GENERAL

1. The people who work on the different aspects—tires, vehicles, safety, and human elements—of reducing wet-pavement accidents should maintain continual contact, preferably at the international level, to optimize the development of knowledge.
2. Road administrators and legislators should become familiar with the problems and responsibilities of pavement engineers.
3. Simplified methods of determining road surface characteristics should be developed for the use of those agencies who, because of limited resources, do not have access to highly specialized equipment.

PAVEMENT CONSTRUCTION

1. Accurate and high-speed test equipment should be developed for measuring surface texture. The U.K. Transportation and Road Research Laboratory has been working on this problem.
2. Additional experience is needed in the use of sprinkling techniques that enable the use of polish-susceptible aggregates in bituminous and portland cement concrete mixes. Methods are also needed for making use of poor-grade local aggregates, such as the blending of polish-susceptible and polish-resistant aggregates in bituminous mixes.
3. Further development of pervious bituminous mixtures should be promoted. Two types are now in use: the open-graded or "popcorn" mix and the sand-asphalt mix, which the state of Kentucky has greatly improved in recent years.
4. The skid-resistance characteristics of aggregate supplies should be determined. The British polished-stone value is one method that can be used.
5. Methods should be developed for producing low-cost, artificial aggregates on an industrial scale.
6. Geometric design characteristics should be optimized in relation to pavement skid-resistance knowledge, especially with respect to water layer thickness.
7. Pavement markers should be developed that have good visibility on wet roads, do not prevent water runoff, and have adequate skid resistance.

MAINTENANCE

1. Texture properties should be evaluated in detail with respect to rubber deposits on runways. Low-cost and quick maintenance procedures are desirable.
2. Simple methods are needed for locating and evaluating road sections, like transition zones and ruts, that have undesirable water accumulations. Additional criteria should be developed with respect to tolerable water layer thickness.
3. The relations between skidding and road-surface characteristics such as rutting and road roughness should be evaluated.

ACCIDENTS AND PAVEMENTS

1. Provision should be made for the translation of experience gained in improving the pavement at known locations where a high number of wet-pavement accidents occur, or black spots, into measures for ensuring against the construction of such black spots.
2. Provision should be made for feedback on the effect of remedial measures to the pavement engineer.

PROBLEMS IN ADJACENT AREAS

1. The interrelations among road surfaces, tires, and noise should be described in detail. The optimization of pavement textures should not be restricted by noise generation, unless the detriments from noise outweigh the benefits from improved textures.
2. The accuracy and reliability of friction measuring equipment should be improved. This implies no objection to the use of present equipment.
3. The accuracy of skid inventories should be improved by developing further knowledge on seasonal variations in skid resistance.
4. Predictions of pavement skid numbers, on the basis of parameters such as materials, climate, and average daily traffic, should be used to improve pavement design and maintenance planning.
5. More use of skid-resistance knowledge should be used in the development of pavement management systems.

Report of Subcommittee on Wet-Weather Accident Experience, Human Factors, and Legal Aspects

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IMPLEMENTATION KNOWLEDGE

A low skid resistance has a marked influence on accident levels at basically two types of road locations. The first is a location at which drivers are not required generally to take emergency action but at which nevertheless their friction demands may not be satisfied in wet-road conditions. An example of such an area is a curve without adequate superelevation and with a low skid resistance at which single-vehicle accidents predominate. The second type of location is that at which conflict accidents predominate. Examples of such accidents are rear-end collisions on freeways in saturation conditions and vehicle-pedestrian or vehicle-vehicle collisions at road intersections. Conflict situations cause the driver to take some form of emergency action such as braking or altering direction as a result of which his or her friction demand rapidly increases. Whether a collision occurs in this circumstance will be determined by the available friction resistance that controls the minimum stopping distance of the vehicle.

There is a general acceptance of a relation between wet-road accidents and skid resistance, and several reports have shown a continuous curve indicating that there is no upper limit to skid resistance beyond which no reduction in accidents is possible. These relations are useful and usable in planning an overall strategy but not necessarily appropriate for analysis of single black-spot sites for which the forecasting of statistically significant probabilities based on relatively low numbers of accidents can be relatively inaccurate. Opinions appear to differ on whether the percentage of wet-road accidents or the accident total is the best basis of analysis, but both bases of assessment if coupled with skid-resistance measurements are probably equally effective.

