PREDICTION OF WET SURFACE INTERSECTION ACCIDENTS FROM WEATHER AND SKID TEST DATA

L. F. Holbrook, Michigan Department of State Highways and Transportation

Both urban and rural state trunkline intersections are examined with regard to their wet accident percentages. The examination first takes account of the estimated percentage of highway surface wet time for each month. Because precipitation data are available only for designated time intervals, a method is developed to convert these data into percent wet time - a factor necessary in assessing wet surface exposure at intersections. Using this conversion method the precipitation data from 120 of Michigan's weather stations are transformed to give a month by month wetness profile for the entire state for the years 1963 to 1974. The range in monthly wetness for this period is from less than 1 percent to more than 25 percent. This potential 25 to 1 ratio is very influential in wet accident incidence and should be taken into account before other variables are examined. Nearly 40,000 accidents occurring at over 2,000 intersection locations for which a skid coefficient value was available were tabulated to provide wet accident percentages. These data together with the location's wet time percentage, as estimated from the nearest weather station, provide an opportunity to statistically fit a wet accident model for the variables included. The fit is satisfactory and suggests an accelerating function for skid coefficient. For all levels of wetness, a skid coefficient less than about 30 is accompanied by an accelerating increase in wet accident percentages; although the actual shape of the curve depends on wet time. The model appears useful in designing cost-effective intersection resurfacing plans which minimize wet accident occurrence.

It is well known that wet pavements reduce tire friction and thereby lengthen vehicle stopping distance. It is also known that this results in increased accident incidence. Many studies over the years have attempted to quantify the relationship of wet surface accident frequency with surface friction (e.g. British Pendelum number, BPN, and skid number, SN) (1, 2, 3, 4, 5). Generally, these investigations have not taken account of wetness exposure because wet surface records are not available unless an accident occurs. Even if weather records are available, they are generally for precipitation quantities and not wet surface time duration. Another problem encountered by researchers is that of obtaining enough accident data to provide reliable estimates of wet accident incidence at a given location. Examination of a few high accident locations will not suffice because of the large inherent random fluctuation in accident percentages computed from even moderate sample sizes. Thus, it is not surprising to find that a review of the literature does not produce uniform conclusions on such questions as the relationship of wet accidents to wetness conditions or pavement skid resistance. Indeed, research studies cannot agree on whether or not a "break point" in skid resistance exists below which wet surfaces are hazardous and above which they are not. An SN of about 40 has been suggested as a "break point" (2) but question remains as to whether the supporting research is repeatable and that the critical friction point is not due to ramdom disturbances in accident statistics. This question is especially crucial in the event that minimum surface friction standards are adopted for purposes of maintenance or litigation.

The investigation into wet surface accident occurrence was designed to evaluate as precisely as possible the role of surface friction operating in a context of important contributing variables. Unfortunately, the variables examined had to be limited to only those measured at the accident scene or available from weather stations in the vicinity. Consequently, tire wear, vehicle speed, etc., had to be treated as random disturbances since they are not typically recorded in accident reports. By limiting the examination to a small variable set, nearly 40,000 Michigan accidents, together with all available precipitation records for the relevant accident periods, were processed in order that a suitable mathematical model relating the selected variables could be formulated. This paper is concerned with the development of available surface, weather, seasonal, and accident variables, their quantitative interrelationships and the incorporation of these findings into a rational maintenance program.

The Data

Some of the selected variables undoubtedly influence accident statistics much more than others. Observers have identified as many as 250 to 300 potential accident variables with an average of about 4 per case (6). Measurement and incorporation into models of any but the smallest fraction of these factors is a practical impossibility. What we seek is the identification and modeling of the principal measurable variables; assuming that those remaining operate as random disturbances. For the present study, the following variables were considered important contributors among those measured.

Weather

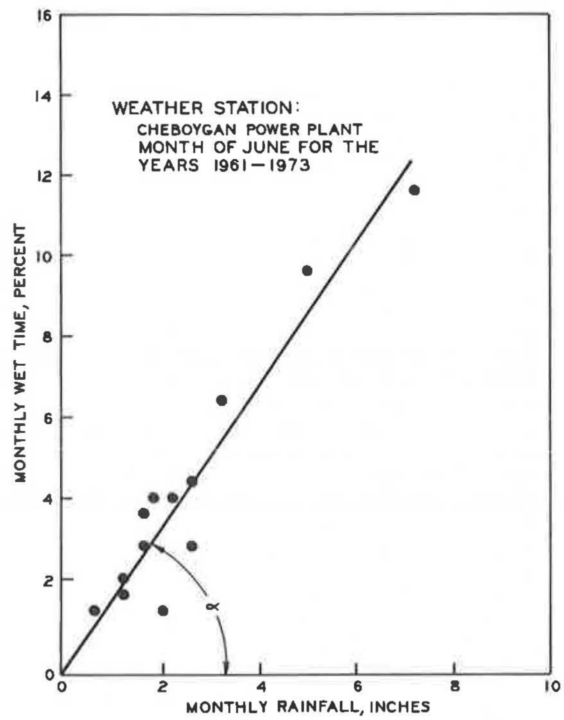
If pavements could be kept dry, the skidding accident problem would be greatly diminished. Virginia estimates that about 34 percent of its intersection accidents occur under wet surface conditions, and that about 57 percent of these are attributable to wet conditions alone (5). Also it is estimated that up to 33 percent of all wet weather accidents involve skidding (7). While perceptual judgements by investigating officers on skidding do not tell us whether or not an accident would have occurred if the pavement had not been wet, it is well known that surface wetness reduces tire-pavement friction, and that friction correlates well with stopping distances for fixed speed(8). Increased stopping distances certainly increase accident probability as is borne out by the statistics. Surely, wet pavement exposure is an important factor, but how can it be estimated for any accident location? We wish to measure it not only for incorporation into a wet accident model but also for maintenance purposes once a suitable model is developed. Most studies assume that wetness exposure per unit time is constant throughout an area so that this particular measurement problem does not arise.

Clearly, precipitation in inches as commonly reported by the Federal Weather Bureau is not, in itself, a suitable substitute variable for actual wet time. This can be seen immediately when one recognizes that an inch of precipitation can be spread over a few hours or a few weeks. This is especially a problem for a Great Lakes state such as Michigan. In the fall months of the year, the Upper Peninsula experiences long periods of drizzle in which much wet time, but relatively little total precipitation, is accumulated. On the other hand, the Detroit area can receive considerable thundershower precipitation during a short summer afternoon. This means that if only precipitation records are available (as is generally the case) they should not be used directly to estimate wet exposure time. One method of transforming precipitation into wet time is to count an hour as wet if a minimum quantity of precipitation occurred. Thus, if the minimum is 0.01 inch (the presumed amount of precipitation necessary to resupply loss by evaporation) the hour is considered wet if it rains 0.01 inches or even 1.0 inches during that period. The method may give acceptable results if the threshold minimum is reasonable. For this study, a threshold of 0.01 inches was used, following the work of Karr and Guillory (9).

