TRANSPORTATION RESEARCH RECORD 623

Skidding Accidents:

Wet-Weather
Accident Experience,
Human Factors, and
Legal Aspects

Proceedings of a conference conducted by the
Transportation Research Board, May 2-6, 1977

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Contents

Preface

Wet-weather skidding on highways and runways is a major contributor to accidents. In the United States alone, deaths from highway accidents have averaged more than 50 000 each year for the past 5 years. A significant number of those accidents can be directly attributed to wet-weather conditions.

Wet-weather accidents result from the interaction of many factors: climate and environmental conditions, vehicle operator, pavement design and construction, maintenance of roadway, and materials properties. Because the responsibilities of both public agencies and private individuals are involved, the question of legel liability for injury and damage is raised.

The First International Skid Prevention Conference, held in 1958 at the University of Virginia, emphasized the definition of problems and identification of research needs. During the intervening years, numerous techniques have been developed for reducing wet-weather accidents. Most of the basic mechanisms and interactions involved are known, and numerous promising solutions have been identified and demonstrated.

The Second International Skid Prevention Conference was organized to facilitate an international exchange of information on all aspects of wet-weather skidding accidents on highways. Primary emphasis was placed on research results and their application, vehicle industry developments, and operating agency practices and programs known to have a significant influence on reducing wet-weather accidents. The interaction among the driver, the vehicle, and the pavement surface was of prime concern. The papers in Transportation Research Records 621, 622, 623, and 624 constitute the proceedings of the conference held May 2-6, 1977, in Columbus, Ohio.

All papers prepared in advance for the conference are included in the proceedings. Records 621, 622, and 623 contain all papers addressing one of the three major topics of the conference; Record 624 contains ancillary papers not included in the conference program but considered to be important contributions to the state of the art.

Organization and direction of the conference were responsibilities of the Conference and Program Committees and Subcommittee on Tires, Vehicles, and Vehicle Components; Subcommittee on Pavement Characteristics; Subcommittee on Wet-Weather Accident Experience, Human Factors, and Legal Aspects. Chairmen and members of these committees and subcommittees are listed on page ii of this Record.

The Second International Skid Prevention Conference was partially funded by the Federal Highway Administration and National Highway Traffic Safety Administration of the U.S. Department of Transportation. The following organizations cooperated to make the conference possible:

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Papers

SKIDDING ACCIDENTS, FRICTION NUMBERS, AND THE LEGAL ASPECTS INVOLVED REPORT OF THE PIARC TECHNICAL COMMITTEE ON SLIPPERINESS AND EVENNESS

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Because of various other factors involved in skidding accidents, friction numbers as measured under standardized conditions of test cannot be expected to give a clear-cut ranking to surfaces according to their safety to traffic under wet conditions. Nevertheless, the concept of standardized test conditions is inevitable from a practical point of view. Regression type analyses compare accident figures or rates with friction numbers (examples from the Netherlands, the F.R. of Germany, and France). The most striking evidence of the important role slipperiness can play in wet-road accidents is yielded, however, by reliable before-and-after studies (examples from Italy and Great Britain). The establishment of standard, guide or minimum friction numbers is mainly based on regression type analyses. From country to country such values are quite different in character and significance. They support highway authorities in decisions on maintenance and renewal work but only in Belgium, the Netherlands, and Switzerland they serve as an acceptance criterion for road works. Current practice is described. For the suppression of black spots in wet conditions the two approaches are systematic routine measuring campaigns and evaluations of the accident statistics, the latter preferably based on the proportion of wet-road accidents. Interdisciplinary work is necessary to elaborate proposals for remedial measures which will generally include factors other than slipperiness (e.g. Safety Operation No. 6 in France). Juridical aspects in skidding cover the contractor's liability, the liability of the highway administrations, and the personal liability of their civil servants. Despite of the great variety in legal conditions. some general remarks can be made.

Preface

In the course of the preparation of the Second International Skid Prevention Conference, a number of non-American experts have been invited to present contributions. Most of these experts, however, are members of the PIARC (Permanent International Association of Road Congresses) and, in particular, of the Technical Committee on Slipperiness and Evenness. During its meeting in Berlin in November 1974, then the Committee decided to propose collective contributions to the Subcommittee on "Pavements" and the Subcommittee on "Accidents and Human Factors" of the international conference.

To characterize PIARC it should be mentioned that it is its main function to organize World Road Congresses to be held every four years in one of the member countries, and to enable a certain number of Technical Committees to work. PIARC (General Secretariate: 43, avenue du Président Wilson, F-75775 Paris Cedex 16, France) includes 59 countries, and 47 of them are member countries, that means that their governments are PIARC members. The financial resources of the Association are limited to the contributions of the members, which are individual or collective members (governments, administrations, ...). The PIARC Technical Committees cover the following subject areas: concrete roads, road tunnels, flexible roads, low cost roads, testing of road materials, winter maintenance, road traffic and safety, economic questions and the questions of slipperiness and evenness.

The Committee on Slipperiness was officially founded in 1949 in order to enable the Permanent International Association of Road Congresses to present an exchange of views on the skid-resisting properties of roads to the IXth Road Congress held in Lisbon in 1951. At the present time the Committee acts as a forum of exchange and discussion among experts in the fields of road skid resistance and evenness. It presents a report to each of the PIARC World Road Congresses outlining the evolution in research, knowledge, and experiences in its field. The Committee is in close contact with other organizations and experts working in the same field of skid resistance and evenness.

Based upon the Report of the Technical Committee on Slipperiness and Evenness to the XVth World Road Congress in Mexico-City 1975 (1) and supplementary material, this contribution has been drafted in accordance with the aim of the Skid Prevention Conference. The specific questions to be treated are:

1. Accident experience related to friction numbers.
2. Establishing guide or minimum friction numbers.
3. Spot detection and decisions on remedial measures.
4. Juridical aspects in skidding.

Human factors are not dealt with in this contribution because specific work on this question has not been done yet in the member countries of the PIARC Technical Committee on Slipperiness and Evenness.

This report has been written by the authors with the help of the Committee members among which Messrs. A. Pasquet (France, Chairman of the Technical Committee), P.M.W. Elsenaar (Netherlands), J.P. Leyder (Belgium) and J. Lucas (France) should be especially mentioned.

This report includes information available up to the 1st of June, 1976, unless otherwise stated within the text of the report.

Background and History

In the historical view, the first activity in the skidding field was measuring friction numbers, and a variety of different methods of test have been developed in the various countries since the early thirties. Although it seems impossible to establish an internationally standardized method of test, useful work in preventing skidding accidents can be done by the application of any one test method if it satisfies the following three criteria (C.G. Giles in line with the Report of the PIARC Technical Committee on Slipperiness to the XIIIth World Road Congress in Tokyo 1967 (2, 3)):

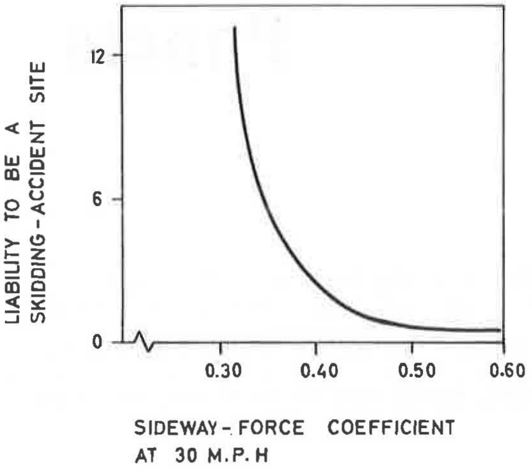
1. That it must be shown to give consistent results.
2. That sufficient tests must have been made over the full range of surfacings under the same test conditions to give a representative background of data with which subsequent results can be compared.
3. That a systematic series of measurements on skidding accident sites must have been carried out so that the readings may be appropriately correlated with the risk of skidding accidents.

That the methods of test employed in the various countries do satisfy these criteria is mostly owing to the strict control of the test conditions. In particular it is essential that the test vehicle incorporates a watering system capable of regulating very precisely the outflow of water in front of the test wheel.

The first efforts to establish a direct relationship between accidents and the skid-resisting properties of roads date back to the end of the fifties when in Great Britain it has been found that many skidding accidents tended to cluster at a few "difficult" places on the busiest roads where the skid resistance was low (C.G. Giles 1957)(4). From a comparison of the skidding resistance as measured with the sideway force method of test in wet weather at skidding accident sites (mean sideway-force coefficient 0.36 at 48 km/h (30 mph)) with that of a random selection of other heavily trafficked road sites (mean coefficient 0.50) the "relative liability of a surface to become the scene of repeated skidding accidents in wet weather" has been calculated (Figure 1). The sharply increasing risk at the lower values of coefficient was so great that in practice it seemed the dominant factor, outweighing the effects of differences in road layout or in the amount of traffic to a considerable degree (4).

These early findings could be confirmed in several subsequent investigations carried out in different countries on a more or less similar basis of skid resistance measurements and accident analyses, but since that time more and more difficulties arose in interpreting the results of skid resistance measurements and in using them for decisions on remedial measures.

Figure 1. Sideway-force coefficient and the relative liability of a surface to become the scene of repeated skidding accidents in wet weather (4).



There are two main factors contributing to these difficulties:

1. The increasing formation of ruts in the wheel tracks - either by abnormal road wear or by unexpectedly large permanent road deformations under heavy vehicle loads - promoted the appearance of thick water films on our roads. At the same time, due to increased vehicle speeds, thick water films got more dangerous than in the past, so that today the actual water film thickness on the road is a tantamount factor in determining the friction level actually available.
2. Road users, and their insurance companies, getting more and more conscious of the important role the frictional resistance of the road surface can play in wet weather accidents, increasingly frequently attempt to hold responsible the road authority "for lack in safety". This tendency, on the other hand, and depending on the legal conditions in each individual country, sometimes calls for a more conservative attitude of the road administration towards establishing minimum or guide values of skidding resistance, taking into account that it is indeed practically impossible for a road authority to guarantee, against the public, that all roads will offer at least "this" level of tire-to-road friction at any time.

These difficulties together with increased traffic flows and their deteriorating effect on the frictional resistance of road surfacings have rendered the idea of suppressing road lengths with insufficient resistance to skidding a complex matter.

Accident experience related to friction numbers

From experience it became more and more clear that two surfaces may be equally ranked by the results of skid resistance measurements, but one could be skid-prone and the other not depending on various other factors involved. These factors that weaken the significance of the skid resistance criterion (which is based on standardized conditions of test) can be grouped as follows:

1. Factors originating from the estimating character of each individual skid resistance measurement:

- The coefficient of friction/speed relationship is different from surface to surface.
- Road surfaces vary in their skid-resisting properties with time and under the influences of weather and traffic (including variations of the coefficient of friction/speed relationship).
- The skid-resisting properties vary also across the width of the road; the lowest value found in the most heavily trafficked wheel tracks may be equal for two sections of road, the overall level may not.

2. Factors originating from different characteristics of each individual site (site parameters):

- The frictional resistance is substantially variable with the actual water film thickness on the road. It would be wrong to identify the water film thickness chosen for testing (according to the standardized conditions of test) with that encountered by vehicles travelling along the same length of road during rainfall. Although the water film thickness used in testing is generally chosen as to simulate a relatively unfavorable surface condition within the spectrum of unfavorable conditions, the skidding resistance criterion determined in this way implies that it is not possible to discriminate between road sections which, during actual rainfall, exhibit unfavorable degrees of wetness like this only on isolated points and those sections where such conditions occur over a major part of their surface area.
- Frequency, distribution and intensity of rainfalls vary from place to place. Therefore, different road sections included in a skidding resistance/accidents survey are not strictly speaking, comparable.
- The effect of the surface irregularities on actual wheel load fluctuations can be different from road to road resulting in different reductions of the frictional forces available at a certain point of travel, apart from vehicle parameters which are also involved.
- The frictional requirements of traffic are different from site to site. According to a definition given by H.W. Kummer and W.E. Meyer (5) it is possible to distinguish between normal, intermediate, and emergency frictional requirements. Reduction in traffic safety in wet conditions depends on the degree of discrepancy between the demand and the availability of the tire-to-road friction.

From this consideration of some of the more important factors involved in the skidding accident problem it can be concluded that friction numbers as measured under standardized conditions of test cannot be expected to give a clear-cut ranking to surfaces according to their safety to traffic in wet conditions (or to the risk of skidding in the wet). On the other hand and from a practical point of view, it would by no means be advisible (if not impossible) to give up the concept of standardized conditions of test. To vary in routine skid-testing only a few of the parameters involved would not only cause immense additional work but also produce considerable new difficulties in interpretation because statistical distributions rather than individual figures for the friction numbers would be obtained.

Thus, in the view of the PIARC Technical Committee on Slipperiness and Evenness, there are, at present, still two practical approaches to establishing skidding resistance/accidents relationships: (1) regression analyses, (2) before-and-after-studies, with both of these approaches based on friction numbers as obtained under standardized conditions of test.

Regression Analyses

From a theoretical point of view a multiple regression analysis which includes some of the factors representing site parameters would offer the best chance of reaching a close relationship between relevant accident rate and skidding resistance. The site parameter of paramount importance would be a quantity related to water film thickness distribution (e. g. the average water film thickness at a representative rainfall intensity). Particularly prone to water accumulations are the transition areas between left-hand and right-hand curves (or vice versa) due to the directional change of the crossfall at the turning point by carriageway distortion. As it can be seen in Session 1 - Report of the Technical Committee on Slipperiness and Evenness on pavement characteristics and skid resistance - research work aimed at assessing the true surface drainage conditions of any given section of road is still in progress.

It is well possible, of course, to estimate, from empirically determined relationships (nomogram type (6)), for a given intensity of rain, the water film thicknesses and their distribution over a road section with known design features, assuming an ideally even surface. But this estimate will only indicate the general trend rather than express actual conditions which are complicated by tolerated deviations from the design figures and by the irregularities due to surface roughness and ruts in the wheel-tracks.

Therefore, at the present state, all the known relationships rely upon the skid resistance criterion only, since they compare simply accident figures or rates with friction numbers measured under standardized conditions of test. However, there is a practical way of discriminating between different frictional demands of traffic, that is by making separate studies for different types of road site (e.g. straight sections, sharp bends, approaches to traffic lights etc.). Such separate studies are less advisable on motorways and other high standard roads because of their more uniform design characteristics. Here, unforeseeable, sudden changes in the traffic situation can be considered the major cause of high frictional demands rather than different geometric design features. As a general rule, the number of emergency situations may increase with an increase in traffic flow.

Before-and-after Studies

Fundamentally different from regression analyses, before-and-after studies eliminate the majority of difficulties originating from the various parameters involved in the skidding accident problem. Before-and-after studies imply that there is, at least approximately, only one factor changed. This is the frictional level of the road surface as evaluated by the skid-testing technique employed. Therefore, reliable before-and-after studies yield the most striking evidence of the important role that skidding resistance plays in the complex system.

Examples of Relationships

Regression Type Analyses. In the Netherlands all accidents on state roads during two years have been used in a regression type survey. The accident rate was derived from the number of accidents during a certain period on a selected section of road and the total number of kilometers travelled over that section of road during the same period. Friction numbers for each road section were measured by the Dutch standard test method (i.e. test wheel under 86 per cent slip). Wet friction numbers were used for all accidents that occurred in wet weather, dry-friction numbers for those accidents that occurred in dry conditions. A relationship was established between friction level and accident rate (Figure 2)(1).

In the Federal Republic of Germany a regression type analysis between friction numbers and accidents was based on the proportion of accidents that occurred under wet conditions. In general, on most road sections the proportion of accidents in the wet, i.e.

$$P_w = (A_w/A_t)\cdot 100 \quad (\%)$$

A_w Number of accidents in wet conditions

A_t Total number of accidents (in wet and dry conditions)

varies between zero per cent and approximately 50 per cent and averages about 33 per cent for the road network with slightly different figures from year to year. If on any particular section of road the proportion of wet-road accidents significantly exceeds this range of percentages, then this can be taken as an indication of reduced traffic safety under wet conditions (7). The survey (Figure 3)(8) covered 80 sections of motorways and main roads; the skid numbers (locked wheel braking force coefficients) were measured at a speed of 80 km/h (60 mph). Although there is a large scatter in the percentage of wet-road accidents for each friction level, the general trend of the increasing percentage of wet-road accidents with the decreasing friction level is unmistakable.

Figure 2. Accident rate (mean and standard deviation) against friction level (dry levels for dry-road accidents, wet levels for wet-road accidents). The Netherlands, 1965 and 1966.

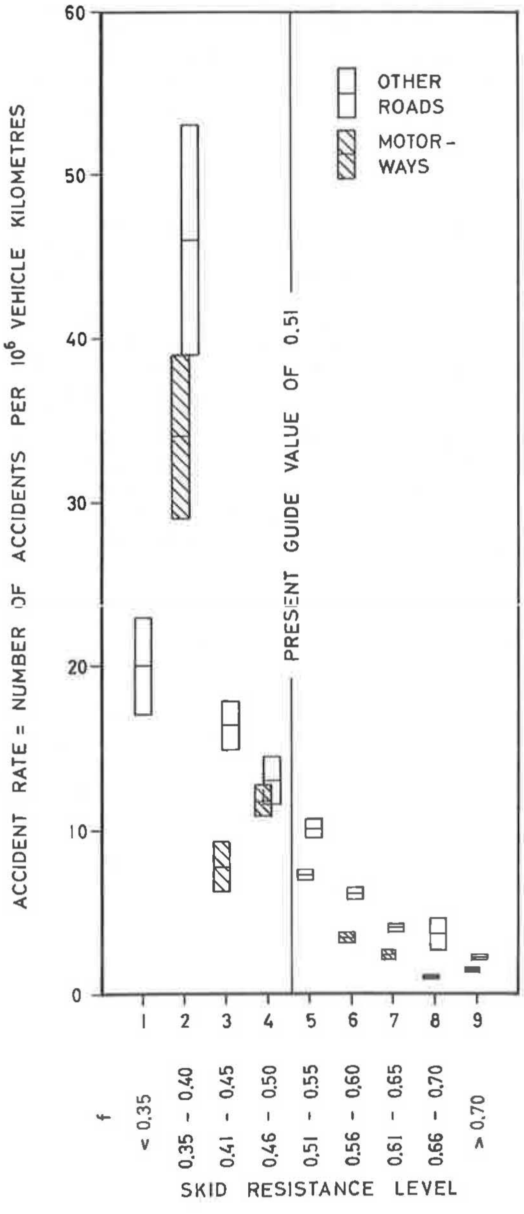
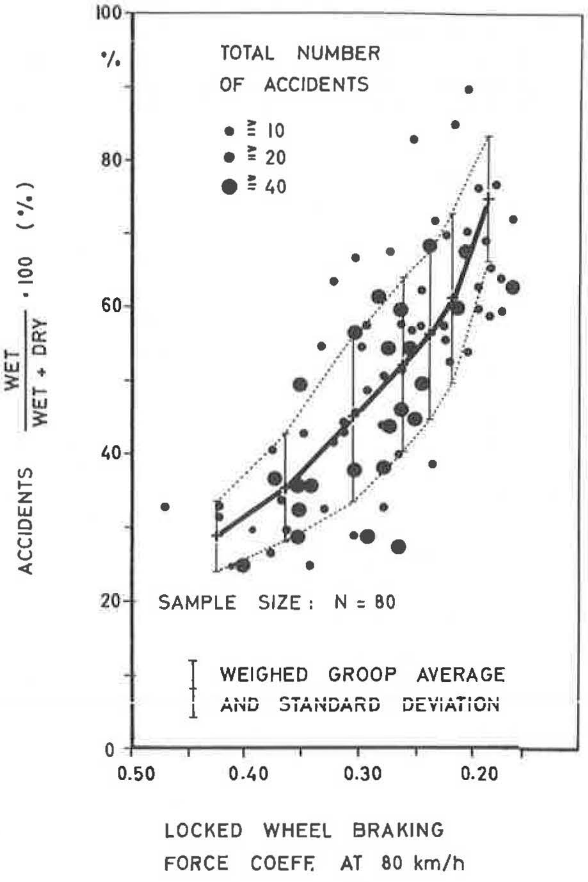


Figure 3. Percentage of wet-road accidents against friction number. F.R. of Germany, 80 sections of motorways and main roads, each over one or two years within 1964-1971.



In France, skid-prone sites are being detected by the following method (17):

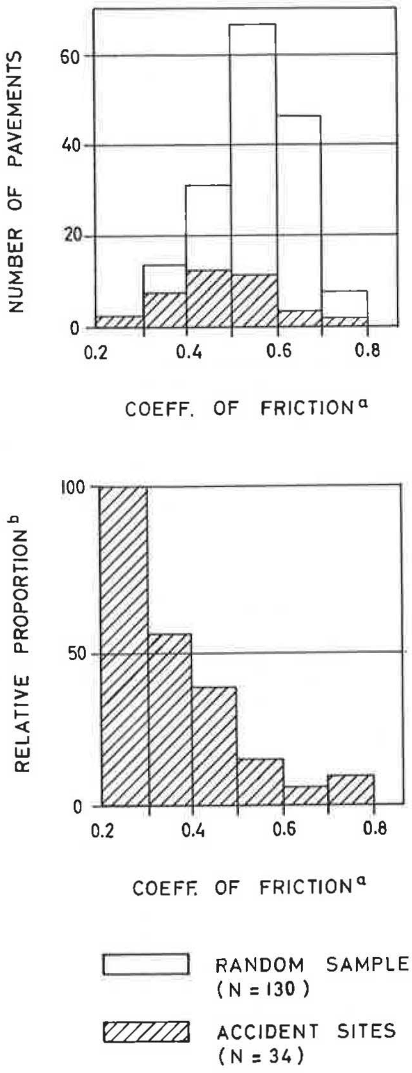
1. The first step is black spot detection in a general sense (all accident causes mixed) using the nomogram given by Thedie and based on the binomial distribution.
2. Then, for these sites or sections of road, the number of accidents that occurred under wet conditions (M) is compared with the total number of accidents (M + S), and the confidence interval for the ratio R = M/(M + S) is estimated for a certain level of significance. If the lower confidence limit determined in this way exceeds a certain value, say 25%, then the section of road in question is said to be

"skid-prone".

According to this investigation, the detected sections of road exhibited skid resisting properties in the medium range (Figure 4), but slipperiness was not the only major factor involved. Other factors intervened, such as:

- The horizontal alignment: 40% in straight sections, 54% in curves, 6% at junctions.
- The vertical alignment: 54% horizontal, 46% up-grades, 0% down-grades.
- The evenness of the road: 37% in good condition, 46% in bad condition, 17% intermediate.

Figure 4. Histograms of locked wheel braking force coefficients on accident sites and on randomly selected sites, France (16).



[a] LOCKED-WHEEL BRAKING FORCE (LPC-TRAILER, SMOOTH TIRE)

[b] OF ACCIDENT SITES FOR EACH LEVEL OF SKID RESISTANCE

Before-and-after Studies. Among the before-and-after studies carried out in recent years an Italian survey and a British investigation should be mentioned especially. In Italy a particular interest was taken in the British experience with epoxy resin/calcined bauxite surface dressing (9). Surfaces of this type give a sideway force coefficient of 0.78 - 0.88 at 50 km/h (30 mph) after one year and of still 0.67 -0.70 after eight years of exposure to intense traffic. At the same time a reduction in the total number of road accidents during one year has been reported (10).

In Great Britain, an instructive before-and-after study relates to the elevated section of M4 Motorway (11), where after some years of intense traffic the skidding resistance of the existing bituminous surfacing had fallen to a relatively low level. Afterwards the road was surface-dressed (calcined bauxite and/or Gilfach gritstone with PVC-tar binder). During the years following treatment the friction level of the surface remained well above that of the previous surfacing. The accident figures, including both injury and damage accidents, show that there were 28 per cent fewer dry-road accidents and 63 per cent fewer wet-road accidents of all kinds during the period following treatment than in the two years immediately preceding the work. In particular it can be seen that the reduction in wet-road accidents is primarily a reduction in wet road skidding accidents.

Establishing Guide or Minimum Friction Numbers

Examples of Current Practice

At the moment that highway administrations have knowledge of the importance of the skid-resisting properties of road surfaces in accident prevention they have the duty to use, in the interest of safety, the figures obtained. Consequently, attempts have been made in several countries to put forward standard, guide or minimum values of skidding resistance. Such values are aimed:

1. To support the highway authorities in taking decisions on maintenance or renewal work on existing roads, mainly based on sporadic measurements when and as the need arises.
2. To serve as an indicator for unsatisfying skid resistance in systematic road network investigations or black spot detection campaigns.
3. To serve as an acceptance criterion for road construction work if the specifications do include the skid-resisting properties explicitely (as it is the case in a few European countries only).

For all these purposes standard, guide or minimum values of skid resistance are used in a technical sense only and not in a legal sense (with the exception of their legal significance in the relationship between road work contractor and highway administration).

How standard, guide or minimum values of skid resistance are actually used in the different countries may be demonstrated by the following examples of current practice.

At first, the well known early British recommendations may be mentioned that date back to 1957 (4) and relate to the sideway-force method of test; different coefficient values are given for different categories of road according to the different frictional demands of traffic ("easy sites", "general requirements", "most difficult sites").

In a much more strict sense minimum values of skid resistance are in use in Belgium since 1962, where they have to ge guaranteed by the road contractor, forming a part of the contract conditions (19):

The skidding resistance of the pavement surfaces is verified by the Highway Administration by means of sideway-force coefficient measurements. Per pavement category a number of tests (n) given by the following formula is carried out by the Administration:

$$n = S/4000$$

where S is the surface area of the pavement in question, expressed in square metres. The number of tests n has a lower limit of 10 and a upper limit of 50. "A category" is understood to be any continuous pavement surface described in one contract item. However, in the case of motorways and other highways with at least two traffic lanes per carriageway, each traffic direction represents "a category". Anyhow, both parties may arrive at an agreement and subdivide the pavement of one contract item into several distinct conventional categories.

The tests are carried out at any time the Administration deems necessary and at locations pointed out by the Administration, and at any date at the time of the provisional acceptance and the final acceptance. When a result obtained during a test carried out in accordance with the standardized test conditions (20 °C, at 50 or 80 km/h according to the type of road) is lower than 0.45 for one of the two test wheels of the measuring apparatus, the Administration has a right to test any part of the pavement surface in order to delimit the defective areas.

At the time of the provisional acceptance, as well as at the final acceptance, the different pavement categories have to present over their whole length the characteristics in accordance with the clauses of the specifications, i.e. any change in the nature of the pavement surface is subject to approval by the Engineer.

As a rule the measurements are carried out at 80 km/h on motorways and other highways with four traffic lanes or more and at 50 km/h on all other roads. However, when local conditions (gradients, bends with small radii) do not allow to meet this condition, the tests are carried out at a speed considered possible by the Administration. In this case the measured sideway-force coefficient is affected by a speed correction factor.

Before undertaking any repair work the contractor submits the corrective measures he intends to perform in order to restore a sufficient sideway-force coefficient to the approval of the Administration. The fact that the Administration approves of the repairs proposed by the contractor does not diminish the responsibility of the latter to achieve a satisfying sideway-force coefficient.

Any point of the pavement not presenting during a 3-years period a minimum sideway-force coefficient of 0.45 measured at each test wheel (speed of 80 or 50 km/h according to the type of the road; temperature 20 °C) is rejected. These areas have to be repaired by and at the expense of the contractor over a length of at least 100 m and right across the carriageway. The repair methods are subject to approval by the Administration. An additional 2-years guarantee period, beginning on the day of the repair, is demanded for the sideway-force coefficient of repaired pavements or pavement sections.

The percentage of unsatisfactory results varies over the seasons from 5 to 8 per cent.

Another example for the use of friction numbers forming part of the contract conditions can be reported from the Netherlands. Here, minimum values of skidding resistance have generally been introduced into contracts for main roads (including resurfacings of existing roads) since 1967.

Examiniation of the friction coefficient is usually carried out before the opening of the new surface to traffic, but not later than four weeks after the opening. The minimum value prescribed in the contract was 0.51 during the period 1967-1974 and is 0.56 since 1975 (measured longitudinally, at a speed of 50 km/h, test wheel with constant brake slip of 86%, standard patterned tire).

During the period 1967-1974 in the average about 4% of the finished and examined surfaces (totalling 6700 km of lane, width about 3.50 m) did not meet the (old) specification ($f = 0.51$); this percentage was 5% in 1975 (examined length of lane 1000 km, lane width 3.50 m); in the average the percentage below the (new) specification ($f = 0.56$) was 20% before 1975 und 24% in 1975.

In the contracts for asphaltic concrete wearing courses the spreading of 2 kg/m^2 chippings 2-5 mm onto the hot surface during rolling is prescribed. This strongly contributes to achieving the specified minimum skid resistance value in a high percentage of road lengths. If friction coefficients below the specified values (now 0.56, and formerly 0.51) are found, payment reductions ("penalties") are applied. Moreover, surfaces with $f < 0.51$ had, and still have to be improved, mostly by means of a treatment with white spirit and crushed sand. This method is rather labour-intensive and costly. But if carried out carefully the method is generally effective. In some rare bad cases locally a 40 mm extra new top layer had to be applied. These improvements were made and paid for by the contractor.

All these regulations have been developed and introduced by the government authority in continuous deliberation with the contractors' organizations. As they are accepted by them. the specifications, as a rule, do not lead to big problems.

The third example of a country where friction numbers form part of the contract conditions, is Switzerland. First in 1964 Swiss Standards (20) defined acceptance values as follows, related to the British Portable Skid Resistance Tester (pendulum SRT) and depending on the design speed V_a of the road:

- for roads with $V_a < 80$ km/h: SRT $\geqq 50$
- for roads with $V_a > 80$ km/h: SRT $\geqq 55$
- for most difficult sites: SRT $\geqq 60$

As far as it is known, these standards - that may be classified as "moderate" - have not been satisfied only in four cases during the last six years. In all these cases the problem was a problem of the initial skid resistance after the construction of a bituminous concrete surfacing, and traced back to excess rolling at high air temperatures with the result of excess binder accumulating at the top of the surfacing.

Only in one of these cases the excess binder was removed mechanically from the surface of the road. The method proved successful, and afterwards the acceptance values were easily attained. The other three cases related to minor roads where the posting of warning signs "danger of skidding" and the introduction of a speed limit (60 km/h) were considered sufficient care. Satisfying friction numbers have then been measured on all these sections after the first winter period has passed.

Generally spoken, there exist no serious problems with the initial skidding resistance of asphalt pavements in Switzerland, so that difficulties can only arise from "failure".

Apart from these examples, most of the European countries, however, are still hesitating to include minimum friction numbers into their contract conditions. Some prefer to prescribe specifications for highway constructions (e.g. texture depths and resistance to polishing of the aggregates as to ensure, from experience, acceptable friction values) rather than demand explicitely minimum values of coefficient. A particular example of this type of policy has been implemented in France (13). In addition to that, however, France has recently started periodic or systematic measurements within the road network by using the machine SCRIM (18). The results of the 1974 measuring campaign are given in Figure 5 and Table 1.

Figure 5. General results of the SCRIM measuring campaign in France in 1974.

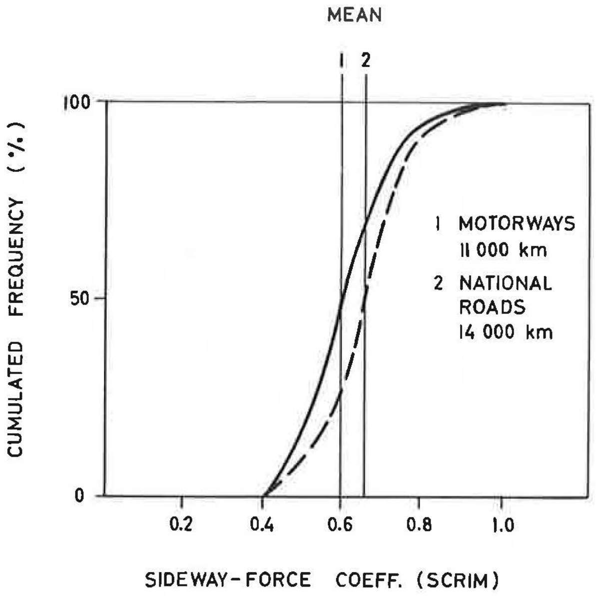


Table 1. Main results of the SCRIM measuring campaign in France in 1974 (18).

SFC = Sideway-force Coefficient	3000 km of Motorways	4000 km of National Roads[a]
Mean of SFC	0.60	0.64
Standard deviation	0.11	0.13
Percentage SFC below 0.50	16%	9%
Percentage SFC above 0.70	21%	32%

[a] Reinforced according to the directive scheme.

These few examples may suffice to indicate that friction standards if established, are quite different in character and significance as well as with regard to the practical consequences drawn, much depending on the particular conditions in each individual country. (For more details on the figures actually used in the various countries and their significance see the Committee's contribution to Session 1, "Pavement characteristics and skid resistance", chapter III, Analysis of regulations in European countries). There are two main reasons for this variety in policy, the one originating from the principal difficulty in defining safe minimum friction numbers, the other originating from the legal aspects referred to later in this contribution.

"Safe" Minimum Friction Numbers ?

The question of how minimum or guide values of the friction number should be formulated cannot be answered by means of single before-and-after studies. Regression analysis appears to be the only way to proceed but then the whole complexity of the skidding accident problem is under question, since, under the influence of the other factors involved (site parameters in particular), any relationship between friction numbers and accidents so far established shows a residual variance larger than desirable from the viewpoint of practical application for measures to prevent vehicles from skidding.

As a consequence of the large variance, only extremely low values of the skid resistance criterion used are definitely associated with an unusually high percentage of accidents (chiefly skidding accidents) in the wet; and only with rather high friction numbers can the influence of the road surface on accidents be excluded. Between high and low values, however, there is a large transition zone of friction levels around and below the average where an interrelation between frictional level and accidents can neither be excluded nor be assumed with certainty. Against this background it would be desirable, following the classic principles of materials testing, to select guide values of skidding resistance which are definitely "on the safe side". This would lead to guide values corresponding to the average friction level found in the road network. It would be unwise, however, to proceed without considering what friction level is possible to obtain and to maintain and, if need be, to restore under the conditions of intense and heavy traffic with the given natural materials in relation to the financial limitations.

Therefore, it is mainly for economic reasons that standard, minimum or guide values of skidding resistance have been chosen in the different countries which cannot be considered to be definitely "on the safe side". However, there is the practical way of adapting to different frictional demands of the traffic by applying different guide values according to a classification of sites as to their "difficulty". There is also the method of adjusting the guide values within prescribed limits from site to site in the light of accident records (14). In this case instead of providing surfacings of uniformly high resistance to skidding, a compromise situation seems possible to achieve in which the risk of the occurrence of skidding accidents would be uniform within the road network. This concept brings out the problem of defining the admissible risk of the occurrence of skidding accidents, or the "degree" of safety under wet conditions to achieve. The real dilemma the road engineer is exposed to, and to which no solution is in sight, is that from the standpoint of jurisdiction, "safe" and "unsafe" is the only distinction admitted (1).

Spot Detection and Remedial Measures

To detect road sections with insufficient friction levels there are, in principle, two approaches:

(1) Systematic routine skid resistance measurements,
(2) Evaluations of the accident statistics.

For systematic measurements to be used as a means of spot detection it is a pre-condition that minimum or guide values of skidding resistance have been formulated in relation to the standard method of test employed. Clear decisions can be taken in all cases where the test result falls definitely short of the minimum. A more complicated situation will arise from test results just exceeding the minimum. Then it is

Table 2. Reduction in accidents as the result of black spot treatments during the Safety Operation No. 6 in France (17). Relative figures related to 51 black spots in wet conditions improved during 1971 and 1972.

	Number of accidents[a]			Number of victims[a]			
	Total	On wet surface Total	On wet surface Per cent	Total	Fatal	Seriously injured	Slightly injured
Before treatment (1969)	85.31	63.98	75	177.71	14.55	56.99	106.17
After treatment (1972)	34.98	6.64	19	59.43	4.10	21.40	33.93
Reduction following treatment, per cent	59	90	75	66	72	62	68

[a] Annual mean value.

necessary to take into account the particular situation of the spot with special attention to be drawn to the conditions of surface drainage, and also to the level of the frictional demands of the traffic.

The comparison of measured friction numbers with standards implies a certain degree of merely schematic application which not necessarily results in optimum utilization of funds unless the friction numbers found are extremely low. Therefore, there is a tendency to base decisions on remedial measures on more comprehensive considerations with the accident figures as the starting point.

Spot detection by the use of accident figures can be successfully based on two inputs for any section of road under consideration:

1. On the proportion of wet-road accidents involving skidding related to all wet-road accidents (skidding accident rate).
2. On the proportion of wet-road accidents related to the total number of accidents (wet and dry conditions).

The use of the first input is bound to the precondition that the question of whether a vehicle skidded during an accident is recorded in the accident report form filled-in by the police for each (injury) accident, as it is the case in Great Britain. If this information is not explicitely available, as in most other countries, then the use of the proportion of wet-road accidents is most recommendable. In this way successful campaigns of spot detection have been carried out in the F.R. of Germany (15) and in France.

Due to its comprehensive disposition the French "Safety Operation No. 6" (16, 17) provides guidance for developing skidding accident prevention strategies. Indeed, the method not only necessitates an analysis of the accident statistics and the detection of "black spots" in wet conditions, but also a thorough site investigation for decision making on how the section of road in question can be improved in order to prevent further accidents of the same type. These improvements possibly include road characteristics other than the resistance to skidding. As it is considered in France, it is this site investigation that guarantees the rentability of this type of safety operation: In general, the cost of the accidents prevented during one year is well superior to the cost of the site investigation work. More precise information on these different points is given in the sections to follow.

The following definitions have been used (16): A "black spot in wet conditions" is a section of road where, on the 0.05 level of significance, the proportion of wet-road accidents exceeds the value which would be obtained by using the Poisson distribution. In an other region, the first step was the selstion of road sections where the total number of accidents was abnormally high, and then, by using the binomial distribution, those of them were selected for further investigation where the proportion of wet-road accidents was abnormally high. The sections of road detected on the basis of these definitions did not necessarily prove to reveal low friction numbers when measured. Consequently, and in accordance with other investigations (15), even with medium friction numbers safety against an accumulation of accidents in the wet is - under some circumstances - not ensured.

Under these conditions where other characteristics of the road were involved, it has been concluded that an interdisciplinary working group (road engineers specialized on construction and maintenance work, on road alignment, on surface properties, as well as other specialists on vehicle dynamics, on driver psychology) in cooperation with the local authorities should analyse, by means of in situ studies, the situation of the spot and elaborate proposals for remedial treatments. Among a sample of 51 sections of road with totally 210 fatal accidents recorded during three years, the following types of remedies related to a summed-up length of 10 km (with a total surface area of 4000 m^2) have been proposed solely or in combination:

- Signalization and warnings to road users: 36 times.
- Improvement of the evenness of the surface: 21 times.
- Anti-skid surface treatment: 26 times.
- Widening of the road and other particular measures: 11 times.

From before-and-after studies of the accident figures remarkable reductions in the numbers of accidents and victims have been reported (Table 2). To assess the effectiveness of the treatments an estimate was made on the basis of the average cost of one accident (53.000 Francs) and the average cost of one black spot treatment (63.000 Francs), and under the following assumptions:

- That after treatment the proportion of wet-road accidents will render normal (about average) if compared with a reference section of road.
- That the total number of accidents will increase linearly with the growth in traffic flow.

According to the estimate, the annual advantage gained from the improvement of 51 "black spots in wet conditions" amounts to 3,800,000 Francs for a period of one year in the average after treatment.

Juridical Aspects in Skidding

The juridical aspects in skidding can be divided into three parts related to

- The contractor's liability.
- The liability of the administration.
- The liability of the civil servants.

The liability of the contractor depends largely on the specifications for road construction work given in each individual country. In general, there are three types of regulations in use.

The first type implies friction numbers to be achieved as part of the contract conditions (as in Belgium, the Netherlands, and Switzerland). In this case, the liability for non-compliance with the standards is, during the guarantee period, completely due to the contractor, and remedial measures (with laying a new surfacing as the extreme solution) have to be performed on its own cost.

In the second case the contract conditions as far as skidding resistance is concerned, are restricted to prescribing a minimum value for the polished stone coefficient (as for example in France). If nevertheless the finished surfacing reveals poor resistance to skidding, the road authority will be concerned with and finance remedial measures, unless the next case applies.

In the third type of regulations the contractor can be held responsible for any failure in the skid-resisting properties of the finished surfacing only when he can be convicted of not having observed "the generally accepted rules of the art". Otherwise, the administration will be concerned with and finance remedial measures that might be necessary to perform.

The liability of the highway administration is a much more complicated matter. It must be viewed in two stages: (1) Can the standards (what form and significance they ever have) be called into question during an accident and lead to a judgement against the highway administration ? (2) More general, can the highway administration be found liable for a wet road accident because of lack of maintenance or insufficient signalization ?

The answer to the first question depends, of course, on the legal conditions given in each individual country. In general, there is a tendency to acknowledge that the simple measurement of the friction number by the skid testing technique employed is not suitable for a judgement to be based on. It is realised that it is necessary to consider the problem of safety in terms of overall stresses and responses between the vehicle and the road. Therefore, in analysing the causes of any one wet-road skidding accident the local features of the road, the vehicle parameters, the mechanical condition of the vehicle, the environmental factors and the partilucar circumstances of the accident have to be taken into account. As a rule, courts will base their decisions preferably on expert evidence.

A particular situation, however, arises when it can be clearly shown that there was a case of "negligence or disregard". For instance, the highway authority has been previously informed of the inadequacy of the surface properties, and has not taken any suitable measures. Then the state will be held responsible for the lack in safety. In this context there is a tendency to regard the absence of clear signalization of dangerous spots more and more a failure in duty.

