THE RELATIONSHIP BETWEEN ACCIDENT EXPERIENCE AND WET PAVEMENT SKID RESISTANCE

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Wet accident experience of rural highway sections in New Brunswick, Saskatchewan, Ontario and Kentucky was related to measurements of average wet pavement skid resistance, SN_{40}, in separate and combined analyses. Two classes of highway were analysed: two lane undivided rural arterials having posted speeds 96-104 km/hr (60-65 mph), and average annual traffic volumes 0-8400 vpd; two lane divided rural freeways and parkways having posted speeds 112 km/hr (70 mph), and average annual traffic volumes 1100-34000 vpd. The data exhibited strong non-linear variation and considerable scatter. Ten point moving average plots of wet accident experience vs SN_{40} served to subdue scatter and identify SN_{40} levels at which significant increases in wet pavement accident experience occurred. Plots of wet accidents per mile vs SN_{40} appeared to have less scatter than those in which the significant relative frequency of wet accidents was used as the wet accident variable. In addition, wet accident experience averaged over 2 or more years gave less scatter than plots of yearly wet accident experience. Preliminary equations were developed from the data using a non-linear least squares computer program. Two lane undivided rural highway data exhibit a higher level of wet pavement skid resistance demand than that for four lane divided rural highways. Wet pavement skid resistance ranges at which marked increases in wet accident experience occurred were, for two lane rural arterials: SN_{40} = 55-60; for four lane rural freeways and parkways: SN_{40} = 43-50. Present recommended minimum wet pavement skid resistance levels for highways having mean speeds in the range of 64-112 km/hr (40-70 mph), appear to be low when the trends of this study are examined.

In its simplest form, the measure of motor vehicle traffic safety, as related to wet pavement skid resistance, is the magnitude of the number of accidents that can be attributed directly to a deficiency in wet pavement skid resistance.

Unfortunately, accident experience is a measurement of all exposure factors of which wet pavement skid resistance is only one. Even by classifying accidents by road surface condition and degree of access control, highway class, geometry, etc., and, thereby controlling some accident causation exposure factors, the vehicle-driver-traffic-roadway system interacts to describe actual accident experience. In addition, even if exposure factors remain unchanged over given periods of time, accident experience will vary along a given section of highway from time period to time period.

With these basic limitations in mind, therefore, considerable variation in results of studies directed toward the relationship between wet accident experience and skid resistance can be expected, (1, 2). Additional primary sources of variability are seated in the differences between accident report forms of jurisdictions. Analyses will vary according to how the accident report identifies both road surface condition and skidding.

Most North American accident report forms contain the options of road surface condition and presence or absence of a road defect in the way of repairs, potholes, ruts, etc. It is possible, therefore, to determine the number and location of accidents occurring on wet road surfaces under otherwise good road conditions in most jurisdictions. The manner in which skidding is reported varies. In some cases, skidding of one or more vehicles is one of a multiple choice selection contained in the 'direction of travel' component of the report, (5). Most reports do not contain a reliable and exclusive indication of whether or not one or more vehicles skidded prior to the accident event (4, 5). The success of any analysis using accident reports is dependent upon data extraction using both the wet road surface condition and skidding options. The British accident report contains this facility and reasonable success has been reported (3) in describing the variation of wet pavement skidding accident experience with wet pavement skid resistance. In addition, the same accident predictor has been used to demonstrate reduced wet pavement skidding accidents following a remedial treatment to an apparently 'slippery-when-wet' highway location.

A more recent study (5) identified the following major limitations of previous work directed to the relationship between accidents and skid resistance:

1. Lack of a large sample encompassing the entire range of skid resistance.
2. Lack of an attempt to account for the natural variability in accident experience of the same highway location from time period to time period.
3. Modification of actual accident experience by reducing the rather exact numbers of accidents to a rate expression by dividing accidents by the relatively crude measure of the number of vehicle-miles travelled during a particular time interval. (Use of a vehicle mile accident rate reduces the entire exposure factor question to vehicular volume and length. Further correlations of this rate with exposure factors such as wet pavement skid resistance are questionable because the pure measure of hazard - the actual number of accidents - has been modified.)
4. Lack of control of major exposure variables such as vehicular volume, highway classification, roadway geometry, and representative highway sections.