Of 120 Federal weather stations in the state, 42 recorded hourly precipitation for the study period (1963 to 1974). This allowed percent wet time to be computed for each station for each month. The winter months were initially excluded from analysis because ice, snow (and its removal), and rain together with salting (particularly in the Detroit area where most of the accidents occur) are factors which complicate the transformation of precipitation into percent wet time. However, it was found that to some extent these factors could be absorbed in statistical estimation parameters and winter months could be used for wet accident prediction. These 42 stations gave a good picture of monthly and yearly wetness patterns throughout the state. However, the remaining 78 stations would contribute to a more detailed wetness picture if they could be brought into the analysis. This was important since many high accident locations may be closest to these weather stations. While these stations did not record hourly precipitation figures, they did record monthly precipitation totals. The question arose: could monthly proportion wet time be estimated from monthly precipitation. If it could, then two sources of wetness data could be used to develop wetness maps for the state.

Turning now to the 42 weather stations recording hourly precipitation, we find that on a monthly basis, correlation exists between precipitation and percent wet time. Figure 1 shows a single selected weather station for the month of June. In this graph, the data points represent June precipitation in inches and wet time percentages for the years 1961 to 1973. The linear relationship, $W = \alpha P$, where W = percent monthly precipitation, is generally well defined and designates α as the transformation of P to W. Regressions similar to the one in Figure 1 were used to generate α's for all months for each of the 42 weather stations

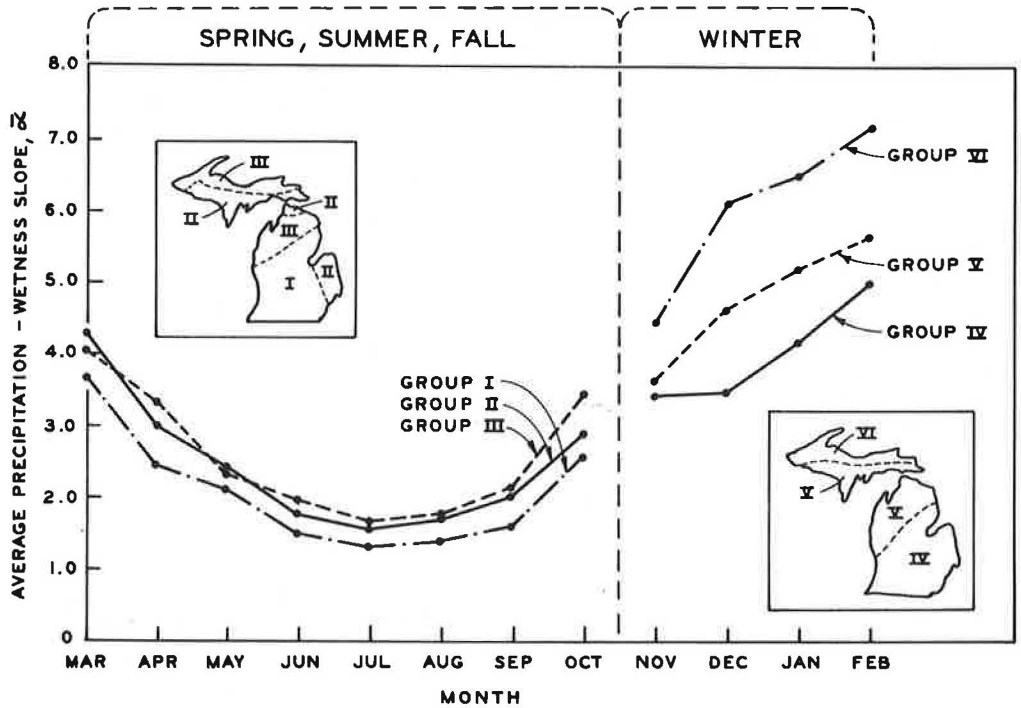
Figure 1. Relationship between monthly rainfall and monthly wet time.



which recorded hourly precipitation data. Examination of the station — α matrix showed that neighboring stations tended to have similar α's for the same month. Consequently, it was thought that a regional α grouping would be possible. Moreover, an α grouping would solve the problem of assigning α's to stations which did not record hourly precipitation. Often these stations were geographically surrounded by a number of hourly stations, thus making the assignment ambiguous. If α's could be combined into a regional classification system, then non-hourly stations in each region could be assigned the pooled regional α estimate.

A standard method of classification for intercorrelated variables is factor analysis. Using the principal axis method two distinct seasons emerged: November, December, January and February formed one season while the remaining months formed the other. Within each season, further factor grouping showed that station α's could be grouped into three regions for each season. These regions are not the same for each α - season however. Further grouping explained very little additional variance in the correlation matrix. By assigning each station to the group with which it had its highest correlation (factor loading) all 42 hourly stations could be regionally classified for each of the two seasons. There were no stations which had highest correlation with a fourth group (factor). The monthly regional α estimate was then obtained as a factor loading weighted average of all member station α's. Since non-hourly stations had to fall geographically within one of the three groups, each of these stations could be assigned the group $\bar{\alpha}$ for each month. Examination of the month, region matrix immediately revealed that for all regions, $\bar{\alpha}$ varied considerably from month to month (See Figure 2).

Figure 2. Regional and seasonal variation in the transformation of rainfall into monthly wet time.



It is clear from Figure 2 that even though there are regional differences in $\bar{\alpha}$ the predominant variation is monthly. From this analysis it is evident that regional and seasonal factors should be part of any method which estimates monthly wet time from monthly accumulated precipitation. The development of a precipitation transformation method facilitated the incorporation of the 78 non-hourly weather stations into the wet time analysis by transforming monthly precipitation into estimated monthly percent wet time. Either actual, or regionally estimated percent wet time was computed for each weather station for each month for each year, 1961 through 1974. The monthly percent wet time appropriate to monthly accident statistics for each accident location was estimated from data obtained from the nearest weather station to that location. Since exact locational rainfall data were not available, this was the only method that could be used.

Wet Accident Locations

The selection of wet accident locations is complicated by the conflicting problems of surface friction uniformity and accident frequency. Ideally, an accident location should be short enough to provide uniform surface friction, yet long enough to deliver reliable accident statistics. In this regard, intersections are analytically preferable to ordinary roadways and consequently were selected for analysis. In particular, Michigan's "high accident" locations, selected since 1963 for skid resistance testing, provided the best compromise data set. Of course, not all accidents, even at these locations were examined since records exist of only those accidents (perhaps only 25 percent) serious enough to be reported (10). All types of accidents were combined so that the ratio of wet accidents to total accidents for each intersection for each month could be computed. Thus, basic data points were defined for the years 1963 through 1974 which would ultimately be grouped with other data points according to weather and surface friction criteria.