While, in certain cases as has been explained, the government can be held responsible with respect to an accident on a slippery road, it is exceptional for the road engineer himself to be liable personally. Theoretically, the case of personal legal liability is possible but exceedingly rare in practice. As a general rule, it must be clearly shown that a flagrant offense committed by the officer, or even a criminal action, was involved. Within these margins, however, different definitions, stronger or weaker, are possible.

Finally, it should be noted that the extent of problems raised by legal responsibilities with regard to skidding varies considerably from one country to another. At the present time only Belgium appears to be developing significant action aimed at incriminating, as often as possible, the public organisation, or even its agents, in the case of an accident on a wet road which is "abnormally" slippery.

Conclusions

Suitable techniques are available to determine the skid-resisting properties of road aurfaces. It is a question of management and implementation to use them in the most effective way.

It is, however, necessary to emphasize again and again that friction numbers measured under standardized conditions of test do cover only one aspect of the complex problem of skidding accidents, unless the friction number obtained is extremely low. Then remedial surface treatment is, in the long run, the only possible action to be taken.

The purpose of standard, guide or minimum values of skid resistance is

- To serve as an acceptance criterion if the road construction work specifications do include the skid-resisting properties (in a few countries only).
- To assist highway authorities in taking decisions on maintenance or renewal work.

The significance of the standard, guide or minimum values is technical and administrative and not legal (except for the relationship between road contractor and highway administration if and when they are used as an acceptance criterion).

The most promising approach to develop strategies for skid prevention is to combine systematic skid resistance measurements with the evaluation of the accident statistics as related to each individual section of road. Close contact and effective exchange of information between highway authority and highway police is of paramount importance for this purpose.

Black spots in wet conditions can be successfully detected by calculating for each section of road under consideration the "proportion of wet-road accidents" to be compared with what is to be regarded as "normal" from a statistical point of view.

In situ analyses of detected sites by a multidisciplinary working group of experts are necessary to elaborate proposals for remedial measures which can be multifold (e.g. improvements in skidding resistance and road evenness, improvements of the surface drainage, improvements in road alignment or geometric dimensions, augmentation of the sight distances, signalization).

The suppression of "black spots in wet conditions" belongs to the most effective actions ever thinkable in accident prevention.

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TRAFFIC ACCIDENTS AND ROAD SURFACE SKIDDING RESISTANCE

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In this research a statistical relation was sought between the skidding resistance of road surfaces and the relative road risks. In the concept of accident quotient the number of accidents that occurs on a certain section of road within a certain period of time is related to the total number of kilometers travelled on that section in the period concerned. The involvement quotient is the number of vehicles which, per million vehicle-kilometers travelled, subdivided into the categories passenger cars and goods vehicles, has been involved in an accident on a certain road surface. In order to eliminate influences other than skidding resistance, a distinction has been drawn between two types of road. Type I comprises roads with dual carriageways. Type II, which is a more discontinuous type, comprises all the other roads. The accident data (60,000 accidents) were based on records kept by the police. Vehicle-kilometers have been calculated only in so far as they were travelled during rainfall or, alternatively, when no rain was falling. The accidents which occurred on a wet road surface, but not during rainfall, constitute a situation concerning which little can be said with certainty and have been assigned to the skidding resistance class of the wet road and to the class of dry road surfaces too. It appears from the research that each lower skidding resistance class is associated with a higher accident quotient. On the evidence of the statistical relation that has been found the highest possible skidding resistance is to be recommended for both types of road.

Purpose of the Research

Skidding has been defined as a car movement involving the sliding of one or more wheels. It is evident that such a phenomenon cannot always be clearly reconstructed after a traffic accident has taken place. In addition, there is no category for skidding accidents in the Dutch accident registration system, although under the heading short description of the accident in the Central Bureau of Statistics' questionnaire it is quite often indicated whether the accident was strongly influenced by skidding. Therefore, the extent of the phenomenon skidding and consequently, the importance of road-surface skidding resistance for traffic safety, have been hidden almost completely.

However, some earlier investigations have already indicated that road-surface skidding resistance may have an important part in the occurrence of accidents. Due to these observations, the controlling authority of national motorways was able to establish a guide value for the minimum skidding resistance of a wet road-surface. The desired level of this guide value, however, was not defined distinctly. These circumstances have lead to an extended investigation.

The present study forms part V of this investigation. Its object is to develop a procedure to find a statistical relationship between road-surface skidding resistance and road risk per million vehicle kilometers, using actual data. The investigation had to confirm such relationship, on the basis of the actual data.

In this part of the investigation influencing factors other than the road-surface skidding resistance were taken as constant as far as possible. It has been realised that it would be difficult to find a sufficient number of road sectors of corresponding geometrical parameters and traffic flows. When the influence of bends, intersections, on and off ramps, had to be considered, the difficulties seemed to be so considerable, that the decision was made, even in the preparatory stage, that the investigation could not be carried out strictly according to the original plan. However, a comparative study seemed possible, if the limited nature of a single-factor investigation was partly modified.

Scope of the Investigation

Data

The accident data have been derived from the statistical questionnaires, issued by the Central Bureau of Statistics in the Netherlands, filled in by the police. Since 1967, in this questionnaire no data are included concerning minor material damage. It is not yet known how this new procedure will affect the quality of the accident statistics. The present investigation, therefore, needed to use the data of the more complete accident statistics as they were before the above-mentioned modification. The data relating to motorways are available at Rijkswaterstaat.

The available volume data were obtained from the general five-yearly traffic census by Rijkswaterstaat, taken in 1965 and 1970. On a more limited scale counts are regularly made and also intermittently on the most important motorways.

The data of skidding resistance used in this study were obtained from the Dutch State Road Laboratory, which carried out systematic annual measurements on the motorways and the most important roads of the provincial and municipal road systems. These measurements covered, among other things, the skidding resistance of wet road surfaces.

Finally, the precipitation data are permanently recorded by the Royal Netherlands Meteorological Institute. These data play an important part in determining the periods during which road-surfaces were wet.

On the basis of the available data, the investigation area was limited to the most important Dutch motorways over the years 1965 and 1966. In this connection it must be pointed out that this choice is not absolutely essential either to the form of the relation to which the investigation was directed, or to the relative importance of the studied factors of influence.

Relative Road Risk

The investigation aims at drawing conclusions from a number of traffic accidents concerning the actual importance of road-surface skidding resistance related to the traffic. It can be assumed that an accident will occur more easily at a lower road-surface skidding resistance than at a higher one. However several other factors will also contribute to the cause of an accident, with the result that the effect of road-surface skidding resistance as such may be masked. For this reason it is important to take into account all the relevant factors. Therefore in addition to road-surface skidding resistance, some additional factors will be studied. For other observed or unobserved factors or imponderable effects, suitable assumptions will be made, sufficient for an approximation.

The number of accidents occurring on a given road sector will increase - under otherwise identical conditions - firstly, with increasing length of the road sector, and secondly, as a function of the number of cars passing the given sector; thus, finally, depending on the number of vehicle kilometers performed thereon. Therefore, in order to be able to compare road sectors, the relative road risk, and not the number of accidents, is taken into account.

Type of Road

A second factor, which has a great influence on the occurrence of accidents, is the presence of intersections, bends or other discontinuities in the course of the road. Since it is rather difficult to indicate the measure of discontinuities present on a road, the study was limited to making a distinction between more or less discontinuous road types.

Road type I comprises roads with two separate dual carriageways, each comprising two or three lanes and grade-separated intersections (motorways). All other test-roads belong to road type II, which comprises all roads with level intersections, and roads with grade-separated intersections, insofar they have only one path (dual carriage ways and single lane roads).

Traffic Volume per Hour

The traffic volume per hour is also of such importance related to the occurrence of accidents, that it cannot be neglected. Combined with the road type, it determines to a large extent the traffic flow characteristics, such as average follow-up distances, driving speed and the number of overtaking manoeuvres. The possible interrelation of traffic volume on road-surface skidding resistance is to be taken into consideration.

It is understandable that Rijkswaterstaat tends to establish a high level of road-surface skidding resistance on motorways with very heavy traffic. Lower skidding resistances are then found, relatively more frequently, at the lower volumes per hour of dual carriage ways with less heavy traffic. Conversely it could be that the heavily loaded road-surfaces will often be less rough due to the polishing effect of traffic.

Type of Vehicle

Goods vehicle traffic and passenger car traffic have different requirements relating to road-surface skidding resistance. These vehicle categories differ from one another in respect to tyre characteristics and loads, and the parameters of motion and dimensions. For this reason the study preferred to establish not only the accident rates, but also the rate of involvement for each vehicle category.

The category of goods vehicles includes all types of lorries with or without trailer from delivery vans to trucks. Minibuses, combination-cars and passenger cars, all with or without trailer belong to the category of passenger cars. Other types of vehicles (for example motorcycles) have a small share in traffic volume which can easily be neglected.

Weather Conditions

Up to now general road factors, factors of driving behaviour, and vehicle factors, were given a greater, although somewhat sketchy attention. It is important that these factors facilitate more differentiated measures, relating to road-surface skidding resistance.

The occurrence of accidents will also depend on weather conditions. Moreover, a wet road surface will display a considerably lower skidding resistance than a dry road surface. All that is known about the skidding resistance of dry road-surfaces is that it is in general higher than the highest skidding resistance found on wet road surfaces. Such high degrees of skidding resistance are not of great importance for the purposes of the present study, and for this reason they will only be discusses incidentally.

Furthermore, no definite answer can be found to the following questions: how long does it take for a road-surface of a certain quality to dry under the effect of sun, wind and traffic, when can the road-surface be regarded as dry after a heavy shower and before a further rainfall starts. For this reason vehicle kilometers can only be computed for the periods of rainfall or for the periods of no rainfall. So, for technical reasons too, the study is mainly concerned with weather conditions of rain.

Based on the above mentioned factors it is possible to classify the general traffic situations, roughly, with regard to the number of accidents caused thereby. Other circumstances of the accident and the process of the accident itself are not taken into account, even if they can be established and made available for countermeasures. The skidding resistance of the road-surface by itself, within wide limits, and even under exceptional circumstances, must ensure that the car can be steered in a sufficiently safe manner, thereby contributing to the prevention of accidents.

Definitions of Terms

Skidding Resistance

The measure of skidding resistance, as used in this study, is defined as the coefficient of longitudinal force (quotient of braking force and vertical wheel load), such as is found on wet road-surfaces according to the standard measuring process retarded wheel, between a standard measuring wheel and a road-surface. The measuring wheel is 5.60 x 13" and has a natural rubber running surface with a V83 profile. Under a tyre load of 2000N the tyre tension amounts to 2.10^5 N/m^2. A water film, 0.5 mm thick, is spread over the road-surface to be measured. The measuring wheel is pulled at a constant speed of 50 km/hr over the wet road-surface. By means of gearing it is made to rotate at such an angular speed, that skidding resistance can be measured with a forward slip of 86%.

Figure 1. Skidding resistance measuring truck of the Dutch State Road Laboratory.

The Dutch State Road Laboratory posesses a measuring truck with these specifications, type SW8 (see figure 1) for carrying out its annual systematic skidding resistance investigations. Measurements are normally made in the months of August and September. The skidding resistance of the road-surface generally attains its lowest value at this time of the year. On all roads with three or more lanes the skidding resistance is determined at the right hand wheel track of the traffic. The overtaking lanes, which are not included in the measuring programme, display, as a rule, a skidding resistance higher by one class, but can be indicated by the skidding resistance of the adjoining lanes (see classification in table 1). On roads with two-way traffic measuring is done in one driving direction. The result obtained is then applied to the other lane. This is permissible, in the case of roads having the same sort of pavement which have been exposed over their entire length to the effects of climate, and a comparable traffic flow.

Table 1. Value of skidding resistance per class of skidding resistance.

Skidding Resistance Class	Skidding Resistance
1	<0.36
2	0.36 - 0.41
3	0.41 - 0.46
4	0.46 - 0.51
5	0.51 - 0.56
6	0.56 - 0.61
7	0.61 - 0.66
8	0.66 - 0.71
9	≥0.71

In the systematic measuring investigations the skidding resistance is measured, depending on the road length, in one or more sectors of 100 m length, chosen at random. During the investigation period The Dutch State Road Laboratory carried out, in this way, skidding resistance measurements on approximately 2000 sectors over a road length of more than 3500 kilometers.

After road reconstruction extra measurements were made on about 2000 sectors. The new skidding resistance value was found to be valid, for the road sector in question, a month after the reconstruction.

Volume per Hour

The total number of vehicles passing through a given section of the road, in the same direction, during 1 hour, is indicated in the present study as the volume per hour for that section, in the driving direction, during a periode of one hour.

If each of a number of vehicles drives over a given distance, their total performance, i.e. the given distance multiplied by the number of vehicles in question, is expressed as vehicle kilometers. During the general traffic census in 1965, Rijkswaterstaat carried out counts on an extended scale, at 38 basic counting points. During the whole year these counting points were provided with pneumatic counting devices, which recorded the number of vehicle axles passing, on mechanical counting instruments. The counts were read daily at a fixed time. In addition, during 40 days of that year, at each basic point the partial volumes of the most important vehicle categories were counted visually.

On the basis of the material collected, which had been extended into 1966 to a limited extent, a number of mechanisms, assumed constant, were formulated, which facilitated to forecast the manner in which the traffic would take place, to a certain extent, at the chosen basic counting point. Such mechanisms are:

1. The percentage distribution of the annual average of traffic volume over 24 hours for a working day, a Saturday and a Sunday. These hour-distributions were applied unchanged to both investigation years. For roads with separated lanes, on which a separate pneumatic measuring tube was placed in each lane, the hour-distributions have been established for both driving directions.
2. The relative level of the annual average traffic volumes for a Saturday and a Sunday with regard to the annual average traffic volume on a working day. These two level-factors were applied unchanged for both investigation years.
3. The percentage distribution of the annual average partial volume of goods vehicles over the 24 hours of a working day. The distribution per hour was applied unchanged for both investigation years. The volume of goods vehicle traffic on Saturdays and Sundays could be neglected.
4. The relative levels of average daily volumes in each of the 12 months. These monthly coefficients did not refer separately to goods vehicle traffic, which was found to take place at the same level approximately throughout the year.
5. The relative level of average daily volume in 1966 as compared to that in 1965.

The above mentioned mechanisms have been established for a road section studied at an absolute level, from two basic figures:

1. The absolute level of annual average traffic volume on a working day on a given road section in 1965.
2. The absolute level of the annual average partial volume for goods vehicles on a working day, on the given road section in 1965, expressed as the average portion of goods vehicles in the total annual average traffic volume on a working day.

The basic figures were obtained for the road sections at the basic counting points from the above mentioned counts (Road section in this connection means a continuous stretch of road, determined as a measuring sector for skidding resistance measurement. It is assumed that this road section will display the same overall skidding resistance).

For the other road sections a supplementary counting system was set up, with about 800 common counting points, during 1965. For this purpose Rijkswaterstaat, established on motorways, at each counting point, mechanical counting systems during two weeks. Alternatively for one week or for three whole days, visual counting systems were applied.

Duration of Rainfall

In the study, The Netherlands have been divided into 21 rainfall zones. Within each zone there should be two mechanisms governing the occurrence of rainfall. The assumed constants are:

1. The percentage of the average duration of the daily rainfall during the 24 hours.
2. The period of time for which, calculated in absolute figures, rain must fall (on average) in order to obtain 1 mm of rain.

For the central zone and the four corner zones, these quantities could be measured directly for each test month. The main meteorological stations De Bilt (central zone), Den Helder, Vlissingen, Beek (L) and Eelde are in these zones. From these stations, which all have automatic recording precipitation meters, the Royal Netherlands Meteorological Institute collects data, following a continuous and extensive measurement programme, relating to the duration and quantity of the rainfall. All the other meteorological stations only make daily measurements of the quantity of rainfall at fixed intervals. Both mechanisms are quantified for all other rainfall zones, by lineair interpolation, based on the established constants of two or three neighbouring basic zones.

The absolute levels, concerning the distribution per hour of the duration of rainfall, formed part of a set of measurement results from the basic stations. For each of the 82 meteorological stations, which were selected from the observation stations of the Meteorological Institute for the purposes of the investigation, assessments were made for these levels, based on the quantity of rainfall measured locally. In this case, use was made of the second mechanism, relating to the month in question in the corresponding rainfall zone.

Accidents

All accidents which occurred on the test sectors of the Dutch national road system during 1965 and 1966, have been processed in the investigation, in sofar as they were registered by the police. In general, the road lane is unknown. From practical considerations there could have been some selection, in the police reports, on the basis of injury, the degree of material damage or legal severity of the offence. In 1967 these aspects resulted in an official limitation of police recording activity in The Netherlands.

In each separate accident several vehicles can be involved; their number is dependent on whether the police regarded their involvement as having the same cause with regard to place, time and circumstance. Relative road risk is expressed in various terms in the study. Accident quotient indicates the number of accidents per million vehicle kilometers. The quotient of involvement for a certain vehicle category indicates the number of vehicles of a given category, involved in accidents per million kilometers covered by vehicles of the given category.

Execution of the Investigation

Collection of Data

Each test road is divided into sectors. It is assumed that within each sector approximately identical volume and skidding resistance data are obtained. A road sector is accurately defined by its road type, road number, road sector number and length in hundreds of meters. The basic material of skidding resistance data comprises the skidding resistance in the case of a wet road-surface, for each road sector. With regard to double lane roads, the sector is divided into two part-sectors of opposed driving direction, each having an individual skidding resistance.

The longitudinal force coefficients of wet road-surfaces are divided into nine skidding resistance classes, with a band width of 0.05 except for the lowest and highest class which have no under and upper limit respectively. The

Table 2. Number of vehicles per volume per hour class for road type I.

Volume per Hour Class	Number of Vehicles
1	0 - 100
2	101 - 200
3	201 - 300
4	301 - 400
5	401 - 500
6	501 - 600
7	601 - 700
8	701 - 800
9	801 - 900
10	901 - 1000
11	1001 - 1100
12	1101 - 1200
13	1201 - 1300
14	1301 - 1400
15	1401 - 1500
16	1501 - 1600
17	1601 - 1700
18	1701 - 1800
19	1801 - 1900
20	<1900

lowest skidding resistance class 1 refers to coefficients less than 0.36. Dry road-surfaces are assessed as belonging to class 9, with a longitudinal force coefficient of 0.71 or greater (see classification table 1).

The fundamental material of volume data comprises, for each road sector, the two above mentioned basic figures referring to the level of volume. In addition each sector is related to a basic counting point, while a connection is established between the above described mechanisms relating to the volume. In the case of a double lane road, each of the two part sectors of opposite driving directions, has its individual portion of the total volume per hour.

The total volume per hour, as causal factor in the occurrence of accidents is divided into 20 classes, with a band width of 100 vehicles per hour per driving direction, for road type I. For road type II, 15 classes are provided, with a band width of 200 vehicles per hour, for both driving directions, taken together, in case of single-lane roads; and separately for each driving direction, in the case of double-lane roads. The highest classes have no upper limit (see classification table 2 and 3 respectively).

Table 3. Number of vehicles per volume per hour class for road type II.

Volume per Hour Class	Number of Vehicles
1	0 - 200
2	201 - 400
3	401 - 600
4	601 - 800
5	801 - 1000
6	1001 - 1200
7	1201 - 1400
8	1401 - 1600
9	1601 - 1800
10	1801 - 2000
11	2001 - 2200
12	2201 - 2400
13	2401 - 2600
14	2601 - 2800
15	<2800

Each road sector is related to a weather station, while each weather station, in turn, is related to a given rainfall zone. In this manner the above mentioned rainfall data were made available for the study.

The accident data used consist of the following:

1. The road sector of the accident.
2. Weather conditions at the location of the accident in terms of rainfall or no-rainfall.
3. The condition of the road-surface at the time and place of the accident in terms of wet or dry.
4. Date and actual time of the accident.
5. The number of passenger cars, lorries and other vehicles involved in the accident.

Data Processing

The investigation data have been processed essentially in three phases:

1a. The accidents are classified according to the skidding resistance class of the road sector where they occurred. Accidents on dry road-surfaces are placed in the highest skidding resistance class 9, whereas accidents occurring during rainfall are assigned to the class of wet road surface skidding resistance. If there was no rainfall at the time of the accident, but the road-surface was wet, the accident was related to the highest skidding resistance class 9. In addition to this, all accidents occurring on wet road-surfaces, but not during rain, are subdivided into different classes of wet skidding resistance. In this way it was possible to make a comparison between accidents occurring on a wet road-surface during rainfall and accidents occurring on a wet road-surface, when no rain was falling. When an accident occurred on a sector of a double-lane road, the driving-direction being unknown, it was assigned on a 50-50% basis, to each of the skidding resistance classes of both part sectors. The passenger cars, goods vehicles and the total number of vehicles, involved in the accident, were also related individually to the skidding resistance class established.

1b. The accidents were also divided according to the class of volume per hour of the time at which the accident took place. If the accident occurred on a sector of a double-lane road, the direction of driving being unknown, it was again assigned on a 50-50% basis to the volume per hour classes of both part sectors. The passenger cars, lorries and total number of vehicles involved in the accident were again related individually to the volume per hour class established.

2. The total volume per hour was then calculated for all the road sectors of the investigation, essentially for each interval of an hour of both investigation years. Firstly, this total volume per hour is related each time to a volume per hour class; secondly, the total volume per hour allows the total number of vehicle kilometers to be determined (by multiplying by the road sector length) for a given road sector, in the interval of an hour concerned. In addition, the partial volume of goods vehicles was established for the road sector and for the time in question. Upon multiplying by the road sector

Table 4. Processed number of accidents occurring on the test-road sectors and the number of vehicles involved, related to the degree of wetness of the road-surface and according to road-type.

Degree of Wetness of the Road-Surface	Rainfall		No Rainfall, Wet Road-Surface		Dry Road-Surface		Total	
Type of Road	I	II	I	II	I	II	I	II
Accidents	2360	5243	1426	3968	6033	15729	9819	24940
% of type of road-total	24.0	21.0	14.5	15.9	61.5	63.1	100	100
Involved								
Passenger cars	3932	8207	2424	5845	9402	22308	15758	36360
Goods vehicles	729	2110	626	1785	2648	6790	4003	10685
Vehicles total	4661	10317	3050	7630	12050	29098	19761	47045
Average number of vehicles, involved by accidents	1.98	1.97	2.14	1.92	2.00	1.85	2.01	1.89
% of goods vehicles	15.6	20.5	20.5	23.4	22.0	23.3	20.3	22.7

length, the figure obtained indicates the number of goods vehicle kilometers, in a similar way. The difference in vehicle kilometers, then refers only to passenger car kilometers. Finally, the three types of kilometers, already associated with a volume per hour class, were also apportioned according to the skidding resistance class of the road sector. For this purpose the duration of rainfall was calculated for the road sector and the interval of an hour in question. The portion of time, during which there was rain, with consequent wet road-surfaces, must correspond to the portion of mileage which had been covered on wet road-surfaces. The corresponding number of kilometers were related to the skidding resistance class of the road. The remaining mileage is indicated by the skidding resistance class 9.

3. From the foregoing, three types of cross-reference tables are obtained. The first type comprises four tables of the number of accidents or the number of vehicles involved in accidents. The tables of the second type are compiled exclusively on the basis of data about accidents, which occurred on a wet road-surface, but not during rainfall (in sofar as they were classified into the class of actual wet road-surface skidding resistance). The third type comprises three tables with the kilometers covered. The horizontal variable in the tables indicates the road-surface skidding resistance class, the vertical variable - the class of volume per hour. The fourth type of cross-reference tables which must be established, will have four tables per road type and quotients for accidents, and can be obtained by comparing the elements of the first type of tables with the corresponding tables of the third type.

Results

For the 36,364 traffic accidents registered during the chosen two years on the test-road sectors of the Dutch road system, - of which 2,360 occurred on road type I and 5,243 on road type II, during rainfall - it was possible to establish the road-surface skidding resistance classes and volumes per hour. About 4% of the accidents occurring on road-surfaces which were made extra slippery by snow, sleet or dust, have not been included in the investigation.

Accidents during rainfall form more than 20% of the total number of accidents (see table 4), while only about 8% of the total vehicle mileage occurred during rainfall. In total, about 35% of all accidents occurred on a wet road-surface.

The accidents relate to a road length of about 1100 km on road type I and about 2300 km on road type II (Figure 2). More than 40% of the total vehicle mileage was driven over roads of type I, while less than 30% of all accidents occurred on these roads.

The average number of vehicles involved in an accident increased from about 1.5 to about 2.5 with increasing volume per hour of the traffic. The overall average was nearly 2. In the accidents the proportion of goods vehicles amounted to about 20-23%, except on road type I, where this proportion was less than 16% under conditions of rain. However, only 15-17% of the mileage covered relates to goods vehicle traffic.

In comparison with accidents during rainfall, accidents on wet road-surfaces, but not during rain, occurred less frequently at higher volumes per hour, than at lower volumes per hour (table 5 and 6). Where the traffic volume per hour is important to the drying process of the wet road-surface after rain, a relatively lower vehicle mileage could be driven at higher volumes per hour with no rain on a wet road-surface, than at a lower volume per hour. However, no data are available in this respect.

Conclusions from the Investigation

A lower skidding resistance results in a higher relative road risk. Thus the relationship between road-surface skidding resistance and relative road risk can be established, from the investigation carried out according to the requirements of the assignment (see figures 3, 4 and 5).

It was pointed out that many factors have an influence on this relationship. The investigation mainly dealt with the mechanisms of the probably most important of these factors. As already indicated a greater relative road risk can be observed for more discontinuous types of roads and for vehicles of a heavier category. The relative road risk increases in general with increasing total volume per hour of traffic, with the exception of the lowest and highest classes (Figure 6 and 7).

Table 5. Standardised relationships between number of accidents on wet road surfaces during rainfall and no-rainfall, according to volume per hour/skidding resistance class for road-type I.

Skidding Resistance Class	2	3	4	5	6	7	8	Total
Hourly Volume Class								
1	-	.24	1.16	1.27	1.53	2.32	-	1.46
2	.55	1.66	1.02	1.27	1.18	1.42	3.31	1.21
3	.83	-	1.13	1.27	1.26	.77	.33	1.18
4	.41	.46	.44	.83	1.20	.85		.92
5	-	.83	.93	.59	1.11	1.69		.91
6	.95	1.38	1.66	1.02	1.25	1.13	-	1.18
7	.99	1.16	2.43	1.11	.97	1.37	-	1.13
8	.92	1.32	.81	1.30	1.12	.63	-	1.11
9	1.03	2.65	.91	.96	.89	1.44		.98
10	.55	1.42	1.33	1.13	1.09	.72		1.10
11	1.66	.99	.92	.91	.81	.47	-	.87
12	.99	1.10	.46	.95	1.04	.91	-	.89
13		16.55	.67	.88	.94	1.61		.94
14	.95	1.10	1.37	.89	.85	.23		.89
15	-	1.10	1.46	.87	.43	-		.82
16		.55	.19	1.01	.45	1.66		.70
17		-	.33	.43	1.29	-		.62
18			.24	.63	.55			.55
19		-	.92	1.42	.89			1.22
20			.85	.52	2.21	-		.82
Total	.93	1.21	.90	.95	1.06	1.07	2.36	1.00

Table 6. Standardised relationships between number of accidents on wet road-surfaces during rainfall and no rainfall, according to volume per hour/skidding resistance for road type II.

Skidding Resistance Class	1	2	3	4	5	6	7	8	Total
Hourly Volume Class									
1	.17	1.21	2.51	1.10	1.18	1.31	1.45	1.98	1.31
2	1.32	1.16	.72	1.22	1.03	1.23	1.34	.59	1.16
3	.74	1.13	1.06	1.11	1.05	1.08	.80	1.32	1.05
4	.84	1.13	.66	.99	.89	.85	1.39	1.32	.90
5	.33	.50	.76	.79	.81	.86	1.25	-	.83
6	-	.22	.64	1.04	.61	.84	.53	-	.71
7	-	.88	.51	.73	.77	.93	1.54		.81
8	-	.38	.66	.71	.74	.61	1.32		.73
9	.44	2.64	.22	.84	.42	.85	5.29		.68
10	.66		1.32	.66	.41	.78	2.64		.61
11	-			.66	.57	.50			.26
12	-	-		.22	.51	.50			.40
13	-	-	-	-	.17	.88			.38
14					-	1.32			.33
15					-	.66			1.65
Total	.74	.97	.89	1.00	.90	1.06	1.24	1.11	1.00

The irrationality of some of the results can be ascribed to chance fluctuations in the quotients of accidents and involvement. It was found that the relationship between road-surface skidding resistance and relative road risk, which was required to be investigated in the inquiry, always displays, apart from the level, the general pattern as described above.

Comments

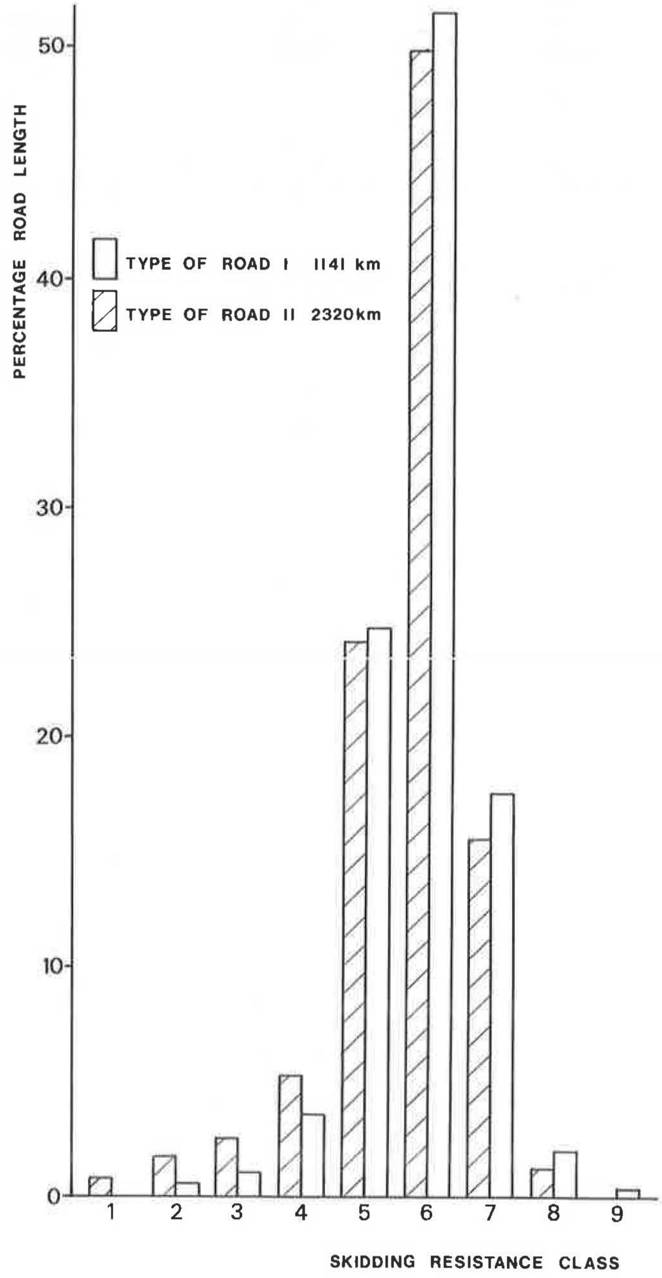
As stated already, road-surface skidding resistances have been measured during the period of the year, when they would display, on average, a relatively low level. This fact will not have a great influence on the form of relationship between the road-surface skidding resistance and relative road risk. However, the skidding resistance class will tend to be shifted towards a lower value.

Overtaking lanes, especially for roads of category I, were given much too low a skidding resistance. In sofar as accidents occurred on these overtaking lanes with no recording of it in the accident data, this should result in a more pronounced curve in the relationship to be established.

The result of the skidding resistance class 9 differs from the other results in that rainfall conditions are nearly often absent. Also included in skidding resistance class 9, are those accidents which took place on wet road-surfaces, but not during rainfall. Since the drying process of wet road-surfaces is not sufficiently understood, the same procedure had to be followed with regard to the mileage covered on wet road-surfaces, but not during rainfall. Thus, it might happen that the relative road risk in class 9 is calculated too high.

In the case of non-separated road lanes, the study established average values for the volume per hour of traffic in both directions. However, it can be imagined that peak traffic in the morning is higher in one direction, while the evening peak is higher in the other direction. The effect of this phenomenon on the results of the investigation for road-type II where it mainly occurs, is neglected. The highest volumes per hour are determined by the commuting traffic, while the lowest by evening and night traffic. Thus, in addition to the volume per hour the investigation implicitly established other factors which effect the accident pattern. It can be imagined, in this connection, that a somewhat higher relative road-risk will be determined for the lowest skidding resistance class, due to the higher relative road-risk in twilight.

Figure 2. Total road length of the test road sectors, as a percentage of the annual total per road-type.



It is pointed out that, generally, in the investigation, the volumes per hour for both road-types I and II were registered in classes having a band width of 100 vehicles per hour for each driving direction. It will be evident that in this way the same class of volume per hour will indicate quite different traffic circumstances for roads of road-type II, with essentially one lane per driving direction, than for roads of road-type I with, in general, two lanes per driving direction. The division into two road types is no more than a means to make the influence of various factors affecting relative road risk, to some extend, evident. The same applies to the distinction between passenger cars and goods vehicles.

Finally, it must be pointed out, that accidents on road sectors such as road entrances and exits, would not be included in the investigation. The pattern of accidents established cannot be applied directly to such accidents, which occur, relatively infrequently, on road type I. With regard to the difference in road risk between roads of type I and II, it is more important that accidents occurring on intersections have been included in the investigation, simply for the sake of emphasising the greater degree of discontinuity in road-type II.

Recommendations

The investigation, yielding the results described above, established a procedure, according to which a relationship can be established between the skidding resistance of the road-surface and the relative road risk, from the available data, provided in routine data collecting programmes. In this way such a procedure can be used by the authorities in establishing various traffic safety measures.

However, the procedure can be applied to a limited extent only. Firstly, because changes may occur in the traffic pattern, beyond the range of road-surface skidding resistance, changes which could invalidate comparison and interpretation of the results of the investigation. As an example, the limitation of the police registration activity, relating to traffic accidents, can be mentioned. Further study has to be done as to whether it is possible to establish improved and more detailed investigation procedures in this respect.

Furthermore, no socio-economic considerations are included in the investigation. In the first place it should be possible to make a more detailed distinction between the accidents and the vehicles involved in the accidents, with regard to the severity of damage. At the same time conclusions should be drawn and investigations made as to how such conclusions could be incorporated into a determinant model.

Finally, the applicability of the procedure is limited by some aspects of methodology. An inherent characteristic of each statistical

Figure 3. Accident quotient related to class of road-surface skidding resistance.

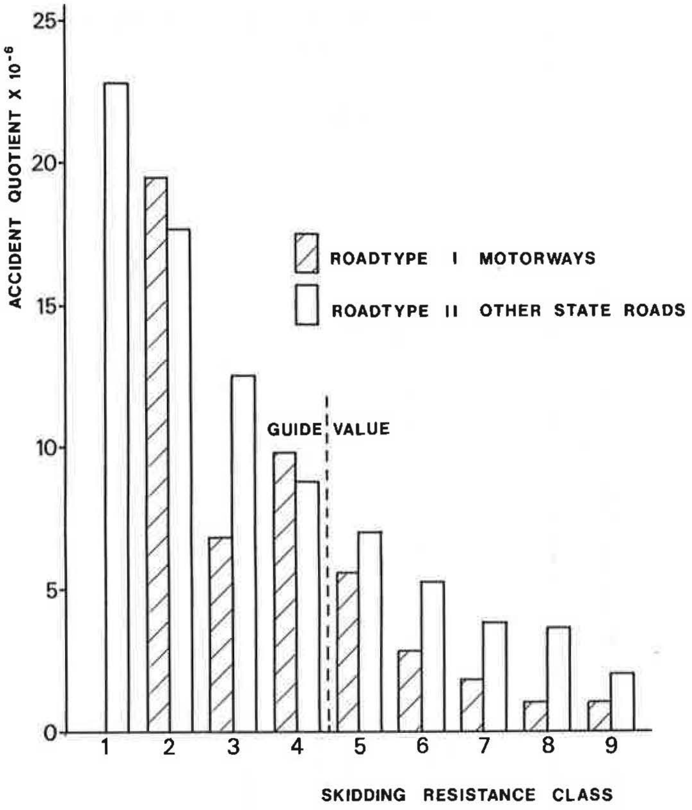
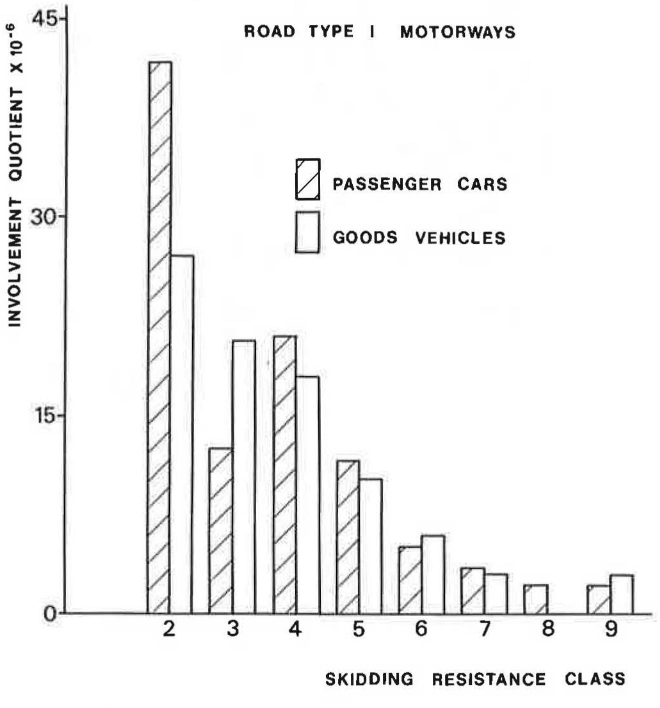


Figure 4. Involvement quotient related to class of road-surface skidding resistance for motorways.



approximation is the fact that no causal relationships can be established. In principle, it is not possible to forecast the effect of a change in road-surface skidding resistance on the number and severity of accidents. Moreover, a change in road-surface skidding resistance can, simultaneously, influence other traffic circumstances, and thereby have an indirect effect on the accident pattern.

However, the skidding resistances of road-surfaces, as established by the Dutch State Road Laboratory are statistically indicative of the relative road risk. The results obtained are in accordance with the expectation, that an increase of road-surface skidding resistance, in general, will result in a decrease of the number of accidents. Thus, a general conclusion of the investigation is that any increase in the skidding resistance of wet road-surfaces outside built-up areas, will improve traffic safety. For practical purposes this conclusion has to be translated into the recommendation that, as a general measure promoting traffic safety, the minimum skidding resistance has to made as high as possible.

It must be emphasised that the result of the investigation has a global character. It is quite easy to imagine that, at certain places, it is not road-surface skidding resistance, but other factors which have a considerable share in causing accidents, and which could be improved by suitable measures.

Figure 5. Involvement quotient related to class of road-surface skidding resistance for dual carriageways excluding motorways and single lane roads.

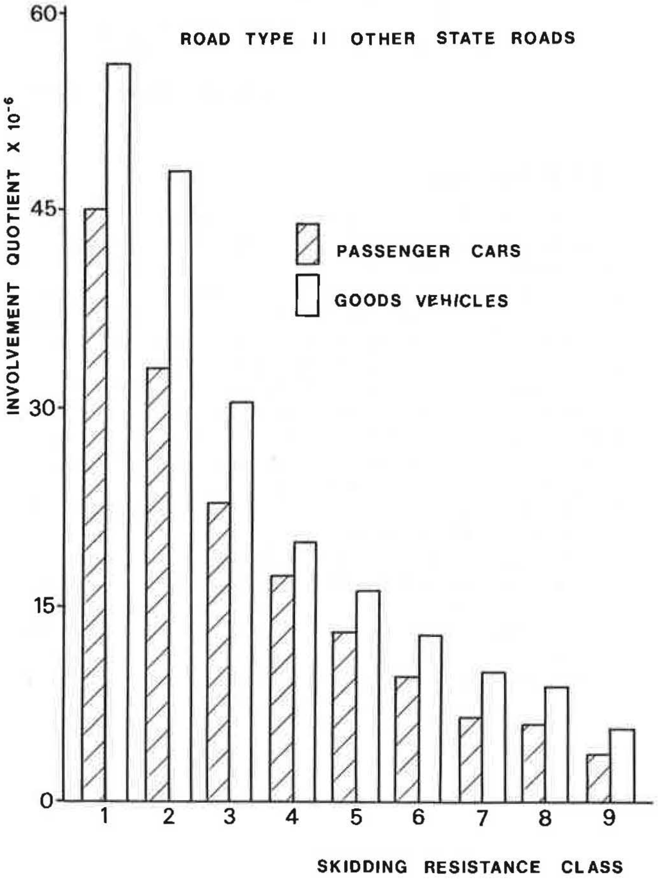
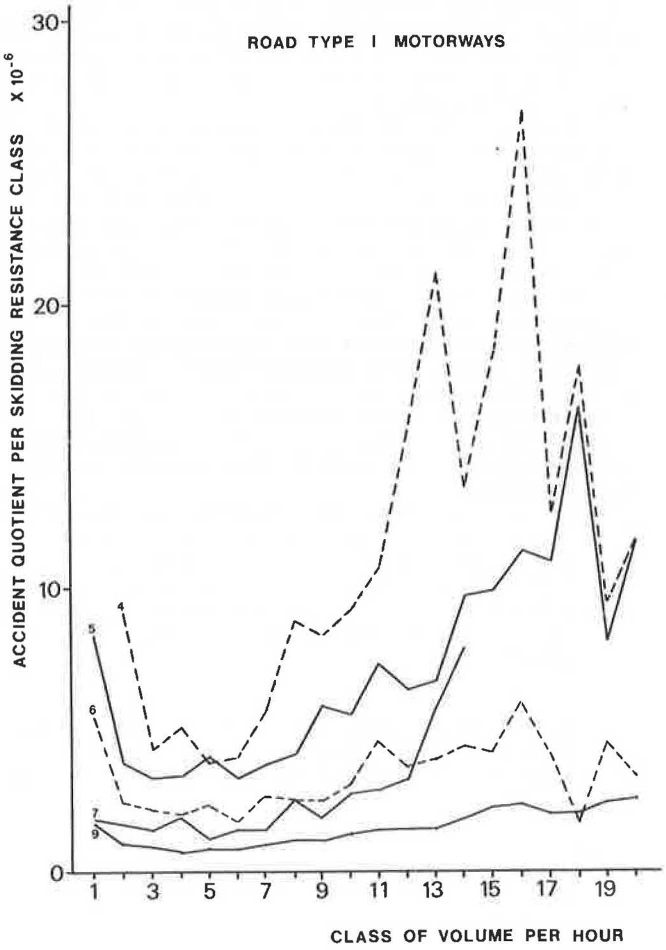


Figure 6. Accident quotient per skidding resistance class related to volume per hour class for road-type I.