The following sections of this paper describe the pertinent analyses and results of a recent study (5), in which the primary sources of variability in reported relationships between wet pavement accident experience and wet pavement skid resistance were controlled where possible subject to practical constraints of budget and time.

Description of Highway and Traffic Data

In order to obtain a large sample, accident data and associated skid measurements for New Brunswick, Saskatchewan, Ontario and Kentucky were used in separate and combined analyses (5). Data from all three jurisdictions apply to rural highway systems having a range of climatic conditions and differing geographic locations within North America. With few exceptions, as noted herein, the data was compatible in all major aspects and was classified as described below.

Selection of Accident Predictor Variables

The accident report forms and accident location systems of all agencies were similar for the purpose of extracting wet pavement accident events. All report forms were deficient in that they did not contain the provision as to whether or not one or more vehicles skidded - as contained in the British report described above. It was not possible, therefore, to obtain an expression containing both the wet pavement condition and wet pavement skidding accident event - the ratio of the number of vehicles skidding in wet pavement accidents to the total number of wet pavement accidents. Expressed as a percentage, this ratio, has been called the relative risk of skidding in wet pavement accidents. This ratio can be given statistical significance to account for chance (3, 50). For example, if 4 wet accidents out of 10 within a highway section involve skidding by one or more vehicles, the relative risk of skidding is 0.40 or 40%. However, to account for chance in small numbers the significant relative risk of skidding in wet accidents is only 12% at the 2 1/2% level of significance.

The theory and application described above was extended to the accident data available in the four jurisdictions studied. In lieu of a significant relative frequency of skidding in wet accidents, a significant relative frequency of wet pavement accidents can be determined from the ratio of the number of wet road surface condition accidents to the total number of accidents occurring under all road surface conditions. Use of this ratio as an accident predictor, therefore, removes the variability associated with small numbers of accidents and subsequent use of raw ratios in many forms. See, for example, (4, 5, 6).

In addition, and in an attempt to account for natural fluctuation in accidents from time period to time period - in this case annually, accident experience was averaged over 2 or more years. The cummulated accident events for each highway section for which a representative skid resistance was known was averaged. This resulted in a cummulated, average, annual significant relative frequency of wet pavement condition accidents for each highway section.

A second accident predictor variable selected was, simply, the number of wet pavement condition accidents per mile of highway section for which a representative skid resistance was known. This ratio was also averaged using 2 or more years of accident experience in an attempt to account for natural variability in accident occurrence from time period to time period.

In each jurisdiction, accidents were reported by one police agency, and were located by mileage within each highway section and were retrieved by data processing using computer files within each jurisdiction.

Friction Measurement and Highway Section Definition

Friction measurements were obtained for highway sections, described hereinafter, by skid trailers complying with ASTM E 274 and representing the friction between a standard test tire and a wet pavement with the exception of measurements available in New Brunswick.

New Brunswick data was available in the form of BPN, British Pendulum Number, performed in accordance with ASTM E 303. Conversion of BPN units to SN_{40} units was in accordance with the equation, (1).

$$SN_{40} = 1.75\ BPN-70 \qquad 1$$

Test speeds of the skid trailers were essentially 64 km/hr and 112 km/hr, (40 mph and 70 mph), for 2 lane undivided and four lane divided rural highways respectively. SN_{70} measurements were converted to SN_{40} using the correlation developed by the agency, (4). Measurements of skid resistance were made by each agency during late spring, summer and early fall.

Two lane undivided friction data was almost exclusively that for bituminous concrete pavements. A mixture of portland cement and bituminous concrete surfaces comprise the four lane divided data.

The highway section definition varied slightly from jurisdiction to jurisdiction. For the most part, however, they are individually defined as a section of pavement of uniform age and composition subjected to uniform wear throughout their length. Where it was possible to do so the highway section skid measurement was that which best characterized the skid resistance of the pavement section in which the majority of wet pavement accidents occurred. In New Brunswick, for example, the primary highway section considered was the established control section having the general definition of "a length of highway along which the characteristics of the highway and traffic are relatively uniform". Wet pavement accident data for each control section were reviewed as to whether or not an apparent grouping occurred, and, if so, the skid measurement best fitting the dominant accident location for both directions of travel was used as the highway section skid resistance. Where no apparent accident grouping occurred the average skid resistance for both directions of travel of the control section was used. Average skid resistance readings on four lane divided highways were those for lane "one" or outer lanes in both directions of travel.