Skid Number

Since Michigan's "high accident" intersections are routinely skid tested, each has an average skid number (SN) available for comparison with the other variables. The skid number used is generally an average of a number of tests conducted in each lane in the deceleration approach to the intersection. These locations were generally tested between June and September of the year following the high accident year that signaled the test itself. This single SN value, strictly speaking, was relevant only for the period of the test itself. However, it was the only yearly value available and had to be assigned to all months belonging to that year. Various investigators have reported seasonal variation in the skid number. This would mean that a single value would not apply to all months. In order that this possibility could be accommodated, seasonal flexibility was incorporated into an initial specification of the model. However, results did not indicate a consistent enough pattern to warrant further work.

Data Grouping

Since a small number of simple variables do not completely characterize wet accident occurrence, there is no single quantitative specification which relates these variables such that reliable prediction for each accident location is possible. Also, because large numbers of variables are involved in accident causation, wet accident percentages fluctuate considerably over locations and time periods. For purposes of reliability, model simplicity and data availability, most of the variables causing these fluctuations must be treated as random disturbances under the assumption that they do not interact with those measurable variables selected for incorporation into the model. In this study, monthly wet accident percentage, monthly percent wet time, the month itself, skid number, lane number, and surface type were considered the most important variables for which complete data were available. Wet accidents, even at high accident intersections, do not generally occur with high enough frequency to enable the calculation of really reliable percentage estimates. Table 1 shows the 95 percent confidence range for various sample sizes for selected long term wet accident percentages. Even with an unrealistic 500 accidents occurring per month at a given intersection having a long term wet surface accident percentage of 50, monthly estimates will range between 46 and 54, 95 percent of the time. Therefore, it is necessary to pool accident locations if relatively stable data are to be used to construct a wet accident model. With this in mind, accident locations were grouped into skid number-percentage wet time-monthly cells. Percentage wet time was classified into five groups:

0.00 - 3.99 percent wet time
4.00 - 7.99 percent wet time
8.00 - 11.99 percent wet time
12.00 - 16.00 percent wet time
over 16 percent wet time

Skid numbers were classified into eight groups:

0 - 24
25 - 29
30 - 34
35 - 39
40 - 44
45 - 49
50 - 54
55 and over

Thus, each accident location could be assigned to any one of 12 months x 5 wetness groups x 8 skid numbers = 480 cells. Hopefully, these cells then contain enough wet and dry surface accident data to facilitate graphical and statistical fitting of the model.

The Model

Rationale

As wet exposure increases, so should the accident proportion occurring under wet surface conditions. Functionally,

$$\frac{WA}{TA} = f\left(\frac{WH}{TH}\right) \qquad (1)$$

where WA/TA represents wet accident proportion and WH/TH represents proportion wet time. The criterion for an hour of wet time, i.e., 0.01 inches of precipitation per hour originally postulated seemed reasonable. However, it was still a guess since one still does not know what quantity of rainfall is required to maintain an hour of sufficient wetness to alter skid resistance on partially drained pavement surfaces. Moreover, rainfall evaporates in accordance with seasonal patterns of temperature and wind. Therefore, the model must be sufficiently flexible to allow for seasonal variations in the wetness criterion. Since we do not know how to specify the criterion's monthly drift one can do little more than specify a polynomial of sufficient degree to follow any major variations. In the present case, proportion wet time was multiplied by a third order polynomial so that

$$\frac{WA}{TA} = f\left[M(i)\frac{WH}{TH}\right] \qquad (2)$$

where $M(i) = 1.0 + \theta_1 i + \theta_2 i^2 + \theta_3 i^3$. The θ's are fitting parameters to be estimated from the data, and the i's designate the months of the year.

As monthly wetness varies, wet accident proportions must conform to certain necessary limitations. For example, if there was no wet time during the month, then there would be no wet accidents. Also, as proportion wet time approaches the limit of 1.0, so too, should the wet accident proportion. Therefore, any other variables affecting wet accident incidence should be introduced in such a way as to permit these boundary conditions. One method is to specify them in an exponential form:

$$\frac{WA}{TA} = \left[M(i)\ \frac{WH}{TH}\right]^{g(\text{other variables})} \qquad (3)$$

Of the variables available, lane and skid number seemed most promising. A preliminary analysis with lanes was not conclusive so that skid number was the only variable remaining to be specified. Since the role of skid number in the model is of primary importance, a second flexible polynomial specification was used for this variable. The only parameter reducing restrictions made were the obvious ones which require that as SN approaches 100, wet accident incidence should approach the percent wet time encountered that month, and as SN approaches 0, friction is

Table 1. Accident percentage reliability.

Long Term Accident Percentage	Total Number of Accidents Required to Provide Sample Wet Accident Estimates Within the Indicated Range 95 Percent of the Time		
	100	500	5000
10	4 - 16	7 - 13	9 - 11
20	12 - 28	16 - 24	19 - 21
30	21 - 39	26 - 34	29 - 31
40	30 - 50	36 - 44	39 - 41
50	40 - 60	46 - 54	49 - 51
60	50 - 70	56 - 64	59 - 61
70	61 - 79	66 - 74	69 - 71

so reduced that wet accident percentages approach 100. These conditions restrict the general third degree polynomial to the following form written in terms of the skid coefficient, $\mu = \frac{SN}{100}$:

$$g(\mu) = \theta_4\left[\mu^3-\mu\right] + \theta_5\left[\mu^2-\mu\right] + \mu \qquad (4)$$

so that the model becomes:

$$\frac{WA}{TA} = \left[M(i)\frac{WH}{TH}\right] g(\mu) \qquad (5)$$

Again θ_4 and θ_5 are fitting parameters to be determined by the data.

Fitting the Model to the Data

The locations for which intersection skid numbers were available spanned 11 years and provided a data set of nearly 40,000 accidents from which monthly wet accident percentages were formed for the skid number and wetness groups. This reduced nearly 40,000 accidents to 480 possible wet accident ratios which constituted the potential derived data set. Of the 480 potential ratios, 418 could be formed from the accident data set.

Since the functional form of the model is inherently non-linear, ordinary least squares methods could not be used for parameter estimation. Instead, a non-linear least squares computer program was used for the estimation of θ_1 - θ_5 for all pavement surfaces taken together.

The non-linear least squares procedure provides parameter values which bring the model into close agreement with actual wet accident proportions. Figures 3, 4, and 5 illustrate the relationships between actual and predicted wet accident percentages for the group averages of the primary variables incorporated into the model. In general, when the group wet accident percentage is computed from a very large number of accidents (e.g., 2,000 or more) the difference between it and the model's prediction is only of the order of 1 or 2 percent. As would be expected from Table 1, group percentages computed from only several hundred or so accidents deviate from expectations somewhat more.

Figure 6 shows the shape of the wetness adjustment polynomial M(i). Notice that the 0.01 inch per hour percipitation criterion overestimates July wet time thus requiring that M(i) adjust that month's wetness downward. This is to be expected since higher mid-summer temperatures would cause greater evaporation rates so that the 0.01 inches per hour would not be enough rainfall to keep the pavement surface sufficiently wet for one hour. From the minimum of July, the adjustment polynomial increases through the winter months, suggesting that as fall approaches, reduced precipitation intensities and evaporation rates result in longer surface wetness times for each 0.01 inch of rainfall. It seems evident that while a seasonally unadjusted wetness criterion may be adequate for some states such as California, it does not adequately measure wet time for states such as Michigan which experience substantial seasonal shifts in temperatures.