There is a general agreement that skid-resistance measurements alone are not a sufficient guide to the need for improvement and for planning purposes; account should be taken of total wet time and accident histories as Holbrook has shown by means of a model (1). If, however, precipitation data are not available, then the average wet-weather accident rate can be used as a guide and can be easily established on an area basis from existing accident records.

Since sufficient money is never likely to be available to improve the skid resistance of all existing roads in any given area, a strategy must be developed to optimize cost benefits. In fact whether an overall improvement in skid resistance is desirable can be debated since this approach might well generate a change in general driver behavior with a consequent increased accident risk.

A cost-benefit model exists in a form in which it can now be used. As experience is gained of the effect on accidents of skid-resistance improvements, the model can be refined and its accuracy consequently improved; but the need for refinement should not inhibit the initial use of this model. Consideration should be given to the inclusion of the probable effect of the use of advance road-marking or delineation techniques into the model. Such techniques can frequently be used effectively to reduce driver demands for skid resistance.

The conference proceedings (2) contain papers on methods by which the skid resistance of road surfaces can be improved. The methods discussed included high- and low-density grooving of concrete pavements and the use of epoxy resins with calcined-bauxite aggregate. There is agreement that adequate knowledge exists to select the most appropriate form of treatment for any given location. Committee recommendations can be summarized as follows.

1. Great emphasis should be placed on resurfacing or other appropriate remedial measures at wet-road sites, such as sharp curves, junctions, pedestrian crossings, areas of critical geometry, and conflict areas, that have a known high-accident record, particularly in urban locations.
2. Sites for treatment should not be selected on the basis of wet-pavement skid resistance alone. The selection procedure should take account of the probable time the pavement is wet and also the accident history of the location being considered.
3. The use of existing cost-effective methods for accident reduction should be encouraged by the provision of training and incentives for highway maintenance management personnel.
4. Consideration should be given to the use of advance delineation techniques for the reduction of wet-weather accidents.

GAPS IN KNOWLEDGE

Since before the First International Skid Prevention Conference nearly 20 years ago, we have been aware of the substantially greater risk of highway accidents on wet pavements compared to dry pavements. Although the relative danger varies from country to country and region to region, the risk of having an accident on wet pavement is of the order of 1½ times greater than on dry pavement. Rainfall intensity, type of traffic, vehicle volumes, speed of operation, and type of pavement-surface treatment are among the important variables that influence the accident likelihood.

This subcommittee evaluated the state of knowledge to determine major gaps in information. These gaps and needs for additional research are listed below.

1. The functional relation between pavement skid resistance and wet-weather accidents should be defined. Empirical relations have been developed between accident likelihood and pavement skid resistance for highways without severe traffic conflicts or good geometrics. Some sets of data display a decreasing monotonic relation between skid resistance and accident likelihood. Other data display a transient that suggests that progressive increases in skid resistance will yield small gains in improved safety. A number of hypotheses regarding wet-weather accidents and pavement conditions have attempted to rectify apparent inconsistencies in these data.
2. The margin-of-safety hypothesis needs to be tested. The relation between wet-weather accidents and pavement skid resistance appears to be mediated by a number of factors at locations that have poor geometrics or that experience large numbers of traffic conflicts. There is substantial evidence that at such locations the driver's demand for friction exceeds available pavement friction during many maneuvers when the pavement is wet. Further the increased abrasive action of braking and maneuvers in these locations reduces available friction even more. Although models of the relation between wet-weather accidents and skid resistance appear to have reasonably good prediction capabilities, substantial improvements in prediction capabilities can be expected by direct tests of the margin-of-safety hypothesis and by the pooling of data from several sources.
3. The skid-accident model needs to be adjusted for seasonal variations in skid resistance. The predictive capability of wet-weather accident models depends on the ability to measure reasonably accurately the tractive characteristics of pavements. This accuracy can be ensured by understanding how the systems that measure skid resistance operate. Today we can make measurements of skid-resistance characteristics with an excellent repeatability on high-grade surfaces. On many surfaces the resistance varies as much as 60 percent from one season of the year to another. For large highway systems in which skid resistance of pavements must be measured throughout the year, this factor has affected the correlation between skid resistance and accident likelihood. Considerable improvement can be made in wet-weather accident prediction by making adjustments in data based on the effect of seasonal variations in skid resistance.
4. Tractive characteristics of commercial vehicles should be included in wet-weather accident models. Research previously conducted indicates that, for roads without control of access, the involvement rate of trucks and other large commercial road vehicles in wet-weather accidents is substantially higher than the rate of passenger vehicles. A basis for accommodating the larger traction requirements is needed, based on both the traction requirement and the proportion of travel of trucks

and buses operating on such roads.

