates, an empirical Wet Weather Safety Index (WWSI_e) was formulated as:

$$WWSI_e = \frac{56 - WAR}{60} (100)$$

The constants 56 and 60 were chosen in an arbitrary manner in order to produce values for $WWSI_e$ which would be expected to lie between zero and 100. The maximum wet accident rate observed in this study was about 40. A safety factor of 1.5 was applied to give a base number of 60 for the denominator. The obvious choice for the constant in the numerator was 60 but it was noted that it is possible to predict low negative numbers in some of the equations. Therefore 56 was chosen so that the predicted value of WAR could be as low as -4, a very unlikely occurrence, without the value of $WWSI_e$ becoming greater than 100. This empirical index ($WWSI_e$) will usually lie between 30 and 100.

The following combinations of equations could be used in a wet weather accident reduction program:

	R^2 Values (%)
(1) Eqns (1) and (2)	58 and 46
(2) Eqns (3) and (4)	63 and 42
(3) Eqns (1) and (4)	58 and 42
(4) Eqns (2) and (3)	46 and 63.

If the equations were selected that gave the maximum R^2 levels, the best combination would be eqns (2) and (3).

Figures 14-18 illustrate the actual differences in the predicted values of $WWSI_e$ for the four equations. These figures illustrate two other possible reasons for using eqns (2) and (3), one negative and one positive. The negative reason is that Fig. 17 shows a slight rise in the $WWSI_e$ as a function of TW (time wet) using eqn (4). Qualitatively, this trend is difficult to rationalize. The choice between eqns (2) and (4) would seem to be (2), which shows no significant influence. The positive reason is illustrated by Fig. 15 which shows a decrease in sensitivity to SN at high SN levels, a change in sensitivity which is in keeping with much of the literature and a major school of thought.

There is a valid argument for the simplicity of the linear equations (1 and 2) considering the relatively minimal difference in predictive power, even though eqn (1) lacks the sensitivity

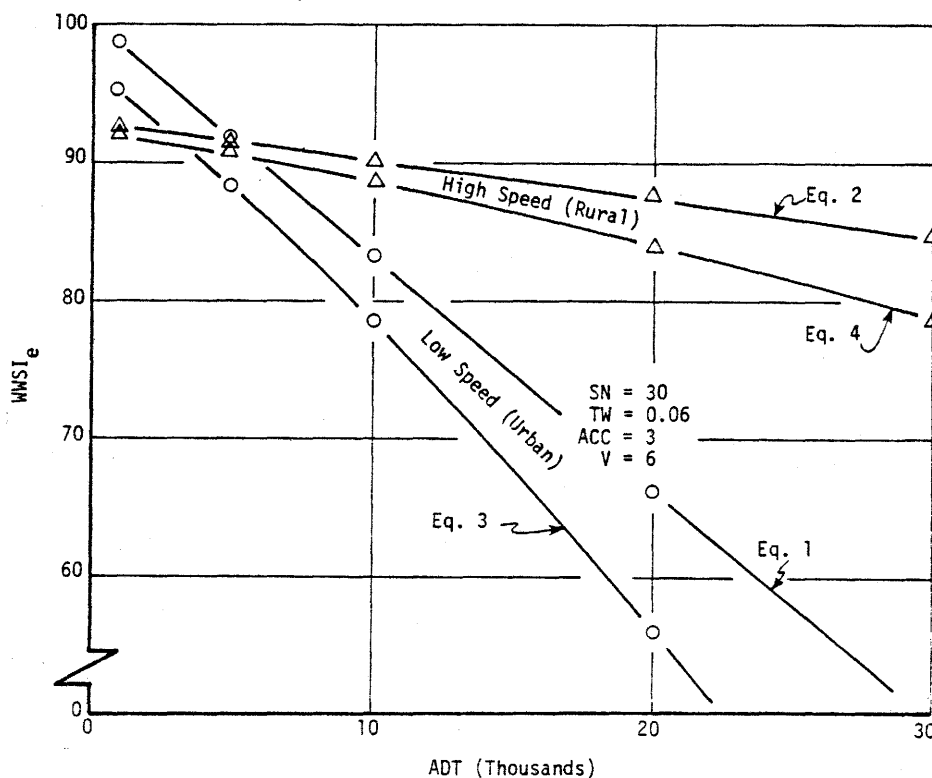


Fig. 14. Influence of ADT on $WWSI_e$.