Figure 3. Relationship between actual and predicted wet accident percentages for each month.

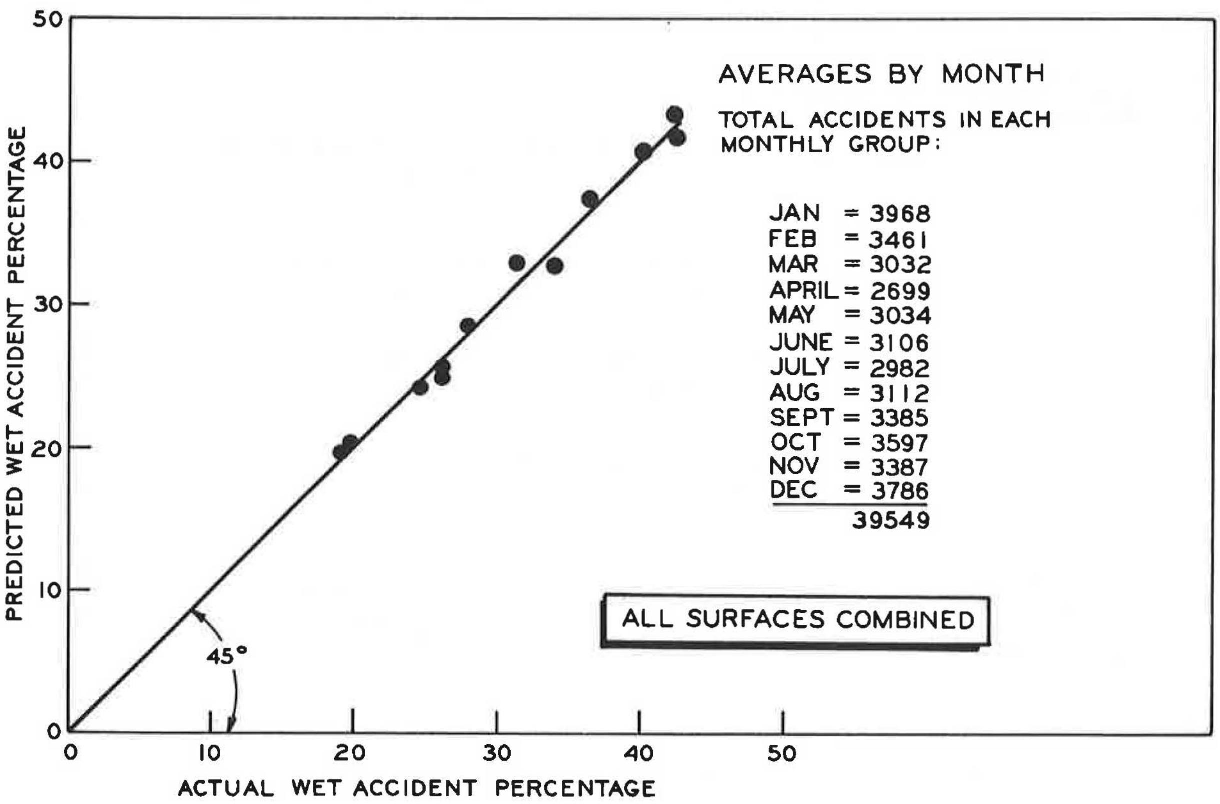


Figure 4. Relationship between actual and predicted wet accident percentages for each skid number group.

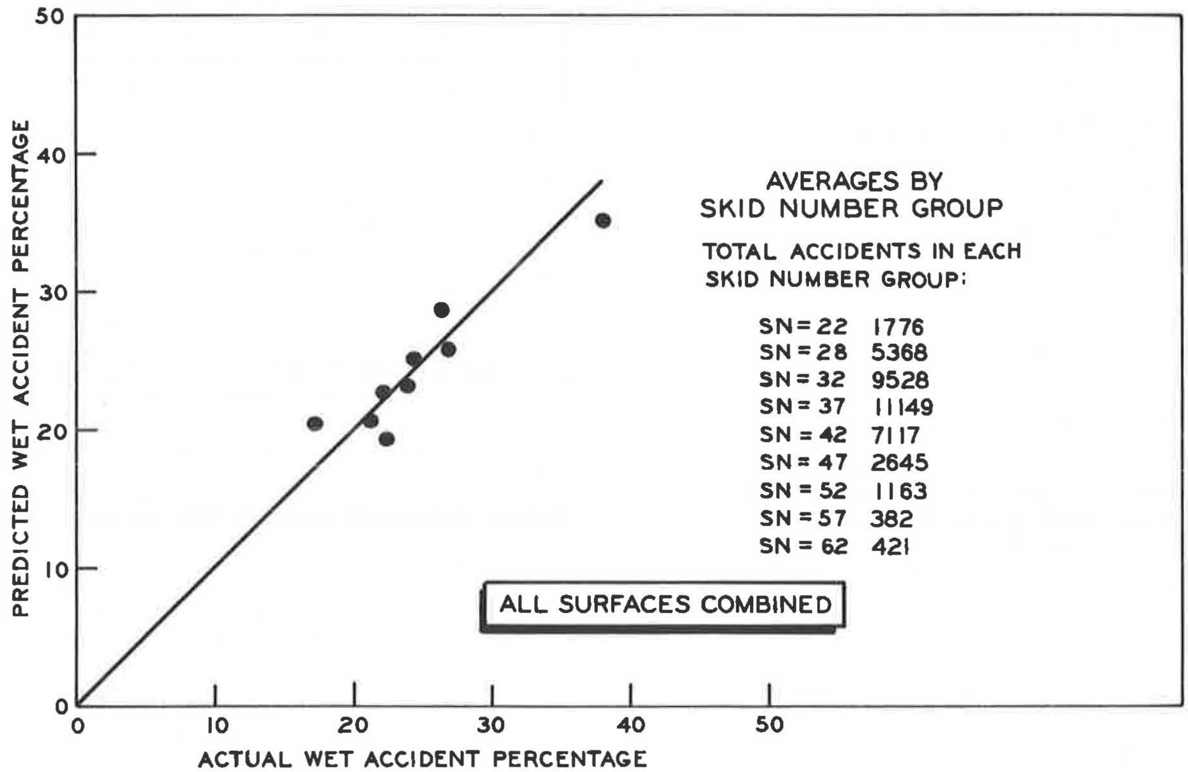


Figure 5. Relationship between actual and predicted wet accident percentages for each wetness group.

