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Evaluation of Winter-Driving Traction Aids

An NCHRP staff digest of the essential findings from the final report on NCHRP Project 1-16, "Evaluation of Winter-Driving Traction Aids," by G. F. Hayhoe and P. A. Kopac, The Pennsylvania Transportation Institute, University Park, PA

THE PROBLEM AND THE SOLUTION TO IT

The all-weather movement of traffic is vital to today's economy and a matter of public demand. In addition to transporting the work force, it is essential to maintain emergency transportation services. In response to these needs, highway agencies spend large sums of money for the removal of snow and ice from roads and streets. To aid in the efficient movement of people and materials during the winter season, industry has developed various winter-driving traction aids, such as tire chains, snow tires, studded tires, improved rubber compounds, limited slip differential, nonlocking brakes, and four-wheel drive. These aids do not appear to be equally effective on snow- and ice-covered roads, and some of them also are quite damaging to pavement surfaces. The primary purpose of this project was to develop standard procedures for evaluating the relative performance and pavement wear effects of various types of winter-driving traction aids. The study involved (1) the selection of methods for evaluating the performance on ice- and snow-covered surfaces of passenger cars and light trucks equipped with various winter-driving traction aids, (2) the conduct of an experimental program to evaluate the performance of specific traction aids, and (3) the preparation of a procedure for overall ranking of traction aids considering such factors as performance on snow and ice, pavement wear, economics, user convenience, and practicality.

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Research has been completed with partial accomplishment of project objectives. A set of vehicle performance test methods has been selected for evaluating winter-driving traction aids. An experimental program to evaluate traction aid types on ice surfaces was conducted on an indoor ice rink. Testing on snow surfaces was not conducted because of lack of snow and difficulties characterizing snow surfaces. A cost-effectiveness model for evaluating winter-driving traction aids has been developed and illustrative examples have been prepared. The use of the standard test methods for determining performance and mobility on ice and snow to a lesser extent permits different traction-aid types to be compared on a common basis. A reference can thus be provided against which the performance of newly developed aids can be gauged. The information in the agency's final report will be of interest to individual users of traction aids, manufacturers of traction aids, and highway agencies. (The full report will not be published in the NCHRP report series. It has been distributed to Program Sponsors and other interested parties and is available on a loan basis from NCHRP.)

FINDINGS

A set of test procedures has been selected to measure the braking, driving traction, and controllability of (1) vehicles fitted with tires and tire-associated traction aids intended to increase available friction on ice and snow surfaces and (2) vehicles fitted with drive-train aids intended to make better use of available friction.

The performance of traction-aids intended to increase available friction, such as tire chains, snow tires, studded tires, and improved rubber compounds, may be determined from a combination of the following test data:

1. Locked-wheel braking friction or locked-wheel stopping distance at a speed of 20 mph (32.4 km/hr).
2. Spinning driving traction at a vehicle speed of 5 mph (8.1 km/hr) with the traction force measured at a slip ratio greater than 1.
3. Spinning driving traction with the test vehicle stationary and tire slip speed greater than 10 mph (16.2 km/hr).
4. Limiting (minimum) lateral tire force measured with a single-wheel tester.

The standardized test procedures for obtaining the test data are described in the report.

The performance of traction-aids intended to make better use of available friction, such as the limited slip differential, nonlocking brakes, and the four-wheel drive, may often be calculated directly from the relevant vehicle characteristics and an assumed tire/friction factor. A simulation program was written and used to study the controllability performance of vehicles fitted with these aids.

EXPERIMENTAL PROGRAM

A test program was conducted on an indoor ice rink to evaluate the selected test procedures and to provide experimental measurements of driving aid performance.

Aspects of the test procedures given particular attention were surface preparation, test repeatability, the effects of tire pressure, and the effects of test speed and tire slip.

A substantial number of traction and controllability tests were conducted. This work showed that accurate and repeatable results can be obtained from testing on an ice rink, although testing studded tires causes problems of surface damage and contamination from ice chips generated by the cutting action of the studs. Similar damage and contamination will be present when studded tires are used on naturally occurring ice, but to an unknown extent. A standardized procedure for testing studded tires cannot be specified, therefore, without a knowledge of highway operating conditions. Unstudded tire performance was also adversely affected by contamination, although mainly by a reduction in peak tire force levels; partly because of this effect, the standardized procedure for testing unstudded tires specifies that limiting (minimum) performance levels be measured.

The results from the locked-wheel braking and driving traction tests carried out on ice surfaces suggested a mechanism of tire force generation, namely, that tire performance can be expressed as a function of sliding speed at low sliding speeds and as a function of slip ratio at high sliding speeds. If these results are confirmed, tire performance on ice could be completely described by only one or two tests. Locked-wheel braking tests on ice also showed that radial-ply-tire performance increases as tire pressure is reduced, whereas bias-ply-tire performance peaks at nearly normal operating pressures and falls off as pressure is either increased or decreased. Factors important in obtaining repeatable test results on ice are accurate measurement of ice temperature, maintenance of standard tire pressure, and suitable conditioning of the ice surface by running preliminary tests.

