INTRODUCTION

During the period of the past five winters in Minnesota, we have witnessed a startling increase in the amount of surface wear in the wheel tracks on many pavements—both bituminous and Portland cement concrete. Previously when similar pronounced surface abrasion occurred it was generally related to some deficiency such as unfavorable construction conditions or materials or mixture design that was marginal for the particular circumstances or traffic demands involved. However, the wear that we are now experiencing is not associated with such causes. It has affected pavements of the highest quality including some that had performed satisfactorily in service for several years before being subjected to studded-tire traffic. Other pavements were affected that were exposed to studs in their initial year of service.

The condition has become alarming—developing in the same period in which studded tires have been legally permitted during winter months on Minnesota’s highways. It is quite natural, therefore, that many highway engineers generally blame the wear upon the studs. There are other engineers, however, who ascribe the attrition to increased use of salts and sand contending that the chemicals attack the pavement materials, and that they, together with abrasive sand, make the pavement surfaces readily susceptible to wear from the studs. This argument, however, overlooks the fact that salt and sand have been used freely for a good many years prior to the advent of studs with little or no damage to pavements. Still other proponents of studs take the position that the safety benefits—accidents prevented and lives saved—outweigh any cost of pavement damage that may be incurred.

STUDDED TIRE “EXPLOSION” IN MINNESOTA

By way of background, studded tires originated in Europe where they came into vogue in the early 1960’s particularly in the Scandinavian countries and Germany. By 1964 they began to appear in
Minnesota in very small numbers. They were ruled illegal under the then-existing law of the State, and movements were soon initiated to enact legislation that would legalize their use.

Because there was considerable concern within the highway department about possible damage to pavement surfaces, field-driving tests were started with an automobile equipped with studs on all four wheels to determine the nature of the damage, if any, that might result from the studs. Although the tests indicated a definite possibility of objectionable wear, the tests were not extensive enough to convince the law makers that studs should not be permitted as a safety measure.

The 1965 Legislature authorized a two-year "trial" period for the winters 1965-66 and 1966-67 during which further investigations were to be conducted. These studies also were not sufficiently conclusive, and so the 1967 and 1969 Legislatures each again authorized additional two-season extensions. Thus we are now nearing the end of the fifth winter of studded tire traffic in Minnesota, and at least one more winter is assured before further legislative action will be required—to either continue or prohibit their use. This is the decision that will have to be made in 1971. Studies now in progress will help to shape that decision.

The use of studs has increased phenomenally in the last five years. During the first winter, 1965-66, the number of studded tires used in the Twin City metropolitan area was very low, only about 3.8 percent of the cars being so equipped on the rear wheels. The second winter saw an increase in the proportion to about nine percent, the third winter to 23 percent, the fourth winter to almost 32 percent, and this winter to about 40 percent. These proportions are based upon surveys conducted on randomly selected parking lots and street parking. It was also estimated by tire sellers that for the winter just past approximately 90 percent of all snow tires sold would be studded. Added to these percentages of growth we must also recognize the normal annual increase in number of vehicles as well as an increase in vehicle miles driven.

Reasons for the popularity of studs are the increased safety and convenience benefits that are claimed for them when driving on ice, including improved stopping capability, more effective control in steering, and improved traction. Actually, the latter element seems to have most appeal to many motorists who have problems traversing slippery approaches to their garage entrance or slippery alleyways and streets where snow plowing, sanding, salting, or other aids to traction are lacking. The results of tests such as the controlled winter driving
tests conducted by the National Safety Council, which have been extensively publicized, lend support to these declared benefits.

OBSERVATIONS OF PAVEMENT WEAR TO DATE

Extensive field observations of pavement wear in Minnesota during the past five years have revealed some interesting facts.

Our earliest field driving tests with studs included accelerated starts and hard stops from 50 mph, and 30 mph drive-overs. The number of repetitions was only 7,000, which is very abbreviated and insignificant as compared with highway traffic. From these first tests it had been anticipated that the most severe wear might develop at locations of channelized traffic with concentrated stopping and starting actions such as at semaphore-controlled intersections. It was thought that excessive wear in such rather limited areas could be tolerated and controlled by special maintenance efforts. This appears now to be a less critical problem than first expected by comparison with the extensive wear on the high-traffic volume roads.