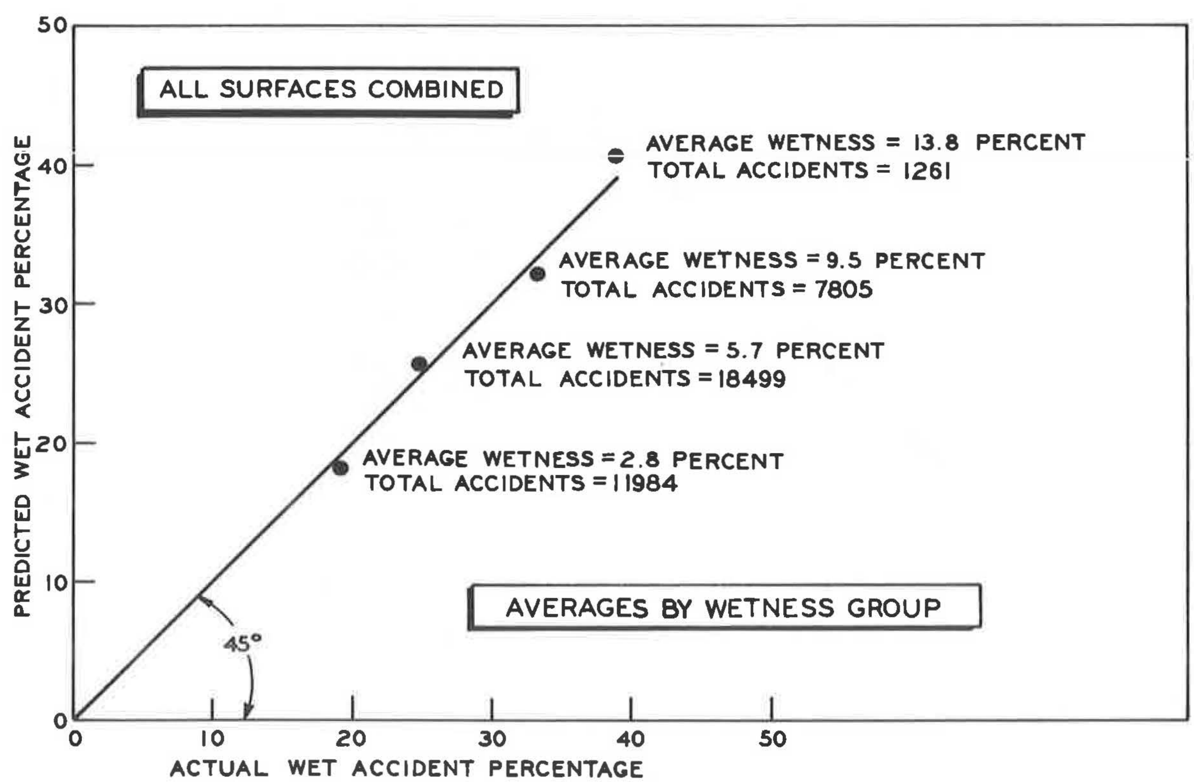


Figure 6. Seasonal wetness polynomial M(i) as a function of month.

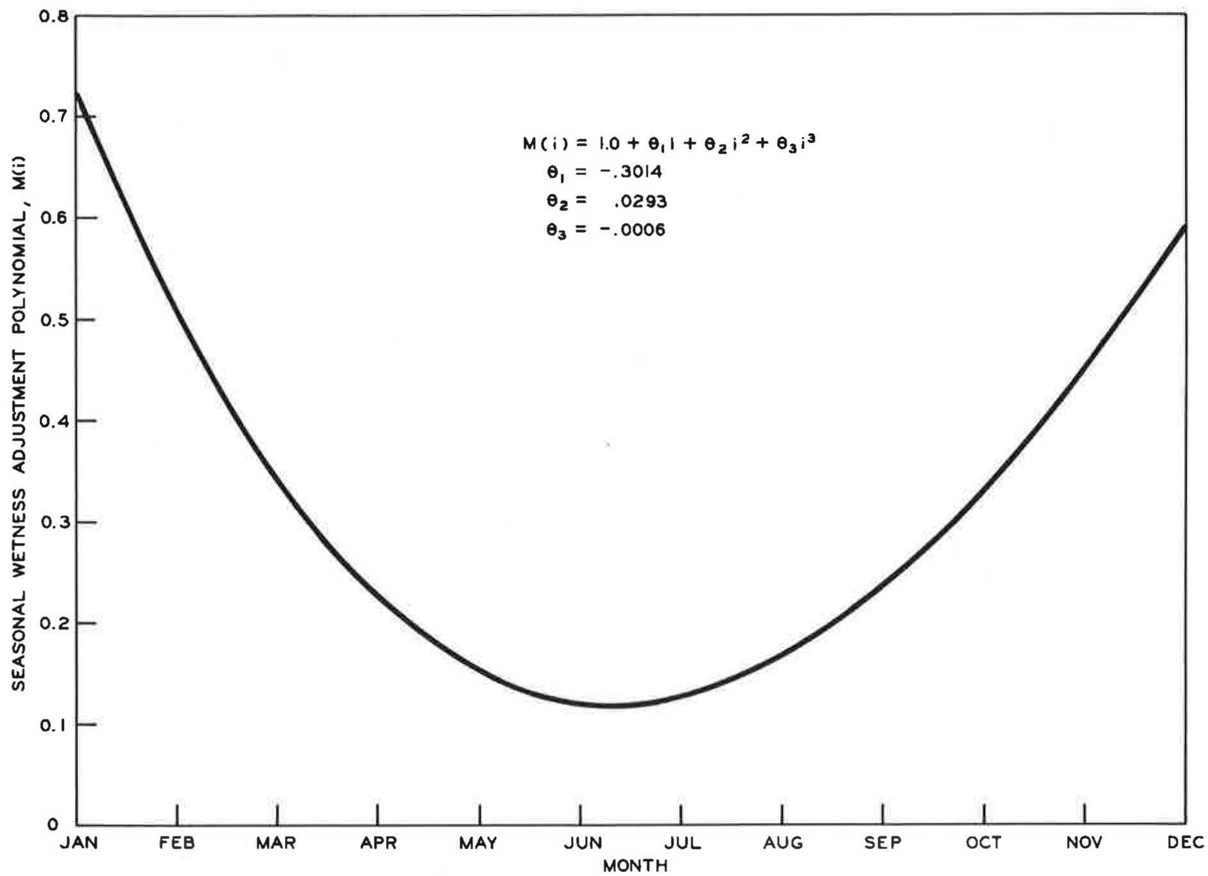


Figure 7 shows the skid number polynomial, $g(\mu)$ which governs the influence of μ in the model. The important point here is that the polynomial is not "flat", that is, it increases as μ increases which indicates that skid number is an important variable in the model and that low skid numbers are associated with higher wet accident percentages. Actually, in the range $0.30 \leqslant \mu \leqslant 0.60$ $g(\mu)$ is essentially linear. This means that for most surfaces encountered, a simpler specification of $g(\mu)$ is possible.