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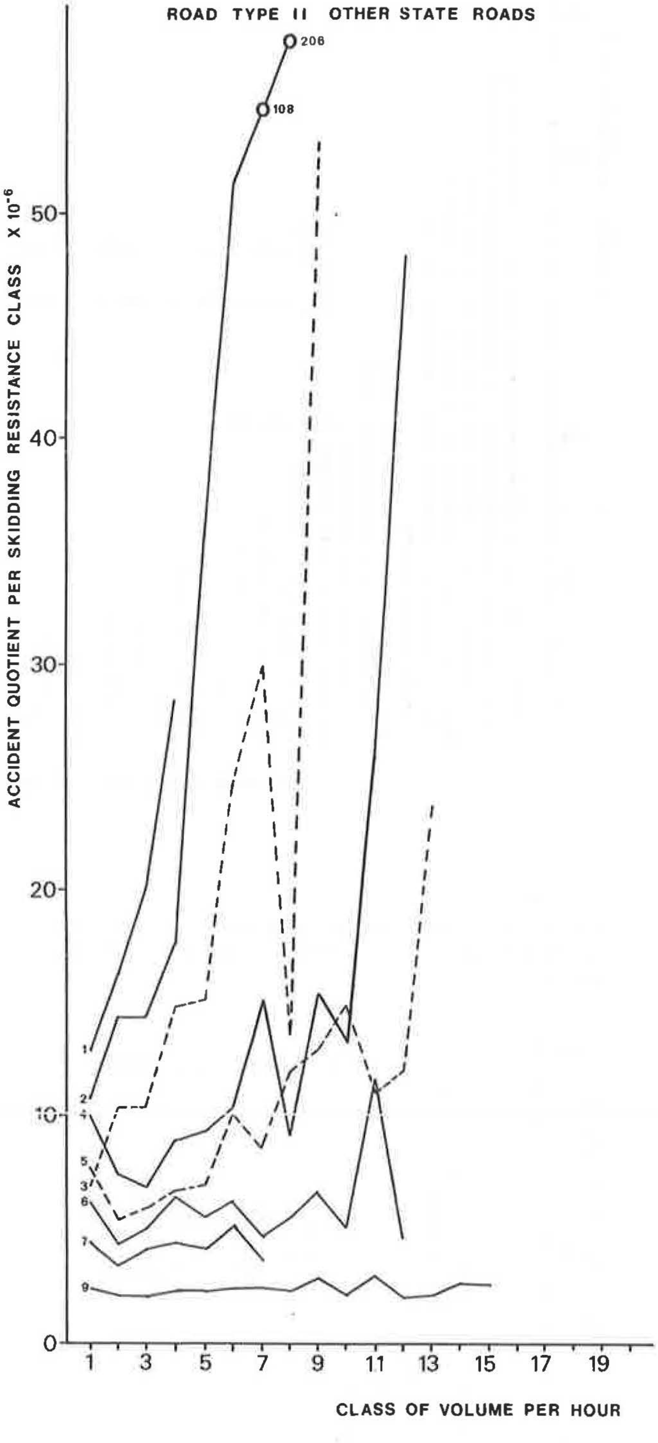
Dutch State Road Laboratory: Messrs. J.C. de Bree and P.M.W. Elsenaar.

Traffic and Transportation Engineering Division Rijkswaterstaat: Messrs. E.W. Hennevanger (successor to Mr. S. Cohen Rodrigues) and Mr. G.J.V. Hotze (successor to Mr. J.H. Jenezon).

Institute for Road Safety Research SWOV: Messrs. J.M.J. Bos, J.C.A. Carlquist and H.G. Paar (earlier also Mr. M. Slop).

Figure 7. Accident quotient per skidding resistance class according to volume per hour class for road-type II.



THE LOCATION AND TREATMENT OF URBAN SKIDDING HAZARD SITES

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The first part of the paper reviews the research that has been carried out in recent years by the Transport and Road Research Laboratory and others in Great Britain and shows that for asphalt surfaced roads the sideway force coefficient can be predicted from a knowledge of the stone in the surfacing, the traffic intensity and the amount by which vehicles are manoeuvring. The difficulty of establishing minimum standards for skid resistance is discussed and it is suggested that the selection of a minimum standard depends upon economic considerations. Many roads which can be shown to be slippery when judged against existing standards are not necessarily hazardous and their treatment may not be economically justifiable. The majority of personal injury accidents occur in urban areas and the majority of these occur at road intersections. In London for example there are approximately 55,000 personal injury accidents each year and over 70% of these occur at road junctions. For this reason, action in London has been aimed at the junction problem and more than 800 junction and other similar hazard areas such as the approaches to pedestrian crossings have now been treated with an epoxy resin/calcined bauxite form of surfacing dressing. 'Before and After' accident studies on groups of the treated sites are presented and the economics of this form of treatment are examined. Two methods of locating sites where the accident rate can be reduced by surface treatment are described, based upon the use of a machine for monitoring skid resistance and the use of computerised accident data. It is suggested that the philosophy and the methods described in the paper could be applicable to many other urban areas.

The Wet Road Problem

The drivers' greatest hazards in wet weather are slipperyness of the road surface and impaired visibility, the latter presenting different problems by day and by night. In 1971 in Great Britain, there were 258,535 personal injury accidents of which 73,374 occurred on wet roads. Codling (1) has shown that the increase in accidents on wet roads (whether raining or not) is about 50% over the expected number on dry roads when all other conditions are the same. This means that in 1971 there was an excess of about 25,000 injury accidents on wet roads which would not have occurred had the road been dry.

Sabey (2) suggests that a measure of the increase in accidents involving skidding due to road wetness can be obtained by comparing dry and wet road skidding accident rates (i.e., the percentage of accidents in each condition which involve skidding). The accident records for 1971 show that the dry road skidding rate was 11.8% and the wet road skidding rate was 27.8%. Since the same roads exist whether it is dry or wet and they carry largely the same vehicles with the same tyres and driven by the same people, Sabey concluded that it was reasonable to assume that the difference in skidding rates between dry and wet conditions is primarily due to the change in skidding resistance brought about by the wetness of the road. The increase in the wet road skidding rate over the dry road rate represents and increase of 13,000 injury accidents in 1971. Sabey further noted that the reporting of skidding on wet roads tended to be under-estimated so that the figure of 13,000 injury accidents may well be a conservative estimate.

Nationally, therefore, it would appear that there is a potential saving in accidents of at least 13,000 annually which could be brought about by an improvement in road surface skid resistance. Experience in London particularly, as described later in this paper, suggests that the accident saving potential may be considerably higher than these figures, at least in so far as accidents in an urban situation are concerned.

The annual cost to the community of these 13,000 accidents attributed to low skid resistance is conservatively estimated to be £35,000,000 (1974 values). (3).

The Factors Which Affect Skid Resistance Of Roads

These are, for vehicle speeds up to about 40 mph and for asphalt roads:-

1. The character of the stone exposed on the surface of the road,
2. The traffic intensity and
3. The extent to which vehicles are manoeuvring.

For many years, the significance of the type of stone predominantly exposed in the surface of the asphalt road wearing course has been understood and it is widely accepted in the United Kingdom that the resistance to polishing of road stone can be measured by the polished stone value (psv) test of British Standard 812 (4). In general terms, the higher the psv of the aggregate then the higher will be the skid resistance of the road surface.

The most significant new knowledge in this field concerns the effect of traffic wear on skid resistance of road surfaces. When new, most surfacings have a high resistance to skidding but it falls during the first year under the polishing action of traffic. The extent to which it falls depends upon the nature of the stone exposed in the road surface and also on the traffic intensity, particularly, it seems, on the intensity of heavy vehicles with high tyre contact pressures. Thereafter, provided the traffic is constant, the mean skid resistance will decrease and if for any reason traffic is reduced then the skid resistance will increase to a higher value. In other words the action of traffic in polishing the road surfacings is balanced by the natural weathering which makes the surface rougher. The heavier the traffic, the lower will be the skid resistance at which this balance is struck.

Salt and Szatkowski (5) have illustrated the combined effects of traffic intensity and stone type by Table I which shows the polished stone value of aggregates necessary to achieve a given skid resistance in a bituminous surfacing where coarse aggregate forms the majority of the exposed surface, under differing traffic conditions. The Table refers to a straight road condition in which traffic is rolling without braking, turning or accelerating. Hosking and Tubey (6) have shown that there is a further reduction in skid resistance caused by the effect of turning and braking and conclude that aggregates to be used in surfacings at most sites where traffic is turning or braking should have a psv at least 5 units higher than that which is indicated for similarly trafficked event-free sites in order to maintain the same level of resistance of skidding.

In general terms, it has been found in London that the predicted values agree reasonably well with measured values although it is not always easy in practice to establish the various factors with precision.

The implications of this work are indeed unfortunate. It is immediately apparent that it is virtually impossible to obtain a sideway force coefficient (sfc) in excess of about 0.45 using natural aggregates on any road carrying more than 4,000 commercial vehicles per lane per day since in Great Britain there are no natural aggregates available with a psv above 75. There are only 2 or 3 quarries producing hard and durable aggregates with psv's between 70 and 75. Higher sfc's can be obtained only by using expensive artificial aggregates having a high resistance to abrasion and to polishing such as the R.A.S.C. (Refractory Grade A, Super-Calcined) grade calcined bauxite from Guyana (7).

However, the highway engineer is now in a position to specify and use an aggregate to give any required sfc within the limitation given above, based upon a knowledge of the probable traffic intensity.

The above comments apply to roads surfaced with bituminous materials where traffic speeds are relatively low. Where traffic speeds are high, skid resistance is affected by coarse or macro-texture which is required to provide a path for water to drain from the road surface and to be dispelled rapidly away from the contact area between tyre and road (2). It is the macro-texture which influences the rate at which skid resistance falls off as speed increases. Fortunately the lack of macro-texture does not present a problem in a city with a predominantly slow speed traffic pattern. Since all of the heavily trafficked roads in London are surfaced with bituminous materials the particular problem associated with concrete roads will not be discussed in this paper.

The Urban Accident Pattern

This can best be illustrated by the situation in Greater London which includes an area of some 1,600 sq.km. containing about 10,000 km. of roads of all types. Some 50-60,000 road accidents involving injury or death occur in Greater London each year of which no less than 35,000 or 70% occur at road junctions. Further, about 80% of these road accidents occur on the 10% or so of the roads which carry the heaviest traffic loads, A situation thus exists in which there is a large concentration of accidents at clearly defined locations on a small proportion of the total road network. Nationally, about 50% of all of the road accidents involving injury or death occur at urban road junctions. It is at such locations that the skid-resistance of the road surface will be lower than elsewhere on the road network because of the concentration of vehicles in clearly defined lanes, with a high proportion of them executing manoeuvres such as braking, turning or accelerating and thus imparting extra polish to the road surfacing.

There has been little positive information on the relationship between the skid-resistance of the road surface and accident levels at these high risk areas in urban situations but nationally skidding is considered to be a contributory factor in about 28% of accidents occuring on wet roads. In London the wet road skidding rate is rather less than 15% so that it could perhaps be considered that lack of skid resistance is not a major factor in causing accidents. Because of the lack of positive information and also because of a suspicion that the wet road skidding rate was not a good index of the risk rating in a city, the Greater London Council embarked upon a programme of localised skid resistance improvement at accident-prone junction sites in 1968 after a series of preliminary trials to establish the feasibility of using a system of surface dressing with an epoxy resin binder and calcined bauxite aggregate (8). The results from the first series of trials were so encouraging in terms of accident reduction that it was concluded that the incidence of skidding on wet roads in a city was very largely under-estimated. This may well have arisen because of the slow traffic speed in urban situations and the difficulty of establishing whether a vehicle is in a locked wheel condition before the accident impact occurs.

Standards Of Skid Resistance

There have been several published tentative minimum standards for skid resistance (9), (10), most of which suggest minimum values for selected types of sites. In general, the most dangerous sites require the highest skid resistance but it has now been shown that the higher values proposed are very often not obtainable with natural aggregates because the most dangerous sites generally carry the most traffic with the greatest amount of

Table 1. PSV of aggregate necessary to achieve the required skidding resistance in bituminous surfacings under different traffic conditions.

Required mean summer SFC at 50 km/h	PSV of aggregate necessary					
	Traffic in commercial vehicles per lane per day					
	250 or under	1000	1750	2500	3250	4000
0.30	30	35	40	45	50	55
0.35	35	40	45	50	55	60
0.40	40	45	50	55	60	65
0.45	45	50	55	60	65	70
0.50	50	55	60	65	70	75
0.55	55	60	65	70	75	*
0.60	60	65	70	75	*	*
0.65	65	70	75	*	*	*
0.70	70	75	*	*	*	*
0.75	75	*	*	*	*	*
AAV	not greater than 12			not greater than 10		

* SFC values in these traffic conditions are sometimes achievable with aggregates of extreme hardness and very high resistance to abrasion, such as certain grades of calcined bauxite.

polishing action.

The most recently published set of tentative standards, by Salt and Szatkowski (5) introduces, for the first time, the concept of risk rating. From his knowledge of accident history and local knowledge, the highway engineer is required to assess the relative accident risk of a given site and it is suggested that lower minimum standards can be assigned to low risk areas in each particular category. In theory this is a sound concept, but it pre-supposes a good accident recording system and also implies the acceptance of a given level of accident risk which few engineers would be prepared to quantify. On the other hand, it provides a method of apportioning priorities when expenditure is limited, and as such it is a valuable document.

for several years the authors have been attempting to derive basic relationships connecting road surface skid resistance with accident levels at various standard types of junction or hazard areas in a city. The establishment of such relationships is clearly desirable to permit the development of an overall strategy for road maintenance management based upon a sound economic assessment of accident costs. It must be recognised that because numerous factors other than skid resistance are involved, some of which are impossible to quantify, the relationships cannot precisely predict the performance at individual sites. The work to date has demonstrated that there is a statistically significant correlation between accident rate and skid resistance. There is evidence to suggest that the statistical relationships defined by the regression equations are also functional relationships and that an increase in skid resistance results in a reduction in accident rate.

These studies also supported the important finding reported by Schulze et al (11) and Schlösser (12) that, within normal ranges of skid resistance, there is no threshold level of skid resistance beyond which a further reduction in accident levels cannot be achieved. It would appear that the concept of a general minimum acceptable level of skid resistance is illusory and that the selection of an appropriate minimum value must be based upon an economic assessment of the cost of attaining it in relation to the possible accident savings.

In London sites where accident reductions can be achieved by a road surface skid resistance improvement have been selected by the operation of one or both of the two simple measurements. These are:

1. The number of accidents reported to have occurred when the road was wet is substantially in excess of 26% which is the annual average for London as a whole or
2. The road surface skid resistance has been found to be significantly lower than on the rest of the road being examined.

The selection process has been greatly simplified by the existence of computer-stored details of all personal injury accidents in London from 1969. Details are now readily available for about 350,000 accidents and since the recording system is based upon a nodal concept, where the nodes are normally major road intersections, it is relatively easy to obtain details such as the percentage of accidents which occur on a wet road surface for the major road junctions in London. The introduction of SCRIM (13) (Sideway Force Coefficient Routine Investigation Machine) has enabled a regular annual monitor to be made of the skid resistance of the 1300 km of main road controlled by the Greater London Council. This machine was developed by the Transport and Road Research Laboratory and automatically measures the sideway force coefficient every few metres and records the results on punched tape.

The data is analysed by computer and produced in the form of a multi-coloured transparent overlay to 6" maps so that the existence of relatively short lengths of slippery road are evidenced by a colour change. For the specific problem of junction and similar areas, digital output is also used.

Having located sites for treatment by either or both of the above methods it is then necessary to apportion priorities and this is normally done on the basis of total numbers of accidents. It is clearly a more economic use of resources to treat those sites first which have the greatest accident saving potential.

Methods Of Improving Skid Resistance At Urban Junctions Or Similar Hazard Areas

In a developed city such as London the need to improve the road surface skid resistance in small areas such as road junctions and the approaches to pedestrian crossings presents a difficult problem both in the choice of material and in the application method. All of the heavily trafficked roads in London are surfaced with Hot Rolled Asphalt with a variety of road bases but mainly Portland cement concrete. Any addition to the road construction thickness by overlaying with premixed bituminous materials is generally not possible because of the restraints imposed by surface drainage, the presence of road furniture and the presence of hard surfaced footways. It would be possible to heat and plane the existing asphalt surface and replace it with another of higher polish resistance but this operation would be both costly and difficult because of the presence of road furniture, man-holes and in many cases traffic signal apparatus. A thin surface overlay was therefore sought which could be applied without auxiliary work and which would satisfy the following requirements:

1. It should be of small thickness to avoid the need for lifting kerbs etc.
2. It should be capable of being applied overnight between about 2100 hours and 0600 hours because of the need to avoid traffic congestion.
3. The binder should adhere to asphaltic wearing courses and be sufficiently strong to resist embedment of the aggregate under heavy traffic loading.
4. The surfacing should have a high resistance to skidding and should have a life in excess of five years.

The early experiments carried out in 1967 confirmed that a particular type of extended epoxy resin in association with calcined bauxite aggregate was capable of satisfying all of these requirements and to date about 800 sites have been treated.

The process and the materials employed have been described elsewhere (14) and for the purpose of this paper it is probably sufficient to comment that experience of its use has shown that it has a life in service of at least 7 years and probably substantially in excess of 10 years and it has been found to be the only practical method by which relatively small areas of road surface can be treated in the context of heavily trafficked city roads.

It is normal practice to treat a length of about 50m. of road on the approaches to a junction or hazard area, together with the centre of large

Table 2. 'Before and after' accident studies on 23 junction sites treated with resin/bauxite and 14 untreated but otherwise similar sites in London.

Accident Type			12 months Before	12 months After	Nett change as a result of treatment %
All		treated	269	152	*
		control	179	147	-31.2
Wet Road		treated	109	33	*
		control	73	42	-47.3
Skidding (wet and dry)		treated	15	2	
		control	15	6	-66.7
2 or more moving vehicles same direction.	Wet	treated	10	2	
		control	6	4	-70.0
	Dry	treated	20	16	
		control	17	10	-36.1
2 or more moving vehicles different directions.	Wet	treated	40	11	*
		control	23	13	-51.3
	Dry	treated	45	41	
		control	24	23	-4.9
1 moving vehicle - no pedestrians.	Wet	treated	29	8	*
		control	12	10	-66.9
	Dry	treated	32	20	*
		control	10	19	-67.1
1 moving vehicle - pedestrian injured.	Wet	treated	21	9	
		control	23	12	-17.8
	Dry	treated	36	21	
		control	37	44	-51.0
bus passenger and other accidents	Wet	treated	9	4	
		control	9	3	+33.3
	Dry	treated	27	19	
		control	18	10	+26.6

* Statistically significant at 95% confidence level.

Table 3. Possible 10-Year Programmes
Forecasted accident and cost reductions
on Metropolitan road junctions using
resin/bauxite treatment (1970 values).

Initial assumptions:-

cost per site = £2,000
accident reduction = 30%
cost of P.I. accident = £1,090
mean life of treatment = 5 years
total number of accidents on all roads in London Area = 56,000 p.a.

Annual Expenditure	£100,000	£200,000	£300,000	£400,000	£500,000	£600,000
No. of sites treated per annum (inclduing maintenance).	50	100	150	200	250	300
Total No. of sites treated after 10 years.	375	750	1,125	1,500	1,875	2,250
Total accident reduction in 10 year period.	10,800	17,300	22,300	26,300	29,600	32,700
Total cost of accidents saved in 10 year period.	£.1.8m	£18.8m	£24.3m	£28.7m	£32.2m	£35.6m
Total cost of anti-skid treatment.	£1m	£2m	£3m	£4m	£5m	£6m
Cost of preventing one accident in 10th and subsequent years.	£61	£78	£92	£107	£119	£131

Note: The annual expenditure after 10 years would continue at about the same rate but without increasing benefit. The continuing expenditure would be required to maintain the treated areas.

junctions, but increased lengths (up to 100m) are treated where traffic approach speeds are high.

The sfc of the junctions before treatment was of the order of 0.4 and after treatment of the order of 0.8 Although the macro-texture is relatively unimportant in a city because of the slow traffic speeds, it is relevant to note that the texture depth provided by this form of treatment has been found to be of the order of 1mm (14). This would be considered to be adequate for high speed roads.

The Results Obtained By The Use of Localised Skid Resistance Improvements

Many 'before and after' accident studies have been done on junctions and other similar areas treated with the epoxy resin/calcined bauxite material since its widespread use was commenced in 1968. All of these have shown a very substantial reduction in accidents and the results of one such study is given in Table 2. A series of sites was selected and 23 were treated with the epoxy resin/calcined bauxite material and 14 selected upon the same basis were left untreated as controls. All of the 37 sites were selected on the basis of their accident records and before and after studies were made on all of them. The results are summarised in Table 2 from which it will be seen that the average net change in accident numbers was a reduction of 31%. Before treatment the average number of accidents per site used in the study was 12 per annum so that the treatment has reduced accidents on each of the treated areas by an average of about 3½ per annum.

The Table gives details of the effect of the process on most common categories of road accident and it is interesting to note that there was an increase in the number of injury accidents involving bus passengers. Whilst there was only a small number of accidents in this category, all of the other accident studies that have been made in this project have shown the same trend. Possibly this has resulted from the increased ability of public service vehicles to brake and stop more rapidly, thus possibly causing injury to standing passengers.

The Economics Of This Form Of Treatment

In 1970 the economics of using this form of treatment at typical junction sites in London were examined (8) The conclusions from this study are given in Table 3 which shows the various costs involved at differing rates of annual expenditure. This Table was drawn up on the basis of the stated assumptions and on this evidence, it was decided to commence a 10 year laying programme at an annual rate of expenditure of £300,000. It was appreciated at the time the decision was made that the probable excess of the accident cost saving over the cost of the anti-skid treatment was so large that the economic analysis was relatively insensitive to the initial assumptions, but it is nevertheless interesting to examine the accuracy of this forecast in the light of further experience.

The more recent accident studies, the results of which are in Table 2, show that the average accident reduction due to anti-skid surfacing was 31% compared with the 30% assumed in Table 3, and the mean life of the treatment has now been established as being at least 7 years and probably in excess of 10 years. The overall economic picture is thus even more favourable than the early study suggested. The annual rate of expenditure since 1970 has been increased to keep pace with inflation and is at present at approximately £420,000. Thus it may be said that the initial economic assessment of the viability of this form of treatment has been amply substantiated in practice.

It should perhaps be emphasised that the quoted figures apply strictly to the situation in London where treatment is given to the most accident-prone sites in order of priority. Whilst a similar economic forecast could readily be made for other major cities, somewhat different figures might result depending on the average numbers of accidents per site, the traffic pattern and intensity and the number of days in the year in which the roads were wet. Table 3, however, shows that the excess of accident cost savings over expenditure is so high that it would seem probable that the economics of this form of treatment could well be favourable if applied to road junctions on heavily trafficked roads in many major cities.

The annual reduction in personal injury accidents in London at the beginning of 1976 is estimated to be 2,500 or 5% of the total accident numbers. This reduction has resulted from the treatment of some 800 sites and will increase further as more sites are treated.

General Conclusions

1. In Great Britain about 70 per cent of all road accidents occur in urban areas.
2. In London, about 70 per cent of all accidents occur on road junctions on about 10 per cent of the total road network. Nationally about half of all road accidents occur on urban junctions.
3. The skid resistance of asphalt roads can be predicted from a knowledge of the stone used in the surfacing, the traffic intensity, and whether or not the traffic is manoeuvering (braking, turning or accelerating).
4. Although the existing tentative minimum standards of skid resistance for city junctions are suspect, routine measurements of skid resistance and accident data may be used to indicate junctions where a skid resistance improvement can be expected to reduce accidents.
5. Over 800 junctions and other hazard areas such as the approaches to pedestrian crossings in London have been treated with epoxy resin/calcined bauxite which has reduced accidents by 31 per cent or about 2,500 per annum, at the treated sites.
6. The economics of this form of treatment are shown to be exceptionally favourable and an expenditure of £3m over a 10 year period is estimated to produce a saving in accident costs of at least £24m at 1970 values.
7. The localised treatment of city road junctions could well be a successful method of accident reduction in many major cities.

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

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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

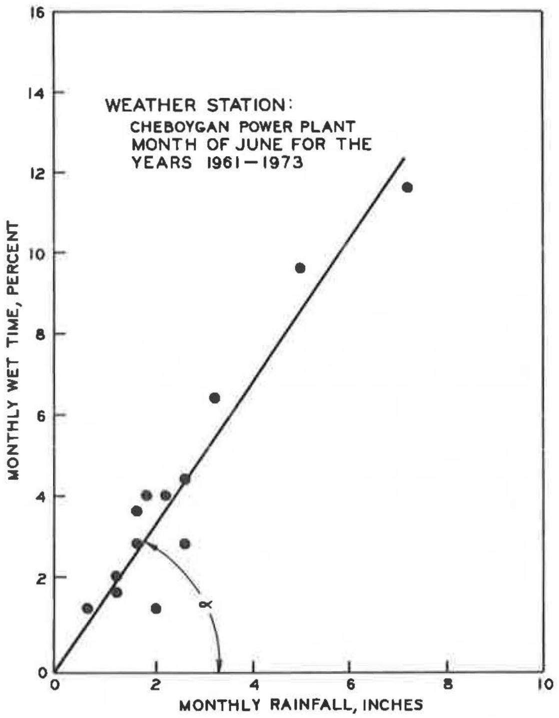
If pavements could be kept dry, the skidding accident problem would be greatly diminished. Virginia estimates that about 34 percent of its intersection accidents occur under wet surface conditions, and that about 57 percent of these are attributable to wet conditions alone (5). Also it is estimated that 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.

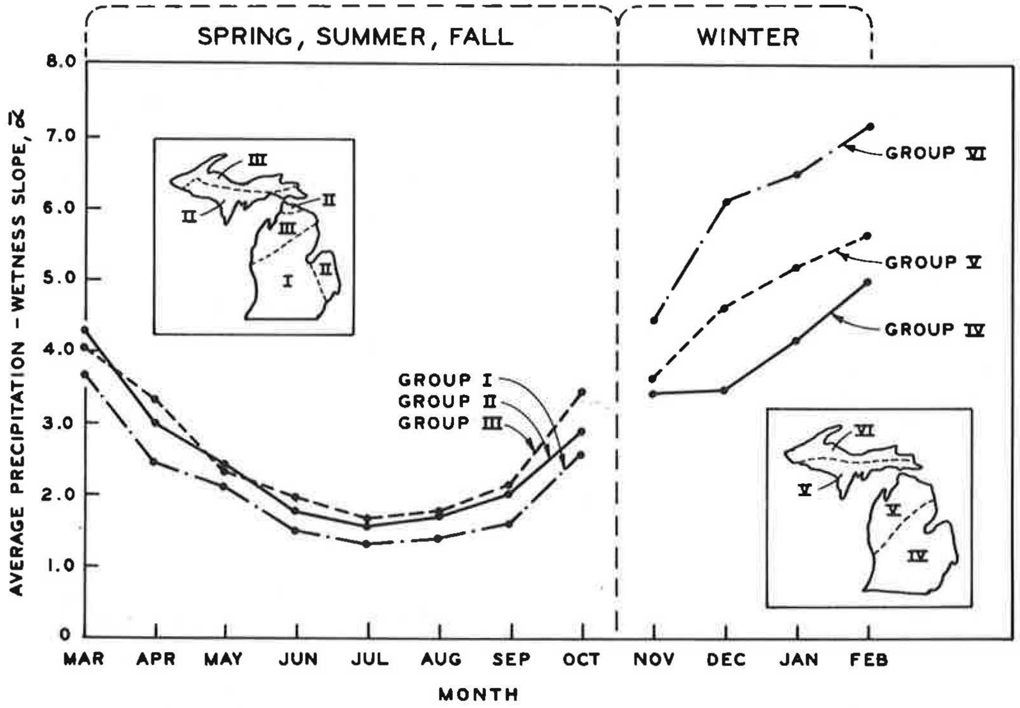
Turning now to the 42 weather stations recording hourly precipitation, we find that on a monthly basis, correlation exists between precipitation and percent wet time. Figure 1 shows a single selected weather station for the month of June. In this graph, the data points represent June precipitation in 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 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.

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



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 $\overline{\alpha}$ for each month. Examination of the month, region matrix immediately revealed that for all regions, $\overline{\alpha}$ 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.

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

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 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.

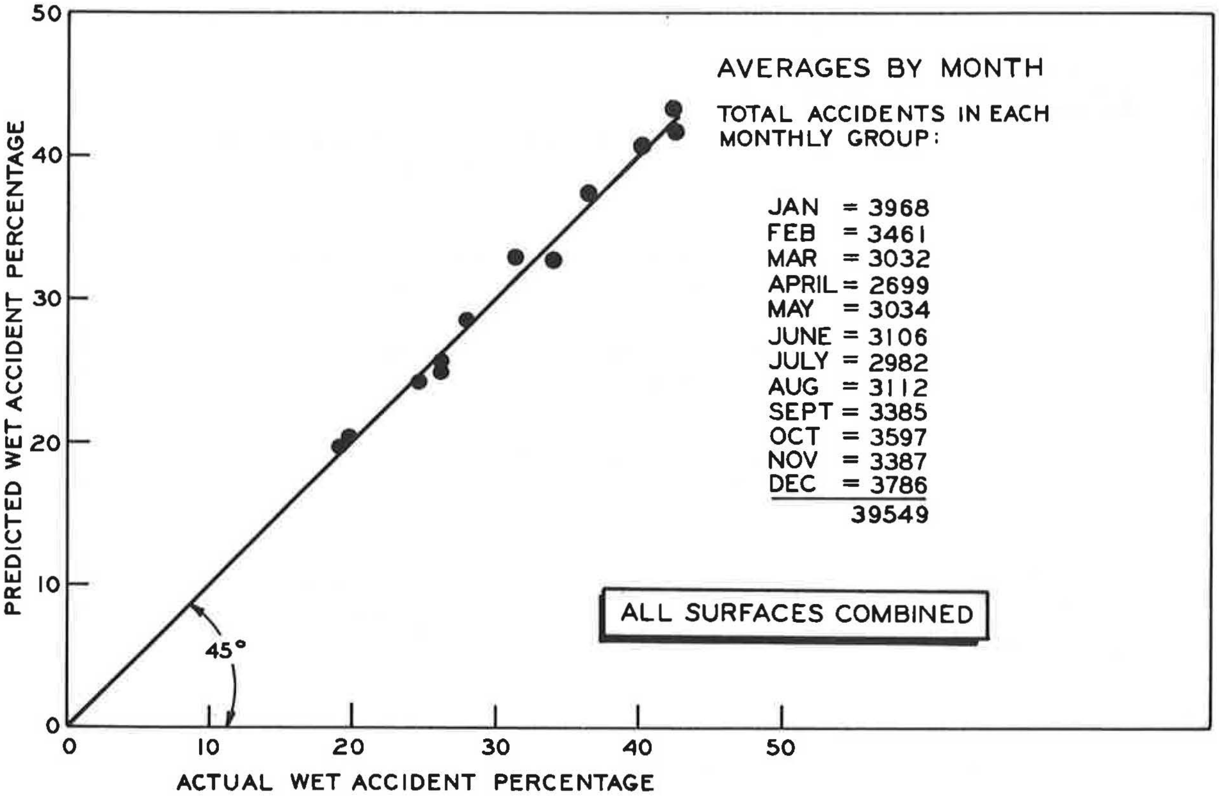


Figure 4. Relationship between actual and predicted wet accident percentages for each skid number group.

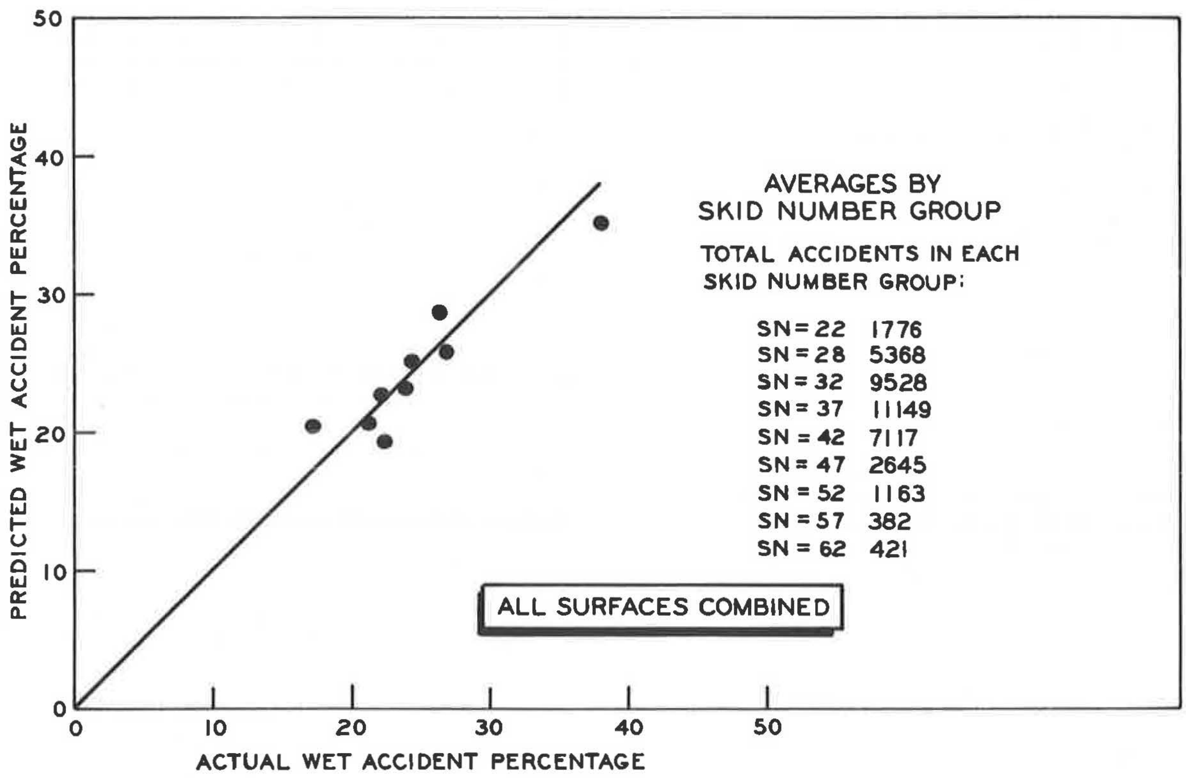


Figure 5. Relationship between actual and predicted wet accident percentages for each wetness group.

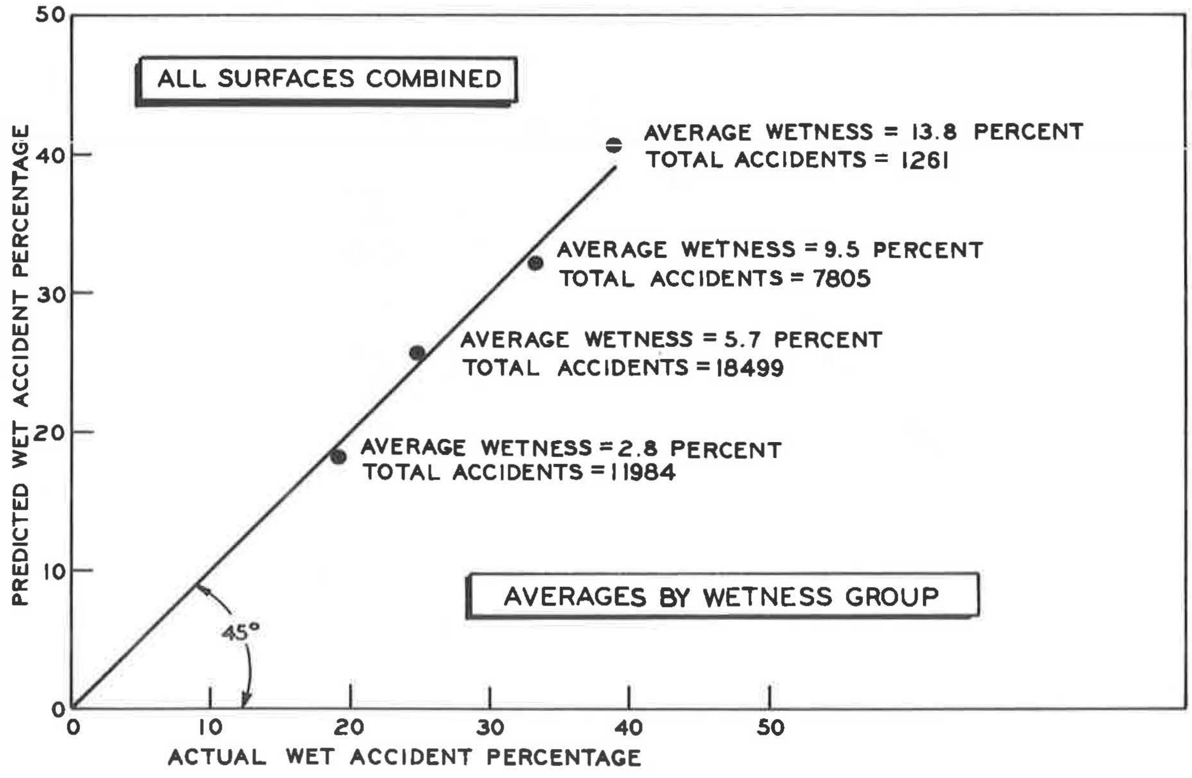


Figure 6. Seasonal wetness polynomial M(i) as a function of month.

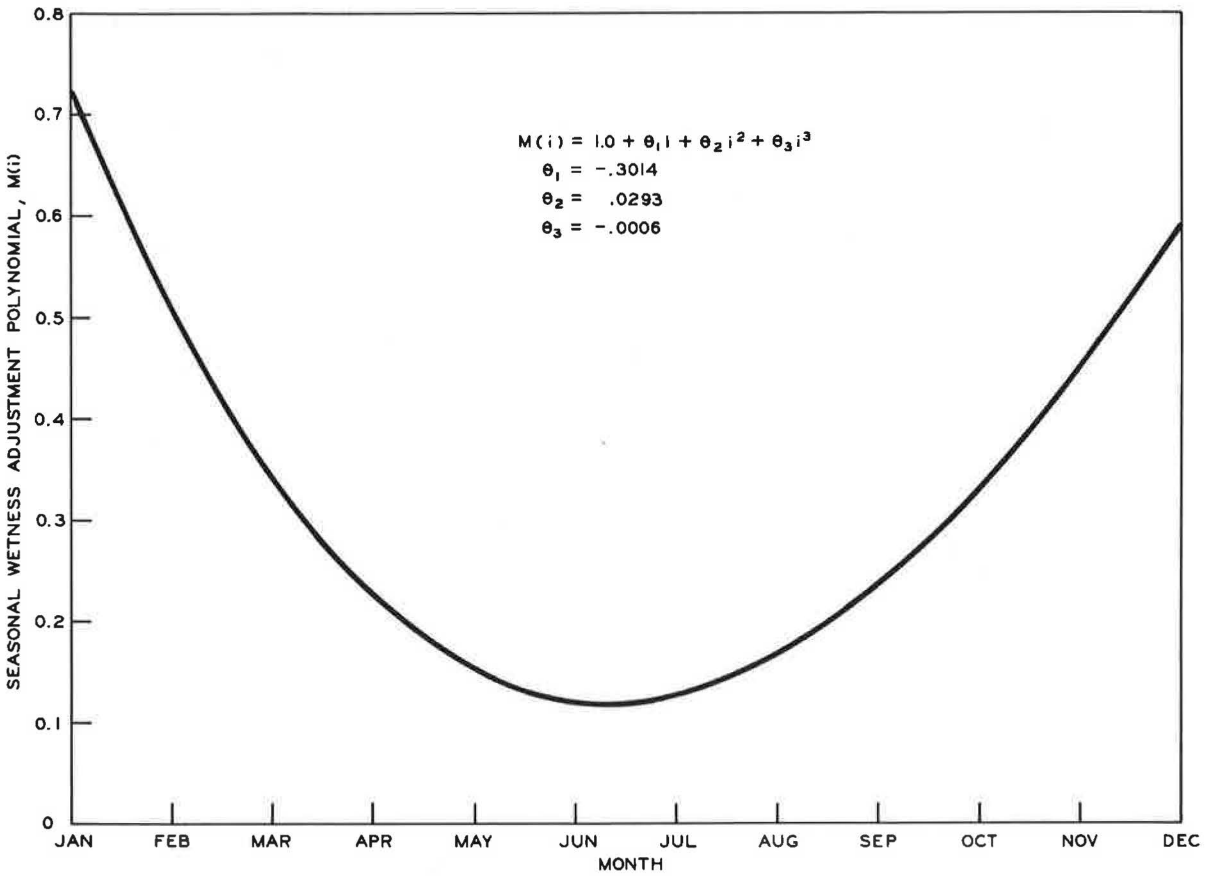


Figure 7 shows the skid number polynomial, $g(\mu)$ which governs the influence of μ in the model. The important point here is that the polynomial is not "flat", that is, it increases as μ increases which indicates that skid number is an important variable in the model and that low skid numbers are associated 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

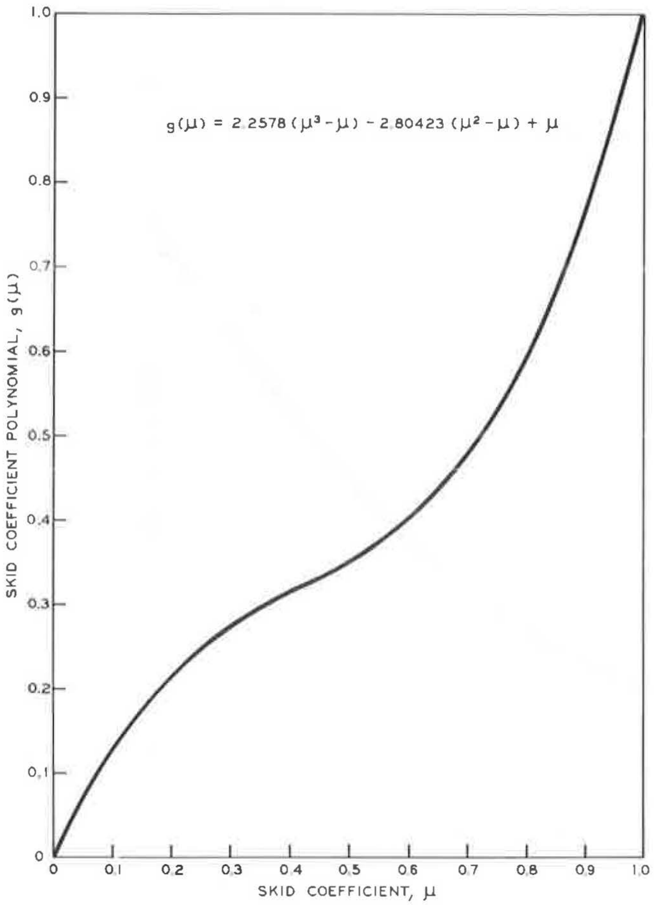
It is difficult in one representation to show the interrelationship of all variables in the model. Consequently, they are shown pairwise in Figures 8 through 10. The relationships between and wet accident percentage for selected wet times and the month of June are shown in Figure 8. It is obvious from 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.