Traffic Volume and Speed

Each highway section defined above was associated with an average AADT for the purpose of stratifying the relationship between wet pavement accident experience and skid resistance. The AADT was, therefore, the average annual traffic volume on the highway section over which the accident experience was cummulated and averaged.

Two lane undivided rural highways of all jurisdictions had posted speeds of 96-104 km/hr (60-65 mph), and four lane divided rural highways had a posted speed of 112 km/hr, (70 mph).

Two Lane Undivided Rural Highways

Yearly and cummulated wet pavement accident and skid resistance data, stratified by AADT, were plotted for New Brunswick, Ontario, Saskatchewan and Kentucky in separate and combined analyses (5). Combined data cummulated over 2 or more years and averaged gave the best results in terms of variability and trends.

Figures 1 through 6 illustrate the relationship between the accident experience predictors Significant Relative Frequency of Wet Pavement Accidents and Wet Pavement Accidents per Mile and Wet Pavement Skid Resistance, SN_{40}. Study of these scattergrams indicates a definite non-linear exponential relationship; this is more evident in the AADT stratifications 0-3000, Figures 2 and 5. Considerable scatter is present.

Trends were determined by analysis of data using a moving average smoothing technique (4, 6). The purpose of plotting a moving average was to detect whether or not marked changes in accident experience occurred at a given skid number, the locations of data instability, and, to determine the general trend of the data. Figures 7 through 12 illustrate 10 point moving average plots of accident experience vs SN_{40}.

In general, moving average plots of the accident predictor wet accidents per mile of highway section-Figures 10, 11 and 12, illustrate relatively more distinct changes in accident occurrance vs SN_{40} than those of significant relative frequency. Both predictors show, however, marked changes in accident experience at SN_{40} ranges, of 38-45 and 55 to 60. Within these SN_{40} ranges, Figure 11 indicates that a sharp tendency of an increased level of accident experience occurs at SN_{40} = 44 and 55. For the higher AADT stratifications, Figures 9 and 12, no clear evidence of marked changes exist except for the overall horizontal tendency of moving averages at SN_{40} levels > 38.

Four Lane Divided Rural Freeways and Parkways

Yearly data for Kentucky and Ontario combined are shown in Figures 13 and 14 for AADT levels greater than 3000 vpd using as the accident predictor - wet accidents per mile (of highway section). Figure 14 illustrates an abrupt change in the trend and moving average variability at an SN_{40} level of 43. The moving average of Figure 14 is only reliable to SN_{40} = 45 because no data exists in the range SN_{40} = 50-55. Trends using the significant relative frequency of wet accidents illustrated more variability but a change occurred at SN_{40} = 43. Yearly plots of all jurisdictions were more variable with less distinct trends than those wherein cummulated average accident data was used.

Because the Ontario data were for one year of accident experience, cummulated plots of four lane undivided data was restricted to Kentucky. Figures 15 and 16 illustrate the trend lines for both accident predictors. Figure 15 shows a general rise in accident experience in the range of SN_{40} = 44-46 and another relatively steeper increase at SN_{40} = 40. Figure 16 shows abrupt increases at SN_{40} = 43 and 39, although that at SN_{40} = 43 is more dramatic.

Discussion and Conclusion

Comparison of trends shown in Figures 11 and 16 indicates a greater level of skid resistance demand exists on two lane rural highways compared to four lane divided highways for a correspondingly similar accident experience. For an average accident experience of 0.15 accidents per mile (per year), limiting SN_{40} values are approximately 55 and 43 respectively at apparent marked changes in moving averages. This may offer some factual evidence of what heretofore has been intuitively suspected: that skid resistance demand is higher on two lane highways carrying low to intermediate traffic volumes than on controlled access highways where many accident causation factors are minimized. Increased variability of moving averages for high volume two lane undivided highways may be due to the more complex exposure situation normally experienced along these highway sections.