How the Variables Behave

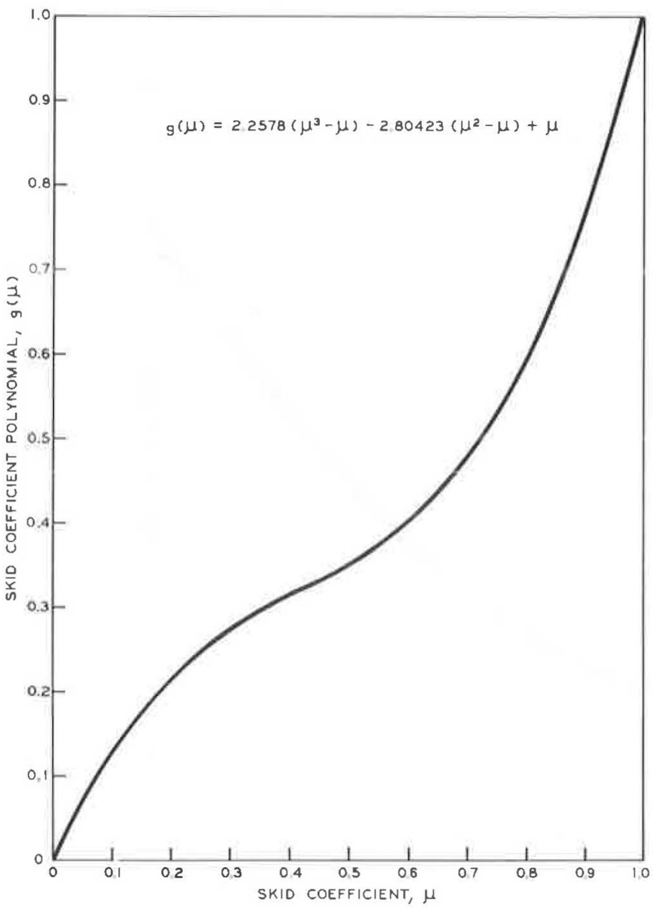
It is difficult in one representation to show the interrelationship of all variables in the model. Consequently, they are shown pairwise in Figures 8 through 10. The relationships between and wet accident percentage for selected wet times and the month of June are shown in Figure 8. It is obvious from these graphs that regardless of wetness exposure, wet accidents decline as skid resistance increases. There is no evidence of any critical skid coefficient below which wet surfaces are hazardous, even though wet accident incidence increases in a non-linear fashion below skid coefficients of 0.30 or so.

The monthly weather effect for fixed skid coefficient and for several wet times is shown in Figure 9. This shows clearly that wet time as measured by the 0.01 inch per hour criterion requires seasonal modification of the sort provided by M(i), the consequence is that summer rainfall produces shorter wet times as measured by the 0.01 criterion and hence fewer wet accidents. In Figure 10, we see the effect of wet time on wet accidents for several skid coefficients for the month of June. Wet time has a profound effect on wet accident incidence, especially in the fall when weather conditions extend the wet surface time for a given quantity of rainfall.

Applications

When low skid resistance pavements are resurfaced it is assumed that a resulting benefit will be lowered wet accident incidence. The question is how much benefit can be expected from resurfacing a given location. Using regional or nearby weather station wet time percentages, together with a minimum permissible or existing location skid number, an estimate can be made of the expected yearly wet accident percentages. This estimate can be compared with actual yearly wet accident percentages in

Figure 7. Skid coefficient polynomial.



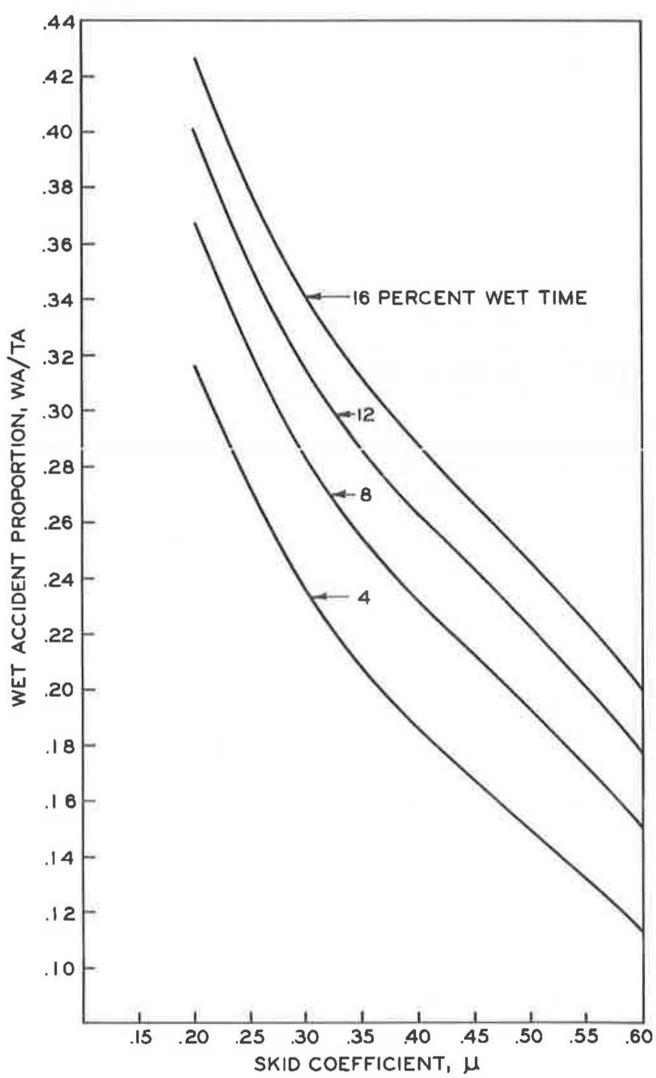
order to determine whether or not these statistics are realistic, or merely the result of random fluctuation always found with small samples. This would provide the basis for development of "quality control" procedures designed to detect "excessive" wet accident percentages which are not the result of unusual wetness exposure or random fluctuation. These procedures would be of considerable value in deciding which accident locations should be skid tested each season. Beyond skid testing plans, the model also has applications in resurfacing policy evaluation. At the time locations are considered for resurfacing, it should be possible to employ the model to predict expected accident reduction for each location, thereby facilitating a resurfacing priority list based on maximum accident prevention. We turn now to the evaluation by computer simulation of several intersection resurfacing plans.

The plans investigated all depend upon first, the assembly of a skid testing list which dictates the priority in which intersections are to be resurfaced or otherwise upgraded. The difference in the plans is in how these lists are formed; the formation methodology depending on the basic goals of the program.