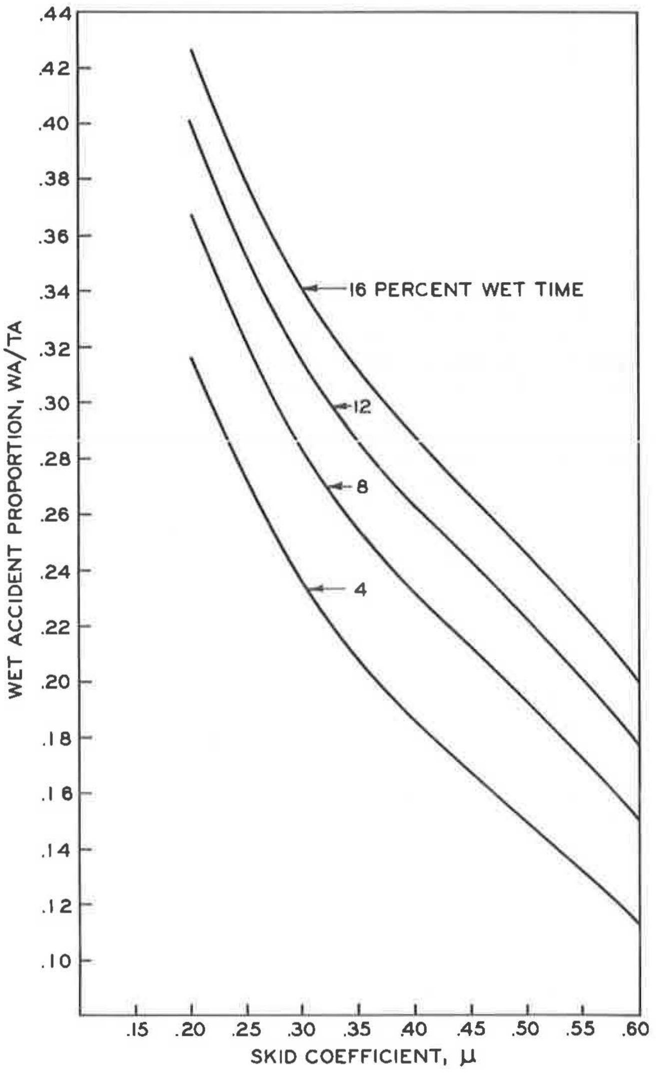
order to determine whether or not these statistics are realistic, or mearly the result of random fluctuation always found with small samples. This would provide the basis for development of "quality control" procedures designed to detect "excessive" wet accident percentages which are not the result of 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

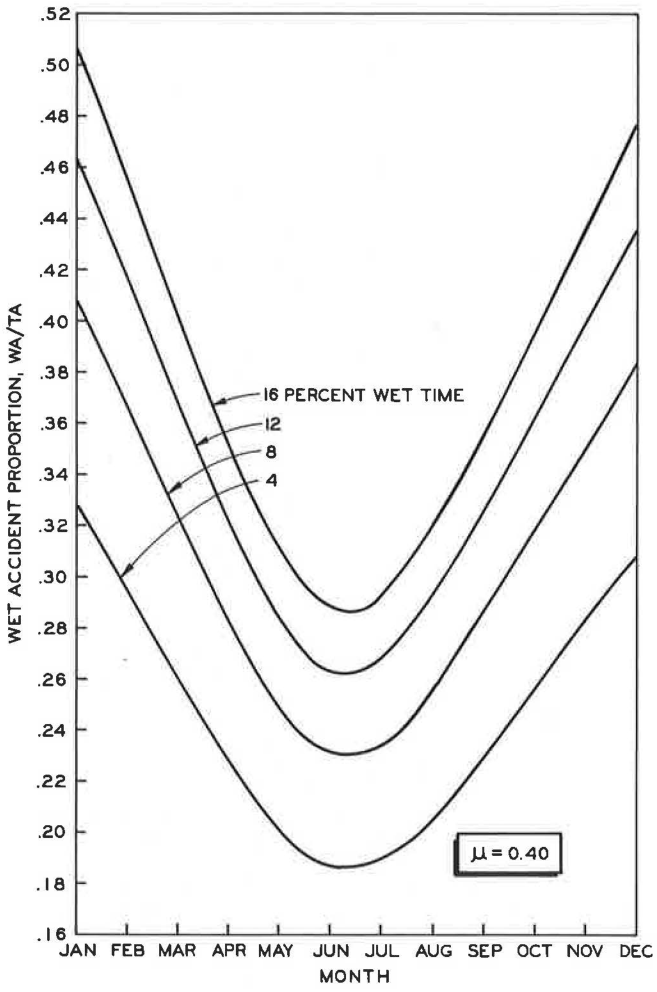
This plan seeks to first identify, and second to upgrade, low skid coefficient intersections. The philosophy behind this plan is that low skid resistance surfaces, *per se*, must be found and repaired. No attention is given to traffic volume, local rainfall, or any other variable. An administration following 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

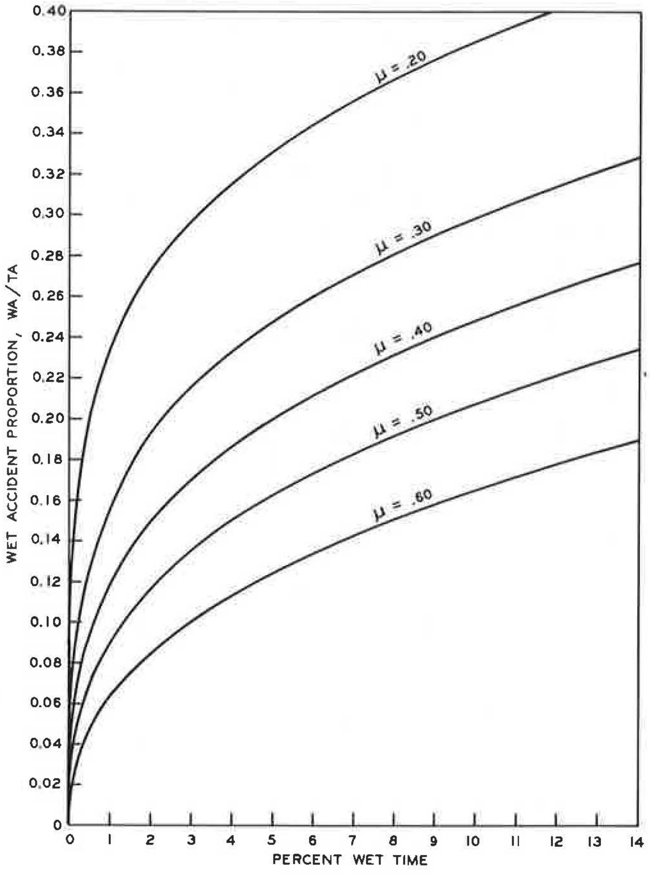
Plan II differs from Plan I in that expected accident prevention benefits are used to form both the testing and resurfacing priority lists. For the testing priority list, wet accidents estimated from dry accident history, local wetness and a presumed skid coefficient of 0.40 are used in the wet accident 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.

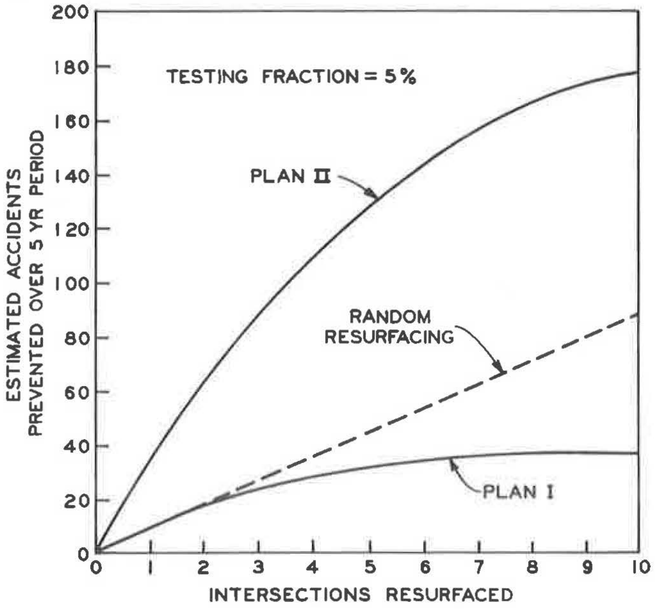


Each skid testing plan was based on a testing fraction composed of the top 10 of the 190 intersections rank ordered as specified by the skid testing plan. Expected wet accident reduction benefits were then accumulated as through 1 or 2 or 3 or ... up to 10 intersections had been resurfaced according 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

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HUMAN FACTORS IN SKIDDING: CAUSATION AND PREVENTION

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This paper provides a state of the art overview of the human factor in skid accident causation and prevention. Available literature is summarized in two parts. First, the driver and skid potential are covered in terms of driver perception and responses in skid hazardous driving situations. Second, candidate traffic control techniques are reviewed as potential remediation techniques. The detection and appreciation of hazardous situations during wet weather conditions tends to come from knowledge of the fact that it is raining, the pavement appears wet or road alignment is changing (as on horizontal curves). Communicating potential hazards to motorists through static signing is generally ineffective; whereas flashing signals and dynamic displays and advisory speeds at such highway sites are effective in modifying control behavior and presumably in the reduction of loss of control. Specific road geometric conditions can lead to higher than acceptable frictional demands because their difficulty in negotiation is underestimated by motorists. Suggestions are made for readily implementable accident countermeasures and necessary research required for more effective countermeasure development is delineated.

There currently exists an urgent need for the integration of human engineering techniques into skid accident reduction programs. For more than two decades, the highway research community has directed its efforts almost exclusively to studying tire-pavement interactive phenomena. Concurrently, developments of the automotive industry have been primarily limited to radial tires and anti-skid braking devices. No systematic effort to examine broadly based causes of skidding accidents has ever been documented. Most sorely neglected is the cause of all skidding accidents - the driver.

This paper provides an overview of what limited documentation is available regarding the human factor in skid accident causation and prevention. An extensive literature review was conducted to, first, exploit the driver in a potentially skid hazardous environment and, secondly, to describe certain promising human factors remediation techniques. From this synthesis of knowledge, suggestions were formulated regarding direction of future research and development in the area of skid accident reduction as well as suggestions for currently implementable countermeasures.

Summary of Relevant Literature

Currently available documentation regarding the human factor in skid accident causation and prevention is summarized under two primary headings. The first section, the driver and skid potential, relates to accident causation by describing what is known in terms of driver perceptions and responses during driving conditions characterized by skid accident potential. The second section, countermeasures considerations, deals with prevention in terms of a review of candidate traffic control devices capable of reducing skid accidents.

The Driver and Skid Potential

There currently exists a dearth of empirical data regarding driver assessment of skid accident potential. Among hundreds of literature items searched on skidding, only three references were found relative to driver assessment of hazard. The area of greatest research need is field experimentation.

One published item (1) attempted a laboratory study of steering and the detection of skidding by the motorist, but the project was dropped after five years of effort. This study was originated in The Netherlands, and it was not possible to contact the researchers for further information. Another laboratory study (2) was augmented by a small sample of field observations of driver perceptual processes involved in curve negotiations. Visual search patterns and motor control movements were measured on the road, and curve psychophysics, information processing abilities and susceptitility to visual illusions were studied in the laboratory. The major results of the study were a) traditional measures of curve length and central degree were unrelated to accident statistics, drivers' perception of curvature, and drivers' tendencies to decelerate before the curve. b) Two driver-performance indexes of curvature were developed and were found to be significantly related to accidents on curves. Curves' perspective angle (as viewed by the driver) correlated highly with accidents (r = .51) but drivers are relatively insensitive to this information. Eye-movement patterns showed that drivers tend to successively fixate the edge-line of the curve before entering it, indicating that drivers perceptually negotiate the curve several seconds before entering it.

A field evaluation of signing to warn of skid hazards at three curve sites under wet and dry pavement conditions (3) peripherally dealt with motorists' cues of skid hazard. During the driver interview portion of the evaluation, drivers were asked if they thought the section of highway they had just driven through might be a skid hazard. Seventy percent of the 305 interviewed motorists assessed the sites as hazardous and cited the following cues:

1. Sharp roadway curvature.
2. Appearance of the pavement.
3. Pavement superelevation (banking).
4. Pavement wetness.
5. Known accident history of the site.
6. Driving behavior of other motorists.
7. Presence of the skid hazard warning sign.
8. Other reason.

The proportion of drivers citing each cue remained fairly constant over all ambient conditions with about one-third citing sharp curvature, about one-sixth citing driver behavior of other motorists, and almost one-third saying that the site was not a skid hazard. During wet pavement periods, some motorists' attention was diverted from sharp curvature to the fact that the pavement was wet or looked slippery. Only 4 out of 305 motorists interviewed cited the skid warning sign as a cue of potential hazard. Three of the four motorists citing the sign as their cue did so during wet pavement conditions. Specific sign conditions cited during wet pavement conditions were: the international symbolic "Slippery When Wet" shield used by itself; the shield with flashing lights; and with both the flashing lights and advisory speed limit. A "Slow When Wet" panel was cited during the dry condition.

Numerous other items of literature cited in the review that relate to elements in the driving environment which contribute to skidding accidents are now summarized as a basis for inferences relative to the effect of those elements upon motorist reaction to a potential skid hazard.

In a report presented during the First International Skid Prevention Conference (4), the driver was recognized as a dominant factor in skidding accidents. An analysis of the driver-vehicle-highway relationship in skidding accidents prompted a listing of matters which are misunderstood by the driver. The directly quoted list is as follows:

1. Friction between tires and road is often greatly reduced when the road surface is wet, increasing vehicle stopping distances very greatly. The effect of wetness on slipperiness varies greatly with different road surfaces, however.

2. Such friction for an emergency stop on most wet road surfaces is much lower in high speed stops. In a quite high-speed stop on a wet road, such friction is almost as low as that on ice.

3. Some road surfaces which are very non-skiddy when dry become treacherously slippery when wet.

4. When a road surface is wet, its slipperiness cannot be judged at all by a motorist looking at it.

5. A shower after a dry spell on a heavily traveled highway may cause the highway, due to oil drippings and road film, to suddenly become very slippery until the rain cleans off the surface - even on the best of road surfaces.

6. Even the slightest swerve, brake application, or speed-up can "trigger" a skid on wet or icy road surfaces. The higher the speed, the more true this is.

7. Unevenly or badly worn tires may result in skidding and loss of control on wet roads, the conditions of which are otherwise excellent.

8. Skidding is especially likely to occur at curves, near intersections, on steep hills, at traffic circles. One reason is greater pavement wear resulting in lowered friction coefficients. These are also places where drivers decelerate sharply, swerve, or otherwise change course rapidly.

9. Many drivers have not developed patterns for action in skids - and understanding of what not to do. These are things which cannot be learned by reading alone - they must be experienced.

Following the generation of that list, the subcommittee made a series of recommendations for remedial measures, one of which was that research agencies should study what motorists know about skidding. However, no such research was cited during the conduct of this literature search.

The role of the driver was included in an analytical systems approach aimed at identifying the interdependence of factors influencing the skidding accident (5). The resulting model was rather complex as can be seen in Figure 1. It was asserted by the authors that the driver's portion of the model is the most difficult to evaluate because of problems in determining the driver's psychological and physiological conditions. A primary factor affecting the driver is his experience, in addition to his psychological and physiological makeup. Components of all three factors are shown in Figure 2; it is the sum total of these interactions which affects the driver's perception of his overt actions which lead to accidents.

The importance of the physical environment as it communicates to the driver was also seen from the model. Figure 3 illustrates the formal and informal sources of communications to the motorist. Formal channels are traffic control devices (signs, signals, markings) specifically intended for the purpose of communication to the motorist. Informal communication is derived from geometrics, guardrails, delineators and roadway alignment. The combination of these elements influences the motorist and elecits a maneuvering response.

A study of driver sensory capability at the Ohio State University (6) has led to a driver's longitudinal control task model derived from the elementary stimulus - response concept of classical psychology. Figure 4 depicts the model in which the human controller is seen to receive vehicle dynamic stimuli and to determine the appropriate response as a function of both his perceptual characterisitics and operating criteria. The combination of models derived by Hankins and Rockwell seem to represent a conceptual description of the driver in a potentially skid hazardous environment.

In a recent study of vehicle and roadway interaction, the requirements placed on the motorist in a potential skid hazard can be seen in terms of the maneuvers which create a frictional demand (7). Applicable driving maneuvers are classified as acceleration, deceleration, and cornering. Deceleration demand has been defined as "numerical" equivalent to pavement frictional requirements. The importance of vehicular deceleration capabilities as they relate to pavement skid resistance is cited in numerous studies (8, and others). The high demand which deceleration places on roads in an emergency stop is illustrated in Figure 5.

Of the basic maneuvers, acceleration generally imposes the least frictional demand since few drivers try to achieve the maximum level of acceleration

Figure 1. Skidding accident systems model (Hankins, 1971).

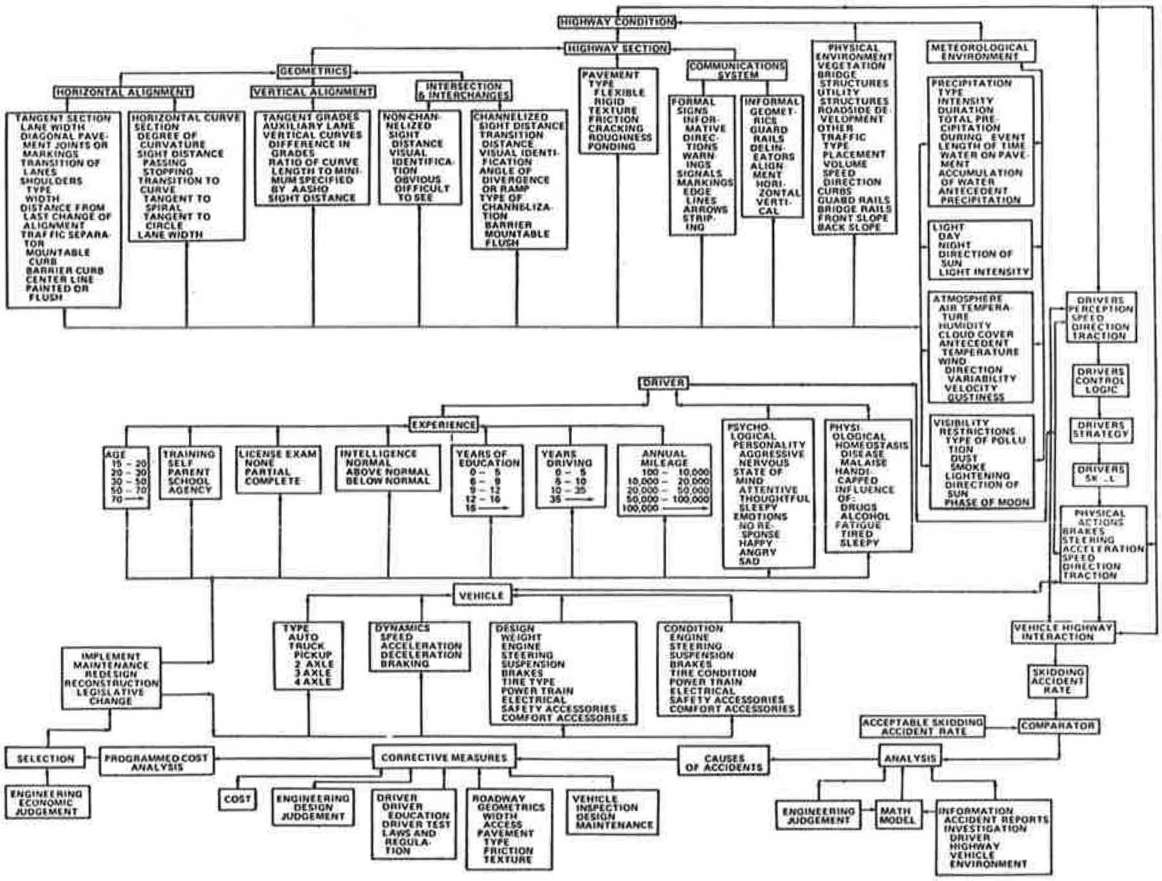


Figure 2. Driver components in the skidding accident systems model (Hankins, 1971).

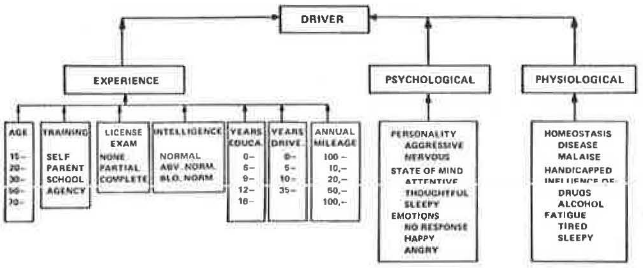
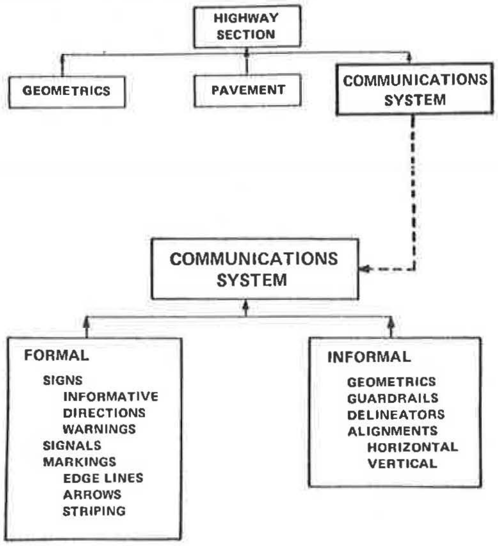


Figure 3. Communications system components of the skidding accident system model (Hankins, 1971).



of which their vehicle is capable. Further, the acceleration capabilities of vehicles are not as violent as deceleration capabilities. Cornering has been one of the principal concerns of skid studies ever since investigations of skidding commenced. Relationships developed for connering forces, by functions such as degree of curvature, have indicated that the maximum cornering force of the 95th percentile driver occurs at a curvature of 20 degrees (9). Recent work has demonstrated that drivers' choice of speed approaching a curve is related to perceived lateral g-forces (10). The driver demands resulting from combinations of cornering and decelerating or cornering and accelerating have not been a subject of published literature to date. Studies of these conditions have been confined generally to an examination of tire performance capabilities.

A recent study by the Texas Highway Department (11) regarding maneuvering along horizontal curves indicated that drivers develop much sharper curvature than the design curvature. In addition to providing information relating to skid hazard, the research is intended for use by highway agencies in developing allowable speed values in regulatory speed zoning during inclement weather.

Figure 4. Hypothesized function of driver in longitudinal control task (Rockwell & Snyder, 1968).

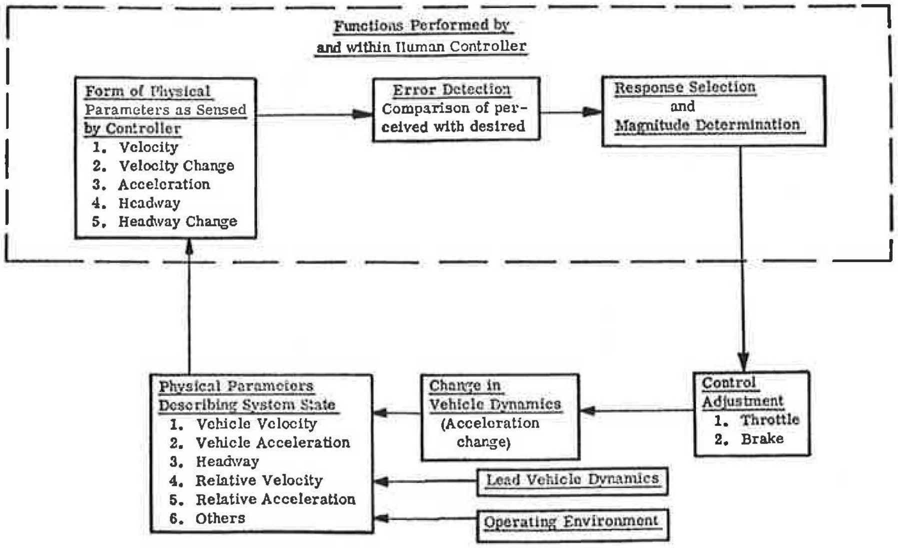
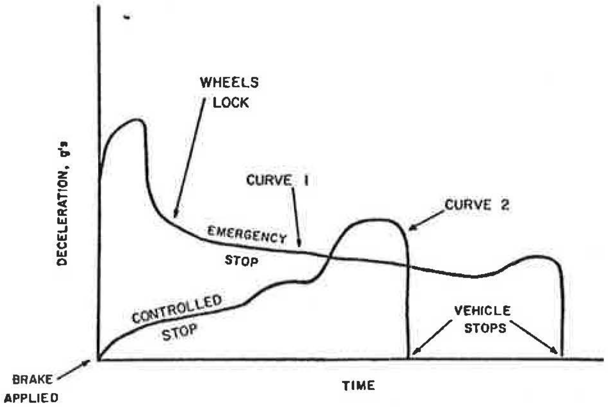


Figure 5. deceleration patterns for controlled and emergency stops (Ivey, 1971).



A later Texas study (7) addresses the issue of driver visibility during rainfall as one factor affecting wet weather accidents. The report presents a limited number of direct visibility observations and develops a framework useful in interpreting these data to determine the influence of reduced visibility on the operation of motor vehicles. Information from the literature shows the low probability of high intensity rainfalls. Conclusions concerning the hazard of passing maneuvers during rainfall of 1 in./hr. or more and the need to reduce speed under wet weather conditions are also presented.

Any overview of human factors in skid accident causation and prevention should note that driving schools comprise a valuable source of knowledge regarding driver behavior. Such schools are capable of generating considerable information relative to motorists' reactions in potential (or actual) skidding situations. A race-driving school records g-forces to which their students are subjected in each turn on the track (12). The purpose of the record is to show in which turns the driver could have achieved a higher speed and remained below his limiting or "break-away" g-force. There is a tendency for drivers to increase these safety margins as their speeds increase. Another school, the Liberty Mutual Insurance Company Skid Control School, has been innovative in developing a method for educating motorists. The program consists of two parts: a seminar on skid theory and a laboratory session on a practice skid pan. Objectives of the program are as follows:

1. To make a significant contribution to the present knowledge of skid causes so that control measures may be improved.
2. To demonstrate the practicality of skid instruction and encourage qualified traffic authorities and driving schools to undertake similar programs.
3. To make available to the driving public, through printed and visual means, a better understanding of the causes, prevention, and control of skids.
4. To provide a training ground for Liberty Mutual's highway safety engineers, for its fleet policy-holder driver trainers, and certain public agencies concerned with highway safety.

The Skid Control School is an educational technique consistent with a basic approach advocated at the First International Skid Prevention Conference. A human factors-oriented paper by Forbes (13) presented at the Conference stressed methodologies to assist the motorist in coping with skid hazards. In addition to the provision of favorable road conditions, highway engineers were encouraged to provide assistance to the driver by means of the following:

1. Driver understanding of basic factors relevant to skid accidents should be promoted by means of widespread advanced driver education.
2. Additional sensory cues should be provided to drivers to assist them in evaluating the situation. A device is needed to inform the motorist of hazardous geometry by means of a type of "feedback" which would enable him to sense vehicle instability through his controls or external vibrations.
3. Driver education can teach more advanced skills in evaluating highway conditions than it does at present. New techniques are needed to give the driver practice in evaluating a situation involving indications of slippery conditions or other skid hazards ahead.

The probabilities with which traffic signs are registered by drivers are rather low in ordinary road traffic conditions, and the differences in the registration probability are large. (Here, the term "registration" means that the driver sees the sign and is able to report it in the interview.) The registration percentages were found to be as follows: The "general warning" sign, 28 percent; the "general warning" sign with a supplemental sign "driving control", 62 percent; the 70 km/h speed limit sign, 78 percent; and the 50 km/h speed limit sign, 80 percent.

The speed at which the test sign was passed did not affect the registration probability. The change in action (deceleration) and the registration of the sign were closely interdependent. A large majority of the drivers who failed to obey the speed limit had not registered the speed limit sign.

The driver's familiarity with the road did not affect the registration of the sign per se. The groups differed significantly only as far as the registration of the supplementary sign was concerned. The drivers using the road frequently paid attention to the supplementary sign and recalled it more frequently than the other drivers. The distance travelled before the interview did not affect the registration of the test sign. The registration probability for a given driver was not affected by his annual mileage driven. Specific results of correct identification responses for each sign and as a function of driver familiarity are depicted in Figures 6 and 7.

Figure 6. Right answers, by road and experiment (Hakkinen, 1965).

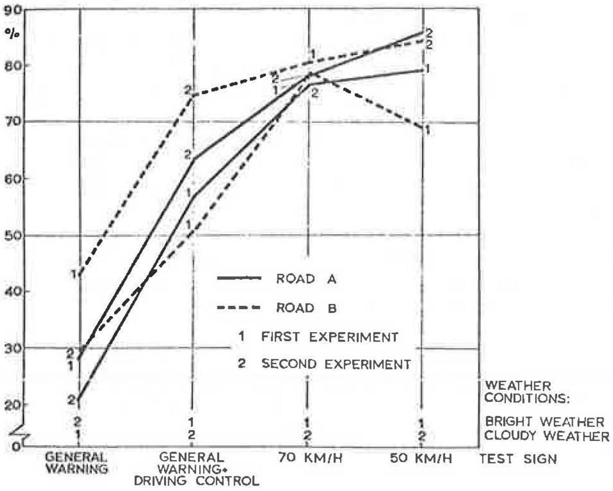
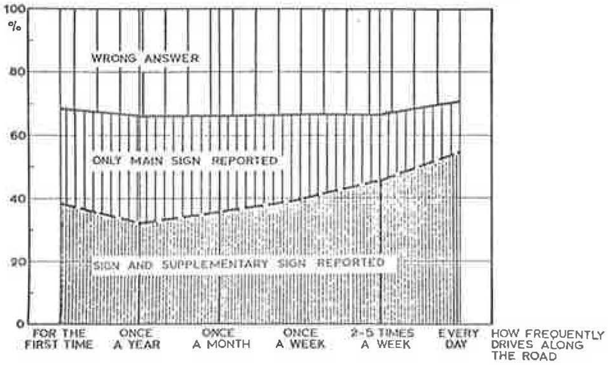


Figure 7. Dependence of answers on driver's familiarity with the road (Hakkinen, 1965).



Johannson (25), in analyzing 1,000 drivers' perception of five different warning signs, found that the percentage of drivers who noticed any one given sign was 47 percent. This fact is postulated as reflecting "urgency of information" based on past experience; that is, the more urgent the information, the more often it is perceived.

Howard (26) compared drivers' perception to a sign requiring driver action at a number of locations. Some of these locations were chosen so that the sign (sound horn) would make sense, others so that the sign would appear ridiculous. Data were recorded as to response, vehicle speeds and position, occupancy, and sex of driver. An advance warning sign was used in some cases and, as might have been expected, driver perception and response were greater with a replication (the probability of perceiving one sign is 13.9 percent; the probability of perceiving one of two signs is 25.9 percent). Howard concluded that perception of signs increases sharply the more "reasonably" the sign relates to roadway conditions.

Pages et al. (27) investigated the minimum brightness required for a traffic sign to be seen by the driver in different positions in relation to the sign. This experiment was conducted in a laboratory. In addition to reacting to a sign (slowing down or braking), the driver had to steer the simulated vehicle to keep two vertical bands in coincidence. Typical visual nighttime vehicular signals (white and yellow headlights, blinkers, etc.) were introduced. The findings indicated that the lighted sign is perceived if its brightness is at least equal to that of its surroundings.

A literature review (28) of motorists' perception of highway signing reminds us that there is a lack of knowledge in the area of warning sign design.

Sign Effectiveness as Hazard Warning. Numerous inferences can be drawn from the above cited studies regarding signing effectiveness to warn of skid accident potential. A number of studies which are more specifically applicable to the skid hazard situation are now discussed.

Marsh et al. (29), in discussing the specific problem of skidding hazard, indicated that drivers should be given clues as to what is ahead. Included among these should be: (1) realistic speed guide signs for sharp curves; (2) warning signs effective day and night for sharp curves, steep hills, dangerous intersections, and traffic circles (these being likely skid locations); (3) reflectorized curve delineators; (4) signs warning of pavement which is especially slippery when wet. Moreover, it is well documented that motorists are more likely to respond to a warning sign in the presence of a perceived hazard (13, 26, 30, 31, and others).

A recent field study (3) investigated the driver's general awareness and his response to warning signs for the hazard of wet pavements subjected to high driver frictional demands. Vehicle speeds were used as the primary indication of hazard awareness and sign response and driver interviewing was used to establish the motorist's cognizance of the hazard and his observation of the warning sign.

Three curved highway sections were treated using five experimental signing conditions. Comparisons between all signs and the "no sign" condition were made for wet and dry pavements. Normative driving behavior data were used to resolve time-of-day speed variations. Experimental signing

4. Training in actual emergency and recovery is needed.

5. Additional research is needed; too little data exists on how much drivers really know about basic factors involved in skidding.

Traffic Control Devices as Skid Accident Countermeasures

That no systematic human factors study of skid accident causation has been conducted to date has resulted in a knowledge gap regarding applicable accident prevention techniques. Thus, numerous attempts to increase driver awareness of potentially hazardous highway locations have relied on signing as an accident countermeasure. Yet, conflicting evidence has traditionally resulted regarding the effectiveness of signing in the regulation of driver behavior. In an attempt to exploit signing as a skid accident countermeasure, this review will address specific topics of signs to regulate vehicle speeds, to elicit driver perception, and to warn of hazardous locations.

Vehicle Speed Regulation. Several studies on the use of signing to affect driver speed behavior indicate less than optimum results. When signing violates driver expectancy, the driver apparently adheres to self-imposed safe speeds based on observed and expected conditions rather than on posted limits.

Bezkorovainy (14) examined the influence of horizontal curve advisory speed limits on the behavior of drivers of passenger vehicles on rural two-lane highways. Twelve horizontal curves (from 2 degrees to 12 degrees curvature) served as data collection sites, and statistical analyses (student t, analysis of variance) were used to compare the effects of an experimental standard sign versus no signing for nine testing conditions. During daylight hours and favorable weather conditions, drivers did not differentiate between the signs. Their speeds in negotiating the curves were not related to the posted advisory speed but rather to curve design geometric characteristics. Standard advisory signs (18" x 18") indicating "X" mph, experimental advisory signs (18" x 18") indicating SLOW to "X" mph, and combinations adding a standard curve sign (36" x 36") showed no significant differences in speed at the center of the curve. One item of interest was that, after passing the advisory sign, faster vehicles decelerated a greater rate than slower vehicles so that as they reached the center of the curve their speeds were the same.

A California study (15) evaluated the effectiveness of devices similar to those described in the Bezkorovainy study. The "Before-After" study used accidents as a criterion measure of effectiveness. Standard curve warning signs (designated in the MUTCD as W3R or W5R signing) were found to exhibit no significant accident reducing effect. However, when standard advisory speed signs (W46R) were added to the curve warnings, significant accident reductions resulted. The specific accident type impacted upon was the "nighttime single vehicle running off the road". Results were so impressive that the study recommended placing advisory speed limit signing at every location requiring curve signing. The study further recommended special oversize curve warning - advisory speed sign combinations in severe problem areas.

Brackett (16) indicated that signing had little influence on the motorist's choice of speed. He further noted that similar findings had been obtained by Rowan and Keese (17), the California Highway Department (18), Ottini (19), and Wiley (20). These studies were likely to conclude with such statements as:

> "Surveys show that motorists ignore speed limit signs."
> "Most drivers are careful and drive according to the existing conditions, not according to the signing."
> "Traffic ignores posted speed limits and generally runs at speeds which the drivers consider reasonable."

Driver Perception of Signs. Many studies have been performed relative to drivers' perception of signs. Among the variables considered were: sign observation, sign conspicuity, sign color and shape, sign brightness, vehicle speed and position, driver characteristics, and the "importance" or "urgency of information" of the sign message.

A Swedish study (21) examined the general motorists detection probability of highway traffic signs. Laboratory experiments simulating traffic conditions produced unrealistic sign awareness, so in-traffic experiments were conducted. Five persons driving along a 170 km stretch of road registered 91 percent of the signs. In an attempt to find out to what degree road signs are recalled, 6,000 drivers were questioned regarding the last road sign passed. This procedure took into account drivers' familarity with the road, experience, exposure, whether or not they had been interviewed before. The signs were changed at various intervals and degree of road visibility was reported hourly.

Drivers familiar with the road and experiment gave the largest percentage of correct answers. Sign violators gave the lowest percentage of right answers. Sparse traffic tended to decrease driver awareness of signs.

A study conducted in Finland (22) dealt with factors affecting the conspicuity of traffic signing. Laboratory observations of driver recollections of numerous signs to develop the concept of conspicuity yielded the following conclusions:

1. The brighter a sign or the larger its brightness contrast, the better its conspicuity.
2. The simpler a sign is visually, the better its conspicuity.
3. The more a sign differs from other signs, the better its conspicuity.
4. The more frequently a sign appears on the road, the better its conspicuity.
5. The more obligatory a sign is, the better its conspicuity.

Ferguson, et al. (23) used questionnaires to evaluate driver awareness of sign colors and shapes. He found that there is a direct relationship between driver recognition and the uniformity of signing color and shape. There is a high carryover from traffic signal color since the signals require action and merit attention. Drivers do not pay much attention to or are not aware of particular sign colors. Red, yellow, and white in that order were the colors recognized most often. Shape and message were indicated as the most important sign variables.

Hakkinen (24) interviewed 2,768 drivers to determine the impact of some curve warning signs, some of which were augmented by advisory speed signs. Test signing was placed in advance of a curve in the roadway, and motorists were stopped ahead to report what they had recalled of the sign. Speed measurements were recorded for interviewed drivers.

Findings of the report are summarized as follows.

conditions were comprised of variations to the "Slippery When Wet" symbolic sign, ranging from its use by itself through increasing levels of specificity and conspicuity, to its use with flashing beacons and an advisory speed limit.

The primary measure of signing effectiveness was mean speeds at critical curve locations. The highest quartile speed group (fastest 25 percent) of vehicles arriving in advance of the curve was selected as the target sample. Significant speed reductions at critical curve locations were observed as the result of signing which employed flashing hazard beacons. Greatest slowing was observed during use of higher level signing with sign conspicuity having a greater impact than specificity. Higher speed reductions generally resulted from the supplementary use of advisory speed limits. These observations took into account normal hour-to-hour speed variation.

Questionnaire results were revealing in terms of motorists' responses to experimental signing. Vehicle speeds of interviewed motorists demonstrated that motorists who saw signing slowed down more than those who did not. Maximum speed decreases were observed at the most hazardous portions of curvature. The more familiar motorists were more likely to see the signs, and those with longer driving experience were more likely to read them. However, it was shown that the experimental skid hazard warning signs have a marginal effect on motorists' verbal assessment of the site as being a skid hazard.