The data and analyses exhibit strong non-linear tendencies with relatively distinct changes in accident experience at certain SN_{40} levels although scatter and trendline variability is present in all analyses of separate and combined data.

Figures 11 and 12 can be compared directly with results obtained in a recent 2 lane undivided highway study in Kentucky (6) where a marked increase in accident experience is indicated at SN_{40} = 46 and 40 for volumes below AADT = 3000. No trends were available at skid numbers > 50 due to lack of test sections having skid resistances higher than SN_{40} = 50. For AADT's > 3000 similar results are indicated except for the relatively more distinct changes illustrated in Figure 12 at SN_{40} values of 40 and 45. Kentucky researchers employed the ratio of wet pavement to dry pavement accidents as the accident predictor variable.

In a study of four lane divided highways, (4), a SN_{40} = 40 appeared to be the skid resistance at which a marked change in accident experience occurred, however, considerable scatter and variability was evident in moving average plots. This may be due to the use of a vehicle-mileage based wet pavement accident rate as the accident predictor. Comparible results using wet pavement accidents per mile are shown in Figure 16. Distinct changes are shown at SN_{40} = 43 and 38.

Figure 1. Scattergram of cummulated relative significant frequency of wet accidents (F_{sig}) vs SN_{40}; N.B., Sask., Ky.; AADT 0-8400; 384 data points.

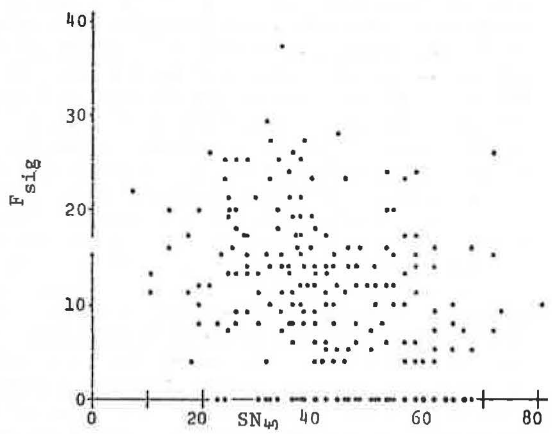


Figure 2. Scattergram of cummulated relative significant frequency of wet accidents (F_{sig}) vs SN_{40}; N.B., Sask., Ky.; AADT 0-3000; 232 data points.

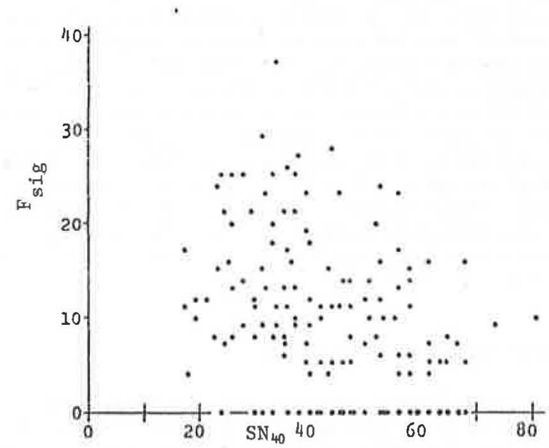


Figure 3. Scattergram of cummulated relative significant frequency of wet accidents (F_{sig}) vs SN_{40}; N.B., Sask., Ky.; AADT 3000-8400; 152 data points.

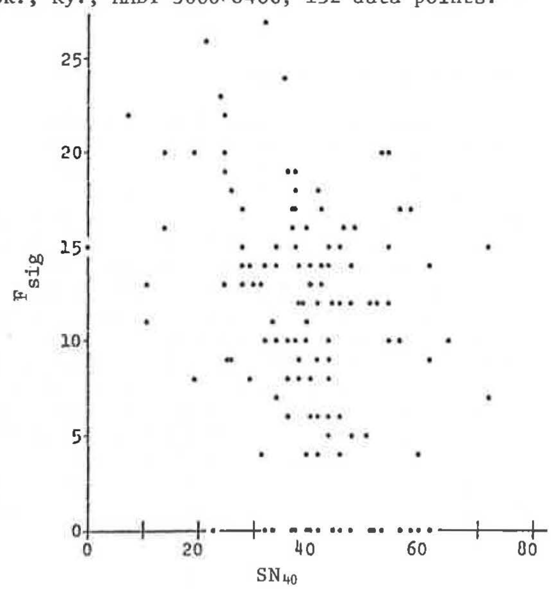


Figure 4. Scattergram of cummulated wet accidents per mile vs SN_{40}; N.B., Sask., Ky.; 2 lane undivided; AADT 0-8400; 384 data points.