The amount of pavement wear that developed in the first two winters was relatively minor apparently because of the small number of cars equipped with studs. As the proportion of users increased rapidly in the third winter the wear became pronounced. By the end of the fourth winter the wear had become severe on some roads reaching a depth as much as \( \frac{1}{4} \) in. in the wheel tracks on both bituminous and Portland cement concrete. Recently this past winter, while only about half way through the fifth studded-tire season, for each of two high-traffic roads—one bituminous and one Portland cement concrete—measurements at one location on each showed total mid-track wear depth of 0.3 in.—the maximum observed to date. This indicates a continuing progression of the surface wear.

Measurements made at a limited number of test points at the beginning and end of winter seasons have indicated that the amount of wear occurring during the summer months was much lower—generally insignificant—compared with that experienced in the winter months.

The most severe and extensive wear has developed on the high-traffic volume, high-speed roads such as the interstate and other freeways and expressways within and around the metropolitan area. These roads are carrying from 30,000 to 95,000 vehicles per day or from about 8,000 to 15,000 vehicles per lane per day. Thus the rate of pavement wear appears to be definitely related to the number of stud applications though speed may also be a factor. No general quantitative
relationship has yet been established, but, as an example, at one location where the wear depression was nearly $\frac{1}{4}$ in. by the end of the fourth winter, it was estimated from traffic data that there had been about 1.6 million stud applications or about 0.16 in. of wear per million stud applications.

In contrast, on rural roads, having low traffic volumes, there is little evidence of stud wear even though travel speeds may be high. On the other hand, on urban streets, even with high traffic volumes, the wear rate is usually much lower probably because of the slower speeds. The wear may, however, be quite pronounced where there is a concentration of fast acceleration or heavy braking action such as at semaphores, on entrance or exist ramps to and from freeways, or where there are sharp turning movements.

The manner in which the abrasive wear affects pavement surfaces appears to be much the same for both bituminous and Portland cement concrete pavements. As the surface film or coating of either asphalt or Portland cement mortar wears away, the coarse aggregate particles gradually become exposed so that the first clearly visible evidence of significant wear is the mosaic-like appearance of the surface. The area affected in the wheel tracks is generally approximately 2½ ft. wide for each wheel path.

As the wear progresses—on some surfaces—the matrix is eroded from between the harder coarse aggregate particles. It is noticeable that where the coarse aggregate is either crushed stone, composed entirely of hard, wear-resistant igneous or metamorphic rock or is crushed gravel containing a high proportion of such pebbles, these hard particles are left protruding above the surrounding matrix. This produces a knobby, rough-textured surface which is readily discernible visually and by sound and feel as a car travels over the pavement.

Coarse aggregate composed of relatively softer limestone, such as occurs in southeastern Minnesota, tends to wear down more or less evenly with the removal of the matrix. The result is that the wheel track surface is not as rough and may not appear to be as badly abraded as is the case with the hard rock materials or gravel aggregates containing a preponderance of hard particles. In some cases the limestone coarse aggregate may even wear somewhat more rapidly than the matrix so that the surface of the coarse aggregate particles is actually slightly recessed below the matrix. This situation would be dependent largely upon the hardness of the coarse rock particles or pebbles and the composition and character of the matrix including the quality of the sand and the proportion of binder material in the mixture.
These observations with reference to the aggregates are only generalizations at this point and need verification before firm conclusions may be drawn. It seems apparent, however, that the kind of aggregates used, both coarse and fine, may have some influence upon the rate or nature of pavement wear. It is expected that further light on this will be gained from both the laboratory project and the related field studies that are under way.

The question has frequently been raised as to what effect this type of abrasion may have upon the skid resistance of pavements. The development of wheel track wear produces, in effect, shallow surface ruts that could conceivably influence the skid characteristics. Plans last Fall to conduct rather extensive skid test measurements with the two-wheeled trailer type skid tester that had been purchased by the highway department failed to materialize because of late delivery of the unit. However, a limited number of measurements were made with the trailer test unit furnished through the courtesy of the Portland Cement Association.

At a number of locations readings were taken both in the worn wheel track and on the adjacent unworn area outside the wheel path. In nearly all cases, for companion readings inside and outside the wheel track, the skid numbers obtained were within two or three points of one another. At most points a slightly lower reading—two to three skid numbers—was recorded within the wheel track as compared with that outside the wheel track. Because of the very slight difference between these companion measurements it can hardly be regarded as a significant difference in skid resistance other than to suggest the possibility of a trend. On the basis of these readings any conclusion as to the polishing effect that studs might have on the aggregates or the aggregates' influence on the skid resistance would be premature.

RESEARCH PROGRAM FOR IN-DEPTH STUDY

While authorizing, at the 1969 session, the latest time extension for studs, the Minnesota Legislature directed the commissioner of highways to make an in-depth study of the studded tire problem to determine:

1) The damage, if any, to pavements which results from the use of metal tire studs, salt deicing materials and other materials of chemical or physical nature used upon the highways.