Certain driver characteristics were linked to general perception of skid hazard. Younger drivers and those with prior skidding experience were seen to be more prone to assess test curves as potential skid hazards. Motorists who drive more miles per year exhibited higher speeds throughout the sites, but they were divided in their assessments of skidding potential. Female drivers were seen to be generally more sensitive to wet weather driving hazards because they gave lower estimates of safe wet pavement speeds, predominantly indicated that skid hazard warning signs were helpful, and indicated a tendency to panic in the event of an unexpected skid.

A recent British article (32) suggests a procedure for increasing the effectiveness of advisory speed limits in a way that would overcome motorist's known disregard for posted speeds. The article notes that a fixed speed limit is not necessarily suitable for all times of the day and night, nor is it suitable when the reduced speed is only required over a very short length of road such as on a bend or the approach to a road junction. This paper discusses the use of advisory speed signs, the effect of having a speedometer which can be seen while the driver is looking at the road ahead, and finally the use of pavement markings which give the driver the illusion that his speed is increasing causing him to slow down.

Suggestions for Accident Reduction Programs

The reviewed literature has demonstrated that, while there are vast gaps in human factors knowledge of skid accident causation, certain traffic control devices have been effective at deterring driver behavior known to contribute to skidding accidents. On the basis of this review, suggestions are made regarding both implementable remediation devices and direction for future research.

Implementable Countermeasures

Advisory speed signing at curve locations has been subjected to evaluation both through before-after accident study (15) and driver behavioral study (3) using rain-activated signs. Favorable results were obtained in each evaluation. Moreover, the use of advisory speed signs were shown to be legally feasible as a demonstration of prudent practice on the part of highway agencies (33); and a documented technique to determine applicable wet weather speeds is available (34).

The suggestion follows that activated warning signing be used as a skid accident reducing countermeasure. Specifically recommended signing is that designated in the 1971 Manual on Uniform Traffic Control Devices as the Slippery When Wet sign (W8-5) in conjunction with the Advisory Speed Plate (W13-1) and rainfall activated hazard identification beacons (similar to that called out in Section 4E of the MUTCD). The activation device should insure that beacon flashing will terminate as the pavement becomes dry. Sign location with respect to the curve should be in accordance with current practice.

Future Research Needs

A systematic human factors analysis of the driving task in a potentially skid hazard environment is necessary to examine broadly based causes of skidding accidents. Segmented progress toward such an endeavor already exists. Levels of driver performance have been defined (35); components of the driver's communication system relevant to skidding accidents have been identified (5); and search and scan patterns of drivers in a potential skidding situation have been studied (2). The integration of these and other human engineering findings in a system analysis can potentially lead to the development of additional skid accident reducing measures.

That more and better countermeasures are needed is evident from the facts that (1) skid resistive pavements are costly, and (2) signing has yet to be proven effective in a large-scale implementation effort. Moreover, signing was shown in one study to have a limited impact as the primary cue of potential skidding hazard. Other environmental components of roadway geometry, surface appearance, and prevailing ambient conditions are more apt to be sensed by the driver. Therefore, a more in-depth human factors study, incorporating sensitive measurement techniques such as driver eye movement photography, is needed to determine the appropriate sensory inputs used in certain skid prone driving situations. With such information, it is possible that more operationally effective, economic, and politically feasible countermeasures can be developed to alert the driver to skid accident potential.

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LEGAL IMPLICATIONS OF REGULATIONS AIMED AT REDUCING WET-WEATHER SKIDDING ACCIDENTS ON HIGHWAYS

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This paper analyzes the legal implications of regulations aimed at reducing wet-weather skidding accidents, including adoption of uniform minimum standards for skid resistant highways; pavement design, mix and selection; resurfacing or grooving; erection of warning signs; accident data collection; and establishment of general inventories of highways to set priorities for rehabilitation and repairs. The thrust of the paper is to identify those areas of state action in skid reduction that may either be immune from liability, or, conversely, subject to liability, for injuries or property damage arising out of motorists' accidents on highways with low or inadequate skid resistance. The admissibility into evidence and use of the skid reduction regulations at trial are discussed also. The paper is documented with references to federal and state statutes, case law, articles, and, in particular, FHWA skid reduction program regulations.

One problem of highway safety that is receiving increased attention by federal and state authorities is the high frequency of skidding accidents. An alarming three million highway accidents occur each year on wet pavements resulting in an estimated 7,500 fatalities and 250,000 injuries. Testimony, records, and films before the Congress have documented both the severity of the highway skidding problem and the success of new measures to improve skid resistance of highways having a high number of wet-weather skidding accidents.

Several methods are being considered to alleviate the highway skid problem. Among the alternatives are (1) the promulgation of minimum skid numbers with the requirements that states upgrade pavements with skid resistance below minimum acceptable standards, (2) the collection and use of accident data to identify hazardous locations, (3) the inventorying of locations designated for corrective measures, and (4) the systematic measurement of the skid resistance of pavements to locate unsafe areas.

It is because of the anticipated programs aimed at reducing the number of wet weather skidding accidents that there is a need for research on the question of state liability for the failure to exercise reasonable care in (1) the design, construction, and maintenance of highway pavements to achieve acceptable skid resistance; (2) selection of the appropriate method to reduce skidding accidents; (3) inventorying of hazardous skidding locations; (4) collection of accident data; and (5) standardization of skid measurement practices and procedures. Of interest are the discretionary nature of several of these objectives and the admissibility into evidence and use at trial of any skid regulations.

States are being encouraged to see that pavement surfaces are constructed and maintained for the best possible skid resistance and that inadequate pavements are identified and corrected. Following the enacement of the Highway Safety Act of 1966, skid resistance has received increased attention. The paper sets forth the background of federal policy in some detail, with referenced publications or regulations included in the Appendix.

Current skid resistance policy and procedures are set forth in Volume 12 of the Highway Safety Program Manual on Highway Design, Construction, and Maintenance. Regulations published February 3,1976 in the Federal Register urge the states to adopt a systematic skid reduction plan having three basic activities: evaluation of pavements to insure that good skid-resistant qualities are present, detection of wet-weather high accident locations by using the state accident record system, and the analysis of skid resistance for all roads with a speed limit of 40 m.p.h. or greater.

The paper analyzes the legal implications of wet-weather skid reduction objectives or methods, beginning briefly with discussion of the suability and liability of the state highway departments. Because of tort claims acts or court decisions in many states, state highway departments are more vulnerable to tort suits. As a result of the erosion of traditional sovereign immunity or governmental immunity, there has been a significant increase in tort litigation involving the departments.

A number of states have enacted tort claims legislation setting forth procedures for filing negligence actions against government agencies. Representative states having a tort claims act are: Alaska, California, Colorado, Hawaii, Idaho, Iowa, Nebraska, Nevada, New Jersey, Utah, and Vermont. Other states have state claims commissions to hear claims against the state agencies. Among the states that have established such boards or commissions are Arkansas, Georgia, North Carolina, Tennessee, and West Virginia.

The remaining states have differing approaches to the suability of agencies such as the Highway department. New York enacted a general waiver of immunity in 1920, while other states may provide for an insurance fund, or have special statutes permitting suit for "defective highways." Nevertheless, several states retain state immunity; among them are Delaware, Maine, Maryland, Mississippi, Missouri, New Hampshire, Ohio, Oklahoma, New Mexico, Pennsylvania, South Dakota, Virginia, Wisconsin, and Wyoming.

Although general rules are difficult to formulate, the state highway departments, in those states where they may be held liable for negligence, may have a duty to guard against or give adequate warning of slippery road conditions. Although the state has no duty to guard against accidents caused by mere natural conditions, it does have a duty to act where some feature of the highway construction, perhaps aggravated by wet-weather conditions, is a proximate cause of the skidding accident. For example, it has been held that where a highway is so constructed that a wet surface becomes very slippery and dangerous, and the public authority is on notice, there may be liability for a skidding accident.

Ordinarily, the duty of the state to correct dangerous conditions arises only when it has notice, either actual or constructive, of the hazard. Notice periods may be prescribed also by statute. Moreover, notice may be deemed to exist where the condition has been present for such a time and is of such a nature that the state should have discovered the hazard by the exercise of reasonable diligence.

The basic aspects of wet-weather skid reduction objectives or requirements must be analyzed in order to determine those for which the state might be held liable for negligence. An important legal defense is this: if the department is able to show that a decision is an exercise of discretion, then it may be immune from liability for any negligence in the performance or failure to perform a duty owed to the public.

This exemption for liability for negligence committed in the exercise or performance, or the failure to exercise or perform, a discretionary activity or duty has its roots in the common law of personal liability of public officials and employees. More recently, the exclusion for discretionary, as opposed to ministerial, functions extends to tort suits against government entities, and may be set forth in a tort claims act.

A long line of judicial decisions hold that certain areas of lawfully authorized planning or decision-making by the executive branch of the government are immune from liability. The paper discusses these cases, as well as others that have further confined the immunity of the highway departments to decisions that are both discretionary in nature and occur at the "planning level." That is, decisions requiring the exercise of discretion that are made at the operational-level are not protected by the immunity for discretionary action.

It is often difficult to distinguish between discretionary and nondiscretionary action. It appears that the defense is available if an injury is the result of a deliberate choice in the formulation of policy, or if the planning activity involves an evaluation of certain policy factors, such as the financial, political, economic, and social efforts of a given plan or policy. Some courts tend to look at the level of government where the decision was made, whereas others will grant immunity only to the initial policy decision, and not to decisions that, although discretionary in nature, only serve to implement the basic decision.

An analysis of the case law that may pertain to the specific objectives or requirements of a skid reduction program, results in the following general conclusions.

The first step, of course, is the initiation, after study and consideration, of a wet-weather skid reduction program. Probably no action could be maintained for the initiation of the program, the issuance of regulations, or the approval of any overall plan, any of which may have a defective feature. Moreover, the decisions of when and how to upgrade highways appear to be protected, for the same reason: it is not a tort to govern and government agencies may undertake public works or other such projects.

In addition, should wet-weather skid reduction programs contain errors or mistakes of judgment, or if regulations are predicated on reasonable, but faulty assumptions, or there are unexpected, hazardous results, probably no action could be maintained successfully. The reason is that all of these areas involve high-level planning requiring the consideration of many factors and the application of special expertise.

To the extent that there is involved any federal approval of a defective plan or program of a state highway department, several cases have held that the federal participation in the review and approval of state plans do not subject the federal agencies to liability. Such approval is discretionary in nature and protected. Moreover, it is improbable that federal agencies would be liable for any negligence of the states in implementing any federal skid program or regulations, unless the federal agency was a participant in the negligent act.

Furthermore, the Highway Safety Act of 1966 has been held not to create any duty on the part of the states owing to any person who is injured on a state highway failing to meet the requirements of the Act. A claimant's cause of action in tort must arise on the basis of state law, and, should state law not afford him a remedy for negligence arising out of highway operations, the fact that the state is not in compliance with the Highway Safety Act or regulations issued pursuant thereto does not improve the claimant's position.

For claims arising out of wet-weather skidding accidents on highways with low skid resistance, it appears that the departments would not be held liable for those aspects of a wet-weather skid reduction program that are discretionary in nature, such as the design and selection of pavements. Because of the expertise that is required and the numerous factors that must be considered in selecting the proper pavement for certain highway conditions, it seems that the highway authority is vested with immune discretion to choose the proper or appropriate pavement surface.

One case holds that a government entity does not have to apply a rougher surface, where the original surface, alleged to have been extremely slippery, was selected by experienced engineers as the most suitable manterial for the involved location. It appears that there is no general duty to pave with a particular material or in a particular way, to have uniformity of construction on all streets, or to reconstruct streets immediately where there is a change or unexpected use. The materials discussed in the paper, and included in the Appendix, suggest strongly that pavement design, mix, and selection are discretionary in nature.

There may be exceptions to this immunity, for obvious, manifest dangers or for unreasonable approval of a design without adequate consideration. Moreover, in a few states there may be a duty to review approved designs where highway hazards result from known "changed conditions."

In the maintenance of highways, states are generally required to correct wet-weather skidding hazards of which they have notice or knowledge. Maintenance is regarded as an operational-level activity, and the discretionary defense has been held to be inapplicable. The cases hold the state to a continuing duty to maintain the highways in a safe condition. This statement is no less true when a claim involves the negligent failure to maintain highways reasonably free of slipperiness.

States have been held liable for failure to maintain or apply highway surfacing materials properly or for failing to apply materials to counteract slippery conditions. States may be held liable for failure to correct highway defects that result in low pavement skid resistance. Where a highway becomes slippery when wet because of wear and the effect of weather, the state may have a duty to maintain and repair it. In sum, states may have a duty to correct known wet-weather skid hazards, or at least to provide adequate warning.

Aside from the basic questions of liability, it appears that accident data prior to an accident that identifies locations prone to wet-weather skidding accidents would be admissible on the issues of the state's notice and of the hazardous nature of the highway.

Regulations setting forth the requirements of a wet-weather skid reduction program would be admissible at trial, particularly where the regulations have the force of law. If the regulations are general and discretionary in nature, they would constitute some evidence of negligence if they were not followed. However, where there was a failure to comply with a specific mandatory requirement, the violation of the regulation could be held to constitute negligence per se.

Finally, a general inventory of hazardous wet-weather skid locations, aside from being admissible on the questions of notice and nature of the hazardous condition, could be a basis for a claim that any highway not in compliance was ipso facto hazardous and that the state has an immediate duty to correct the condition. Cases suggest, however, that the state's decision on which highways to correct first is discretionary, and, that, moreover, to impose such a rigid duty to repair all roads at once is unreasonable.

METHODOLOGY FOR ESTABLISHING FRICTIONAL REQUIREMENTS

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The nature of the wet-pavement skidding accident problem is briefly discussed. A cursory review of the traffic accident literature is given to highlight the roadway geometric and driver maneuver performance specific nature of the problem. A conceptual methodology to establish cost-effective frictional requirements is presented. This methodology is based upon the calculation of a margin of safety (MOS) defined as the difference between available tire-pavement friction and the level of driver demand for friction. Models to calculate the level of available tire-pavement friction and the level of frictional demand as a function of site specific traffic operational characteristics, roadway geometry, and surface characteristics are discussed, and an example is given for the case of two-lane passing.

Introduction

Rising mean traffic speeds and increasing traffic volumes on many highway facilities have resulted in an ever increasing potential for wet pavement skidding accident occurrence. The problem is depicted in Figure 1 where the general relationship between available tire-pavement frictional force and driver demand for that frictional force are shown. The fundamental dependence upon speed, as shown in the figure, arises from the fact that on wet pavements, the tire-pavement contact area is determined by the efficiency with which the tire can expel water from that area. Viscocity and other effects cause this efficiency to degrade at higher speeds — the tire is unable to maintain a dry contact area. In the limit, at high speed, the tire hydroplanes if there is sufficient water film thickness. As will be discussed, the determination of tire-pavement frictional levels is highly dependent upon site specific considerations including the environment, traffic operational characteristics, and most importantly, vehicle maneuver determining roadway geometry. Before discussing these factors, some background on the skidding accident problem is given.

Rizenbergs (1), reports the results of an accident correlation study which indicates that the ratio of wet-pavement accidents to all reported accidents (wet-pavement accident ratio) on high speed facilities in Kentucky is between 0.15 and 0.25. A similar study conducted in Virginia (2) in 1958 indicated a wet-pavement accident ratio of between 0.2 and 0.4.

The accident statistics reported above indicate wet-pavement accident rates but do not differentiate skidding accidents from other wet-pavement accidents. Hankins (3) reports the results of a detailed accident investigation and analysis study in which he found that 63.6 percent of all wet-pavement accidents in Texas in recent years were attributable to skidding. Hankins also was able to demonstrate the fact that different accident rates could be attributed to different vehicle maneuver situations. In particular, his data indicate that 40 percent of wet-pavement accidents involve a cornering action of the vehicle, where a cornering action is also defined to include passing maneuvers. Kummer and Meyer (4) report a survey of six states where the fraction of wet-pavement accidents attributable to skidding was determined. The results of that survey are given below:

Skidding Accidents/Wet Pavement Accidents (5)

	1960	1961	1962	1963	1964	1965
Arizona	--	--	1.4	0.5	0	--
Connecticut	17.2	18.2	15.6	19.6	13.6	11.8
Louisiana	32.6	34.1	11.7	13.5	2.4	--
Maine	--	--	--	--	23.4	--
Montana	12.0	7.5	0.7	4.6	1.5	--
Wyoming	--	0.9	1.4	0.9	20.3	--

Numerous other investigations have obtained results which suggest that the occurrence of skidding accidents is maneuver specific. Smith(5), in his summary of all NCHRP research, states the conclusion that intersections and curves are highway sites of highest accident involvement. Kemper (6) reports that 43 percent of all two-lane traffic accidents in Virginia in 1965 involved overtaking and/or passing, approximately 50 percent of which might be attributable to skidding.

A skidding accident occurs when the maximum force which can be transmitted at the tire-pavement interface is exceeded. This occurs under several circumstances, including:

1. Inadequate tire-pavement frictional potential due to pavement surface wear or inadequate design.

2. Large water film thickness on the pavement due to poor pavement drainage.
3. Inadequate geometric design.
4. Poor vehicle and/or tire condition.
5. Driver error through inattention or carelessness.

The above list indicates general circumstances under which a skidding accident may occur. Each particular situation is the result of a complex interaction between the roadway, vehicle, tire, and driver. Several researchers have investigated these interactions by analyzing accident data in such a manner as to highlight specific highway and traffic parameters pertinent to the particular situation. Sabey (7) reports the results of a study completed in Great Britain where the percentage of wet-pavement accidents correlated in an inverse linear fashion with pavement skid resistance as measured with the British Pendulum Tester. Mahone (8) showed that the percentage of wet-pavement accidents could be related to Predicted Stopping Distance Number (PSDN). The PSDN is a measure of skid resistance characterized by the distance required for a vehicle to perform a full locked-wheel stop from a known initial speed. Mahone also found that for a pavement with a constant PSDN, the percentage of wet-pavement accidents decreased as traffic volume increased. This suggests again the relationship between skidding accidents and vehicle maneuvers.

In addition to highway and traffic parameters, the wet-pavement skidding accident rate is also a function of the local environmental conditions (i.e., rainfall intensity, mean ambient temperature, etc.). Giles (9) has shown that skidding accident rates change with the seasons of the year, being highest in the late summer and fall. This elevated accident rate is attributable to numerous factors, but most notably, the seasonal change in pavement surface condition.

The study of frictional requirements reported by Kummer and Meyer (4) was designed to establish minimum skid resistance levels for main rural highways. The study relied upon information regarding driver behavior, skidding accident experience, and the mechanics of the tire-pavement interface, to develop models for the establishment of frictional requirements. The important conclusions drawn from that study were; (1) the establishment of frictional requirements for a particular site should be based upon a statistical description of the traffic at that site, (2) frictional requirements can only be cost-effectively established with respect to the local demands established by traffic and (3) the upper bound upon the level of tire-pavement friction, which should be available to traffic, is determined by economic considerations, not by safety considerations.

Consistent with the conclusions, as described above, it is suggested that establishing the appropriate level of frictional requirements to reduce skidding accidents, should be accomplished by performing appropriate trade-offs between the desired level of safety (accident reduction), the costs associated with establishing that level, and the impacts on the level of service of the facility. The design level of friction is therefore not determined a priori, but is established by local policy as defined by the safety-cost-service tradeoff. In order to perform such tradeoffs, models are required which relate the key traffic operational, roadway geometric, pavement, and driver performance parameters to these measures.

The basis of the methodology is the hypothesis that the appropriate measure of safety is the difference between the level of available tire-pavement friction, F_A, and the level of demanded friction, F_D. Therefore models to estimate F_D and F_A as a function of operational, pavement and traffic parameters are required. Figure 2 is a flow chart of the major steps of the methodology. The methodology emphasizes that the level of demanded friction is dependent upon specific maneuvers and upon the frequency of occurrence of each maneuver. In addition, since several high frictional demand maneuver types may occur at a site, the methodology allows for the combination of the frictional demand for the individual maneuvers into an overall site frictional demand. A brief example is given to illustrate this point.

Consider a two lane isolated horizontal curve. The following maneuvers may occur (1) constant speed cornering, (2) cornering with acceleration, (3) cornering with braking, and (4) passing. The passing maneuver may be the most severe due to the combination of high longitudinal and lateral accelerations, however the frequency of occurrence of this maneuver may be low. Constant speed cornering has the lowest frictional requirement but the highest frequency of occurrence. The other two maneuvers are intermediate both in terms of severity and frequency. The friction required by drivers at the site is a function of the severity and frequency of occurrence of the maneuvers at the site, and is represented as a weighted average of the severity and the frequency of occurrence as follows:

$$\left(F_D\right)_T \sum_{i=1}^{n} \alpha i \left(F_D\right)_i \qquad (1)$$

where

$\left(F_D\right)_T$ = total frictional demand (SN_{40})

$\left(F_D\right)_i$ = frictional demand for ith maneuver (SN_{40})

α_i = frequency of occurrence of ith maneuver (Number/Day)

The completion of the methodology requires the development of models for estimating available tire-pavement friction, characterized by SN_{40}, and the level of demanded friction characterized by peak maneuver accelerations as a function of site variables. In addition, the means to compare available and demanded friction on a common scale as well as the prediction of maneuver frequencies is required.

Available Tire-Pavement Friction

The lack of general relationships for skid number and key parameters has prompted research directed towared characterizing the effect of the more important design parameters. A description of the influence of the key parameters on available tire-pavement friction, SN_{40}, is given in References (10 and 11). In this context recent work has been directed to the development of relationships between skid number and speed as shown below.

$$SN = SN_{40} + (SNG)\ V \qquad (2)$$

where

SN = skid number (a function of speed and pavement properties)

V = speed

SNG = skid number speed gradient (a function of pavement properties)

A qualitative description of the manner in which surface texture influences the skid number-speed curve has been reported (10, 11). It is generally accepted that while the shape and size of the pavement asperities determined, to a large degree, the hysteresis friction losses sustained by the tire, it is the channels between these asperities (i.e., pavement macrotexture) which facilitate the removal of the bulk water from the surface, and consequently determine the amount of dry contact area in the tire-pavement interface. The drainage characteristics of the pavement, therefore, directly affect the skid number-speed relationship since significant frictional forces can only arise in the dry contact area.

Schultze and Beckmann (12) report the development of a relationship between pavement drainage characteristics and the slope of the skid number-speed curve. Using stereophotographs of 48 pavement textures, it was shown that a correlation does exist between the mean void width of the pavement texture (i.e., the average spacing of pavement asperities) and the skid number-speed gradient. The results are given as Equation 3 and are shown in Figure 3.

$$Y = 14.5 \quad 72.6X \quad 103.6X^2 \qquad (3)$$

where
Y = mean void width (1/100 inch)

$X = SN_{20} = SN_{60}$ (speed in km/hr)

It should be noted that these results are based upon a sample of only 48 pavements and therefore must be applied carefully.

Equation 3 has been applied recently to the evaluation of the skid number speed gradient of a wide variety of in service pavements (13). Further verification of this relationship has been performed by comparing trends in the data reported by Gallaway (14) with those associated with Equation 3. The comparison has shown acceptable agreement, thus providing further confidence in the relationship.

For convenience to this application the original Schulze-Beckman correlation has been modified so that the parameters are expressed in standard units as follows:

define

$$X^* = \frac{SN_{12.5} - SN_{37.5}}{SN_{25}} \qquad (4)$$

and

$$X^* = 1.491 - \left\{-0.122 + 0.156y\right\}^{1/2} \qquad (5)$$

where
y = mean void width (1/100 inch)

More recently new instrumentation has been developed by which more detailed charecterization of pavement characteristics is possible. Moore (15) measured the drainage characteristics of seven laboratory and roadway pavement samples using the Outflow Meter, an instrument which simply simulates the escape of water through texture canals in the tire-pavement contact area. Assigning a drainage number, based on relative drainage capability to each of the surfaces, a significant correlation was developed between the drainage numbers and the skid number-speed gradient. Substantial agreement exists between Moore's results and those of Schulze, and Beckmann, thus further confidence in these parameters as descriptors of SN_{40} is obtained. Equation 5 above will be the predictive relationship employed by the methodology.

Frictional Demand

Frictional demand associated with passing on two-lane rural roadways, and cornering on isolated horizontal curves, were studied experimentally within the study reported in Reference (11). Intersection braking, a high frictional demand maneuver, has been studied by Farber (16). Although the results of that study are employed in the methodology, for brevity, they are not discussed here.

Passing of Two-Lane Rural Roadways

Data was collected at four two-lane passing sites in Louisiana and California in order to characterize the relationship between combinations of lateral and longitudinal acceleration traffic parameters and site variables. The data consisted of time position measurements, which were converted to speed, lateral placement and longitudinal and lateral acceleration values. The site data is summarized below:

Summary of Passing Site Data

State	Route	File Number	Length (ft)	ADT	Sample Size
Louisiana	167	C3-1	> 3000	2180	18
Louisiana	167	C3-1	> 3000	2180	49
Louisiana	167	C3-3	> 3000	2180	38
California	121	T2-1	> 3000	5400	38

The experiments employed an impeding vehicle to encourage selected drivers to perform a passing maneuver. A schematic of the test scenario is given in Figure 4. The driver of the impeding vehicle (I) waits, at the roadedge, for a candidate passing vehicle (P). When an appropriate subject is identified an impeding vehicle pulls onto the roadway and establishes a predetermined impeding speed (Vi), (typically 35 to 45 mph). The passing vehicle after being captured and stabilized at speed Vi is maintained at that speed throughout the impeding section (typically 1/4 mile in length). Upon entering the instrumented test section, the impeded vehicle decides whether or not to pass. The time position signature of the passing maneuver is recoreded for later analysis. A typical recored is shown in Figure 5.

where:

X = distance along passing lane (ft)

Y = lateral position from roadedge (ft)

V = vehicle speed (mph)

ALONG = vehicle longitudinal acceleration (g)

ALAT = vehicle lateral acceleration (g)

RADV = vehicle path radius (ft)

Prior to a discussion of the detailed analysis of the passing data, it is appropriate to consider the general data trends. Figure 6 shows the one σ (one standard deviation) envelope of vehicle trajectories during passing. This figure was developed by referencing all lateral and longitudinal dimensions to the start of the passing maneuver. The transformed lateral coordinate Y_S, represents the lateral deviation of vehicle path during the passing maneuver.

It should be noted that the mean passing path deviation is 9.1 feet for the pullout portion of the maneuver. The 10 envelope represents a maximum distance which is approximately 0.5 to 0.75 of the average vehicle track width. Also note that the length of the pull out portion of the maneuver is approximately 400 feet.

Mean values for lateral acceleration, longitudinal acceleration, and vehicle speed are shown in Figure 7. This figure shows that vehicles tend to continue accelerating throughout the pullout and passing phase of the maneuver. The figure also suggests that critical combinations of lateral and longitudinal acceleration may exist.

The objective of this task was the development of relationships for the prediction of lateral and longitudinal acceleration levels during the passing maneuver. Since individual site sample sizes were insufficient, data from all sites were lumped for analysis. A series of analyses were performed to determine if relationships with the general form of Equations 6-10 could be developed from the data.

$$\text{ALATM} = J_i \text{ALON GA} + K_j \tag{6}$$

$$\text{ALATM} = K_i \text{ALONGM} + K_j \tag{7}$$

$$\text{ALATM} = K_i \text{SPD} + K_j \tag{8}$$

$$\text{ALONGM} = K_i \text{GAP} + K_i \tag{9}$$

$$\text{ALATM} = K_i \text{RA} + K_i \tag{10}$$

where

ALATM = maximum lateral acceleration (g)

ALONGA = longitudinal acceleration associated with ALATM (g)

ALONGM = maximum longitudinal acceleration (g)

SPD = vehicle speed at the first trap (mph)

GAP = passing gap (ft)

RA = vehicle path radius associated with ALTM (ft)

No correlation was found to exist between ALATM and any of the dynamic variables (equation 6 to 9) however, significant correlation was found to exist between ALATM and the associated vehicle path radius, RA (Equation 10). This relationship is shown for selected data in Figure 8 and given below,

$$\text{ALATM} = \frac{170}{\text{RA}} \tag{11}$$

Analysis of data collected by Glannon (17) during a program conducted at Texas Transportation Institute indicates a similar relationship for maximum lateral acceleration. These results are given in Figure 9.

Although the data trends exhibited by Figure 8 and 9 are the same, the magnitude of the maximum lateral accelerations are different. The data collected by Glennon was designed to address high speed passing maneuvers where impeding vehicle speeds were in excess of 50 mph. The data collected in this study was designed to address a more naturally occurring range of impeding speeds, 35 mph to 50 mph. The relationship given in Equation 11 is believed more responsive to this problem, and therefore, will be utilized as the basis for establishing passing frictional requirements.

In order to establish the level of frictional demand for the passing maneuver, the level of longitudinal acceleration and speed associated with ALATM are required. A Kilmogorov-Smirnov 2 tailed test was conducted to establish the normality of (1) the distribution of longitudinal acceleration associated with ALATM (2) the distribution of speed associated with ALATM and (3) the distribution of RA associated with ALATM. Each distribution was found to be normal at the 5 percent level. A similar analysis established that the distribution of ALATM was not normal.

Since the value of RA is not an easily measurable quality, it cannot conveniently be utilized parametically. However, following the analyses performed by Glennon (17) RA can be utilized as a desing guide by calculating the value of ALATM associated with various cumulative percentile levels of RA. Glennon, for example chose the 10th percentile (the value of RA such that 10 percent of the vehicles had path radii smaller than RA) as the design point.

In order to determine the total frictional demand, values of longitudinal acceleration and speed must be calculated in a manner consistent with the choice for cumulative percentile of RA. It is recommended that the following set of predictors be utilized.

$$\left.\begin{aligned} \text{ALATM}_p &= \frac{170}{\text{RA}_p} \\ \text{RA}_p &= \overline{\text{RA}} + Z_p \sigma R \\ \text{ALONGA}_p &= \overline{\text{ALONGA}} + Z_p \sigma_A \\ \text{VA}_p &= \overline{\text{VA}} + Z_p \sigma_V \end{aligned}\right\} \tag{12}$$

where

ALATM = maximum lateral acceleration (g)

RA = vehicle path radius associated with ALATM (ft)

$\overline{\text{RA}}$ = mean of RA (ft)

σ_R = standard deviation of RA (ft)

ALONGA = longitudinal acceleration associated with ALATM (g)

$\overline{\text{ALONGA}}$ = mean of ALONGA (g)

σ_A = standard deviation of ALONGA (g)

V_p = vehicle speed associated with ALATM (mph)

$\overline{\text{VA}}$ = mean of VA

σ_V = standard deviation of VA

Z = normal distribution parameter

P = subscript denoting cumulative percentile level

Passing Frequency

A model has been developed to predict the expected frequency of passes on a two-lane rural road as a function of traffic distribution, speed, and driver behavioral characteristics. The model incorporates past passing behavioral research into an intuitive model and is given in Equation 13 below:

$$\dot{N}_p = \sum_{i=1}^{r} (k_i L) \sum_{j=i+1}^{r} k_j (v_j - v_i) \cdot \int_{x=o}^{\infty} \alpha(x(v_j - v_i))\, \hat{\phi}(x) dx \tag{13}$$

where

$\dot{N}_p$ = frequency of passing (no./mile-hr)

k = concentration of vehicles (no./mile)

L = section length (mile)

V = speed (mph)

α = gap acceptance function

x = passing gap

$\hat{\phi}$ = distribution of inter-arrival times $(\text{ft})^{-1}$

In order to calculate the expected frequency of passing of a particular section of roadway, models for the gap exceptance function must be developed. Farber (18) has measured the gap acceptance function under conditions similar to the ones utilized for testing in this program. Utilizing this data, a model has been developed to fit the gap exceptance data. This model is of delayed exponential form, and is given by the following:

$$\alpha(x, \Delta V) = \begin{cases} 0 & \text{if } x < x_L(\Delta V) \\ 1 - e^{-\theta(x-x)_L} & \text{if } x \geq x_L(\Delta V) \end{cases} \tag{14}$$

where for convenience $(v_j - v_i)$ is denoted by ΔV. Assuming that the dependence of $\alpha(x,\Delta V)$ on ΔV is only due to dependence of x_L on ΔV and the dependence of x_L on ΔV is linear, and further assuming that the distribution of inter-arrival time $\hat{\phi}(x)$ is exponentially distributed with rate λ, a closed form integration can be performed to determine values of $x(\Delta V)$. The results of this integration are given below:

$$\alpha(\Delta V) = \frac{\theta}{\theta + \hat{\lambda}} e^{-\hat{\lambda} x_L} \tag{15}$$

For convenience, various values of the gap acceptance function have been tabulated for traffic flow rates in the oncoming lane of 500 vehicles per hour at a rate of arrival in the passing lane of 0.12 per second. These are shown in Table 1. Based upon the calculated gap acceptance function in Table 1, estimations of the number of passings which will occur on a given section of roadway can be made. An example follows:

Assume that there are two distinct speed bins, V_1 = 30 mph and V_2 = 50 mph and q, q_1, q_2 denote the volume of vehicles, vehicles having Speed V_1 and vehicles having speed V_2, respectively. Also assume that $q_1 = q_2$ and that $q_i = k_i v_i$ where i = 1,2. Then the number of passings of vehicles per hour for L = 0.1 mile is calculated for various values of q and $\hat{\lambda}$. It has again been assumed that θ = 0.12 per second, and $\alpha(v_j - v_i)$ is given in Table 1. The calculations are summarized in Figure 10. The passing frequency model, Equation 13 will be utilized in the development of site frictional requirements.

Constant Speed Cornering

Data was collected at 9 isolated horizontal curves in Louisiana, Mississippi and California in order to characterize the relationship between lateral acceleation, traffic parameters and site variables. The data consisted of time position measurements which were converted to speed, lateral placement and lateral acceleration values. The site data is summarized in Table 2.

The data were analyzed according to the analysis scheme originally outlined by Farber (16). However, normality tests indicated in general that, on a trap by trap basis, peak lateral acceleration, and speed were not distributed normally. Therefore, a series of direct regressions were performed for all sites combined with the following results:

$$A_{P,99} = 2.424\, \bar{A}_{NOM} + 1.097\, \sigma_{NOM} - \frac{295.349}{R} + 0.339 \tag{16}$$

$$A_{p,95} = 2.209\, \bar{A}_{NOM} + 0.617\, A_{N,95} - \frac{285.247}{R} + 0.240 \tag{17}$$

$$A_{p,90} = 2.426\, \bar{A}_{NOM} + 0.472\, \bar{A}_{N,90} - \frac{247.145}{R} + 0.184 \tag{18}$$

$$V_{p,99} = 1.017\, \bar{V}_N + 0.829\, \sigma_N - \frac{1101.721}{R} + 7.611 \tag{19}$$

$$V_{p,95} = 0.914\, \bar{V}_N + 0.804\, \sigma_N - \frac{978.017}{R} + 8.366 \tag{20}$$

$$V_{p,90} = 0.909\, \bar{V}_N + 0.777\, \sigma_N - \frac{743.765}{R} + 7.654 \tag{21}$$

where

$A_{p,99}$ = 99th percentile peak acceleration (g)

$A_{p,95}$ = 65th percentile peak acceleration (g)

$A_{p,90}$ = 90th percentile peak acceleration (g)

$\overline{A}_{NOM}$ = mean nominal acceleration, $V^2/15R$ (g)

σ_{NOM} = standard deviation of nominal acceleration distribution (g)

R = site radius of curvature (ft)

$A_{N,95}$ = 95th percentile of nominal acceleration distribution (g)

$V_{p,99}$ = 99th percentile peak velocity (mph)

$V_{p,95}$ = 95th percentile peak velocity (mph)

$V_{p,90}$ = 90th percentile peak velocity (mph)

$\overline{V}_N$ = mean nominal speed distribution (mph)

σ_N = standard deviation of nominal speed distribution (mph)

These equations are utilized to estimate the specified levels of acceleration demand as a function of speed values measured at the midpoint of the curve as follows

$$A_{NOM} = \frac{V_{mp}^2}{15R} \qquad (22)$$

$$V_{NOM} = V_{mp} \qquad (23)$$

Relationship Between Acceleration and Skid Number

The problem of relating combinations of longitudinal and lateral accelerations developed by a vehicle to resultant vehicle acceleration and pavement skid number, including the effects of vehicle dynamics, vehicle configuration and tire properties, remains unresolved in general. Many attempts have been made to develop simple relationships between these quantities. In particular, the following relationship has been used widely

$$ARES = \left(ALAT^2 + ALONG^2\right)^{1/2} \qquad (24)$$

where

ARES = resultant acceleration (g)

ALONG = longitudinal acceleration (g)

ALAT = lateral acceleration (g)

This relationship is an approximation to a more general relationship which describes the resultant acceleration in terms of the combination of lateral and longitudinal acceleration in elliptical form as follows:

$$\left(\frac{ALONG^2}{ALONGM^2} + \frac{ALAT^2}{ALATM^2}\right)^{1/2} = 1 \qquad (25)$$

where

ALONG = longitudinal acceleration (g)

ALONGM = maximum longitudinal acceleration (g)

ALATM = maximum lateral acceleration (g)

ALAT = lateral acceleration (g)

Data developed at the Texas Transportation Institute and reported by Hayes (17) indicates that the single mode maxima of the longitudinal acceleration and lateral acceleration can be related to speed and SN_{40}. These results are shown in Figure 11. These data were collected during full-scale test track experiments where a single vehicle was maneuvered under a variety of speeds on several different pavement types and the accelerations monitored on-board in the vehicles.

The thrust of the results shown in the figure is that bounding values of combinations of longitudinal and lateral acceleration can be determined as a function of speed and skid number. Although it is not entirely clear from this data that unique correlations between dynamic variables and SN_{40} exist, the limited results thus far do indicate that the bounds can be established for specific pavement types.

Although no universal correlation between SN_{40} and combinations of longitudinal and lateral acceleration has been demonstrated, the formulation shown in Figure 11 has been in widespread use. The original formulation was introduced by Harris and Reilly (18) and subsequently used extensively by Holmes and Stone (19). Also, these relationships form the basis for calculating the coefficient of friction, at the tire-pavement interface, in large scale simulation models including HVOSM (20).

Farber (16) had developed limited data of this kind for one vehicle type. This data is shown in Figure 12, where the skidding bounds are indicated by the best fit ellipse.

The form of the available data is such that it is more convenient to convert SN_{40} levels to equivalent acceleration values utilizing the previous figure. The procedure to accomplish this is based upon a determination of the radius of a circle which passes through the point (ALAT*, ALONG*). These points represent the calculated values of longitudinal and lateral acceleration demand. The resultant acceleration (ARES) corresponding to the specific SN_{40} value is given below

$$ARES^2 = ALATM^2 + (ALONG^*)^2 \quad 1 - \left(\frac{ALATM^2}{ALONGM^2}\right) \qquad (26)$$

where

ARES = resultant acceleration corresponding to SN_{40} (g)

ALATM = maximum lateral acceleration corresponding to SN_{40} (g)

ALONGM = maximum longitudinal acceleraiton corresponding to SN_{40} (g)

ALONG* = calculated longitudinal acceleration demand (g)

The balance between the level of acceleration demand (ARESD)(combination of lateral and longitudinal ma, acceleration) and available tire pavement friction (ARBSA) is evaluated by calculating ARES and described above and comparing that with the level of acceleration demand calculated using Equation 16. A set of example calculations utilizing the data contained in Figure 12 is given in Table 3 also note that the normalized margin of available function over demanded friction is also tabulated. Positive values of the margin imply no skidding.

Utilizing the relationships developed for available tire-pavement friction and the level of demanded friction, the margin of safety can be calculated as their difference as a function of traffic, operational and pavement properties.

As discussed previously, the goal of the methodology development is to provide a tool by which cost, safety, and service considerations can be traded off to establish frictional requirements consistent with local policy guidelines. The concept of this trade-off analysis is shown in Figure 12. In the context of this discussion, the safety parameter, S is given by MOS, the costs are those attributable to establishing the level of safety, and the level of Service, F, is defined in the standard engineering sense by speed and delay.

Conceptually, the trade-off problem is one of simultaneously satisfying multiple objectives for S, C, and F. However, practically the problem is reduced to a single objective problem with constraints. Consider the example in Figure 13.

Suppose the objective is to maintain the cost within the bounds C_1 and C_2 with the constraint that the level of safety should be maintained between S_1 and S_2 and the level of service should be between F_1 and F_2. In addition, it is postulated that there is a bonding relationship between cost and service given by $C = f(F)$. Under these circumstances the skidding accident reduction countermeasures which satisfy these constraints are shown by the shaded region. Several other interesting points can be noted. Point B_2 is the solution for highest level of safety; point B_5 is the solution for lowest cost, and point B_4 is the point of diminishing returns.

In summary, the establishment of cost-effective frictional requirements is a policy issue which requires tools to consider the interaction of highway, vehicle, driver, and environmental factors at specific highway sites. The detailed application of the methodology requires the development of continuous frictional relationships between the variables. Such relationships have not as yet been developed.

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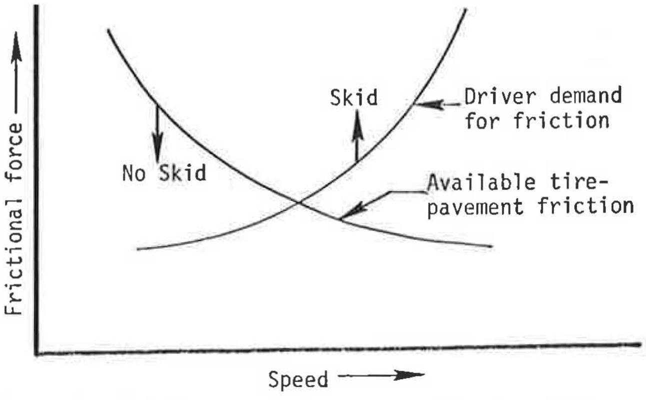


Figure 1. Relationship between available tire-pavement and driver demand for friction.

Figure 2. Flow chart.