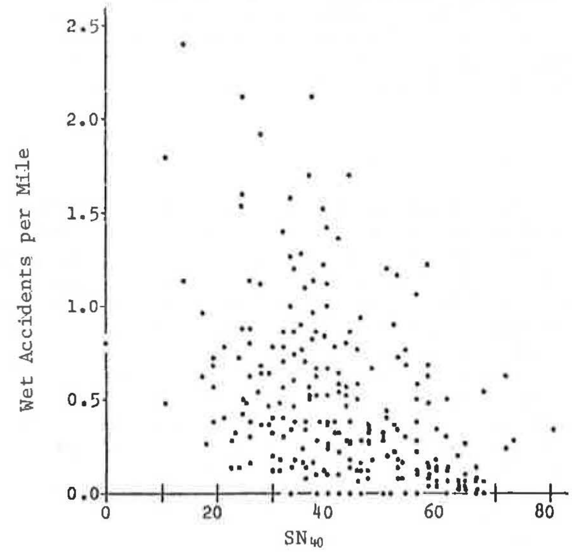


Figure 5. Scattergram of cummulated wet accidents per mile vs SN_{40}; N.B., Sask., Ky.; 2 lane undivided; AADT 0-3000; 232 data points.

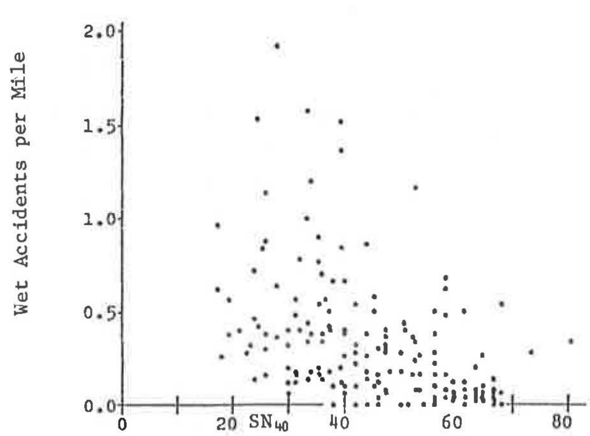


Figure 6. Scattergram of cummulated wet accidents per mile vs SN_{40}; N.B., Sask., Ky.; 2 lane undivided; AADT 3000-8400; 152 data points.

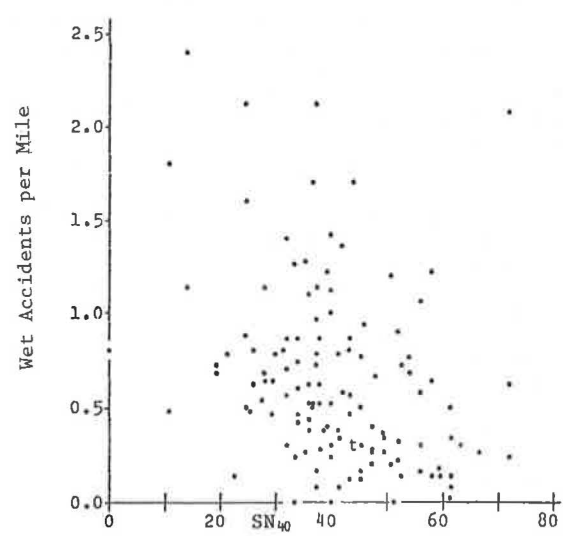


Figure 7. 10 point moving average significant relative frequency of wet accidents vs SN_{40} ; N.B., Sask., Ky.; 2 lane undivided; AADT 0-8400.