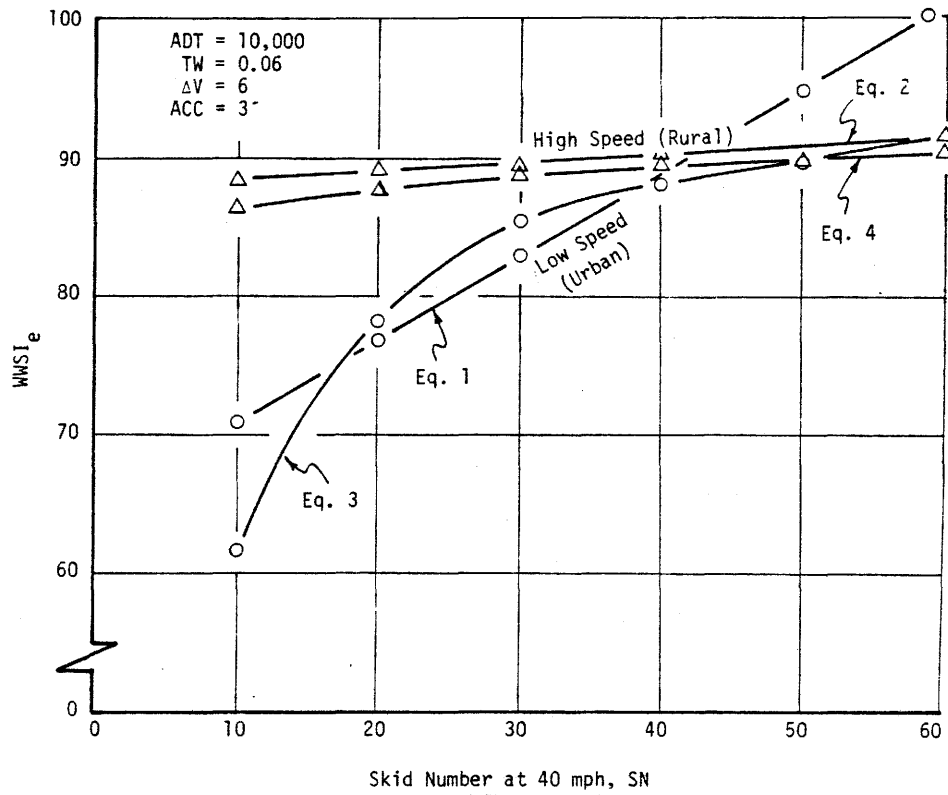


Fig. 15. Influence of skid number on WWSI_e.