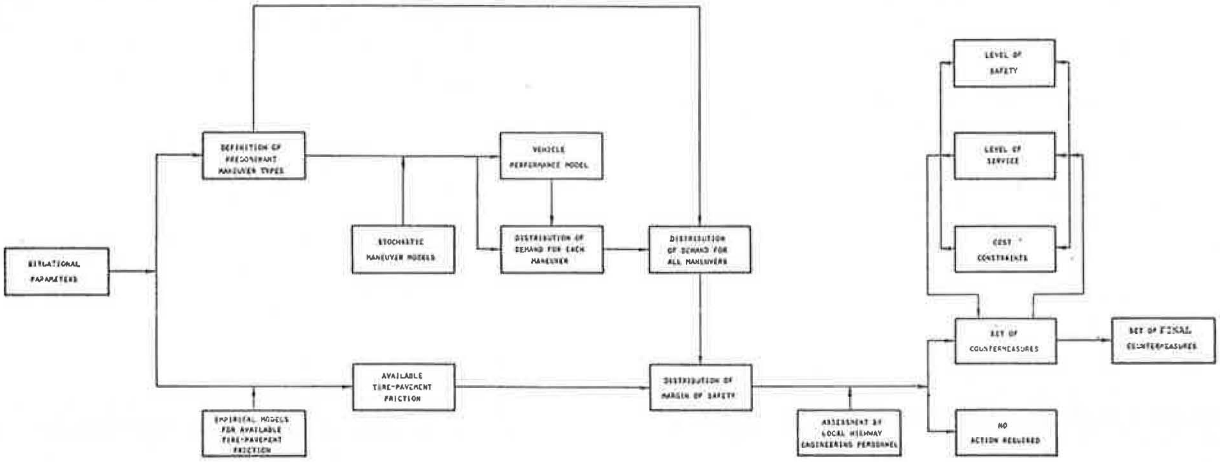


Figure 3. Correlation between surface texture and friction coefficient-speed gradient.

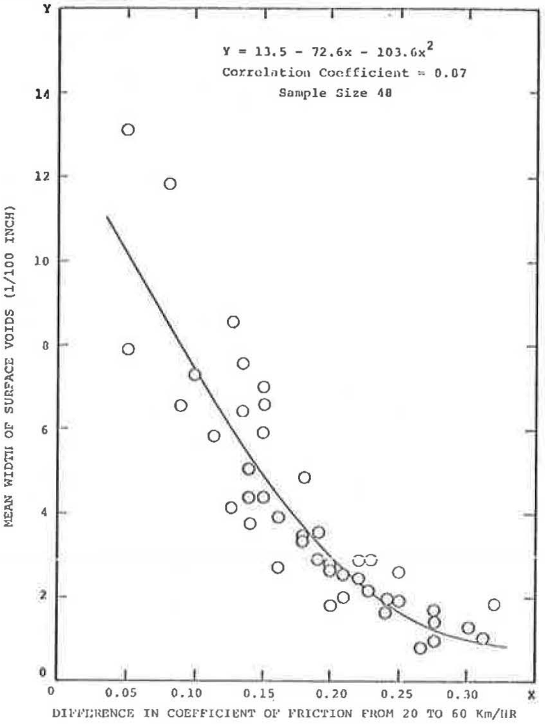


Figure 4. Example of passing scenario using impeding vehicle.

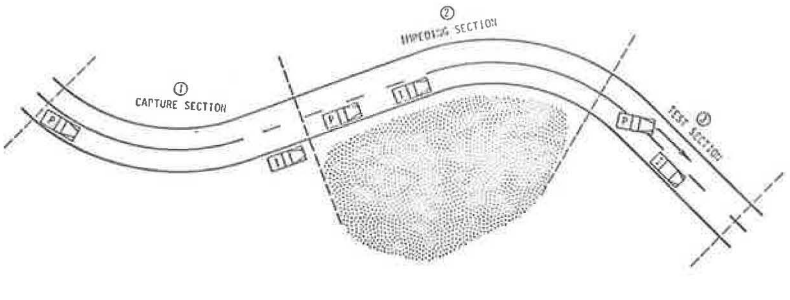


Figure 5. Sample processed passing record.

```
TRAP      X            POS        Y              SPD
   1        0.0          9.74       9.89          41.01
   2       45.0         10.19      10.36          42.61
   3       90.0         11.15      11.20          44.53
   4      135.0         12.25      12.65          46.22
   5      180.0         14.50      14.58          49.59
   6      225.0         16.96      16.94          50.04
   7      270.0         14.66      19.06          54.55
   8      315.0         16.26      20.44          50.51
   9      360.0          0.00      21.09           0.00
  10      405.0         16.60      21.11          56.52
  11      450.0         16.34      20.76           0.00
  12      495.0         15.37      19.13          59.29
  13      540.0          0.00      17.92           0.00
  14      585.0         17.36      16.34          61.63
  15      630.0         15.30      15.23          61.63
  16      675.0         13.02      13.02          62.34
  17      720.0         10.73      11.49          62.70
  18        0.0          0.00      10.73           0.00
  19        0.0          0.00      10.73           0.00
  20        0.0          0.00      10.73           0.00


     V             ALNG       ALAT      RADV
      41.54        0.000      0.000     0.
      42.72         .092       .022     5.525E+03
      44.45         .134       .040     3.305E+03
      46.78         .144       .035     4.170E+03
      48.62         .166       .033     4.856E+03
      51.39         .117      -.020     8.857E+03
      51.70         .056      -.066     2.706E+03
      52.86         .071      -.067     2.782E+03
      53.51         .124      -.059     3.267E+03
      55.98         .182      -.039     5.329E+03
      57.90         .139      -.141     1.508E+03
      59.22         .112       .048     4.848E+03
      60.46         .091      -.044     5.582E+03
      61.24         .064       .057     4.408E+03
      61.87         .045      -.138     1.853E+03
      62.22         .033       .087     2.957E+03
      62.58        0.000      0.000     0.
      62.70        0.000      0.000     0.
      62.70        0.000      0.000     0.
      62.70        0.000      0.000     0.
```

Figure 6. Distribution of mean passing paths for sites in Louisiana and California.

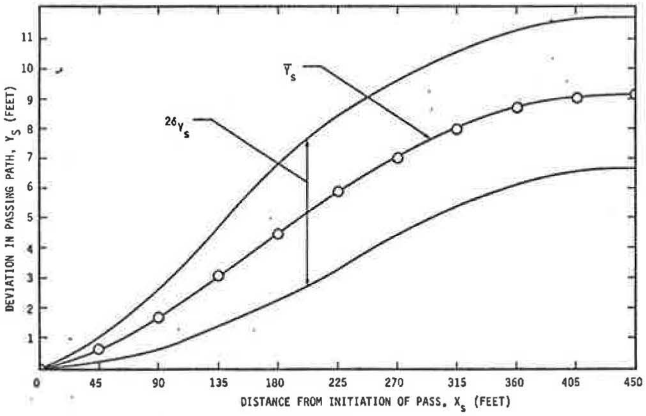


Figure 7. Distance from initiation of pass, Xs (feet).

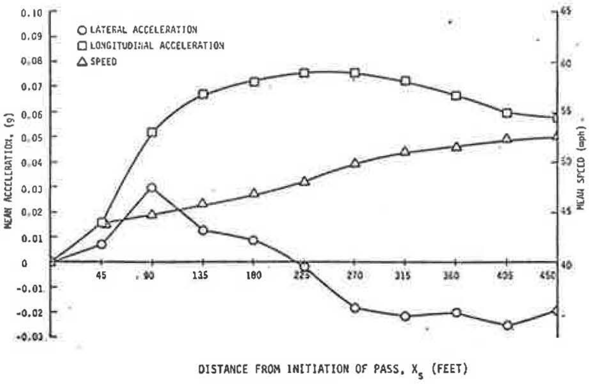


Figure 8. Relationship between maximum lateral acceleration and path radius during passing.

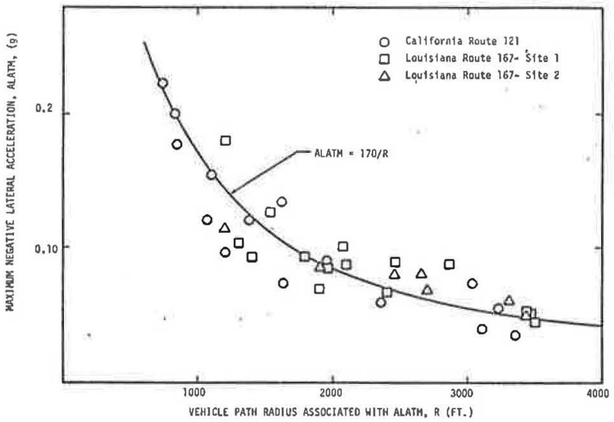


Figure 9. Relationship between lateral acceleration and path radius during passing.

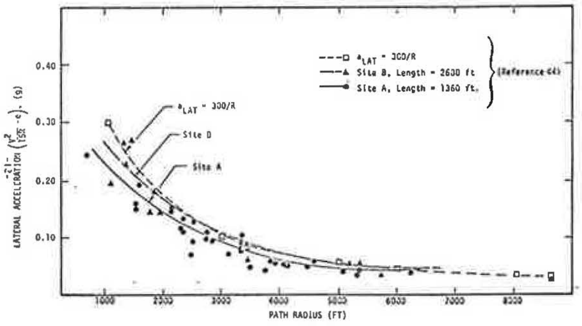


Table 1. Tabulations of the gap acceptance function.

	ΔV = 29 mph x_L = 6.0 sec	ΔV = 15 mph x_L = 6.5 sec	ΔV = 10 mph x_L = 7.0 sec	ΔV = 5 mph x_L = 7.5 sec
x (sec)	α(x,ΔV)	α(x,ΔV)	α(x,ΔV)	α(x,ΔV)
< 6.0	0	0	0	0
6.5	.058	0	0	0
7.0	.133	.058	0	0
7.5	.165	.113	.058	0
8.0	.213	.165	.113	.058
10.0	.381	.343	.302	.259
12.0	.532	.483	.451	.417
14.0	.617	.593	.568	.542
16.0	.698	.680	.660	.639
18.0	.763	.748	.732	.716
20.0	.813	.802	.790	.777
22.0	.853	.844	.834	.824
24.0	.884	.877	.870	.862
26.0	.909	.904	.898	.891

Figure 10. Rate of passing for various q's and $\hat{\lambda}$'s.

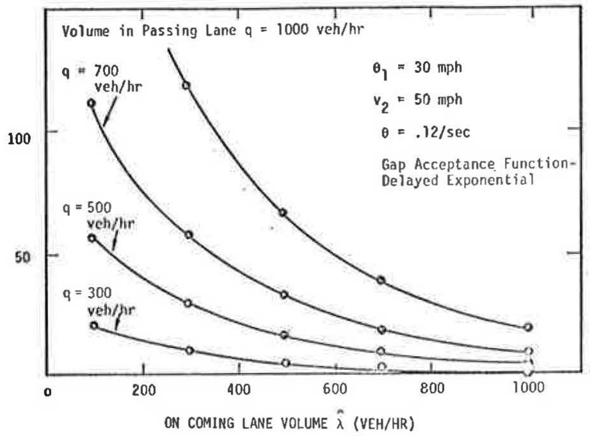


Table 2. List of test sites.

Location	Site No.	Type	Direction of Traffic	Days of Observation	Pavement Condition	Radius of Curvature	ADT
Mississippi							
US 98 Map Section 1375	C9-1	Curve	Both	#1	Dry	1432	1900
US 98	C9-1	Curve	Both	#2	Wet	1432	1900
SR 48 Map Section 260	C8-1	Curve	Both	#1	Dry	1087	1540
SR 48	C8-1	Curve	Both	#2	Dry	1087	1540
Louisiana							
US 167 MP 131	C3-5	Curve	Northbound	#1	Wet	2864	2180
US 167 MP 131	C3-5	Curve	Northbound	#2	Dry	2864	2180
US 167 MP 131	C3-5	Curve	Southbound	#1	Dry	2864	2180
US 167 MP 138	C3-2	Curve	Southbound	#1	Dry	2864	2180
US 167 MP 138	C3-2	Curve	Southbound	#2	Wet	2864	2180
US 167 MP 138	C3-2	Curve	Northbound	#1	Dry	2864	2180
California							
SR 88 MP 7.9	C22-3	Curve	West	#1	Dry	1210	1500
SR 88 MP 7.9	C22-3	Curve	East	#1	Dry	1210	1500
SR 88 MP 10	C22-2	Curve	West	#1	Dry	3200	1500
SR 88 MP 10	C22-2	Curve	West	#1	Wet	3200	1500
SR 121 MP 2.31	C2-4	Curve	East	#1	Dry	1400	7400

Figure 12. Maximum forward acceleration as a function of lateral acceleration.

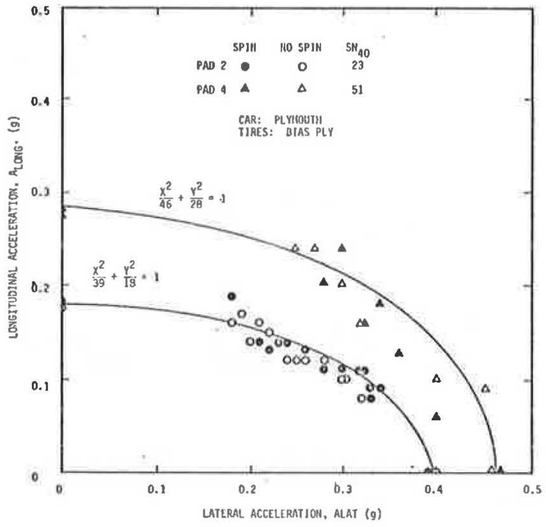


Figure 11. Relationship between acceleration SN_{40} and speed.

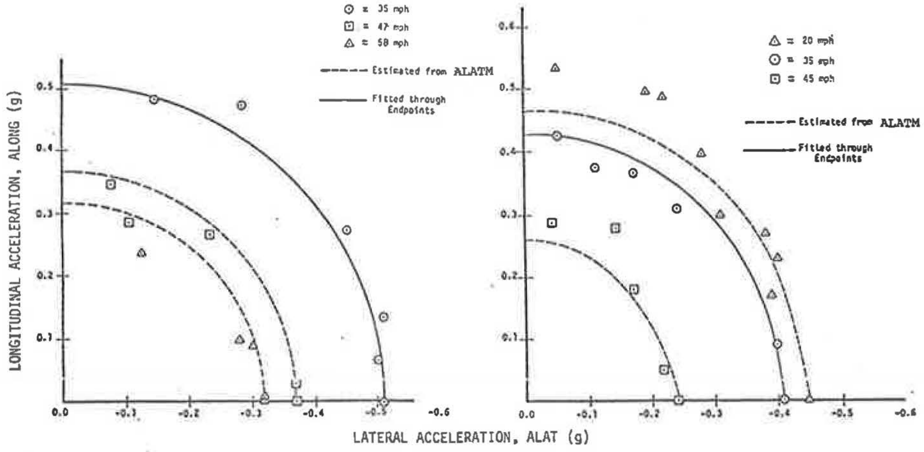
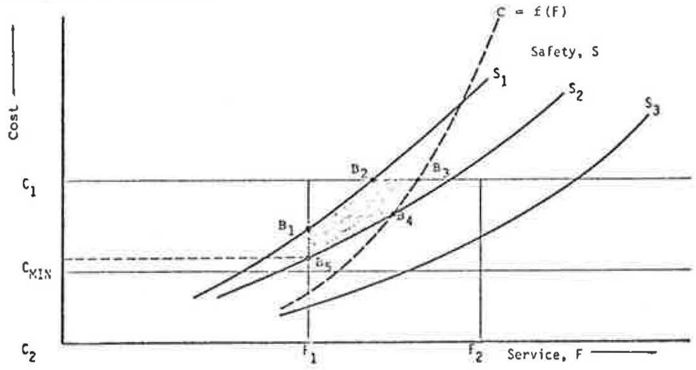


Table 3. Sample calculations for frictional demand and available pavement friction

DEMAND			AVAILABLE MARGIN		
ALAT (g)	ALONG (g)	ARESD (g)	SN_{40}	ARESA (g)	ARESA-ARESD AR2SA
0.2	0.1	0.22	23	0.34	0.35
			51	0.44	0.50
0.2	0.15	0.25	23	0.26	0.04
			51	0.42	0.40
0.2	0.2	0.28	23	0.07	-3.0
			51	0.38	0.26
0.2	0.25	0.32	23	-	-
			51	0.33	0.03
0.25	0.1	0.27	23	0.34	0.21
			51	0.44	0.39
0.25	0.15	0.29	23	0.26	-0.12
			51	0.42	0.31
0.25	0.20	0.32	23	0.07	-3.6
			51	0.38	0.16
0.25	0.25	0.35	23	-	-
			51	0.33	-0.06
0.30	0.10	0.32	23	0.34	0.06
			51	0.44	0.27
0.30	0.15	0.34	23	0.26	-0.31
			51	0.42	0.19
0.30	0.20	0.36	23	0.07	-4.1
			51	0.38	0.05
0.30	0.25	0.39	23	-	-
			51	0.33	-0.18

Figure 13. Concept of the trade-off analysis for cost, safety, and service



A BENEFIT-COST MODEL FOR PAVEMENT RESURFACING AND OTHER COUNTERMEASURES

A. D. St. John, D. W. Harwood and R. R. Blackburn, Midwest Research Institute

A computerized benefit-cost model, developed for the Federal Highway Administration, can be used to evaluate alternative accident reduction countermeasures. The model was designed for use by state highway departments and is capable of evaluating both countermeasures that increase frictional supply and countermeasures that reduce frictional demand. Emphasis was placed on compatibility with typical highway department practices and the capability to provide fair comparisons, in an economic sense, between alternative countermeasures. The model incorporates relationships between skid number and accident rate obtained from an extensive data collection and analysis phase. The effects on accident rate of factors other than skid number are based on the literature. A tested version of the computer program should be available from the Federal Highway Administration in the near future.

This paper describes a computerized cost-benefit model developed for the Federal Highway Administration by Midwest Research Institute (1, 2, 3). The model is intended for use by state highway departments and is compatible with the procedures employed by and the problems facing those organizations. The model was designed to compare alternative accident countermeasures at a given site and to identify the optimal countermeasure on a cost-benefit basis.

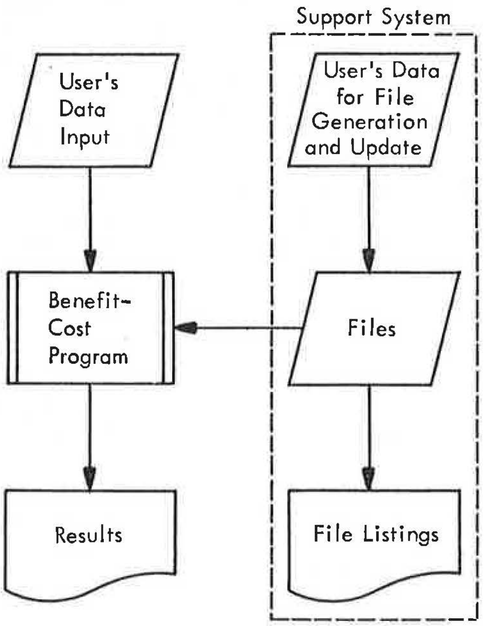
The model is suitable for use in a wet-pavement accident reduction program since it can be used to evaluate and compare countermeasures of two general types: those that increase frictional supply and those that decrease frictional demand. Countermeasures that increase frictional supply include pavement surface modifications such as resurfacing. Countermeasures that decrease frictional demand include geometric and traffic control improvements, such as reconstructing curves and installing warning signs. Although these countermeasures are considered primarily because of their effect on wet-pavement accidents, many of these countermeasures also reduce dry-pavement accidents and such benefits are considered.

Each of the countermeasures to be considered by the model at a given site must be selected by the user. This requires that the user exercise engineering judgment to select appropriate countermeasures. The model assumes that each countermeasure selected for analysis by the user is warranted and physically feasible. Typically, the user will select several alternative countermeasures for comparison at a given site. The model not only selects the most cost-beneficial countermeasure, but also provides detailed information on the costs, benefits and annual net return of each alternative. This information is extremely useful to the highway administrator in programming and budgeting.

System Configuration

The computerized benefit-cost model is part of a system illustrated in Figure 1. Input data for the program is obtained from two sources, as shown in the figure. The first source is the support system files maintained by the user. These files contain long-term values such as countermeasure costs, lives, effectiveness estimates, etc., which must be updated periodically but do not need to be supplied by the user each time the model is used. The second source is the user's input data supplied for each analysis. These data describe the type of analysis to be performed, the site to be analyzed, and the countermeasures to be considered. The user also has the option to override values from the system files in the analysis of specific cases where the typical values contained in the file are inappropriate.

Figure 1. Benefit-Cost Program Operation



Comparison of Alternatives in the Model

Alternative countermeasures are compared in the model with the appropriate base condition using the benefit/cost ratio, defined as:

$$B/C = \frac{AC_b - AC_c + MO_b - MO_c + UC_b - UC_c}{CC_c - CC_b} \quad (1)$$

where AC = Equivalent uniform annual accident costs,

MO = Equivalent uniform annual maintenance and operating costs,

UC = Equivalent uniform annual user costs,

CC = Equivalent uniform annual capital costs, and

subscript b indicates the base condition, while

subscript c indicates the countermeasure challenging the base condition.

Each of these cost items is discussed in a later section of the paper.

Experts are not in agreement on the location in the fraction of the MO and UC terms. We follow Winfrey (4), placing the terms in the numerator. With this form, the denominator contains capital costs exclusively. However, the reader should be aware that, while the choice to place the MO and UC terms in the numerator or denominator does affect the magnitude of the benefit/cost ratio, it does not affect the final ranking of countermeasures determined by the model.

The alternative countermeasures being evaluated are compared in two stages: economic feasibility and project formulation. In the economic feasibility stage, each countermeasure is compared with the existing or planned base condition. Alternative countermeasures with benefit/cost ratios less than unity are eliminated in this stage. Alternatives with benefit/cost ratios greater than unity in the economic feasibility stage are considered further in the project formulation stage. In the second stage, pairs of alternative countermeasures are compared in order of increasing equivalent uniform annual capital costs. The lowest cost countermeasure is the base condition for the first comparison. The first challenger is compared to this base condition. If a benefit/cost ratio less than unity results, the challenger is rejected. If a benefit/cost ratio greater than unity results, the challenger then becomes the base for subsequent calculations. The countermeasure remaining after all challengers have been compared sequentially is the most cost-beneficial.

Economic Aspects

The model logic is applicable to year-end cash flows, which are typically used for highway analyses. For comparative purposes, all costs and benefits are expressed as equivalent uniform annual cash flows. The interest rate (minimum attractive rate of return) used to convert one-time costs to equivalent uniform annual costs can be selected by the user.

Extensive logic is employed in the model to insure that the comparisons between countermeasures are economically fair. The required logic is complicated by the diversity of countermeasure types and the variety of situations where they may be considered for application. However, detailed logic has been provided to make the model compatible with typical highway department practices as described in the next section.

Compatability With Highway Department Practices

The computerized model is designed to handle many of the considerations that complicate benefit-cost analyses for highway applications and to provide results that are fair in an economic sense. Many economic analyses neglect these considerations or depend on judgment rather than quantitative results. The model is designed to handle such situations appropriately within the model, so that the user is not required to supply complex input or extensive judgment.

One common situation which receives special treatment in the model is a decision to resurface or rebuild the analysis facility that has been made, but not yet carried out. Two types of decisions are handled by the model. The first type is a decision and budgeting commitment that will be implemented prior to or simultaneously with the countermeasure(s) evaluated, referred to as a prior decision. The second type is a decision to resurface or rebuild the facility after the countermeasure(s) are implemented, referred to as a future plan.

A typical prior decision is the decision to resurface a site to improve riding quality and to safeguard the pavement structure. Once this decision has been made, but before it is implemented, it may be appropriate to consider resurfacing the facility with a special material to improve its skid resistance properties. In such a case, the economic analysis should include only the additional cost of the special surface course, since the decision has been made and an amount of funds have been committed to resurface the facility. When a special surface course is considered, the model charges the base condition with the cost of the planned surface course. The cost of the special surface course is then compared fairly with the costs already committed by the prior decision. However, if geometric or traffic control countermeasures are evaluated against the base condition, the funds already committed by the prior decision do not enter the calculation. The influence of the prior decision is carried into project formulation by crediting the economically feasible surface countermeasures with the funds already committed. This aspect of the model provides an accurate account of the incremental costs of surface countermeasures where prior decisions for surfaces have been made. Current practices frequently do not provide a systematic method for analyzing this situation, which may involve multiple budget funding.

The other type of decision that receives special consideration in the model is a future plan to resurface, rebuild or abandon a facility. Such decisions may limit the service life normally expected from the countermeasures being analyzed. The term applied life is used to describe the period of time for which the countermeasure capital items will actually be employed for their intended purpose. All countermeasures are not equally vulnerable to future actions. For this reason, the model contains codes for the vulnerability of countermeasure items to future actions and provisions for salvage value or remaining value after removal. There is flexibility to account for situations such as turn-lane countermeasures that can remain as part of the rebuilt facility.

Some countermeasures considered by the model may require acquisition of additional right-of-way. The model logic recognizes that right-of-way costs, lives (ammortization periods), and future worths should often be specified independently from the associated values for the other capital items in the countermeasure. Therefore, the model accepts and processes right-of-way quantities separately from other capital costs, but combines appropriate equivalent uniform annual capital costs in the final analysis. Flexibility is provided for special situations like right-of-way that is required in the future, but must be acquired ahead of schedule for implementation of a countermeasure.

Model Treatment of Major Factors

Traffic Volume

The model user must supply the Average Daily Traffic (ADT) for the analysis site in the year when the countermeasures will be installed. In addition, the user must specify the pattern of ADT change throughout the analysis period by one of four methods: (1) constant ADT (no growth); (2) linear ADT growth; (3) compound ADT growth; or (4) year-by-year values for future ADT. The final option is useful when ADT growth is not expected to follow a simple pattern as, for example, when the opening of a parallel facility is expected to cause a sharp decrease in ADT for a future year. The model requires the ADT for only one facility for analysis of a highway section or a non-intersection location, but ADT for both a major and a secondary facility is required for analysis of an intersection site.

Skid Number

The skid number at 64 km/hr (40 mph), S , is represented in the model as a function of cumulative traffic passages:

$$S = S_o + C_s \ln(T) \qquad (2)$$

subject to the constraints

$$T \geq 1.$$

$$S \leq S_f \text{ when } C_s > 0., \text{ and}$$

$$S \geq S_f \text{ when } C_s < 0.$$

where S_o = Initial skid number

S_f = Final or limiting value of skid number

C_s = Coefficient representing rate of change of skid number

T = Cumulative traffic passages/10^5

The values of S_o , S_f and C_s are characteristic of each type of surface course considered as a countermeasure and are obtained from the support system files. The model can be adapted to any type of surface course aggregate and any rate of traffic wear by selection of appropriate values for S_o , S_f and C_s. Specific values for S_o , S_f and C_s have been identified from several sources in the literature (5, 6, 7). The model uses the above relationship to update the skid number during each year of the analysis period to account for the effect of traffic passages. If the facility is resurfaced during the analysis period, the cumulative traffic passages are set equal to zero in that year.

Accident Rate

The user must supply the expected number of annual accidents for the analysis site in the period before countermeasure implementation. This value is used within the model to calculate the overall accident rate defined for highway sections as:

$$r = \frac{(N)(10^6)}{(L)(ADT)(365)} \qquad (3)$$

where r = Overall accident rate (accidents/MVM)

N = Annual number of accidents

L = Section length (miles)

ADT = Average daily traffic (vehicles)

The model accounts for three factors that influence the accident rate at the analysis site during the analysis period: (1) changes in skid number, (2) changes in traffic volume, and (3) installation of geometric and traffic control countermeasures. The benefit/cost model incorporates specific accident rate-skid number relationships developed during the project. These relationships, presented in detail in the following section, are used to determine the effect on accident rate of both abrupt changes in skid number due to resurfacing and gradual changes in skid number due to traffic passages.

The accident rate at the analysis site is also influenced by changes in traffic volume. The accident rate-traffic volume relationships used in the model are based on regression results reported by Fee (8).

The effects of 87 individual geometric and traffic control countermeasures incorporated in the model are based on percentage accident reduction estimates reported in NCHRP Report 162 (9), as modified by a correction factor discussed in the following section. The effectiveness estimates obtained from the literature are the most reliable presently available. However, recognizing that individual states may have available more reliable estimates for their particular traffic and climatic conditions, the user can update the support system file, and replace the estimates supplied with the model.

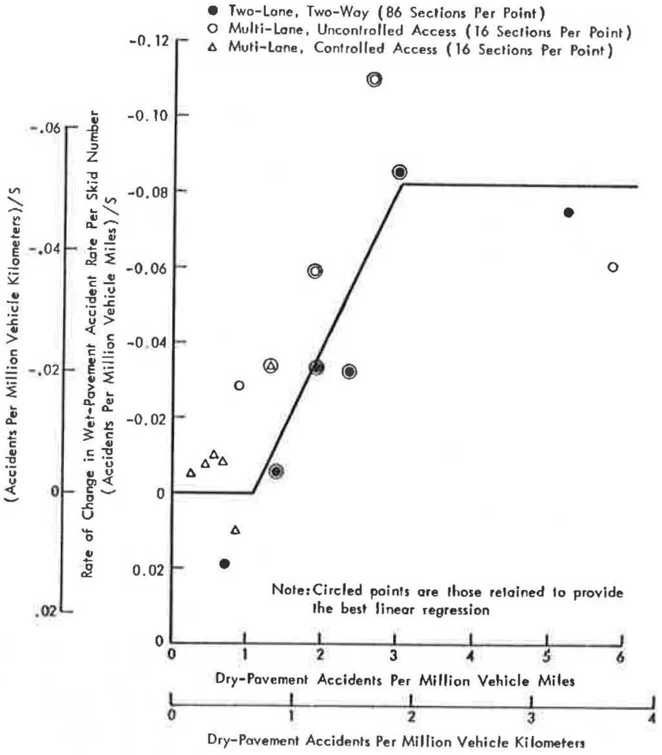
Accident Rate-Skid Number Relationships

The model development included an extensive investigation of the relationship between wet-pavement accident rate and skid number (1). Accident rate, skid number, traffic and weather data were assembled for each of 2 years on 428 highway sections in 15 states. The data were analyzed with a number of statistical techniques. Analysis of covariance proved to be the most useful with factors area type (urban/rural), highway type and ADT. The independent variable was skid number at 64 km/hr (40 mph), S, and the dependent variable was wet-pavement accident rate, r_w, expressed as wet-pavement accidents per million vehicle-miles of travel under wet-pavement conditions.

The analysis of covariance identified a family of linear relationships between r_w and S with a common slope of -0.0286 accidents per million vehicle-kilometers per skid number (-0.046 accidents per million vehicle-miles per skid number). The correlation coefficients ranged from 0.28 to 0.43. The magnitude of the slope indicated that skid number does have a substantial effect on wet-pavement accident rate. For example, an increase of 10 in skid number at 64 km/hr (40 mph) would, on the average, reduce wet-pavement accident rate by 0.286 accidents/MVKm (0.46 accidents/MVM) which is about 15% of the mean wet-pavement accident rate.

Additional analyses showed that the relationship between wet-pavement accident rate and skid number is strongly dependent on the dry-pavement accident rate, r_d. This finding is illustrated in Figure 2 where $(\partial r_w/\partial S)$ is plotted against r_d for all rural highway types. The magnitude of $(\partial r_w/\partial S)$, the sensitivity of wet-pavement accident rate to skid number, was for the most part in accord with expectations.

Figure 2. Rate of Change of Wet-Pavement Accident Rate with Skid Number as a Function of Dry-Pavement Accident Rate for Rural Highways.



Note: Circled points are those retained to provide the best linear regression

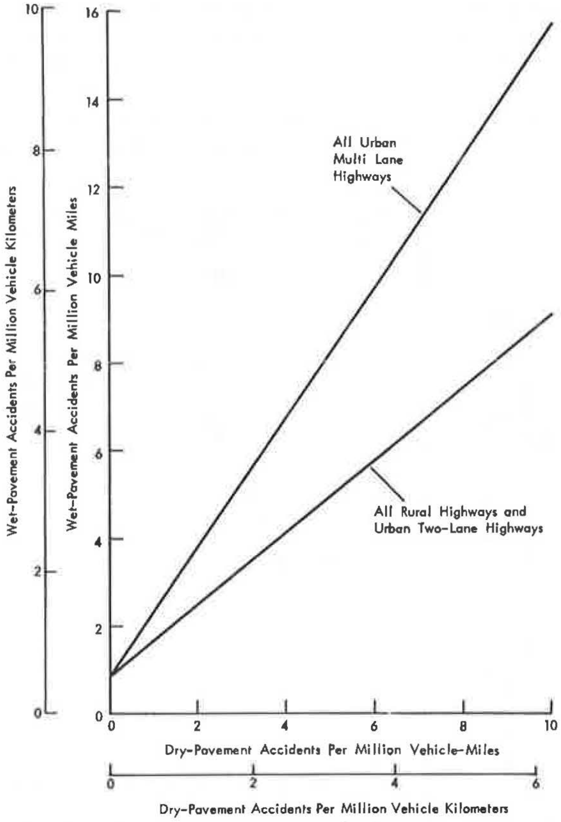
Dry-pavement accident rate was used here as a proxy variable. It was postulated that where dry-pavement accident rate was high there would be more-than-average demand for skid resistance to avoid accidents, and vice versa. The data indicated that this postulate was generally true for rural highway sections. In fact, with dry-pavement accident rate as a factor and skid number as the independent variable, the variance of wet-pavement accident rate is explained as well as it is with more complex multiple factor frameworks.

The sensitivity to skid number $(\partial r_w/\partial S)$, reached a maximum and became constant at large r_d. The data for rural highway sections indicated this unanticipated finding at a high confidence level. In urban areas, the more limited amount of data did not provide an equally well defined relationship between wet-pavement accident rate and skid number. Statistical tests did indicate that the quantitative aspects of the urban relationship were probably different from the rural case, but the general character was probably similar.

The data analyses also found very strong correlations between wet-pavement and dry-pavement accident rates. The regression results are shown in Figure 3.

The intercepts were statistically indistinguishable for all area type-highway type combinations. The slopes were distinguishable for the combinations shown.

Figure 3. Relation Between Dry-Pavement and Wet-Pavement Accident Rates.



The benefit-cost model incorporates the accident rate-skid number relationships shown in Figure 2 and the regression results shown in Figure 3 by employing several simple concepts. First, the overall accident rate on a facility is approximated as a linear combination of the rates under wet- and dry-pavement conditions:

$$r = f_w r_w + f_d r_d \ , \qquad (4)$$

where r = overall accidents per MVM,
f_w = Fraction of time pavement is wet,
r_w = Wet-pavement accidents per MVM under wet-pavement conditions,
f_d = Fraction of time pavement is dry, and
r_d = Dry-pavement accidents per MVM under dry-pavement conditions.

Second, the wet-pavement accident rate is expanded as the sum of a part correlated with the dry-pavement accident rate and a part containing the skid number sensitivity:

$$r_w = b_o + b_1 r_d + \frac{\partial r_w}{\partial S}(S - \bar{S}) \ , \qquad (5)$$

where b_o and b_1 are coefficients from the wet-dry accident rate regressions. S is the skid number measured at 64 km/hr (40 mph); and $\bar{S}$ is the average skid number for which $r_w = b_o + b_1 r_d$.

In agreement with Figure 2, a three segment representation for $\frac{\partial r_w}{\partial S}$ is employed where each segment has the linear form

$$\frac{\partial r_w}{\partial S} = a_o + a_1 r_d \qquad (6)$$

The coefficients, a_o and a_1 are given in Table 1.

Table 1. Regression coefficients a_o and a_1[a]

Range of r_d	a_o	a_1
$0 \le r_d \le 1.082$	0	0
$1.082 < r_d < 3.02$	0.04615	-0.04264
$3.02 \le r_d$	-0.0825	0

[a] The coefficients are based on all rural highway types combined, but are used for urban highways as well, because of a lack of more definitive data.

Equations 4, 5, and 6 combine to form the basic equation:

$$r = f_w\left[b_o + b_1 r_d + (a_o + a_1 r_d)(S - \bar{S})\right] + f_d r_d \ . \qquad (7)$$

Figures 4 and 5, based on the preceding equations, illustrate overall accident rates as functions of skid number and dry-pavement accident rate for climates that produce wet highways 10% and 30% of the time. The effects of countermeasures on accident rates, discussed in the previous section, can be visualized in these figures. The figures show how wet-pavement exposure and skid number can impact the effectiveness of geometric and traffic control countermeasures that act directly, but not exclusively, on the dry-pavement accident rate. When a geometric or traffic control countermeasure is applied, the improvement is reflected by a displacement along a line of constant skid number to a lower accident rate. The model contains a correction factor, based on Equation 7, to correct for this effect. Resurfacing countermeasures involve an improvement in skid number. When the skid number is increased, the improvement is reflected by a vertical displacement to a lower total accident rate (presumably, at a constant dry-pavement accident rate, although some countermeasures may involve both effects).

Figure 4. Overall Rural Accident Rate Versus Dry-Pavement Accident Rate and Skid Number, When Pavement is Wet 10% of Time.

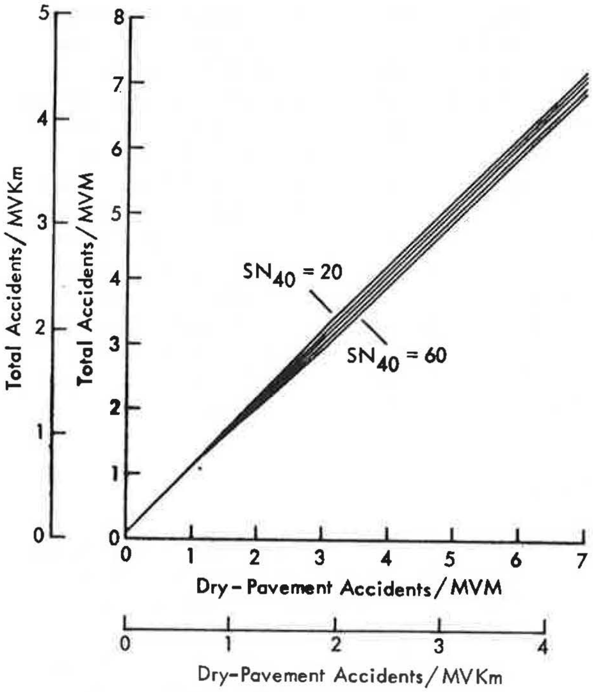
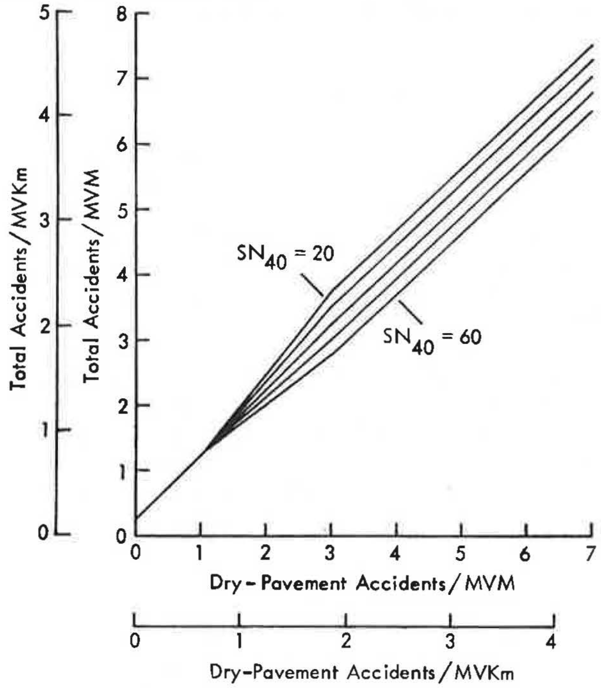


Figure 5. Overall Rural Accident Rate Versus Dry-Pavement Accident Rate and Skid Number, When Pavement is Wet 30% of Time.



The change in overall accident rate with skid number is given by the partial derivative:

$$\frac{\partial r}{\partial S} = (a_o + a_1 r_d) f_w \ . \qquad (8)$$

In the model, an incremental change in skid number (ΔS) produces an incremental change in overall accident rate (Δr),

$$\Delta r = \frac{\partial r}{\partial S} \Delta S \qquad (9)$$

The form for $\partial r/\partial S$ is based on Equations 4 through 8 and is calculated as:

$$\frac{\partial r}{\partial S} = 0 \ . \quad \text{if} \quad r \leq r_1 \ . \qquad (10)$$

where

$$r_1 = f_w \left[b_o + 1.082 \, (b_1 - 1) \right] + 1.082 \ . \qquad (11)$$

If $r > r_1$,

$$\frac{\partial r}{\partial S} = -0.0825 \, f_w \qquad (12)$$

or

$$\frac{\partial r}{\partial S} = f_w \, (r - r_1) a_1 / \left\{ f_w \left[b_1 + a_1 \, (S_o - S) \right] + (1 - f_w) \right\} , \qquad (13)$$

whichever is algebraically larger. In Equation 13, S_o represents the skid number for the time immediately before $\partial r/\partial S$ is evaluated. The coefficients for Equations 10 through 13 depend only on area type and highway type as shown in Table 2. Equations 10 through 13 are employed in the model to calculate $\partial r/\partial S$ and, then, the accident rate is adjusted for changes in skid number according to Equation 9.