2) Whether such damage, if any, could be reduced by making changes in asphalts, concrete aggregates, or other highway surface materials.
3) The effects, if any, that discontinuing the use of studded tires will have on highway safety.

Accordingly, studies in these areas are now being conducted by the highway department through two separate contracts with independent research agencies and through our own continuing field investigations to develop information to report to the Legislature in early 1971. Unfortunately at the present time not enough data have been developed to provide significant quantitative evidence but I can report on the status of the investigations to date.

EXPERIMENTAL PAVEMENTS

As the first part of the research effort a number of test pavement sections were constructed or were established on existing pavements last fall. These include both bituminous and Portland cement concrete, as portions of regular highway surfacing projects, to be subjected to the normal traffic exposure on those roads. The test sections are composed of the same materials and mixtures that are used for some of the test pavements in the laboratory study being conducted for us by the American Oil Company. The purpose is to observe the comparative abrasion resistance of different paving mixtures some of which are in common usage while others are special mixtures containing some of the best natural materials available. The attempt will also be made to correlate the field performances of the test pavements with the results of the laboratory test track study.

Six experimental sections of Portland cement concrete pavement, each 300 ft. long, were constructed on one roadway of a new four-lane divided highway. Various mixtures were used including different coarse aggregates, gravel, limestone and trap rock; some with normal cement content and some with the cement factor increased by 15 percent. Crushed trap rock fines were used instead of natural sand to improve the quality of the mortar in two of the mixes.

Test sites were established on certain existing bituminous pavements representing both our regular asphaltic concrete and an intermediate grade of asphaltic mix. New experimental pavement test sections were also constructed, one being a modification of the asphaltic concrete mix but with the mortar fortified by adding 30 percent of crushed granite fines and increasing the asphalt content to seven percent. Another mix designed to improve upon the wear resistance had aggregate consisting of 100 percent crushed granite, maximum size \( \frac{3}{4} \) in., and with nine percent asphalt content.

Evaluation of these test sections will be made by: (1) measurements
of the transverse profiles across the wheel tracks, (2) visual examination, (3) skid resistance tests, (4) photographs, and (5) traffic counts.

LABORATORY EVALUATION OF PAVEMENT DAMAGE CAUSED BY STUDDED TIRES, SALT AND ABRASIVE SANDS—AMERICAN OIL COMPANY PROJECT

A second and major part of the effort to satisfy the legislative mandate is being carried out as a laboratory study conducted for us under contract by the Research and Development Department of the American Oil Company at its Whiting, Indiana research facility. Four other states, Iowa, Michigan, North Dakota and Wisconsin have made commitments in the aggregate sum of $83,500 in financial support of the project which is estimated to cost about $245,000. These and other states have indicated their concern along with Minnesota about the rate of pavement wear since studded tires have become legal in their domains.

The purpose of this study is essentially two-fold: first, to determine what portion of pavement damage may be attributed to each of the factors, sand, salt and studded tires; and second, to determine whether the damage could be reduced by changing the composition of the highway surface. Since it obviously is impossible on a highway to isolate the effects of unstudded tires, studded tires, sand and salt the use of a test track appeared to be the only feasible approach to the problem.

The approximately 14-ft. diameter test track accommodates 12 pavement test sections at a time. Four full-size tires mounted at the ends of the two main cross axles of the machine are rotated by a center-drive mechanism at the desired speed up to about 35 mph, which will be the speed for these tests. A load of about 1000 lbs will be applied on each tire.

The test program provides for running four separate series of tests. In the first three series the pavements will be bituminous and concrete mixes of types generally used on Minnesota highways at the present time—together with such variations as previously described for the field experimental projects. Studded tires will travel one path on the pavements and unstudded tires on another path. For the first series, sand and salt will be applied to the track intermittently. During the second series only salt will be applied, and for the third series no materials will be applied. From these three series it will be possible to determine the contribution made by each factor—studs, salt and sand—to the surface wear on the various pavements.
The duration of the tests will depend upon the rate of wear. Rotation will be continued until the studded tire path on the majority of the sections is abraded to such a depth that a normal pavement surface would require repair, or until five million passes will have been made, whichever occurs first.

For series-four pavements it is planned to use surfacing types not normally used in Minnesota but which will be selected as those holding most promise in ability to resist abrasion based on preliminary screening by other laboratory tests. Only studded tires will be run on these pavements and sand and salt will be applied as in series one. From this series it is hoped to discover what surfacing types will provide the most effective abrasion resistance for potential use on the highways.