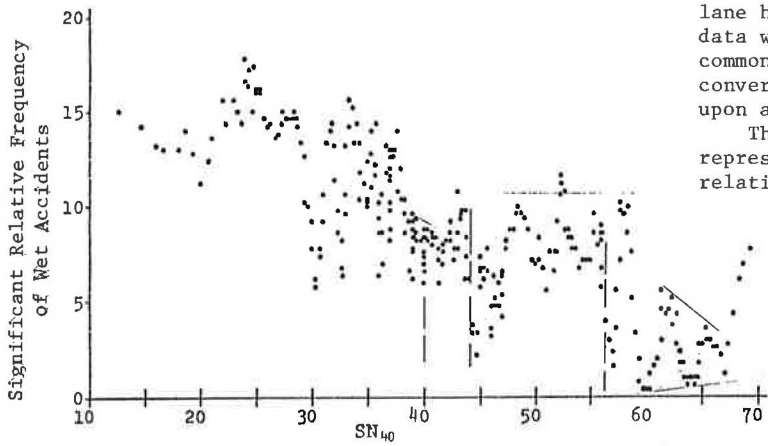


Figure 8. 10 point moving average significant relative frequency of wet accidents vs SN_{40}; N.B., Sask., Ky.; 2 lane undivided; AADT 0-3000.

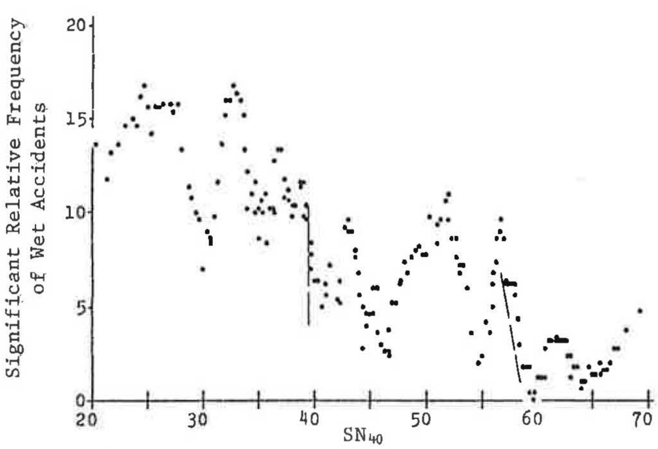
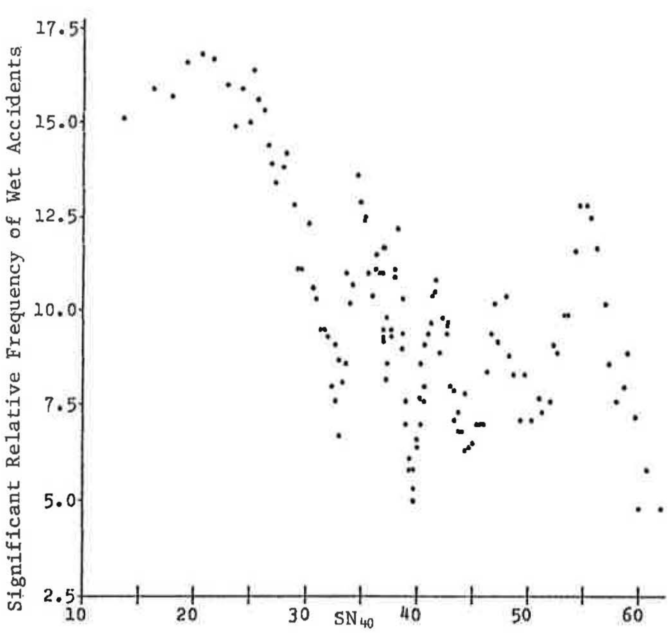


Figure 9. 10 point moving average significant relative frequency of wet accidents vs SN_{40}; N.B., Sask., Ky.; 2 lane undivided; AADT 3000-8400.



While the possible sources of variability were controlled to the extent possible, additional data classification is necessary particularly for two lane highways. In addition, the SN_{40} skid resistance data was measured using three skid trailers without common calibration. The New Brunswick data was converted to SN_{40} by means of a correlation based upon a small sample, (1).