Table 2. Summary of Coefficients for Equations Employed in Model

Area Type	Highway Type	$\bar{S}$	a_1	b_o	b_1
Rural	Two-lane	46.0	-0.64264	0.8066	0.8281
Rural	Multilane uncontrolled access	46.0	-0.64264	0.8066	0.8281
Rural	Multilane controlled access	46.0	-0.64264	0.8066	0.8281
Urban	Two-lane	39.7	-0.64264	0.8066	0.8281
Urban	Multilane uncontrolled access	39.7	-0.64264	0.8066	1.4873
Urban	Multilane uncontrolled access	39.7	-0.64264	0.8066	1.4873

Spot-site accident rates can also be analyzed. The model assumes that analyzed spots have been identified as high-accident locations and that, therefore, such spots have above average accident rates corresponding to the upper end of the fan of lines in Figures 4 and 5. The change in accident rate due to skid number for spot-sites is then assumed to be proportional to the change that would be observed for highway sections, and is evaluated using Equations 10 through 13.

Costs Employed in the Model

The four types of costs employed in the model are: (1) capital costs, (2) accident costs, (3) user costs, and (4) maintenance and operating costs. Each type of cost is discussed below.

Capital Costs

The initial capital outlay and final capital worth (salvage value) for each countermeasure are obtained by the program from the support system files maintained by the user. The capital costs are converted by the model to equivalent uniform annual cash flows, for comparison with the other costs and benefits. The user can override the support system values in specific instances where atypical costs are desired.

Accident Costs

The following accident costs, developed by the National Highway Traffic Safety Administration (10), are supplied with the model:

Definition	Cost
Cost per vehicle involved in a property-damage-only accident	$300
Cost per injury	$7,300
Cost per fatality	$200,700

The average cost of a fatal accident is calculated in the model as:

$$C_{FA} = (C_F)(W_F)(P_F)$$

where C_{FA} = Average cost of a fatal accident
C_F = Average cost of a fatality = $200,700
W_F = Weight factor for fatal accident costs supplied by user (default value = 1.0)
P_F = Average number of fatalities per fatal accident

The user can change the value of C_F as needed by updating the support system files. The user can also adjust the standard fatal accident cost for a particular analysis by selecting a value other than 1.0 for W_F. The value of P_F as a function of highway type and area type has been determined from accident data for a 4-year period supplied by the states of California, Michigan and Washington. Costs for injury and property-damage-only accidents are determined analogously.

The model determines the expected accident rate for each year of the analysis period taking into account the effects of changing skid number and traffic volume. The costs described above are used to define the total accident cost for each year, and these costs are then expressed as equivalent uniform annual accident costs for calculation of the benefit/cost ratio.

User Costs

The only user costs incorporated in the model are costs due to delays and excess fuel consumption arising from countermeasure construction. These costs may be incurred in the year when a countermeasure is first installed and/or in a subsequent year when the countermeasure is replaced. Other user costs, such as normal fuel consumption and operating costs, are not included in the model because the effect of any countermeasure on these costs has not been well quantified.

Maintenance and Operating Costs

The support system files maintained by the user contain typical maintenance and operating expenses per unit length of highway as a function of area type and highway type. In addition, the support system files contain, and the model uses, the additional maintenance and operating costs associated with each countermeasure. The maintenance and operating cost for a given site with a given countermeasure installed can vary as a function of time. For example, the model logic permits decreased maintenance and operating costs immediately following the installation of resurfacing or surface treatment countermeasures, if that is the experience of the using agency.

Status of the Computerized Model

The final programming and encoding of the benefit-cost model, as well as the support system and the computer control instructions, are the responsibility of the Data Systems Division of the Federal Highway Administration. A preliminary version of the model has been programmed and tested. The complete and tested version should be available shortly from the Federal Highway Administration.

The model is being programmed in Fortran IV and is adaptable to a large number of computer systems being operated in the U.S. and elsewhere.

The computerized model should be a useful tool for agencies that need a comprehensive and quantified basis for planning and budgeting their safety programs.

Acknowledgments

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THE INFLUENCE OF GROOVING OF ROAD PAVEMENTS ON ACCIDENT FREQUENCY

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Frequency of accidents and the percentage of accidents on wet and dry road surface for the years 1966 - 1973 have been analysed on a road of 44 km, comprising few very smooth spots on a total length of about 2 km. Data for analyses were provided by official traffic counts, precipitation measurements of the Swiss Central Meteorological Agency and accident reports of highway police. The 2 km long smooth sections have been grooved twice during the observation period with groove distances of 5,0 and 2,0 m. This road represents a good example for a study on the influence of grooving on accident frequency. Relative values of accident frequency per km and 1 million vehicles were determined in relation to the number of wet and dry days of each year, for the grooved and ungrooved sections. The percentage of accidents on wet surface compared to the total number completes the study. The results show clearly a positive influence of grooving, even with great groove distances, and the effect of a reduction of the water film on skidding properties. A clear-cut information is given particularly by the relation of accidents according to the formula:

$$A_N = \frac{A_w}{A_{w+d}} \quad 100 \quad (\%)$$

Economical aspects of this measure and legal questions about the road owner's responsibility are also considered.

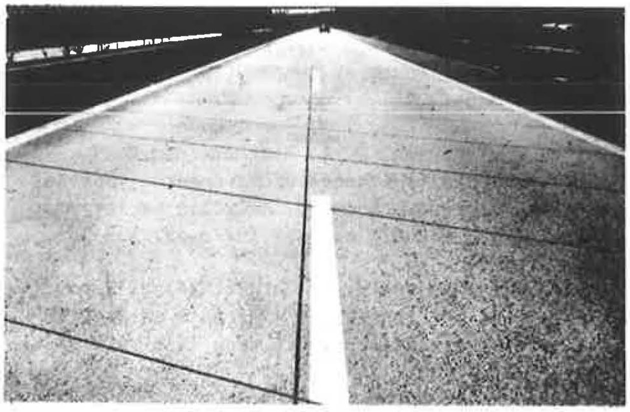
Introduction

In the years 1966 to 1973 police of the Canton Vaud registered an extremely high number of accidents on some particular sections of the National Highway Lausanne - Geneva, km 17 to 39.

Geometric design of the highway was based upon design standards valid at the moment of construction. The road follows the shore of the Lake of Geneva at a certain distance and an altitude varying between 375 and 390 m above sea level. Figure 1 gives a general view of the highway including the grooving of 1970, with groove distances of 2,0 m.

Accidents occurred mostly in particular zones, covering about 5% of the 44 examined kilometers (both directions). A grooving with varying groove distance was therefore ordered for these short sections. The late Prof. Wehner mentioned in his last report (1) good experiences made up to now in America and Belgium with grooving of slippery pavements. However, results of longer observations about the efficiency of such grooves and their condition are still missing. This study can give an answer to both the questions. The condition of the grooves after 7 years of traffic does not present any visible change yet.

Figure 1: General view of the highway (1970) showing the grooving of 1970 with groove dinstances of 2,0 m.



Characteristical Data and Provisions

Weather

Statistical data of the Swiss Central Meteorological Agenci (2) make it possible to determine the number of days with rain in a particular year. Precipitations for this region were calculated from the mean values of 4 meteorological stations nearby. Te assumption was made that only a rain quantity of

1,0 millimeter and more would satisfy the criterion of a wet road pavement. Smaller rain quantities were neglected, assuming that they evaporated in a short time without leaving the road surface in a wet state for a longer period.

Figure 2: Number of wet and dry days for the years 1966 to 1973 (wet when rainfall in 24 hours >1.0mm).

Year	1966	1967	1968	1969	1970	1971	1972	1973
Yearly average								
dry days (365 days)	238.25	246.75	225.25	260.50	236.35	280.25	275.50	277.25
wet days >1.0 mm H_2O	126.75	118.25	140.75	104.50	128.65	84.75	90.50	92.75

Traffic

The highway was opened to traffic at the beginning of the National Exhibition Expo 1964 and had already reached an average daily traffic (ADT) on both directions of 12'696 motor vehicles in 1966. ADT for 1973 amounted to 22'218. We have so total frequencies of 4,64 (1966) to 8,1 (1973) millions of motor vehicles per year on the observed highway section (3).

Figure 3: Annual traffic fequencies for wet and dry days in the years 1966 to 1973 for each direction.

Year	1966	1967	1968	1969	1970	1971	1972	1973
Annual average in millions of vehicles								
Dry days	1.52	1.67	1.73	2.20	2.17	2.74	2.88	3.02
Wet days	0.85	0.80	1.08	0.88	1.18	0.83	0.92	1.03
Total traffic	2.32	2.47	2.79	3.08	3.34	3.56	3.80	4.05

Surface Conditions

At five locations of the highway, on both traffic directions, a much higher concentration of accidents than on the rest of the road was noticed quite early. The observation of a waterfilm covering the road surface immediately after beginning of the rain and staying for a longer time led to the conclusion, that too slow surface drainage could be the cause of this concentration of accidents.

Transverse grooving of these short sections was therefore executed at the end of 1967 and in 1970. The first grooves were cut into the surface with a distance of 5,0 m in 1967. In 1970, after the good experiences of the first years, additional grooves were cut between the existing ones with distances of about 2,0 m.

Those five different sections in both directional roadways were grooved, with a total summed up length of 1,91 km. The residual length of the highway, 42,09 km, remained in the original condition.

All the grooved sections are indicated in the following table.

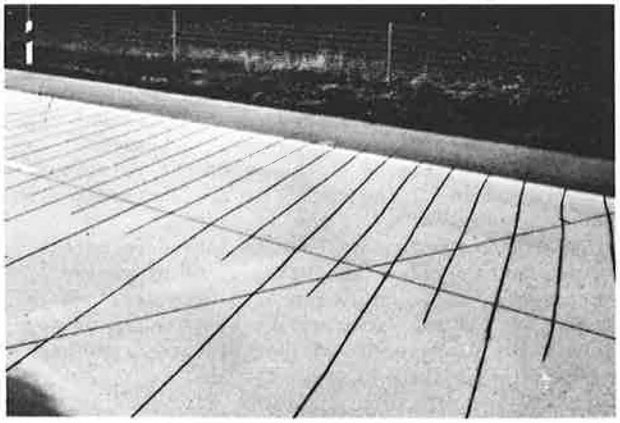
Grooving on the National Highway Lausanne - Geneva

Direction: Geneva	length of Section	grooving type 1967	1970
km 28'350-28'880	530 m	1790 meters 5,0 m distance	1910 meters 2,0 m distance
km 31'020-31'380	360 m		
km 36'100-36'500	400 m		
	1'290 m		
Direction: Lausanne			
km 28'380-28'880	500 m		
km 30'360-30'480	120 m		
	620 m		

grooved pavement=1,91km; ungrooved pavement=42,09km

Actual condition of the grooves is shown in Figure 4, including additional grooves with distances of 0,25 m executed in 1973. The grooves have a width of 6 mm and a depth varying between 6 and 15 mm. The grooves are deeper at the edge side according to a greater amount of water. They are cut in an angle of 10 - 20° to the line of maximum slope, so that they have a greater angle with transversal joints, a shorter drainage distance and better efficiency in spite of relatively great distances between the grooves.

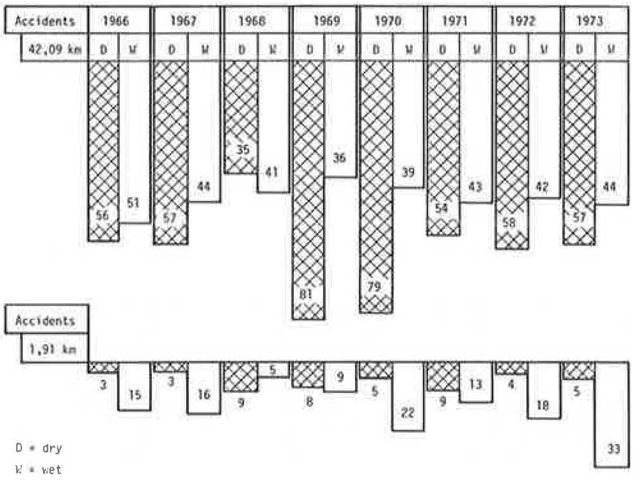
Figure 4: Condition of the grooves after 1973. Additional grooves with distances down to 25 cm were cut after 1973. The position of the grooves in relation to transversal joints can be seen clearly on the picture.



Accident Data

The number of accidents was taken from highway police reports (4) of the years 1966 - 1973. Analyses of these data (Figure 5), particularly of those accidents which occurred on grooved sections, made it possible to draw conclusions on the efficiency of grooving of wet pavements for the traffic intensity existing under these conditions. Relative data (Figure 6) were used for a better comparison of values independently of yearly growing traffic frequencies. These relative data are the number of accidents per km and per 1 million vehicles on wet surface, related to sections with grooved and ungrooved surface.

Figure 5: Number of accidents on wet and dry pavement surfacees for the ungrooved and grooved sections in the years 1966 to 1973.



Other Parameters

Among the factors which cannot be evaluated, we have the influence of traffic intensity, growing yearly with the rate of about 10%, on psychological driver behaviour and a subconscious but unjustified feeling of safety when driving at high speeds, due to different and effective improvements of traffic safety. Both factors can lead to an accident, but they cannot be connected with the alignement of the road or its surface.

After so many years it is also impossible to control whether dust and sand have been deposited in the grooves and how much. This would mean a reduction of drainage quantity towards the pavement edge and ponding on the surface in case of overflow. This could possibly be the cause of the relatively small reduction of the number of accidents after the second grooving of 1970.

These unknown factors have an influence on the results and may reduce the validity of otherwise clear facts. It is however possible to draw general conclusions on the consequences of grooving of sections particularly exposed to accidents from these results.

Skidding Conditions of the Surface

Measurements of skid resistance of the surface were effectuated with a Skiddometer trailer by the Institut for Road Construction and Underground Structures of the Federal Institute of Technology in Zürich (ISETH). Average friction coefficients measured in 1972 on wet surface with blocked wheel and with a slip ratio of 16% are shown below (5).

Direction Geneva, slow lane

Speed	km	µ (average value) blocked wheel	slip 16%
80	18 - 38	26,2 (35)	46,9 (70)*
100	20 - 38	25,2 (30)	45,8 (65)

Direction Lausanne, fast lane

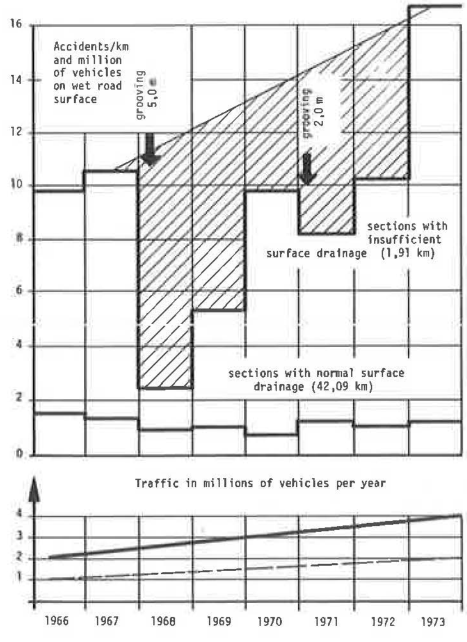
Speed	km	µ (average value) blocked wheel	slip 16%
80	21 - 38	30,5 (35)	53,7 (70)
100	20 - 38	21,8 (30)	48,8 (65)

(..) * : minimal values from experience.

These µ-values are also very low on the grooved sections, and are clearly under the limits set by experience.

A slippery pavement gets a considerable friction reduction when the surface is just wet or covered with a thin film of water. Slipperiness is therefore of the greatest importance as a cause of accidents, and measurement of skid resistance is an important additional criterion as grooving, even with great groove distances, improves drainage of the surface without raising the skid resistance of the surface between grooves. As such it helps to definetely lower the danger of accidents.

Figure 6: Evolution of accidents on wet road surface 1967/73 Highway Lausanne - Geneva (km 17 - 39).



Results

General Presentation

The results of the study are given in Figure 6. The lower curve shows the growth of annual traffic in millions of motor vehicles.

The curve in the middle shows the number of accidents on wet surface per kilometer and million of vehicles for the road length of 42,09 ungrooved kilometers.

The upper curve shows the number of accidents on wet surface per kilometer and million vehicles for those sections with a total summned up length of 1,91 km, which were grooved the first time in 1967 and the second time in 1970.

These sections had not yet been grooved in 1966 and 1967, and the high values of the number of accidents shows the high degree of accident possibility. This value was almost lowered to the level of the number of accidents of the remaining 42,09 km after the first grooving (1968). The fact of a new increase of the number of accidents in the following years leads to the conclusion of a sinking drainage efficiency of the grooves. This behaviour occurred also after the second grooving of 1970.

The number of accidents of 1973 corresponds to a value which could have been expected under the assumption that the drainage effect of the grooves had ceased. This means, in other terms, that water drainage was insufficient or none, so that a reduction of the water-film thickness could not occurr. This condition is comparable to that of a surface without grooves. The increase in percentage of the number of accidents between 1966 and 1973 corresponds to the increase of traffic volume during the same period. This observation could be used later (see: Economical Aspects) for a general calculation on economical aspects of a grooving although not always having the maximum efficiency.

Figure 6 shows a clear decrease of the number of accidents after grooving of the surface. This decrease is stronger after the first grooving than after the second. It is essential to notice, that it is not sufficient just to groove surfaces with bad drainage conditions, but that the grooves must also provide shorter drainage distances in addition to a better and faster drainage. This can be done, as it was the case here, by cutting the grooves in a particular angle to the line of maximum slope. This circumstance made it possible to obtain an efficient drainage even with a great groove distance of 5,0 m (first grooving 1967). The second grooving of 1970 with distances of 2,0 m had then an additional effect.

Accidents on Wet Surface

Interesting results (in percentages) can be obtained by dividing the number of accidents on wet surface (separately for the grooved sections) by the total number of accidents, that is on wet and dry surface, according to the formula:

$$A_N = \frac{\text{Accidents (wet)}}{\text{Accidents (wet + dry)}}\ 100\ (\%) = \frac{A_w}{A_w + A_d}\ 100(\%)$$

This relative value permits a comparison of road section with a great variation of the total number of accidents (Figure 7) (6).

The range of values for the ungrooved sections is around 45%. This value does not indicate any particular danger with wet surface, without considering general skidding properties of the road. Accidents on wet surface go indeed generally up to 50%, according to slope, yearly rain intensities and random effects.

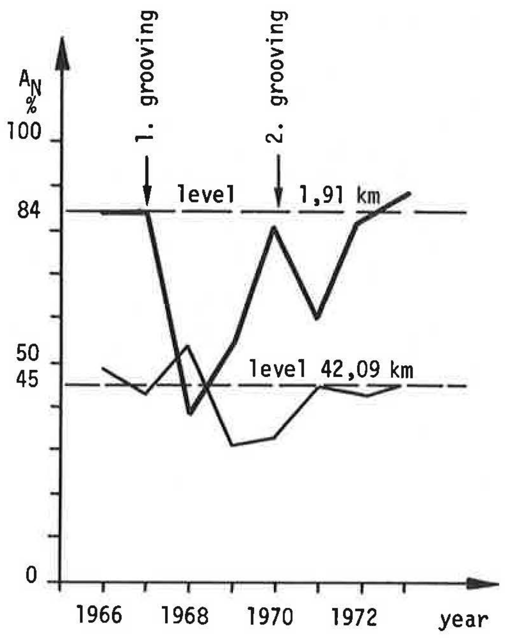
There is on the contrary a great percentage, around 84%, of accidents on wet surface for the grooved sections before grooving was done (1966/1967). These sections had therefore to be judged as highly exposed to accidents and were in a great need of a better drainage. The effect of grooving - a reduction of the water-film - can be seen very clearly in the lower values of the years 1968/1969 and 1971. Grooving can thus reduce the thickness of the waterfilm, but without ever attaining a complete break-through of this film.

It is however difficult to find an axplanation for the reduced long term success of the first grooving (the level of accidents in 1970 was almost the same as before the grooving) and for the efficiency of only one year of the second grooving. The only supposition is a negative influence of dust and dirt filling the grooves.

A graph by Wehner (6) can be used to point out the importance of the average values of Figure 7. It shows the percentage of accidents on wet surface as a function of friction coefficient for 80 road sections in the Federal Republic of Germany.

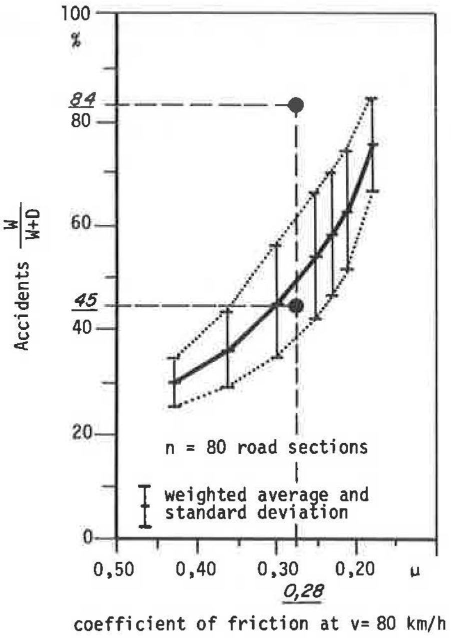
Figure 7: Percentage of accidents $A_N = \frac{A_w}{A_w + A_d} = 100(\%)$ for the grooved and ungrooved sections.
Results in the upper table are given both in absolute values and percentages. (D = dry; W = wet)

Year	1966		1967		1968		1969		1970		1971		1972		1973	
Accidents	D	W	D	W	D	W	D	W	D	W	D	W	D	W	D	W
	59	67	60	60	44	46	89	45	84	61	63	56	62	60	62	77
$A_N = \frac{A_W}{A_W + A_D}$ 42,09	$\frac{51}{107}$	$\frac{\%}{48}$	$\frac{44}{101}$	$\frac{\%}{43}$	$\frac{41}{76}$	$\frac{\%}{54}$	$\frac{36}{117}$	$\frac{\%}{31}$	$\frac{39}{48}$	$\frac{\%}{33}$	$\frac{43}{97}$	$\frac{\%}{44}$	$\frac{42}{100}$	$\frac{\%}{42}$	$\frac{44}{101}$	$\frac{\%}{44}$
1,91	$\frac{15}{18}$	$\frac{\%}{84}$	$\frac{16}{19}$	$\frac{\%}{84}$	$\frac{5}{14}$	$\frac{\%}{36}$	$\frac{9}{17}$	$\frac{\%}{53}$	$\frac{22}{27}$	$\frac{\%}{81}$	$\frac{13}{22}$	$\frac{\%}{59}$	$\frac{18}{22}$	$\frac{\%}{82}$	$\frac{33}{38}$	$\frac{\%}{87}$



It has to be considered, that due to differences in the measuring device, the test-tire and water-film thickness certain variations have to be allowed when direct comparison of the values is discussed. Even when the two average values are evaluated under these conditions it can be seen, that the percentage of accidents on wet surface for the ungrooved sections, with about 45%, could be taken as "normal", whereas the percentage of the very dangerous sections (now grooved) is considerably higher and lies at 84% (Figure 8).

Figure 8: Relationship between friction coefficient μ and percentage of accidents on wet surface (6).



Economical Aspects

Each surface problem needing a special treatment to improve traffic safety is connected with an economical question. It is never possible to tell exactly whether additional costs are higher or lower than the amount of avoided accidents, whether an expensive solution is worth the expenses. This study tries to analyse a possible solution from an economical point of view without tragical human problems involved with every accident.

The economical aspect is interesting for the owner, in this case a public road administration, who must provide the expenses for maintenance and repair after the completion of the work and expiration of the guarantee period.

A comparison of the course of the number of accidents on the grooved sections with the course of yearly traffic frequencies shows that the relative number of accidents increased with increasing traffic. In 1973 it reached the same relation to traffic frequencies as in the years 1966 and 1967, before cutting the grooves.

An attempt to consider these facts and to determine the number of statistically possible, expectable but not happened accidents and to capitalize this number with an average sum for each accident leads to the following results.

On the basis of the assumptions which have been made, it is possible to calculate the number of accidents which "did not occurr" as a consequence of grooving from 1968 to 1972.

YEAR	1968	1969	1970	1971	1972	Total
Difference of accident rate	4,56	3,62	1,95	3,20	2,15	
Number of accidents	19,4	12,2	8,75	10,08	7,54	57,97

With the general assumption of 50'000 Swiss Francs for one accident, we would arrive at a sum of about 3 million Francs in 5 years for 58 accidents.

The costs for a very expensive but locally limited measure to increase traffic savety are very low compared to the calculated sum.

Question of Responsibility

The question of responsibility arises at the moment an accident occurs and the following recourses, when a road surface does not fulfill the requirements any more. There are no problems if the accident occurs during the guarentee time of the surface course. In this case it is the contractor who has to come up for the consequences if he cannot prove that he had to fulfill certain specifications which turned out to be unsuitable.

The owner is responsible if the accident occurs after expiration of the guarantee time and is not caused by a concealed defect, construction or other error. It is therefore advantageous to be informed about actual quality and safety conditions and not to be surprised by an accident. A good register must be kept about the condition and the quality of road surfaces in order to be able to establish in time a maintenance and repair program with suitable priorities.

Jurisprudence knows many cases - the first 1932 in Berlin (1) and many other since - in which a road administration was held responsible for damages caused by unsafe qualities of smooth road surface. However, this happened only when it was proved that the accident occurred in spite of a correct behaviour of all persons involved.

A very recent statement about the question of responsibility of a public road administration in relation to such accidents is the one by R. F. Carlson of California's Departement of Transportation (7): "One of the greatest problems facing highway departements is slippery pavements in non-freezing, wet weather, Because of increased legal duties imposed on public entities, highway departments find themselves exposed to liability for accidents that result from what used to be considered purely weatherrelated causes. Immunities are being weakened, engineering decisions are subject to review, and personal responsibilities are being imposed. A program of skid testing is imperative for early detection of low skid resistance areas. The use of mandatory minimum skid numbers is warned against because of possible adverse legal implications. Grooving, as well as other methods (indicated by the author, (8)), has proven to be a solution to problems of low skid resistance. Generally, a public entity is not liable for a highway made slippery by rain alone; however, public entities may be held liable for hazardous low skid resistance conditions that result from their own actions or inactions (worn pavements; defectively designed, slippery PCC pavements; unplanted eroding cutslopes; improperly applied seal coats; and clogged drains and drainage ditches that cause ponding). They also may be found liable when conditions are purely weather created and the hazard is such that public entity has a duty to remove it entirely or ameliorate it by the use of warning signs. The reasonableness of the public entity's actions generally will be the deciding factor on whether liability will ensue. Justice - so Mr. Carlson closed his words - has put the responsability before the doors of the engineers. It is now in their hands to reach for the correct reaction".

Conclusions

Grooving of polished road surfaces reduces the hazard of accidents when drainage conditions are unfavourable.

The advantage of grooving is the reduction of water-film thickness, which leads to a better contact between tire and road surface for the transmission of forces, although roughness is influenced by very narrow groove distances only. Grooves have a favourable influence on surface drainage if they are cut at such an angle to the line of maximum slope, that water reaches the next grooves after a very short drainage distance. Any further improoved adhesion will however only be reached when grooves at a very narrow distance create an additional keeing action.

The effect of a reduction of accidents by a decrease of waterfilm thickness caused by grooving, as it has been proved in this study, cannot be expected with the same success in all cases. It must be considered that grooving is always just one of the factors, sometimes the most important one, which can influence positively the rate of accidents on wet surfaces. Grooving will always be effective when great water quantities cannot be eliminated rapidely enough from smooth surfaces with insufficient macrotexture.

Grooving has reached the purpose of a reduction of the number of accidents on the observed road. Suitable measures for better skidding conditions on the total length of 44 km would be an additional advantage.

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EFFECTIVENESS OF ANTILOCK BRAKES IN PASSENGER CARS

Nathaniel H. Pulling, Liberty Mutual Insurance Company

At the First International Skid Conference eighteen years ago, Lister and Kemp described experiments with antilock braking for passenger cars. Subsequently a number of systems were developed and several were placed in limited production. Although both 2-wheel and 4-wheel antilock braking systems perform superbly well under treacherous driving conditions, they have not proved to be commercially successful. Several published studies are reviewed which have shown that antilock braking in automobiles has worthwhile potential for skid control and accident avoidance. An economic study of 100 skidding accidents from a randomly-selected sample of 613 insurance cases is described in detail. The benefit/cost ratios for passenger cars was estimated from the data to be 1.4 for 2-wheel antilock braking and 1.3 for 4-wheel systems, and payback periods were determined to be about 7 and 8 years respectively. The outlook for antilock brakes in passenger cars is discussed.

At the First International Skid Conference eighteen years ago, Lister and Kemp described experiments with antilock braking for passenger cars (1). By preventing the rear wheels of an automobile from locking and then skidding during a panic stop on roads slippery with water or ice, an antilock brake system installed on the rear wheels can shorten stopping distances, provide straighter stops and reduce the tendency to spin out on a curve. Furthermore, antilock systems on front wheels enable evasive steering otherwise impossible with wheel lockup. The major car manufacturers experimented with antilock braking systems in the 1960s, and in the early part of this decade they were offered as factory-installed options in a number of American luxury cars (2, 3 and 4). In spite of their functional effectiveness (5, 6 and 7), however, antilock brakes did not sell well as options in passenger cars and most have been withdrawn from the market. Apparently customers were not persuaded that their benefits justified the cost. It is the purpose of this paper to examine the effectiveness of antilock brake systems for passenger cars from an economic standpoint.

Skidding incidents are commonplace occurrences on wet city streets, icy suburban roads and on rainy highways. It has been estimated (8) that 23% of motor vehicle accidents occur on road surfaces which are wet, snowy or icy. Although it can be argued in most cases that skidding is not in itself the causative element, it unquestionably is a major aggravating factor in many motor vehicle collisions. There seemed to be considerable variability in earlier estimates of skidding involvement (9) but on the average they agree with several recent studies (10, 11 and 12) which indicate that about 15% of all reportable motor vehicle crashes probably involve skidding. What we would like to have for our present purpose, of course, are analytical estimates of the cost reduction potential of antilock brake systems in mitigating the consequences of accidents involving skidding. Several automotive manufacturers have researched the cost effectiveness of antilock brakes, but unfortunately they have not been in a position to publish their results. Only three relevant studies in the open literature have come to our attention, and unfortunately none of them consider dollar benefits. They are as follows:

1. Last year the Indiana University Institute for Research in Public Safety evaluated the accident avoidance potential of antilock braking by analyzing 89 accidents which had been intensively investigated by multidisciplinary teams. At "certain or probable levels of assuredness" it was estimated (13) that 2-wheel antilock brake systems would have prevented or reduced the severity of 1.9% of the accidents, and 4-wheel antilock braking had a 9.3% potential payoff in collision avoidance.
2. As part of the Swedish Experimental Safety Vehicle program, the accident avoidance potential of pre-crash steerability with 4-wheel antilock braking was studied in 168 police reports of locked-wheel accidents and 372 interviews with drivers of company fleet cars. It was concluded (14) that 40-50% of the collisions could have been "avoided or considerably reduced" by steering capability. Assuming the 15% skidding involvement reported above for all accidents, these Swedish results suggest an accident avoidance or severity reduction potential of about 7% for 4-wheel antilock braking (i.e., 40-50% mitigation of 15% skidding involvement).
3. In 350 skidding accidents in West Germany, HUK-Verband (German Motor Traffic Insurers) reported (15) that 4-wheel antilock braking systems would have minimized or avoided the accident with "sure benefit" in 7.1% of the cases and with "good use" in another 8.3%.

Economic Study

In order to evaluate the effectiveness of antilock braking for passenger cars, in 1972 Liberty Mutual purchased a 1971-model Chrysler equipped with the 4-wheel antilock Sure-Brake system manufactured by the Bendix Corporation. Special controls were provided so that the antilock feature could be disabled by a selector switch, operated on the rear wheels alone, or provided for all four wheels. In order to evaluate maneuverability, extensive tests were carried out on a skid pan (typical results were reported in (16)) and systematic low speed testing was conducted on actual roads under slippery conditions. On the basis of this experience and published data (2), estimates were made of the loss reduction potential of 2-wheel and 4-wheel antilock braking, as well as skilled drivers, utilizing a random sample of typical skidding accident insurance cases. These data were then subjected to economic analysis.

Case Analysis

The accident cases utilized for the study comprised an essentially random sample of approximately 10% of all the automotive accidents reported by policyholders to the Liberty Mutual office in Worcester, Massachusetts during a twelve-month period during 1970-71. That period was chosen because it was the last one prior to the adoption of no-fault automobile insurance in Massachusetts, and hence complete and detailed accident reports were available (which was not true in the years following). Every tenth accession number in the office register book was chosen. When one of these numbers was found not to represent a developed case, the next number was taken or the one after that. At 42° north latitude and about forty miles from the Atlantic ocean, Worcester has moderately severe winters with substantial amounts of snow and ice. These conditions are exacerbated for driving by many steep hills within the city and outside. The policyholder population came from 51 neighboring cities and towns (3% rural) with a total population of about 600,000. 613 cases involving 1068 automobiles were utilized. Thirty-nine of those automobile collisions involved trucks or buses, two were with motorcycles and there were eight pedestrian claims.

There were 100 skidding cases (16.4% of the total number reviewed), which were defined as those where there was evidence of slippery conditions or a driver reported skidding. Each of them was studied carefully to determine the extent to which accident severity might have been mitigated by: first, skillful drivers trained in skid control techniques; second, by 2-wheel antilock brakes; and third, by 4-wheel antilock brake systems. This was accomplished by estimating for each of the three countermeasures a discount factor by which the cost of the accident was multiplied. If a countermeasure was considered extremely effective, a multiplier of 0.1 was assigned. This had the effect of discounting the accident cost by 90%. If, on the other hand, a countermeasure was considered to have very little effectiveness, a multiplier of 0.9 was applied, which discounted the accident cost only 10%. The multipliers used were: 0.1, 0.3, 0.5, 0.7 and 0.9. For each of the five collisions wherein two cars skidded, an overall effectiveness multiplier could be selected without uncertainty. Two examiners were used for about half the cases and three examiners in about one-quarter of the determinations. Examiners almost always agreed within ± one step (0.3 or 0.7 instead of 0.5, for example), and there were only two instances of greater disagreement.

Damages awarded by the courts were disregarded in pricing the accidents, and for each case the economic loss was determined as follows. The cost of bodily injury was reckoned by adding up actual charges for medical expenses, domestic services necessitated by incapacitation, lost wages and out-of-pocket expenditures incurred because of human injury. There were no skidding cases involving deaths, and no note was taken of any monetary value ascribed to pain and suffering, deprivation of companionship, unrealized loss of potential earnings, and the like. Property losses and the cost of physical damage to vehicles other than passenger cars were taken from estimate sheets, invoices and other evidential sources. In order to provide uniform and complete pricing for the physical damage to the automobiles involved, average repair costs were used instead of the actual appraisals. These data were taken from a study (17) conducted by the American Mutual Insurance Alliance, wherein a representative body of detailed information was collected on a country-wide basis by four large auto insurers from 89,060 crash repair estimates involving 1969-1972 cars. Specific average values were employed for both collision and property damage coverages in each of twelve impact areas (front, right front corner, right front quarter and so forth), which were easy to identify in the accident records. It should be noted that this cost assignment procedure does not include any deductible (generally $50), and hence understates cost somewhat.

Benefit Determination

The total estimated cost of the 100 skidding accidents was $91,200. For 2-wheel antilock brakes the total of the discounted costs was $65,500 for a total saving of $25,700. For 4-wheel antilock brake systems the total of the discounted costs was $42,400, for a total savings of $48,800. There were 1068 automobiles involved in the 613 accidents studied, so that the average savings per car for each accident was calculated as $24 for those equipped with 2-wheel antilock brakes ($25,700 total savings/1068 cars) and $46 for cars having 4-wheel systems ($48,800/1068).

According to the National Safety Council (18), there were 23.8 million accidents reported in the United States during 1971, and the U.S. passenger car population then was 91.9 million. Based on these data it is calculated that on the average 25.9% of the passenger cars on the road in 1971 were involved in accidents. Utilizing data attributed to the R. L. Polk and Company (19), the median life of automobiles registered in the United States during 1971 was estimated (from graphs of model-year registrations) to be 10.1 years. Assuming an average involvement of 25.9% and a 10.1-year life, the lifetime expectation of 1971 cars was calculated to be 2.62 collisions. Multiplying 2.62 times the average savings for each accident which were given in the preceding paragraph, yields estimated lifetime savings of $63 (in 1971 dollars) for cars equipped with 2-wheel antilock brakes, and $120 for 4-wheel systems.

During the initial work on this project in 1971, representatives of several manufacturers of antilock brakes (in private conversations with the author) estimated that for universal application 2-wheel antilock brakes could be expected to have a sticker price in 1971 of $50, and a 4-wheel system a price of $100. Electronics are less expensive today, so that the price of antilock brakes were said by a manufacturer (in private to the author) to have increased only 20% in the ensuing five years, despite much greater inflation. 15% of the selling price has been allowed for maintenance of the antilock brake systems over the lifetime of the automobile. With these 20% and 15% adders, the 1976 prices of antilock brakes in mass production is assumed to be \$69 for a 2-wheel system and \$138 for a 4-wheel system.

In order to prepare an economic analysis in a contemporary frame of reference, it is necessary to adjust antilock braking system benefits in terms of inflation on the one hand and the time value of money on the other. The inflation adjustment for the 10.1-year period from January 1976 to February 1986 was based on the actual movement of the Labor Department's Medical Care Index and Automobile Maintenance and Repair Index from 1971 to 1975 and on Chase Econometrics, Inc. forecasts (20) of these indices for 1976 through 1985. The two indices were combined by weighting medical care 40% and automobile maintenance and repair 60%, which corresponds roughly to the present distribution of injury and car damage premium. The average annual rate of inflation for the period 1971-1976 was 7.8%. For the period 1976-1985 the inflation rate was forecasted to average 7.3%. The adjustment for the time value of money was based upon a discount rate of 6%.

Results

Based on the foregoing, the results of the study are these: First, the present value of the lifetime savings of a 2-wheel antilock brake system assumed to be sold in 1976 is estimated to be about \$95 and for a 4-wheel system to be approximately \$180; second, the benefit/cost ratios are 1.4 for 2-wheel and 1.3 for 4-wheel antilock brake systems; and, third, the indicated payback periods are about 7 years for a 2-wheel system and 8 years for 4-wheel antilock braking.

Discussion

If the payback calculations of the preceding section were used in insurance pricing, conceivably the premium reductions for antilock systems could gradually pay back to car owners the cost of an antilock braking system. However, considering the small annual savings in insurance premiums and the 7 or 8-year payback period, the likelihood that car owners would be motivated to purchase an antilock system is questionable. Motivation would be enhanced if the payback period could be reduced to within the first 3 or 4 years of car ownership, because the resale value of safety devices is minimal.

The foregoing analysis was based on a sample. As with any results derived from a sampling procedure, the results of this study are subject to sampling error. There are potentially at least two important sources of sampling error in this study. First, the most serious potential error derives from the happenstance that the sample drawn did not include any fatalities. However, National Safety Council statistics (18) indicate a 0.22% fatality rate for automobiles reported to be involved in 1971 accidents. No adjustment was made in this study for this potential sampling error because it would have required assigning a dollar value to human life, which at best is extremely difficult to do on an objective basis. Any such correction, of course, would increase the benefits and shorten the payback. The second potential source of sampling error relates to geography. The sample was drawn from the vicinity of Worcester, Massachusetts, as described previously. Whether or not the weather, traffic conditions and driving population in Worcester are typical of North America is debatable. The analysis has made the assumption that on the average they are typical, and that Worcester, Massachusetts may be considered skid-wise to be "Middletown, North America". However, this assumption is based upon subjective judgment alone.

Concluding Remarks

Judging from the results of this study, antilock braking systems seem to be economically justified, on the average, for private passenger cars. For high-mileage and high speed driving, antilock brakes likely would be much more cost effective than average. An example would be a salesman spending 15 or more hours a week behind the steering wheel, much of it in high-speed driving where antilock brakes are a spectacularly effective countermeasure for highway skids.

However, it is difficult to be optimistic about the near future of antilock brake systems after customers have spurned them as options. Nevertheless, automotive history has examples of technological resurrection, and this study indicates that antilock braking might be a good candidate for a successful rebirth. Design improvements, cost reductions and imaginative marketing would be crucial elements in that process.

Acknowledgments

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Abstracts of Papers in French

ACCIDENTS DE GLISSANCE, ADHERENCE ET ASPECTS JURIDIQUES. RAPPORT DU COMITE TECHNIQUE DE LA GLISSANCE ET DE L'UNI DE L'A.I.P.C.R. (Association Internationale Permanente des Congrès de la Route)

K.H. Schulze, Université Technique de Berlin République Fédérale d'Allemagne. A. Gerbaldi, Ecole Nationale des Ponts et Chaussées, France. J. Chavet, Ministère des Routes, Belgique.

La relation entre l'adhérence et accidents n'est pas simple. Pour tenter de l'établir, on peut soit utiliser une méthode d'analyse de régression entre la fréquence des accidents et la valeur du coefficient de frottement pneu-chaussée, soit évaluer la fréquence des accidents avant et après la régénération des propriétés antidérapantes du revêtement. Dans le premier cas, il faut prendre en compte l'ensemble des facteurs d'accident liés à la chaussée, à l'environnement et aux conditions de trafic. Les études "avant-après" apparaissent plus probantes car elles mettent en évidence directement le rôle de l'adhérence.

En fait le choix d'une valeur minimale du coefficient de frottement dépend des contraintes économiques. En outre, le respect de cette valeur ne permet pas de garantir la sécurité dans tous les cas. C'est pourquoi il est très difficile de fixer les responsabilités en cas d'accident de dérapage.

En conclusion, l'amélioration de la sécurité routière dans ce domaine implique des mesures correctives fondées d'une part sur le suivi systematique de l'évolution de l'adhérence et d'autre part sur la constatation des accidents sur chaussée mouillée.