Plan I - Low Surface Friction Detection

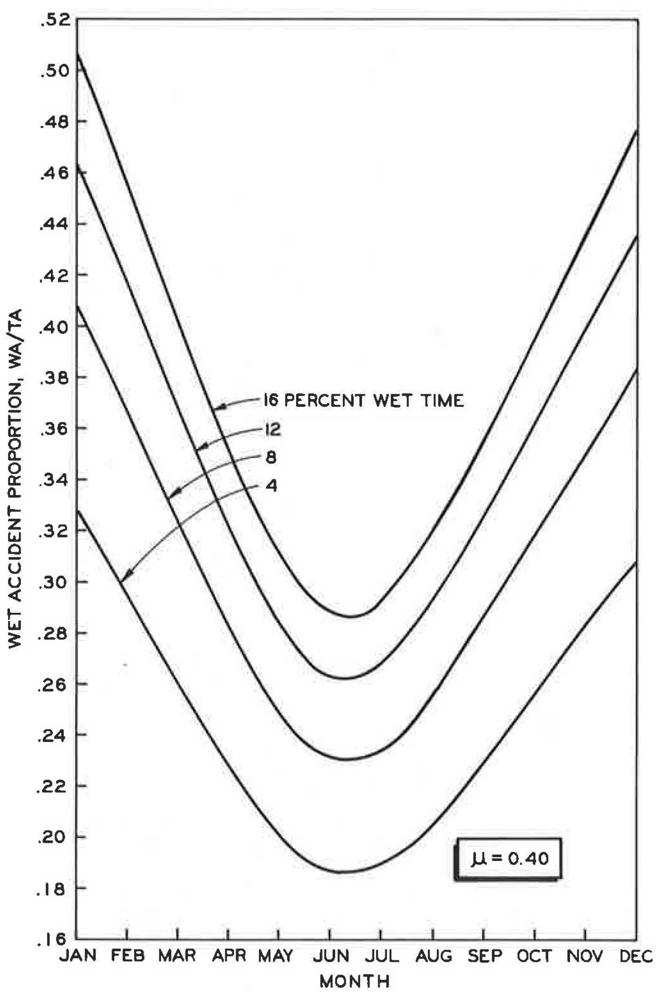
This plan seeks to first identify, and second to upgrade, low skid coefficient intersections. The philosophy behind this plan is that low skid resistance surfaces, per se, must be found and repaired. No attention is given to traffic volume, local rainfall, or any other variable. An administration following this plan might be concerned with complaints of very slippery intersections or it might feel its duty was to maintain a minimum standard for all intersections. The testing priority for Plan I is based on a simple rank order of percentage wet accidents from state trunkline intersection accident records. It is presumed in this plan that the wet accident percentage rank order should correlate with skid number rank order thereby providing a rational basis for the testing program. After the testing program has produced as many skid numbers as is feasible considering manpower, equipment, time, etc., a second list, the resurfacing priority list is assembled from a rank

Figure 8. Relationship between skid coefficient and wet accidents for various wet times.



order of skid numbers. At this point, resurfacing is based on the priorities dictated by the second list and proceeds until allocated funds are exhausted.

Figure 9. Monthly effect on wet accidents for various wet times.



Plan II - Wet Accident Minimization

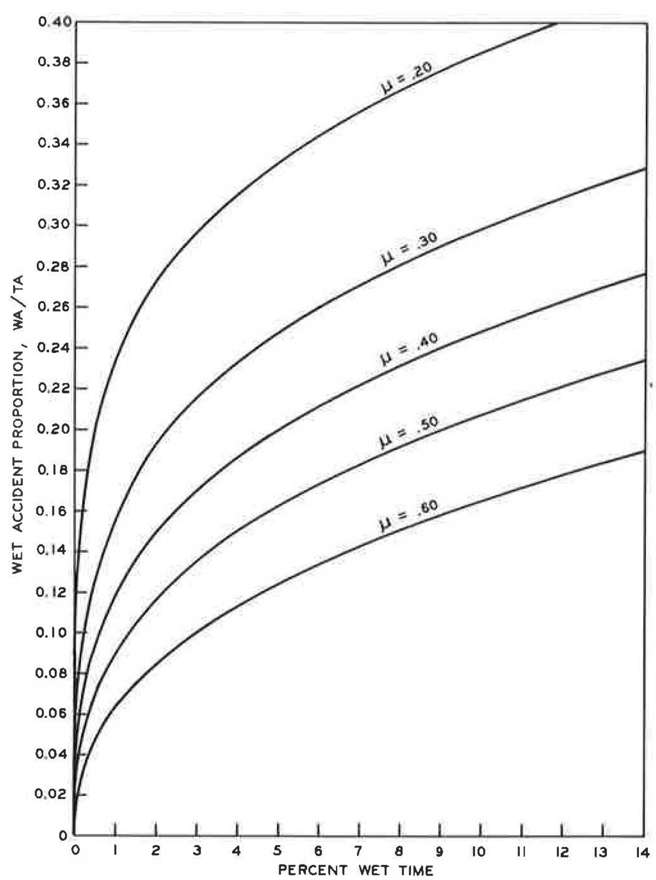
Plan II differs from Plan I in that expected accident prevention benefits are used to form both the testing and resurfacing priority lists. For the testing priority list, wet accidents estimated from dry accident history, local wetness and a presumed skid coefficient of 0.40 are used in the wet accident model to estimate the accident reduction expected if the given intersection were to be resurfaced to a skid coefficient of 0.60. The resurfacing skid coefficient is expected to decline linearly with time from 0.60 to 0.40 in five years.

As with Plan I, once the top priority intersections are skid tested, a new list, the resurfacing priority list, is formed. In the case of Plan II, however, the resurfacing priority list is based on expected wet accidents prevented over a five-year period using the sampled skid number found in the testing program. By substitution into the model we now have improved estimates of expected accident reductions achievable with resurfacing. The rank order of revised estimates of expected wet accident reductions is then used to determine the priority of resurfacing. The philosophy underlying this plan is that whatever the skid number, it is net accident reduction which is most important. Even though the the skid coefficient might be low, regional rainfall and traffic volumes might be such that an intersection ranks low in resurfacing priority. Administrators adopting Plan II would be more concerned with wet expected accident prevention and less concerned with upgrading an intersection just because it had a low skid number.

Comparison of Plans Using Computer Simulation

Each plan is designed for a specific goal and should function best relative to that goal as a criterion. Any comparison of these plans must assume a common criterion which will necessarily favor one plan over others. For comparison purposes, we have chosen wet accident prevention as the criterion since we assume that most administrators would give this as their resurfacing program goal. The data used for plan comparisons were the 1973 Michigan high accident intersection list, together with the corresponding skid numbers and nearby weather station monthly wetness estimates.

Figure 10. Effect of wet time on wet accident proportions for various skid coefficients.

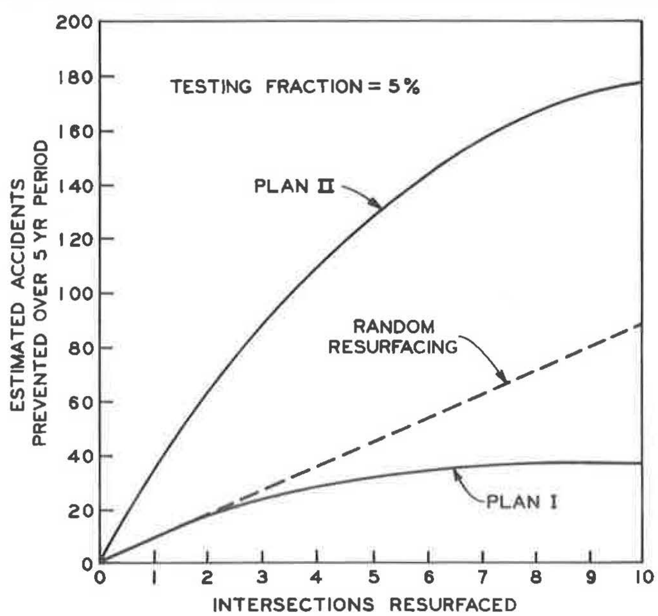


Each skid testing plan was based on a testing fraction composed of the top 10 of the 190 intersections rank ordered as specified by the skid testing plan. Expected wet accident reduction benefits were then accumulated as through 1 or 2 or 3 or ... up to 10 intersections had been resurfaced according to the resurfacing priority list provided by each plan. Figure 11 shows the expected accident totals prevented for each plan using a testing fraction of five percent. Also shown in the figure is the expected wet accident reduction benefit obtainable with a policy of random resurfacing. In this case, resurfacing priority lists are based on random selection of intersections from the 190 used for plan comparison. If a plan does not produce more accident reduction than that obtainable with random intersection selection, it has little to recommend it.