The data can be considered, however, to be representative because the sample is, first of all, relatively large and, secondly, gathered from a number of jurisdictions, and, finally, the accident predictor variables used have a sound statistical basis. The trends illustrated provide the means to assess or predict accident experience at different levels of wet pavement skid resistance and lend themselves to cost effective pavement management practice. Preliminary equations were developed from the data for this purpose using a non-linear least squares program, (8), the results of which are reported in (5).

Acknowledgement

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Figure 10. 10 point moving average cummulated wet accidents per mile vs SN_{40}; N.B., Sask., Ky.; 2 lane undivided; AADT 0-8400.

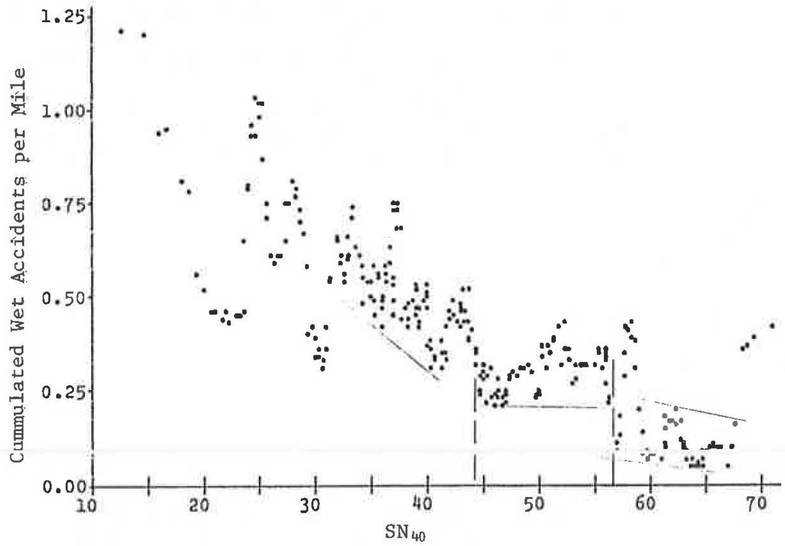

Figure 11. 10 point moving average cummulated wet accidents per mile vs SN_{40}; N.B., Sask., Ky.; 2 lane undivided; AADT 0-3000.

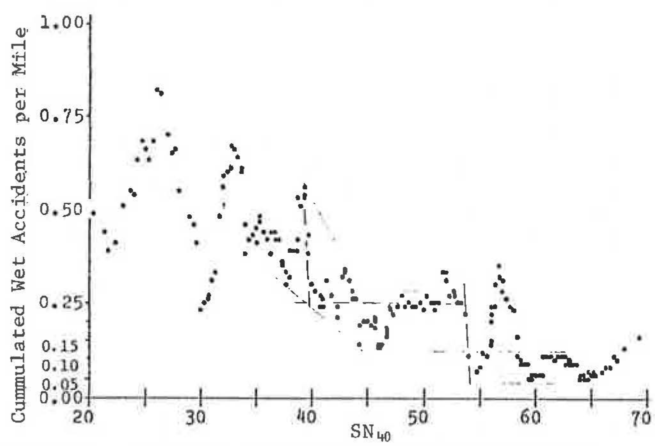

Figure 12. 10 point moving average cummulated wet accidents per mile vs SN_{40}; N.B., Sask., Ky.; 2 lane undivided; AADT 3000-8400.

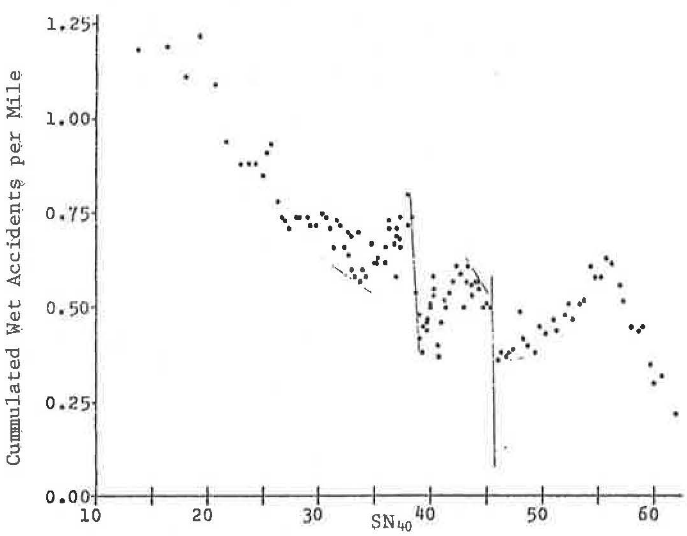

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Figure 13. Scattergram of yearly wet accidents per mile vs SN_{40}; Ont., Ky.; 4 lane divided; AADT 3000+; 305 data points.