Periodically during each test series measurements of the transverse profiles will be made on each pavement surface so that comparisons can be made between the various sections and so the influence of studs, sand and salt can be determined.

SAFETY EFFECTIVENESS OF STUDDED TIRES—CORNELL AERONAUTICAL LABORATORY PROJECT

The third phase of the 1969 legislative directive inquires as to what would be the effect on highway safety if studded tires were to be discontinued. Obviously to answer this it is necessary first to know what advantages or safety benefits are now actually being derived by the use of studs. Generally in attempting to define the benefits of studs it has been customary to relate to their ability to improve upon the vehicle’s stopping and cornering capabilities when travelling on icy surfaces. Controlled tests have demonstrated these advantages only under certain limited conditions. But they do not necessarily reflect what actually happens in traffic under real driving conditions.

There is, in fact, a complete lack of factual data to demonstrate the real overall safety effectiveness of studded tires under actual conditions of highway travel. Many questions may be asked. Are there fewer accidents because of the use of studs? Are the accidents that do occur less serious? Are there fewer fatalities and injuries, and is there less property damage? Or, conversely, are there some accidents that may be attributed to studs such as if a following car without studs were to slam into a preceding one equipped with studs, when the latter might make an abrupt, unexpected stop? Or, do some drivers of stud-equipped cars tend to overdrive because of a false or inflated sense of security?

Answers to these and other questions are not easy to obtain. They cannot be obtained from laboratory studies or even from controlled
tests in the field. They can only be gained by gathering and analyzing data on what actually happens on the highways and streets.

To secure a comprehensive and realistic evaluation of the effectiveness of studded tires under all types of Minnesota traffic conditions, the Minnesota Highway Department has initiated a $50,000 accident research study by Cornell Aeronautical Laboratory, Inc. This study will continue through 1970, for reporting to the Legislature in 1971. Two major features are involved, one, a questionnaire survey sent to a large segment of Minnesota motor vehicle operators, and the other, a special supplementary accident report form to be completed by investigating officers at the scene of accidents.

The questionnaire has been designed by Cornell to provide a representative random sampling of the drivers and the vehicles operating on Minnesota roads and streets. It is being sent to about 100,000 car owners—mailings going out in lots of 2,000 twice a week throughout the periods when studs are legal this winter and next fall through December 1970. Information is requested about the driver (age, sex, amount of driving he does), the vehicle (model, mileage, power brakes or steering, tire condition and whether: snow, studded or not, or chains), and the road conditions prevailing on the day prior to the questionnaire. Questionnaires are being returned to the highway department and thence forwarded to Cornell for processing. A response approaching 40 percent of the mailings has been returned to date.

The special accident report form, also designed by Cornell, is being used to supplement the standard accident report form regularly used in Minnesota. It will supply pertinent information, not contained in the regular report form, that will indicate whether or not studs were in use on an accident vehicle and to what extent they may have had any effect on its involvement in the accident.

The accident reporting will be participated in by the Minnesota Highway Patrol statewide, and by the police departments of the largest cities, Minneapolis, St. Paul and Duluth and about a dozen suburban communities and other out-state cities. The Cornell people have been in contact with and provided instructions to key personnel of the several agencies. All investigating officers have been provided with tire tread-depth measuring gages to facilitate supplying desired information on tire conditions.

It had been estimated that upwards of 10,000 accidents will have been reported by the data collection completion date of January 4, 1971.

All accident data will be processed, analyzed and studied in relation to the data provided by the questionnaires. Through the technique
of weekly mailings of the questionnaires, the influence of seasonal and weather effects on driving behavior and accident causation will be determined by matching the accident reports with appropriately timed questionnaire data. Influences of driver and vehicle differences will also be determined so that effects due to studs can be isolated.

SUMMATION

From the various studies in progress information should be developed on materials, methods and costs for repairing and preventing or reducing the wear effects of studded tires, and other contributing factors. Information should also be indicated as to rates of wear to be expected enabling the prediction of needs and scheduling of repairs or resurfacing projects. Finally, evaluation of the safety effectiveness of studded tires should permit a more factual conclusion as to the reality of safety benefits as well as their economic justification.

In any case, it should be clear at this time that we are presently confronted with a problem that may assume major magnitude in the years ahead. Studded tires may very well continue to be accepted as an effective safety measure. If so, we must recognize that remedying and preventing pavement wear of this kind—whether caused by studs exclusively or by combinations of studs, sand and salt—will place a heavy drain on our future maintenance and construction budgets.