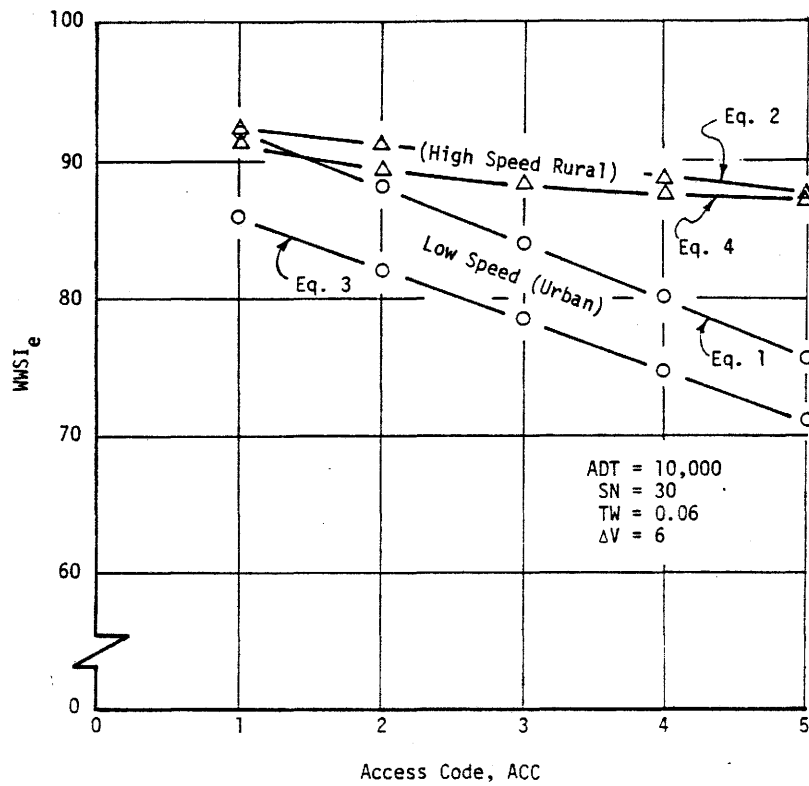
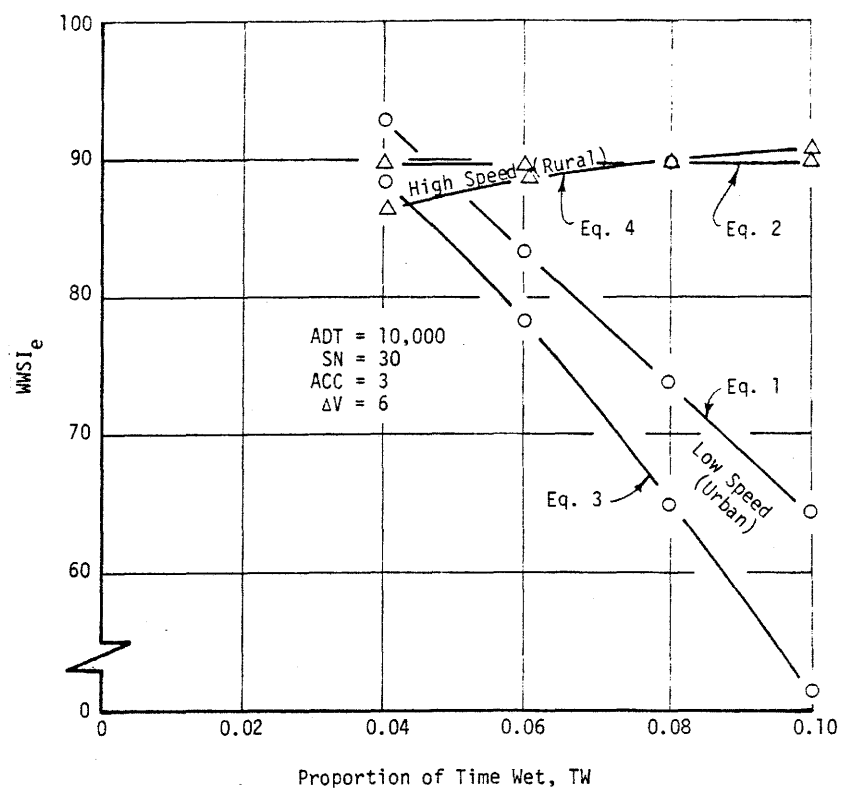
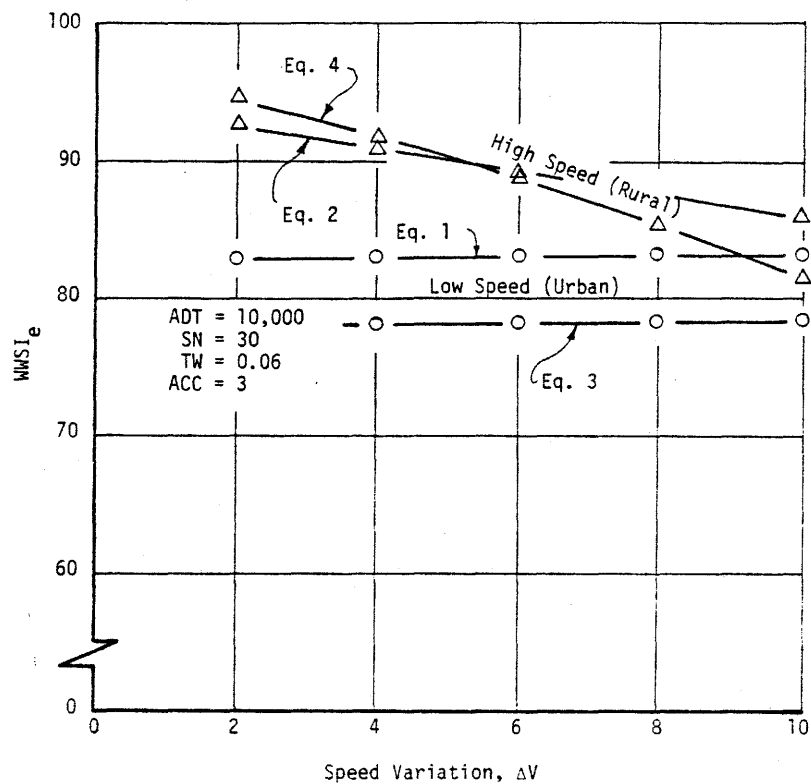


Fig. 16. Influence of access on WWSI_e.