ACCIDENTS ROUTIERS ET ADHERENCE DES CHAUSSEES = RAPPORT SOMMAIRE DE L'INSTITUT DE RECHERCHE SUR LA SECURITE ROUTIERE, SWOV

L.H.M. Schlosser, Institut de Recherche sur la Sécurité Routière - SWOV.

Cette étude fait partie du grand programme néerlandais de recherches sur les pneus, les chaussées et les accidents de glissance. La recherche utilise comme base les données recueillies pendant les années 1965 et 1966. Elle couvre presque toutes les routes principales du réseau routier hollandais où l'on distingue deux types de routes:

1. les routes à chaussées séparées à deux voies
et 2. les autres types de routes, à deux voies et à quatre voies non séparées.

Les données sur l'adhérence se réfèrent pour cette étude des chaussées mouillées seulement. Le volume du trafic, comme paramètre lié au risque, a été mesuré pendant les périodes de pluie. Les données sur les accidents contiennent l'indication des conditions atmosphériques. On a exclu les accidents survenus sur chaussées rendues anormalement glissantes par la neige, le grésil, le verglas.

Les taux d'accidents sont établis par type de route pour le trafic total, et séparément pour les véhicules légers et les poids lourds. Les taux d'implication ont été calculés pour toutes les routes par classe d'adhérence, à partir de données suffisamment précises. En plus, d'autres classifications ont été faites, pour chaque classe d'adhérence pour chaque tranche horaire pour le volume total du trafic.

Cette recherche montre clairement que la diminution de l'adhérence des chaussées est associée à un risque plus élevé d'accident de la circulation. Il est donc recommandé qu'en tant que mesure d'ordre géneral pour la sécurité du trafic, une valeur minimale de l'adhérence soit recommandée sur chaussée mouillée. Cependant on doit prendre soin de ne pas appliquer les résultats de l'étude sans une analyse minutieuse des circonstances du moment, du trafic et de l'état de la route, et dans le cadre des règlements régionaux.

LOCALISATION ET TRAITEMENT DES SITES URBAINS GLISSANTS

L.W. Hatherly et A.E. Young - Greater London Council.

La première partie du rapport est consacrée aux recherches effectuées ces dernières années au T.R.R.L. notamment, et en Grande Bretagne, et montre que pour les mélanges bitumineux, le coefficient de frottement transversal peut être déduit de la nature des roches employées en traitement superficiel, du volume de trafic et de l'intensité de la circulation.

On discute la difficulté de la fixation d'un seuil pour le coefficient de frottement transversal. On montre que beaucoup de chaussées qui seraient jugées comme glissantes d'après certaines normes, ne sont pas nécessairement dangereuses et

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*The abstracts were translated by the Technical Committee on Slipperiness and Evenness of the Permanent International Association of Road Congresses, A. Pasquet (France), chairman, and J. Lucas (France), secretary.

que leur traitement ne serait pas justifié économiquement. On souligne que la majorité des accidents corporels a lieu en site urbain et de plus que la majorité de ceux-ci se produit aux carrefours. A Londres, par exemple, 55 000 accidents corporels se produisent chaque année, dont plus de 70% aux intersections. L'action s'est donc concentrée sur les problèmes de carrefours. Plus de 800 carrefours et d'autres sites dangereux analogues, comme l'approche de passages cloutés ont maintenant été traités avec un enduit superficiel à base de résine époxy et de bauxite calcinée.

Les études d'accident "avant-après" regroupant plusieurs zones sont présentées et les incidences économiques examinées. On décrit deux méthodes de détection des sites où les accidents pourraient être réduits par un traitement de la surface, à partir de l'emploi d'un appareil pour relever en continu l'adhérence, et à partir des données des accidents.

DETERMINATION DES INTERSECTIONS AVEC ACCIDENTS PAR TEMPS DE PLUIE A PARTIR DES DONNEES METEOROLOGIQUES ET DE L'ADHERENCE

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

Les carrefours en zone rurale et en zone urbaine sont étudiées en liaison avec le pourcentage d'accidents sur chaussée mouillée. Les analyses tiennent d'abord compte du pourcentage mensuel estimé du temps pendant lequel les chaussées sont mouillées. Commes les données météorologiques ne sont fournies que pour des intervalles de temps prédeterminés, on a réalisé une méthode pour les transformer en temps de mouillage - facteur nécessaire pour calculer le temps de mouillage aux carrefours. On a utilisé cette conversion pour traiter les données de 120 stations météorologiques du Michigan, pour trouver mois par mois le profil de mouillage de tout l'Etat pour les années 1963 à 1974. La gamme de ces mouillages mensuels varie de moins de 1% à plus de 25%. Ce rapport potentiel de 25 à 1 est très important dans la réalisation des accidents sur chaussée mouillée, et doit être consideré avant tout autre variable.

On a calculé les pourcentages d'accidents sur chaussée mouillée pour environ 40.000 accidents survenant à 2.000 carrefours environ, où l'on disposait des valeurs de l'adhérence (SN). Ces données en liaison avec le pourcentage de temps de mouillage sur le site correspondant, tel que l'on peut le déduire de la station météorologique la plus proche, fournissent un moyen pour ajuster statistiquement un modèle des accidents prenant en compte les variables considérées. L'adéquation du modèle est correcte, et conduit à une fonction croissante pour l'adhérence SN. Pour tous les niveaux de mouillage, un coefficient d'adhérence SN de moins de 30 environ est associé à une croissance rapide du pourcentage d'accidents sur chaussée mouillée; quoique la forme de la courbe réelle dépende du temps de mouillage. La modelisation apparaît utile dans l'analyse coût-efficacité du programme du resurfaçage des intersections qui doit réduire les accidents par temps de pluie.

LE FACTEUR HUMAIN ET LES DERAPAGES = CAUSES ET PREVENTION

F.R. Hanscom, Biotechnology Inc.

Ce rapport donne la synthèse actuelle de l'influence du facteur humain dans la cause et la prévention des accidents de dérapage. On a résumé les analyses bibliographiques en deux parties. La première concernant le conducteur et le risque de dérapage sont traduits en terme de perception et de réponse du conducteur aux situations de conduite entrainant le dérapage. La seconde couvre les techniques éventuelles de régulation du trafic et les techniques correctives.

La détection et l'appréciation du risque de dérapage sur chaussée mouillée dérive du fait que durant la pluie la chaussée modifie la perception des alignements (comme sur une courbe horizontale). L'indication du risque au conducteur par des signaux statiques est géneralement inefficace; alors que des signaux à éclats lumineux, des écrans dynamiques et des vitesses conseillées sur de tels sites autoroutiers sont efficaces, en modifiant le comportement et par là en réduisant les pertes de contrôle.

Des géometries particulières de chaussées peuvent conduire à des demandes d'adhérence plus élevées que la normale, car la difficulté de conduite est sous-estimée. C'est à de tels sites que s'adressent d'abord les améliorations de l'adhérence et les dispositifs de contrôle de vitesse. Quoiqu'il ait été démontré que l'entrainement aux dérapages puisse effectivement modifier la performance des conducteurs,il n'est pas évident qu'un tel entrainement sera encore utile si sa mise en application est différée.

On fait enfin des propositions pour des contre-mesures immédiatement applicables et pour une recherche nécessaire pour la mise au point d'autres contre-mesures plus efficaces pour la prévention des accidents.

APPLICATIONS LEGALES DES REGLEMENTS DESTINES A REDUIRE LES ACCIDENTS SUR CHAUSSEE MOUILLEE SUR AUTOROUTES

Larry W. Thomas, Transportation Research Board.

Ce rapport examine l'application légale des règlements destinés à réduire les accidents sur chaussée mouillée, y compris l'adoption d'une adhérence minimale uniforme pour les autoroutes, la conception des revêtements, de la formulation et les choix, le resurfaçage ou le rainurage, la mise en place de la signalisation, la collation des données des accidents, la mise en place d'un fichier des autoroutes, en vue de définir les priorités pour des réparations ou des aménagements. L'orientation du rapport est de préciser les domaines d'action pour la diminution des accidents de glissance qui peuvait soit prévenir, soit mettre en cause la responsabilité de l'Etat, pour des accidents corporels ou matériels survenant à des usagers sur des autoroutes présentant une adhérence faible ou insuffisante. On discute aussi l'utilité de ces règlements et la qualité des essais. Le rapport s'appuie sur des statuts féderaux ou des états, des publications, des jugements, et en particulier sur les règles du programme pour la réduction des dérapages du FHWA.

METHODOLOGIE D'ETUDE COÛT-EFFICACITE DE LA DEMANDE D'ADHERENCE

J.M. **Zuleback,** Science Application, Inc.

Ce rapport décrit la méthodologie qui utilise les zones particulières des autoroutes, les paramètres de tracé et de trafic comme entrée pour le calcul de la demande locale d'adhérence et du rapport coût-efficacité.

La valeur caractéristique calculée est la marge de sécurité. La distribution de cette valeur est définie comme la différence entre la distribution du frottement utilisable pneu-route et la distribution de la demande d'adhérence des usagers par temps de pluie.

Les meilleurs modèles disponibles pour l'adhérence pneu-route sont décrits. On discute la méthode de prise en compte de la distribution des vitesses dans ces modèles pour obtenir une distribution statistique de l'adhérence pneu-route utilisable. On donne une nouvelle approche du calcul de la demande d'adhérence dans un site particulier. De façon explicite, cette approche tient compte de la nature de la manoeuvre demandée par le conducteur, à partir d'une intégration d'un modèle empirique des manoeuvres réalisées statistiquement par les conducteurs. Des modèles spécifiques pour le freinage aux carrefours, les virages sur autoroutes et le dépassement sont donnés. Des modèles supplémentaires pour le changement de voie en urgence et d'autres manoeuvres complexes sont discutés.

La distribution complète de la demande d'adhérence à des sites particuliers dépend de la fréquence relative d'apparition et de la distribution de la demande d'adhérence pour la manoeuvre considerée. On présente une méthode où une pondération particulière est assignée à chaque manoeuvre-type. Cette pondération est établie à partir des fréquences relatives de chaque manoeuvre, telle que déduite des modèles statistiques des comportements de conduite. On présente une technique conceptionnelle qui permet la sélection systématique de la combinaison route-autoroute -paramètres opérationnels du trafic la plus souhaitable pour obtenir le niveau de sécurité qui satisfait au niveau de service et aux contraintes de coût prédéterminées. On suggère la façon dont la méthode génerale pourrait être utilisée, comme outil itératif de conception, pour des techniques d'optimisation généralisée.

MODELE COUT-EFFICACITE DU RESURFAÇAGE D'UN REVETEMENT

A. St. John, Midwest Research Institute.

En vue de la comparaison de plusieurs méthodes de renouvellement de la couche de roulement pour satisfaire à une adhérence minimale, on a développé, sur calculateur, un modèle coût-bénéfice. Ce modèle demande les spécifications autoroutières, les données des accidents, les caractéristiques géometriques principales, les conditions météorologiques et les données du trafic. Il peut justifier le coût élevé des traitements superficiels (ou de moyens de régulation du trafic) à partir des risques probables d'accidents. Les traitements superficiels classiques (enduisages ou divers rainurages) peuvent être comparés dans la mesure où l'on peut les différencier du point de vue de l'adhérence (mesurée d'habitude aux USA en adhérence SN à 64,6 km/h).

Les traitements particuliers comme les enrobés perméables sont comparés aux revêtements classiques en prenant en compte la différence de longévité, d'entretien et de coût de mise en oeuvre. Cette comparaison prend en compte les meilleurs données disponibles sur les dégradations climatiques, l'effet du trafic lourd et les caractéristiques d'adhérence des divers traitements particuliers. Le programme prend en compte ces informations comme "pénalités", encourageant ainsi les maîtres d'oeuvre ou les autorités routières, à fournir des données plus satisfaisantes si cela est le cas, dans leurs conditions particulières.

Les améliorations sont appréhendées par le modèle de façon incrémentale. Par exemple, si les vitesses effectives sont réduites, le resurfaçage prévu avec l'emploi d'un mélange donné, un rainurage particulier proposé, le rapport coût-bénéfice sera calculé pour le meilleur traitement et l'incrément des rapports coût-bénéfice pour chacun des traitements successivement. Tout traitement ou augmentation ayant un rapport bénéfice/ coût inférieur a 1 sera réjetés.

Ce modèle est applicable, non seulement pour l'ensemble des véhicules circulant sur autoroute, mais peut s'étendre à une grande partie des véhicules poids-lourd; toutefois il faudrait alors tenir compte des dégradations supplémentaires que subiraient les chaussées. Le programme est écrit en Fortram IV, ce qui permet de l'utiliser directement sur de nombreux calculateurs.

INFLUENCE DU RAINURAGE DU REVETEMENT SUR LA FREQUENCE DES ACCIDENTS

E. Zipkes, Université Technique Federale (Suisse)

L'emploi de rainurages longitudinaux ou transversaux s'est montré efficace pour la réduction des accidents sur chaussée mouillée. Les techniques de rainurages usuelles dans la plupart des pays emploient des rainures très serrées pour permettre une meilleure évacuation de l'eau ou améliorer la stabilité du véhicule. Dans le cas d'un rainurage transversal, on peut espacer les rainures et conserver l'amélioration de sécurité (sous réserve de refaire les rainures après usure). On a analysé dans ce rapport, la fréquence et le pourcentage des accidents sur chaussée sèche et mouillée pour les années 1966 à 1973, sur des sections de l'autoroute Genève-Lausanne. Sur 44 km, il n'y avait que très peu de zones lisses (environ 2 km).

Les données analysées sont: les comptages officiels de trafic, la mesure des précipitations par l'Agence centrale suise de Météorologie, et les rapports sur les accidents des polices autoroutières. Les deux kilomètres lisses ont été rainurés deux fois pendant la période d'observation avec des distances entre rainures de 5 m et de 2 m. Cette chaussée est un bon exemple pour l'étude de l'influence du rainurage sur les accidents. On a déterminé la fréquence relative des accidents chaque kilomètre pour un million de passages de véhicules, en liaison avec le nombre de jours secs et mouillés pour chaque année, pour les sections rainurées et non rainurées. Le pourcentage d'accidents sur chaussée mouillée complète l'étude.

Les résultats montrent clairement l'influence positive des rainurages sur la sécurité, même pour les rainures les plus espacées, et l'effet de la diminution de l'épaisseur du film d'eau sur la réduction des accidents. On considère aussi l'aspect économique de ces traitements et les questions légales concernant la responsabilité du propriétaire de la route.

EFFICACITE DES FREINS ANTIBLOQUANTS SUR LES VEHICULES LEGERS

Nathaniel H. Pulling, Liberty Mutual Research Center.

Il y a dix-huit ans, lors de la première conférence internationale sur la prévention de la glissance, Lister et Kemp avaient décrit les essais de véhicules légers équipés de freins antibloquants. Plusieurs dispositifs furent réalisés et certains montés dans de petites séries. Bien que les dispositifs antibloquants (montés sur deux roues seulement ou sur quatre roues) fonctionnent parfaitement bien dans les conditions les plus traîtres,
ce ne fut pas un succès commercial. On cite plusieurs publications qui montrent que les véhicules équipés ont des possibilités bien supérieures d'éviter les dérapages et les accidents. Une étude économique portant sur 100 accidents de glissance, sélectionnés à partir d'un échantillon tiré au hasard de 613 cas est décrite en détail. Le rapport bénéfice/coût pour des véhicules de tourisme a été calculé et a donné 1,4 pour les dispositifs contrôlant deux roues et 1,3 pour les dispositifs contrôlant les quatre roues avec des durées d'amortissement de 7 ans et de 8 ans respectivement. La perspective du développement sur les véhicules de tourisme est analysée.

Abstracts of Papers in German

RUTSCHUNFÄLLE, REIBUNGSZAHLEN (GRIFFIGKEITSWERTE) UND DIE EINGESCHLOSSENEN JURISTISCHEN ASPEKTE: BERICHT DES TECHNISCHEN KOMITEES FÜR STRASSENGRIFFIGKEIT UND STRASSENEBENHEIT DER AIPCR (STÄNDIGER INTERNATIONALER VERBAND DER STRASSENKONGRESSE)

K.-H. Schulze, Technische Universität Berlin;
A. Gerbaldi, Ecole Nationale des Ponts et Chaussées, Paris;
J. Chavet, Administration des Routes, Brüssel

Wegen der verschiedenen anderen Faktoren, die an Rutschunfällen beteiligt sind, kann man nicht erwarten, daß Reibungszahlen (Griffigkeitswerte), die unter standardisierten Versuchsbedingungen gemessen werden, eine klare Einstufung der Fahrbahnoberflächen im Hinblick auf die Verkehrssicherheit bei Nässe ergeben. Trotzdem ist die Konzeption der standardisierten Versuchsbedingungen aus praktischen Gründen unverzichtbar. Regressionsanalysen vergleichen Unfallzahlen oder -raten mit Griffigkeitswerten (Beispiele aus den Niederlanden, der Bundesrepublik Deutschland und Frankreich). Der schlagendste Beweis für die bedeutende Rolle, die Straßenglätte bei Unfällen auf nasser Fahrbahn spielt, wird jedoch durch zuverlässige Vorher-Nachher-Untersuchungen erbracht (Beispiele aus Italien und Großbritannien).

Die Einführung von Standard-, Richt- oder Mindestwerten für die Fahrbahngriffigkeit basiert hauptsächlich auf Ergebnissen von Regressionsanalysen. Von Land zu Land sind solche Werte sehr unterschiedlich in Wesen und Bedeutung. Sie unterstützen die Straßenbehörden bei Entscheidungen über Unterhaltungs- oder Deckenerneuerungsarbeiten, aber nur in Belgien, in den Niederlanden und in der Schweiz dienen sie auch als Abnahmekriterien für Straßenbauleistungen. Die gegenwärtige Praxis wird beschrieben. Die beiden Methoden zum Unterdrücken von Unfallschwerpunkten bei Nässe sind: systematische, routinemäßige Griffigkeitsmeßserien; Auswertung der Unfallstatistik, wobei vorzugsweise der "Anteil der Unfälle bei Nässe" als Kriterium dient. Interdisziplinäre Zusammenarbeit ist erforderlich, um Vorschläge für Abhilfemaßnahmen auszuarbeiten, die im allgemeinen auch andere Faktoren als die Fahrbahnglätte einschließen werden (Beispiel: Sicherheitsoperation Nr. 6 in Frankreich).

Die juristischen Aspekte im Zusammenhang mit Rutschunfällen umfassen die Verantwortung des Deckenherstellers, die Verantwortung der Straßenverwaltung und die persönliche Verantwortung der Bediensteten der Verwaltung. Trotz der großen Unterschiede in den gesetzlichen Voraussetzungen lassen sich hierzu einige allgemeine Feststellungen treffen.

VERKEHRSUNFÄLLE UND STRASSENGRIFFIGKEIT: ZUSAMMENFASSENDER BERICHT DES INSTITUTS FÜR STRASSENSICHERHEITSFORSCHUNG (SWOV)

L. H. M. Schlosser, Institut für Straßensicherheitsforschung (SWOV)

Diese Studie bildet einen Teil des niederländischen Forschungsprogramms über Reifen, Straßenoberflächen und Rutschunfälle.

Die Forschung beruht auf Grunddaten, die in den Jahren 1965 und 1966 gesammelt worden sind. Erfaßt werden nahezu alle Arten von Straßenanlagen im niederländischen Autobahnnetz, in dem zwei Straßentypen zu unterscheiden sind: (1) Straßen mit getrennten Richtungsfahrbahnen, (2) alle übrigen Typen, wie Fahrbahnen mit Gegenverkehr und einspurige Straßen.

Die in dieser Studie benutzten Daten über die Griffigkeit der Fahrbahndecken beziehen sich ausschließlich auf den nassen Fahrbahnzustand. Die Daten über die Verkehrsstärke, die während Niederschlagsperioden erhoben wurden, dienen als Bezugsgröße für die Anzahl der gefährdeten Fahrzeuge bei nassem Wetter. Die Unfalldaten enthalten zusätzliche Angaben über die Wetterbedingungen. Unfälle auf Fahrbahnen, die infolge von Schnee, Graupel oder Eis extrem glatt waren, blieben in der Untersuchung außer Betracht.

Unfallbeteiligungsraten je Straßentyp wurden für die Gesamtheit aller Fahrzeuge sowie getrennt für Pkw und Lkw errechnet. Die Beteiligungsraten wurden für die verschiedenen Klassen des Griffigkeitsniveaus aus recht gut detailliertem Zahlenmaterial ermittelt. Des weiteren wurden innerhalb jeder Klasse des Griffigkeitsniveaus Unterscheidungen nach der stündlichen Gesamt-Verkehrsstärke getroffen.

Die Ergebnisse zeigen klar, daß ein niedrigeres Griffigkeitsniveau mit einer größeren relativen Unfallgefahr verknüpft ist. Es wird deshalb empfohlen, daß ein minimaler Griffigkeitswert, bezogen auf die nasse Fahrbahn als ein allgemeines Maß für die Verkehrssicherheit eingeführt werden sollte.

Es muß jedoch dafür Sorge getragen werden, daß die Untersuchungsergebnisse nicht ohne eine gründliche Analyse der örtlichen Straßen- und Verkehrsgegebenheiten angewendet werden und daß sie sich in die örtlichen Maßnahmen zur Hebung der Verkehrssicherheit einordnen.

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*The abstracts were translated by K.—H. Schulze, Technische Universität, Berlin, Federal Republic of Germany.

DIE AUFFINDUNG UND BEHANDLUNG STÄDTISCHER SCHWERPUNKTE FÜR RUTSCHUNFÄLLE

L. W. Hatherly und A. E. Young, Greater London Council

Der erste Teil des Beitrages bespricht die vom Transport and Road Research Laboratory und anderen Stellen in Großbritannien in den letzten Jahren durchgeführte Forschung und erläutert, daß für bituminöse Fahrbahndecken der Seitenkraftbeiwert aus der Kenntnis der in der Deckschicht verwendeten Gesteinsbaustoffe, der Verkehrsstärke und der Anzahl der Fahrzeuge, die die betrachtete Stelle des Fahrbahnabschnittes befahren, vorhergesagt werden kann.

Die Schwierigkeit der Einführung von Mindestwerten für den Seitenkraftbeiwert wird besprochen. Es läßt sich zeigen, daß viele Straßen, die nach den existierenden Beurteilungskriterien als glatt (schlüpfrig) einzustufen wären, nicht notwendigerweise gefährlich sind, so daß ihre Behandlung wirtschaftlich nicht gerechtfertigt wäre. Es wird betont, daß sich die Mehrzahl der Unfälle mit Personenschaden in städtischen Gebieten ereignet und des weiteren die Mehrzahl dieser Unfälle an Knotenpunkten. In London ereignen sich zum Beispiel pro Jahr 55.000 Unfälle mit Personenschaden, und über 70 % davon entfallen auf Knotenpunkte. Aus diesem Grunde hat man sich in London den Problemen an Knotenpunkten zugewandt. Mehr als 800 Knotenpunkte oder ähnliche Gefahrenstellen, wie Bremsstrecken vor Fußgängerüberwegen, sind mit einer Oberflächenbehandlung (Kunststoffbeschichtung mit kalziniertem Bauxit) behandelt worden.

Vorher-Nachher-Unfalluntersuchungen an Gruppen behandelter Fahrbahnabschnitte werden dargestellt, und es wird die Wirtschaftlichkeit derartiger Behandlungen untersucht.

Zwei Methoden zum Auffinden von Straßenstellen, an denen die Unfallbilanz durch eine Oberflächenbehandlung verbessert werden kann, werden beschrieben; die eine auf der Anwendung eines Griffigkeitsmeßgerätes zum Bestimmen der Fahrbahngriffigkeit, die andere auf der Auswertung der Unfallzahlen in einer Rechenanlage beruhend.

DIE VORHERSAGE VON UNFÄLLEN BEI NÄSSE AN KNOTENPUNKTEN AUFGRUND VON WETTERDATEN UND GRIFFIGKEITSWERTEN

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

Knotenpunkte der Staats-Hauptfernstraßen in bebauten Gebieten und außerhalb werden im Hinblick auf den Prozentanteil der Unfälle bei Nässe untersucht. Dabei wird zunächst für jeden Monat der geschätzte Anteil der Zeit, in der die Fahrbahn naß ist, in Rechnung gestellt. Da Niederschlagsdaten nur für bestimmte Zeitintervalle zur Verfügung stehen, wird eine Methode entwickelt, diese Daten in Prozentanteile "Fahrbahn naß" umzuwandeln - eine Größe, die gebraucht wird, um anzugeben, für welchen Zeitanteil die Knotenpunkte der Nässe ausgesetzt sind. Unter Anwendung dieser Umwandlungsmethode werden die Niederschlagsdaten von 120 der Wetterstationen von Michigan umgeformt, um Monat für Monat und für die Jahre 1963 bis 1974 ein "Nässe-Profil" des gesamten Staates zu gewinnen. Der Bereich der monatlichen Nässe in diesem Zeitraum schwankt zwischen weniger als 1 % bis über 25 %. Dieses potentielle Zahlenverhältnis von 25 zu 1 ist von großem Einfluß auf das Auftreten von Unfällen bei Nässe und sollte in Rechnung gestellt werden, bevor andere Variable betrachtet werden.

Nahezu 40.000 Unfälle, die sich an über 2.000 Knotenpunkten ereigneten, von denen die Griffigkeitswerte (Reibungszahlen) der Fahrbahnen bekannt waren, wurden tabuliert, um die Prozentanteile der Unfälle bei Nässe zu berechnen. Diese Daten, zusammen mit dem für die Örtlichkeit geltenden prozentualen Zeitanteil "Fahrbahn naß", geschätzt nach den Aufzeichnungen der nächstgelegenen Wetterstation, ergeben die Möglichkeit, ein Modell für das Unfallgeschehen bei Nässe auf der Grundlage der eingeschlossenen Variablen zu entwickeln. Die Anpassung an die Wirklichkeit ist befriedigend, und es ergibt sich eine progressive Funktion für die Reibungszahl. Für alle Grade von Nässe ist eine Reibungszahl von unter etwa 30 mit einem progressiven Anstieg des Prozentanteils der Unfälle bei Nässe verknüpft, wenn auch der genaue Verlauf der Kurve von dem Zeitanteil "Fahrbahn naß" abhängt. Das Modell erscheint nützlich, um Kosten-Nutzen-orientierte Pläne für Deckenerneuerungen an den Knotenpunkten aufzustellen mit dem Ziel, die Anzahl der Unfälle auf nasser Fahrbahn auf ein Minimum zu senken.

DER FAKTOR MENSCHLICHES VERHALTEN BEIM RUTSCHEN: VERURSACHUNG UND VERHÜTUNG

F. R. Hanscom, BioTechnology, Inc.

Dieser Beitrag gibt einen Überblick über den Erkenntnisstand zum Faktor "menschliches Verhalten" bei der Verursachung und Verhütung von Rutschunfällen. Die verfügbare Literatur wird in zwei Teilen ausgewertet. Zuerst werden die fahrerbezogenen Möglichkeiten, ins Rutschen zu geraten, betrachtet. Maßgebende Faktoren sind hier die Aufnahme- und Reaktionsfähigkeit des Fahrers in schwierigen, zum Rutschen Anlaß gebenden Fahrsituationen. Zum zweiten werden die in Betracht kommenden Systeme der Verkehrsbeeinflussung als mögliche Verbesserungsmaßnahmen besprochen.

Das Aufnehmen und richtige Einschätzen gefährlicher Fahrsituationen bei nassem Wetter wird sich aus der Kenntnis der Tatsache herleiten, daß es regnet, daß die Fahrbahn naß erscheint oder daß sich die Linienführung ändert (wie in Kurven). Die Möglichkeit, dem Automobilisten gefährliche Situationen durch feste Verkehrszeichen anzuzeigen, ist im allgemeinen unwirksam; wirksam sind dagegen an solchen Straßenabschnitten Blinkzeichen, Anzeigetafeln mit wechselndem Inhalt sowie Richtgeschwindigkeiten, um das Fahrverhalten der Automobilisten zu verändern und voraussichtlich die Fälle von Verlust der Fahrzeugbeherrschung zu reduzieren.

Besondere geometrische Merkmale einer Straße können dazu führen, daß die Anforderungen an die Reibung Reifen/Fahrbahn ein akzeptables Maß übersteigen, weil der Schwierigkeitsgrad der Bewältigung von den Automobilisten unterschätzt wird. Derartige geometrische Bedingungen rufen in erster Linie nach Deckenerneuerung oder nach der Anwendung besonderer Systeme der Verkehrsbeeinflussung, um die Fahrgeschwindigkeiten zu senken.

Während gezeigt werden konnte, daß ein Training im Rutschen geeignet ist, das fahrerische Können der Automobilisten in Rutschsituationen zu verbessern, ist es nicht klar, daß die Kosten eines solchen Trainings gerechtfertigt sind, noch ist es klar, daß die erlernten Fähigkeiten auch noch längere Zeit nach dem Training angewendet werden, wenn sie in der Zwischenzeit nicht gefordert worden sind.

Es werden Vorschläge gemacht für realisierbare Gegenmaßnahmen gegen Unfälle, und es wird aufgezeigt, welche Forschung noch nötig ist, um wirksamere Gegenmaßnahmen zu entwickeln.

RECHTLICHE VERWICKLUNGEN DURCH BESTIMMUNGEN, DIE AUF EINE REDUZIERUNG VON RUTSCHUNFÄLLEN AUF STRASSEN BEI NÄSSE GERICHTET SIND

Larry W. Thomas, Transportation Research Board

Dieser Beitrag untersucht die rechtlichen Komplikationen durch Bestimmungen, die auf eine Reduzierung von Rutschunfällen auf nasser Fahrbahn gerichtet sind, eingeschlossen die Einführung eines einheitlichen Standardwertes für die Griffigkeit der Fahrbahnen, Planung und Rezeptur der Fahrbahndecken, Bauweisenwahl, Deckenerneuerungen und Einschneiden von Rillen, Aufstellen von Warnzeichen, Auswertung der Unfallstatistik, Einführung einer allgemeinen Bestandsaufnahme der Straßen, um Prioritäten für Deckenerneuerungen und Reparaturarbeiten zu setzen. Der Nachdruck dieses Beitrages liegt auf der Verdeutlichung jener Bereiche staatlicher Aktionen zur Verhütung von Rutschunfällen, die entweder keine Verantwortung begründen oder die, im umgekehrten Falle, Verantwortung begründen für Personen- und Sachschäden von Automobilisten, die auf Straßen mit niedriger oder unzureichender Griffigkeit entstehen. Die Zuverlässigkeit der Beweisführung vor Gericht unter Heranziehung der Bestimmungen, die der Reduzierung von Rutschunfällen dienen, wird ebenfalls besprochen. Der Beitrag enthält des weiteren Hinweise auf die Bundesstatuten und die entsprechenden Statuten der Staaten, Gerichtsberichte, Fachaufsätze zum Thema, sowie insbesondere die Bestimmungen des Programms der Bundesstraßenverwaltung zur Reduzierung von Rutschunfällen.

EINE METHODOLOGIE FÜR DIE EINFÜHRUNG KOSTEN-NUTZEN-ORIENTIERTER GRIFFIGKEITSANFORDERUNGEN

J. M. Zuiebach, Science Applications, Inc.

Dieser Beitrag beschreibt die Entwicklung einer Methodologie, bei der streckenspezifische Straßen- und Fahrbahnmerkmale sowie Verkehrsparameter als "Input" dienen, um streckenbezogene Kosten-Nutzen-orientierte Anforderungen der Automobilisten an die Fahrbahnreibung zu berechnen.

Die berechnete Schlüsselgröße ist die Verteilung der Sicherheitsmarge. Diese Verteilung wird definiert als die Differenz zwischen der Verteilung der verfügbaren Reibung Reifen/Fahrbahn und der Verteilung der Anforderungen des Fahrers an die Fahrbahnreibung bei Nässe.

Die besten verfügbaren Modelle für die Reibung Reifen/Fahrbahn werden herangezogen. Eine Methodologie für die Einbeziehung der Geschwindigkeitsverteilung des Verkehrs in diese Modelle, um eine statistisch gegründete Verteilung der verfügbaren Reibung Reifen/Fahrbahn zu erhalten, wird diskutiert.

Eine neue Methode für die Berechnung der streckenbezogenen Reibungsanforderungen wird vorgestellt. Diese Methode behandelt explizit die fahrmanöverabhängige Natur der Reibungsanforderungen des Fahrers durch Zusammenfügen empirisch begründeter Modelle für das Fahrverhalten mit stochastischen Modellen des Verhaltens des Verkehrs. Besondere Modelle für das Bremsen an Knotenpunkten, für das Fahrverhalten in Kurven sowie für Überholvorgänge auf zweispurigen Straßen werden vorgestellt. Weitere Modelle betreffen das Einfädeln bei Spurwechseln sowie andere komplexe Fahrvorgänge.

Die Gesamtverteilung der Reibungsanforderungen für einen Straßenabschnitt ist abhängig von der relativen Häufigkeit der Inanspruchnahme und der Verteilung der Reibungsanforderungen für jedes der eine hohe Reibung erfordernden Fahrmanöver, mit denen gerechnet werden muß. Eine Methode wird vorgestellt, mit der die verschiedenen Fahrmanöver gewichtet werden können. Die Gewichte richten sich danach, mit welcher relativen Häufigkeit die verschiedenen Fahrmanöver auf der Grundlage stochastischer Modelle des Verkehrsverhaltens zu erwarten sind.

Eine Konzeption wird vorgetragen, die es ermöglicht, auf systematische Weise die wünschenswerteste Kombination der Parameter der Fahrbahn, des Straßenverlaufs und des Verkehrsverhaltens auszuwählen, um einen vorgegebenen Sicherheitsgrad bei vorgeschriebener Verkehrsqualität (Level of Service) und Kostenanspannung zu erzielen. Durch verallgemeinerte Optimierungsverfahren wird die Art und Weise vorgeschlagen, in der die allgemeine Methodologie als ein iteratives Entwurfsverfahren anzuwenden wäre.

EIN KOSTEN-NUTZEN-MODELL FÜR DIE ERNEUERUNG VON FAHRBAHNDECKEN

A. St. John, Midwest Research Institute

Um eine Reihe verschiedener Methoden zur Aufrechterhaltung eines Griffigkeitsniveaus der Fahrbahnen oberhalb der Griffigkeitsanforderungen des Verkehrs miteinander zu vergleichen, wurde ein für die Anwendung im Rechner programmiertes Kosten-Nutzen-Modell entwickelt. Dieses Modell, in das detaillierte Angaben über den Straßentyp, zum bisherigen Unfallgeschehen, zu den hauptsächlichen geometrischen Merkmalen des betrachteten Straßenabschnittes, zu den klimatischen und den verkehrlichen Bedingungen eingegeben werden müssen, kann die Rechtfertigung für die höheren Kosten einer Oberflächenbehandlung (oder einer Maßnahme zur Verkehrsbeeinflussung) liefern, und zwar wegen einer höheren Unfallwahrscheinlichkeit. Herkömmliche Oberflächenbehandlungen, unter Verwendung von Splitten und Bindemitteln oder auf der Basis mechanischer Aufrauhverfahren für die Oberfläche, lassen sich miteinander vergleichen, solange es möglich ist, sie bezüglich des erreichten Griffigkeitsniveaus voneinander zu unterscheiden (normalerweise in den USA durch Messung des Griffigkeitswertes (der Reibungszahl) bei der Geschwindigkeit 64,4 km/h).

Besondere Behandlungen, wie sehr hohlraumreiche Asphaltüberzüge, werden mit herkömmlichen Bauweisen verglichen, wobei die ungleiche Lebensdauer der Sonderbehandlungen sowie die Unterhaltungs- und Einbaukosten in Rechnung gestellt werden. Dieser Vergleich berücksichtigt die besten verfügbaren Angaben über den relativen Zerstörungsgrad durch Verwitterung und Verkehrsbeanspruchung sowie über die Einbuße an Griffigkeit, mit denen bei den Sonderbehandlungen zu rechnen ist. Das Rechenprogramm läßt diese Angaben offen, um die Anwender zu ermutigen, ihre eigenen, besseren Angaben einzusetzen, wenn diese von den einzelnen Staaten oder von den örtlichen Straßenverwaltungen aufgestellt werden können und damit besser auf die örtlichen Bedingungen zugeschnitten sind.

Durch dieses Programm werden etwa notwendige Behandlungen in einer Stufenfolge untersucht. Zum Beispiel, wenn die Verkehrsgeschwindigkeit herabgesetzt werden muß, wird für eine Deckenerneuerung mit einer bestimmten geplanten Mischung und für ein bestimmtes vorgeschlagenes Aufrauhverfahren das Nutzen-Kosten-Verhältnis für die höchstbewertete Behandlung ermittelt und sodann der Unterschied im Nutzen-Kosten-Verhältnis bei Anwendung der nächstniedriger eingestuften Behandlung ermittelt usw. Jede zuerst ins Auge gefaßte oder höherwertige Behandlung, deren Nutzen-Kosten-Verhältnis kleiner als eins ist, würde demzufolge verworfen werden.

Dieses Modell läßt sich nicht nur in Bezug auf die Masse der Fahrzeuge anwenden, die heute auf den Straßen verkehren, sondern läßt sich auch auf einen hohen Anteil von Schwerverkehr ausrichten; in diesem Falle müssen Faktoren zum Kennzeichnen der Abnahme der Lebensdauer der Fahrbahndecken eingeführt werden.

Das Programm ist in FORTRAN IV geschrieben und ist mit einer großen Anzahl von Computersystemen, die in den USA und anderswo in Gebrauch sind, kompatibel.

DER EINFLUSS DES RILLENEINSCHNEIDENS IN FAHRBAHNDECKEN AUF DIE UNFALLHÄUFIGKEIT

E. Zipkes, Eigennössische Technische Hochschule, Zürich

Wie vielfach berichtet wurde, ist das Einschneiden von Längs- oder Querrillen in Fahrbahndecken erfolgreich in Bezug auf eine Reduzierung der Rutschvorgänge und der Unfälle bei nassem Wetter. Die gegenwärtig gebräuchlichen Techniken des Rilleneinschneidens in den meisten Ländern erzeugen Rillen in dichtem Abstand, um einen schnellen Wasserlauf von der Fahrbahn zu erreichen und die Richtungsstabilität der Fahrzeuge zu verbessern. Aber auch Querrillen mit größerem Abstand voneinander sind geeignet, die Sicherheit zu erhöhen; solche Rillen müssen jedoch wegen des Verschleißes von Zeit zu Zeit erneuert werden. In diesem Bericht werden für einen Abschnitt der Autobahn Lausanne—Genf von 44 km Länge, der wenige glatte Teilabschnitte enthält (zusammen 2 km), für die Jahre 1966 bis 1973 die Unfallhäufigkeit und die Prozentanteile der Unfälle auf trockener und auf nasser Fahrbahn analysiert.

Die Daten für diese Analyse entstammen den amtlichen Verkehrszählungen, den Niederschlagsmessungen des Zentralen Schweizerischen Meteorologischen Dienstes sowie den Unfallberichten der Verkehrspolizei. Die zusammen 2 km langen glatten Abschnitte wurden während der Berichtsdauer zweimal mit Rillen versehen, und zwar im Abstand von 5,0 m und 2,0 m. Diese Strecke ist ein gutes Beispiel für das Studium des Einflusses des Rilleneinschneidens auf die Unfallhäufigkeit. Relative Zahlen für die Unfallhäufigkeit, bezogen auf einen Kilometer Strecke und eine Million Fahrzeuge wurden vergleichsweise für die gerillten und die ungerillten Streckenabschnitte in Beziehung zu der Anzahl trockener und nasser Tage in jedem Jahr bestimmt. Die Studie wird abgerundet durch die Ermittlung des Prozentanteils der Unfälle, die auf den nassen Fahrbahnzustand entfallen.

Die Ergebnisse zeigen deutlich den positiven Einfluß des Rilleneinschneidens auf die Sicherheit, auch bei Anwendung der größeren Rillenabstände, und damit den Einfluß, den eine Reduzierung der Wasserfilmdicke auf den verfügbaren Kraftschluß ausübt. In diesem Zusammenhang werden auch die wirtschaftlichen Aspekte derartiger Maßnahmen sowie rechtliche Fragen aus der Sicht der Verantwortlichkeit des Eigentümers der Straße besprochen.

DER NUTZEN VON BLOCKIERSCHUTZ-BREMSSYSTEMEN IN PERSONENKRAFTWAGEN

Nathaniel H. Pulling, Liberty Mutual Research Center

Zur Ersten Internationalen Konferenz zur Verhütung von Rutschunfällen vor 18 Jahren beschrieben Lister und Kemp Versuche mit einem Blockierschutz-Bremssystem für Pkw. In der Zeit danach wurde eine Anzahl derartiger Systeme entwickelt, und einige gingen in eine beschränkte Serienproduktion. Obwohl Zweirad- wie auch Vierrad-Blockierschutz-Bremssysteme sehr gut unter tückischen Fahrbedingungen arbeiteten, erwiesen sie sich nicht als kommerziell erfolgreich. Eine Reihe veröffentlichter Studien zum Thema werden besprochen; sie zeigen, daß Blockierschutz-Bremssysteme in Automobilen eine lohnende Verbesserung der Beherrschung des Rutschens bringen und damit zur Verhütung von Unfällen beitragen. Eine wirtschaftliche Studie, 100 Rutschunfälle umfassend, die aus einer Zufallsauswahl von 613 Versicherungsfällen ausgewählt wurden, wird im Detail dargestellt. Das Nutzen-Kosten-Verhältnis für Pkw wurde aus diesen Daten auf 1,4 für Zweirad- und auf 1,3 für Vierradsysteme geschätzt, und der Zeitraum, in dem sich der Mehraufwand amortisiert, ergab sich zu 7 bzw. 8 Jahren. Schließlich werden die Zukunftsaussichten für Blockierschutz-Bremssysteme in Personenkraftwagen diskutiert.