Inspection of Figure 11 shows that, of the two plans, Plan II succeeds in producing the greatest expected wet accident reduction for the skid testing fractions selected and for any number of intersections resurfaced up to the number tested. Plan I always falls short of Plan II in expected wet accident reduction, and in this case does not do as well as random resurfacing. This is probably because Plan I specifies resurfacing on the basis of skid number alone and does not take into account regional wetness or dry accident incidence. Dry accident incidence is an important variable since it is a reflection of traffic volume and location hazard.

In the light of Figure 11 it would seem that skid testing plans based exclusively on skid numbers are very poor in achieving full potential wet accident reduction through resurfacing programs. By giving too much weight to skid coefficient at the expense of other important variables, they may even be inferior to resurfacing on a random basis. While skid coefficient is important it should not be looked at in isolation if optimal accident reduction is to be obtained.

Figure 11. Accumulated intersection accident prevention benefits for two resurfacing priority plans and random resurfacing.



Conclusions

By using nearly 40,000 accidents recorded at some 2,000 intersections, a wet surface accident model was developed which incorporates skid number, wet time, and seasonal weather effects. In order to estimate wet time, considerable effort was expended in developing a method which would reflect seasonal as well as geographic considerations. It appears that this may be accomplished through suitable transformation of monthly precipitation data recorded as inches of rainfall.

Both estimated surface wet time and skid number are important factors in wet accident involvements as expected; however, no critical skid number emerged as a point above which wet accident hazard disappeared. Rather, wet accidents appear to be a continuously decreasing function of surface friction. Below a skid number of approximately 30, wet accident incidence increases at a slightly increasing rate with declining surface friction. This is true for all months and wetness categories.

The effect of monthly wet time on wet accident incidence is considerable. It was the most important variable discovered in this study. Its effect on wet accident percentages is approximately logrithmic for all months and surface friction conditions. Naturally, this variable cannot be controlled. However, the present study makes it clear that variations in monthly surface wet time occur in Michigan on a predictable yearly basis. To the extent that traffic volumes also have seasonal variation, monthly wet time should be included in resurfacing decisions. For example, if traffic volume peaks at a location in the winter months, resurfacing of this intersection would be of higher priority than if it peaked in July. While there are considerable variations from year to year and region to region, a resurfacing policy which takes account of regional and monthly wetness patterns would be valuable. The increase in wet accident percentages due to a drop in skid number of 10 units (40 to 30) could be of the order of four percent. On the other hand, a rainfall increase of 12 percent from July to December would produce a 30 percent increase in wet accidents. Thus, a seasonal change of only 12 percent in wet time can have over seven times the impact on wet accident incidence as a 10 unit decline in skid number. For this reason, we conclude that for a state such as Michigan, where seasonal and regional wetness patterns exist, consideration of surface friction improvements should include expected locational wet time as well as skid number. As experimental skid testing and resurfacing plans have shown, consideration of skid number along will not lead to an optimal reduction in wet surface accidents.

The model can be used to evaluate alternative skid testing and resurfacing plans which seek to identify and select on a priority basis those intersections which could be resurfaced most profitably. Once a plan is developed, regional and seasonal wetness patterns must be estimated if beneficial skid testing plans are to be implemented. Once locations are skid tested, as dictated by the testing plan, resurfacing can proceed for those locations selected on a priority basis as determined by the resurfacing plan. The selection of a testing-resurfacing plan is critical since plans vary considerably in their ability to minimize wet accidents. Based on a limited computer experiment with one year's field data we suggest that accident models can profitably be used in developing a fixed cost, wet intersection accident minimization program. Since a model should take full account of precipitation and seasonal wetness factors, it can be used to develop plans which are more cost effective than those based only on skid number and/or previous accident experience.

We have attempted to show that wet accident prevention is highly dependent upon the type of plan used for intersection skid testing and resurfacing. Further, plan design should proceed from a clear delination of program goals since goals may be inconsistent in the results they produce. The accident prevention simulations of this study are highly tentative and weakly generalizable since they are based on a limited analysis of those plans chosen as representative of the aforementioned goals. Plans serving other goals and embodying different assumptions would, of course, give different results.

Acknowledgments

I would like to thank Ms. Laura Lintner and Dr. Wen-Hou Kuo for their assistance in data preparation and analysis. This research was conducted in cooperation with the Federal Highway Administration.

References

1. Giles, C. G., Sabey, B.E., and Cardew, K.H.F., "Development and Performance of the Portable Skid Resistance Tester." ASTM Special Technical Publication No. 326, pp 50-74 (1962).
2. Kummer, H. W., Meyer, W. E., "Tentative Skid-Resistance Requirements for Main Rural Highways," NCHRP No. 37, 1967.
3. Sabey, B. E., Storie, V. J., "Skidding in Personal-Injury Accidents in Great Britian in 1965 and 1966." Road Research Laboratory Report No. LR 173, P 19, 1968.
4. Mahone, D. C., Rumkle, S. N., "Pavement Friction Needs," Highway Research Record No. 396, p 1-11, 1972.
5. Campbell, E. M., "The Wet-Pavement Accident Problem: Breaking Through," Traffic Quarterly, Vol. 25, No. 2, pp 209-214, April 1971.
6. Johnson, E. M., "An Experimental Study of Accidents, "Traffic Digest and Review (2 parts), Vol. 9, No. 8, pp. 12-18, August 1961.
7. Mills, J. P., Jr., and Shelton, W. B., "Virginia Accident Information Relating to Skidding, "Proceedings First International Skid Prevention Conference, Part 1, pp 9-20, 1959.
8. Mahone, D. C. Rumkle, S.N., "Pavement Friction Needs," Highway Research Record No. 396, p 3, 1972.
9. Karr, J. I., Guillory, M., "A Method to Determine the Exposure of Vehicles to Wet Pavements", State of California, Division of Highways Pub., January, 1972.
10. Billingsley, C. M., Gorgenson, D. P., "Analysis of Direct Costs and Frequencies of Illinois Motor Vehicle Accidents, 1958" Pub. Roads Vol. 32, No. 9, pp 201-213, 1963.