Fig. 17. Influence of time wet on $WWSI_e$.Fig. 18. Influence of traffic speed variation on $WWSI_e$.

change between low and high ranges of skid number. The data on which these equations are based must be considered quite limited. Due in part to this limitation, there are inherent dangers in regression analysis which are well known. Because of these potential dangers, the authors suggest that eqns (1) and (2) be used to predict accident rates in the first implementation efforts. Reliance on more sophisticated formulations should be reserved until such time that variations in sensitivity and interactions between variables can be substantiated by larger data bases.

CONCLUSIONS

Traffic, highway geometric, pavement surface, and rainfall exposure characteristics can be used to predict wet weather accident rates. The accuracy of this prediction, based on regression analyses, is indicated by correlation coefficients from 0.65 to 0.8 (R^2 values from 42 to 63%).

2. Wet accident rates (WAR's) on highways where posted speed limits are less than 55 mph[†] are sensitive to ADT, highway access, skid number and the time of exposure to rainfall. WAR's on these highways are highly sensitive to skid number. There is some indication that this sensitivity decreases as skid number increases.

3. Wet accident rates (WAR's) on highways where posted speed limits are equal to 55 mph[‡] are sensitive to ADT, highway access and the standard deviation of traffic speeds about the mean traffic speed. WAR's on these highways appear to be relatively insensitive to skid numbers in the range of skid number observed (16-58).

4. The empirical Wet Weather Safety Index (WWSI_e) can be used in conjunction with traditional methods to develop priorities for highway improvements to reduce wet weather accidents.

5. The data base used to reach the first four conclusions is limited. Early implementation efforts should be carefully evaluated to determine whether changes are needed to make the predictive equations for wet accident rates and thus for WWSI_e of more general applicability.

REFERENCES

- Blackburn R. R., Harwood D. W., St. John A. D. and Sharp M. C., *Effectiveness of Alternative Skid Reduction Measures*. Vol. I, Draft Final Report. Midwest Research Institute, Contract No. DOT-FH-11-8120, 1977.
- Cost-Effectiveness in Traffic Safety*, prepared by Arthur D. Little, Inc., Frederick A. Praeger, Publishers, New York, 1968.
- Gallaway B. M. and Ivey D. L., *Pavement in Geometric Design Criteria for Minimizing Hydroplaning*. Final Report on Contract No. DOT-FH-11-8269, May 1977.
- Giles C. G., The skidding resistance of roads and the requirements of modern traffic. *Proc. Inst. Civ. Eng.*, pp. 216-249, 1957.
- Ivey D. L., Griffin III, L. I., Newton T. M. et al. *Development of a Wet Weather Safety Index*. Research Report 221-1F, Texas Transportation Institute, November 1977.
- McCullough B. V. and Hankins K. D., *Skid Resistance Guidelines for Surface Improvements on Texas Highways*. HRB 131, Highway Research Board, 1966.
- Rizenbergs R. L., Burchett J. L. and Napier C. T., *Accidents on Rural Interstate and Parkway Roads and their Relation to Pavement Friction*. Research Report No. 377, Dept. of Transportation, Bureau of Highways, Commonwealth of Kentucky, October 1973.
- Rizenbergs R. L., Burchett J. L. and Warren L. A., *Accidents on Rural, Two-Lane Roads and their Relation to Pavement Friction*. Research Report No. 443, Dept. of Transportation, Bureau of Highways, Commonwealth of Kentucky, April 1976a.
- Rizenbergs R. L., Burchett J. L. and Warren L. A., *Accidents on Rural Two-Lane Roads and their Relation to Pavement Friction*. Research Report No. 5, Dept. of Transportation, Bureau of Highways, Commonwealth of Kentucky, November 1976b.
- Schlosser Leonard H. M., *Traffic Accidents and Road Surface Skidding Resistance*. TRR 623, Transportation Research Board, 1977.
- Schulze K. H., *Unfallzahlen und Strassengriffigkeit. Untersuchungen über die Verkehrssicherheit bei Nasse*. Strassenbau und Strassenverkehrstechnik, Nr. 189, 1975. Edited by Bundesminister für Verkehr, Bonn.

[†]This group of highways includes urban areas and high roadside development areas.

[‡]This group of highways includes rural areas and very low roadside development areas.