5. The specific influence of pavement macrotexture in wet-weather accident models should be determined. One characteristic of pavement surfaces that should contribute to safety during wet weather is the macrotexture of pavements. Evidence indicates that high macrotexture contributes to reducing wet-weather accidents on high-speed roads, but the precise contribution of high macrotexture is unknown. Either a rational formulation that explicitly accounts for the contribution of pavement surface macrotexture or a series of carefully controlled empirical studies that permit a partitioning of the relative contributions of both microtexture and macrotexture are required.

6. Wet-weather sensors should be developed or evaluated for use in conjunction with wet-weather advisory signing. Convincing research results indicate that the performance of drivers operating at hazardous locations can be effectively modified by specific wet-weather warning and speed advisory signs. At present there appears to be no reliable wet-weather sensor that local highway agencies can use in conjunction with such signs. The development of such a sensor is highly desirable.

7. The benefits and costs of skid training should be evaluated. Skid training has been incorporated into a few driver education programs, and special courses have been set up to train commercial vehicle operators. The effectiveness of such training has not been established or identified. The potential cost-effectiveness of skid training has yet to be evaluated.

8. The importance of various perceptual cues associated with skidding should be established. To effect efficient training programs or to provide appropriate remedial aids requires an understanding of the perceptual cues used to detect skidding and maintain control of skids. Some fundamental research to fill these gaps is needed.

9. Incentives should be evaluated for maintenance of braking systems and tires. Maintenance of vehicle-braking systems and tires can have a pronounced benefit during wet-pavement conditions. Incentives for maintaining these vehicle components may be cost-effective in reducing wet-weather accidents. A variety of indicators of deteriorating wet-weather performance or the condition of brakes and tires should be evaluated.

10. The scope of cost-effectiveness models should be increased. Models of wet-weather accidents now permit investigators or decision makers to explicitly consider various options for reducing such accidents. Such models, however, are limited with regard to the types of options that can be explicitly evaluated. Evaluation of vehicle-braking systems, tire design, and education of drivers is not possible with present models.

11. Benefits and costs of skid-resistant pavement warranties should be evaluated. In general, highway agencies that have made conscientious efforts to develop systematic programs for identifying and correcting highway skidding sites have been able to effectively defend themselves against adverse litigation. These agencies must continue to improve the effectiveness of their programs. In a number of European countries, individual contractors are responsible for warranty of their construction projects. In these countries, pavement skid resistance must be held at criterion levels for a number of years; therefore, pavement surfaces susceptible to rapid deterioration cannot be used. The legal implications of such a plan should be explored thoroughly to determine whether more widespread use of construction warranties could have a significant positive effect on wet-weather safety.

REFERENCE

1. L. F. Holbrook. Prediction of Wet Surface Intersection Accidents From Weather and Skid Test Data. TRB, Transportation Research Record 623, 1976, pp. 29-39.
2. Skidding Accidents: Pavement Characteristics. TRB, Transportation Research Record 622, 1976, 110 pp.

Conference Summary

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The proceedings of this conference (1, 2, 3, 4) present an overview of the current knowledge on how to prevent wet-weather accidents on highways and airfields. It is the hope of those involved in the conference that this knowledge will be used fully by those who have significant influence on the design and building of vehicles and pavements or have the responsibility of managing traffic and vehicle operators. Gaps still remain in our collective knowledge, but this does not constitute a license not to do what can be done now to reduce wet-weather accidents drastically.

This means not that dry-pavement accident rates are acceptable but that we addressed only that increment of the problem that is chargeable to pavement wetness. To eliminate that increment is an engineering problem because clearly we cannot count on drivers to change significantly because the roads are wet.

Nor would all be well if drivers did change their ways. As Segel points out (5), the variability of tire and vehicle design factors (and he might have added pavement design factors) is secondary to the variability due to operational and in-use factors. Tires wear, wheel loads change during maneuvers, brakes become unbalanced, pavements polish, puddles form, and so on. In traffic the average driver simply cannot deal with all these variables, even if he or she could recognize them and were trained to properly react to them. Drivers need all the help they can get, and this conference has shown the many ways in which significant assistance can be provided to them.

The available implementation measures fall into two broad categories: those that government agencies must apply and those that must be made available by industry and be accepted by the public. These categories are not independent of each other, because in both cases money is involved that eventually comes from the citizenry. There-