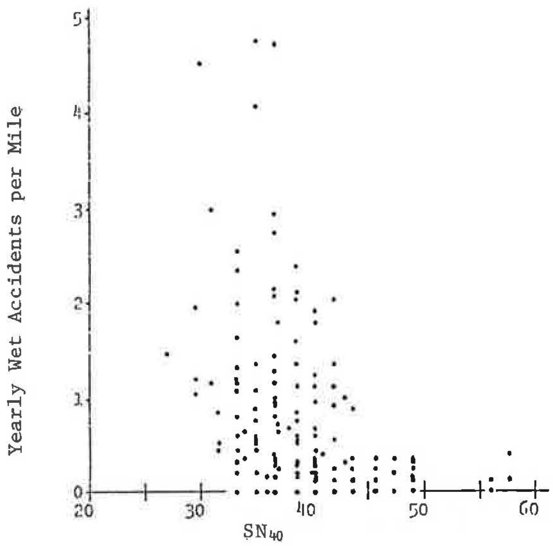

Figure 14. 10 point moving average yearly wet accidents per mile vs SN_{40}; Ont., Ky.; 4 lane divided; AADT 3000+.

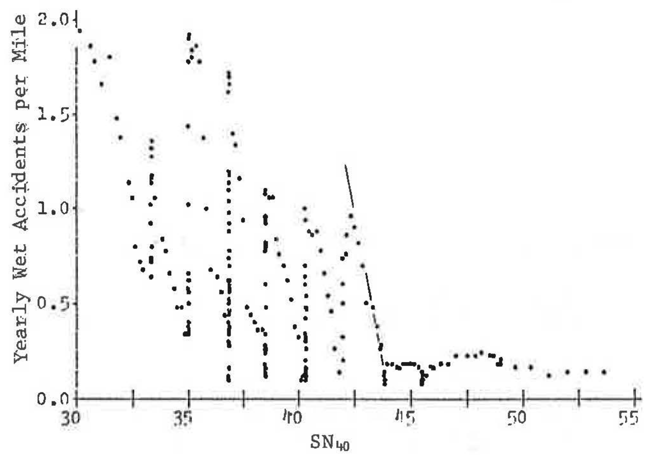

Figure 15. 10 point moving average cummulated data significant relative frequency of wet accidents vs SN_{40}; Ky.; AADT 1100-23540; 4 lane divided; 110 data points.

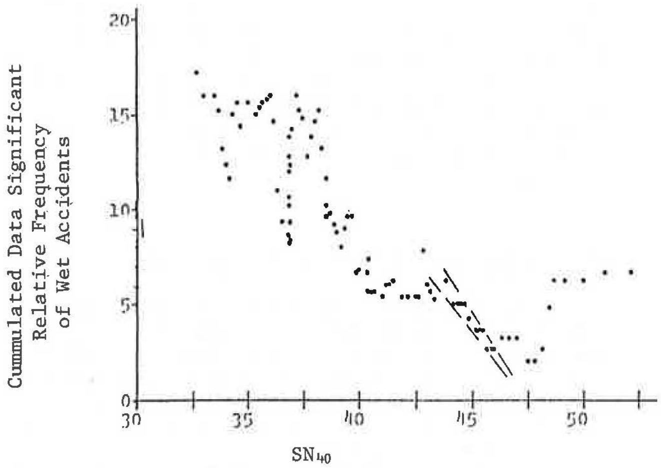

Figure 16. 10 point moving average cummulated data wet accidents per mile vs SN_{40}; Ky.; AADT 1100-23540; 4 lane divided; 110 data points.