Test results from the experimental program and information available in the literature provided the basis for the characterization, by a few fairly well-defined areas of performance, of driving aids that improve tire-pavement traction. Table 1 gives typical values and expected ranges of locked-wheel braking traction and controllability friction factors for a variety of tires and aids. (Friction factor is the force that can be generated by a tire (vehicle) in braking, driving, or cornering divided by the vertical load on the tire.)

APPLICATIONS

A number of winter driving aids were evaluated by means of a cost-effectiveness analysis. The cost component in the analysis included the initial and maintenance costs of the aids and the maintenance cost of repairing aid-induced pavement damage. It was assumed that studded tires are the only traction aids that cause significant pavement wear. (Although tire chains may also be harmful to pavements, they are not run on bare pavements for long periods of time.) The type of pavement surface, the number of studded tire passes, the speed of the studded tire vehicles, the number of studs and their protrusion length are the most important factors influencing pavement wear. The last two factors were not included as variables in the analysis, but estimates of their effect may be made from information in the literature.

Table 1. Vehicle friction factors for various driving aids.

	Locked-Wheel Braking			Traction			Controllability		
	ice	snow	wet	ice	snow	wet	ice	snow	wet
Highway tires (no traction aid)	.08	.15	.4	.024	.03	.19	.08	.15	.4
Snow tires (on rear only)	.08	.175	.4	.024	.055	.19	.08	.175	.4
Steel tire chains (on rear only)	.19	.27	.4	.13	.17	.19	.19	.27	.4
Plastic tire chains (on rear only)	.065	.27	.4	.011	.17	.19	.06	.27	.4
Studded snow tires (on rear only)	.09	.175	.4	.032	.055	.19	.09	.175	.4
Four-wheel drive	.08	.15	.4	.064	.12	.37	.16	.30	.8
Anti-lock brakes (4-wheel system)	.08	.15	.4	.024	.03	.19	.16	.30	.8
Anti-lock brakes (2-wheel system)	.08	.15	.4	.024	.03	.19	.12	.23	.6

To relate absolute measures of driving aid performance as measured by the standardized procedures to effective performance on the highway, it was necessary to introduce the concept of mobility. This, in turn, necessitated a nonlinear transformation from absolute performance values to mobility rating. Two transformations were used: one based on the proportion of accidents occurring on various surfaces because of sliding, and the other based on the probability of not exceeding the maximum absolute performance provided by an aid. Both models are tentative; many aspects of driver behavior, under both normal and adverse winter conditions, need to be investigated before a satisfactory model of effective performance on the highway can be formulated. A more detailed description of the incidence and frictional characteristics of ice and snow surfaces occurring on the highway is needed than that which is currently available.

The aids evaluated in the study were assumed to be operating on a hypothetical highway system comprising 10,000 lane-miles of road, 150,000 passenger cars and trucks, and 150,000 drivers. The roads in the system were classified by average daily traffic (ADT) per lane, average traffic speed, and pavement type.

Cost-effectiveness ratios were found by first considering a standard rear-wheel-drive car with highway tread tires as a base configuration. The cost and effectiveness figures for this car were then subtracted from the figures for all other aid configurations. Suitable factoring of the effectiveness rating then allowed the ratio "added cost per point of added effectiveness" to be calculated. Aids or combinations of aids having a low cost-effectiveness ratio are the most desirable.

A number of examples were worked through, in which it was assumed that only one or two aids were in operation on the highway system at any one time. The procedure for calculating cost-effectiveness ratios is illustrated in the report by presenting three examples in detail. The basic procedure is applicable to highway systems more complex than those assumed for the examples, once the highway system's parameters have been determined. System parameters would typically be averages or estimates for a given geographical area. The parameters required for a complete analysis include the number of vehicles, number of lane-miles of each pavement type, terrain geometry, traffic flow rates and average speeds, ambient temperature, relative amounts of snow and ice cover on pavements, proportions of aids in use, proportion of time for which aids are in use, costs of aids, pavement maintenance policies and costs, and pavement wear rates.

Table 2. Cost per point of added effectiveness for a range of driving aids when individually used on all vehicles throughout the year.

		Cost Per Point of Added Effectiveness (thousand dollars)		
Driving Aid	Added Cost (thousand dollars)	Sliding Accident Model	Probability Model	Friction Factor Model
Snow tires on rear	1,275	18.2	18.2	18.2
Studded tires on rear	5,236	45.9	49.4	66.3
Steel chains	5,070	7.17	4.2	11.1
Plastic chains	3,945	23.6	32.6	11.6
Four-wheel drive	6,750	15.2	13.9	5.0
Four-wheel anti-lock	1,050	5.9	150.0	2.3

Table 2 gives added costs and cost-effectiveness ratios calculated for six different aids. These results were obtained by assuming that each aid, in turn, was used on all vehicles in the system throughout the year. Highway tread tires were assumed to be fitted to the four-wheel-drive and anti-lock-brake system vehicles. The friction factor model results are included as a reference to show the effect of assuming a nonlinear relationship between effectiveness (mobility) and vehicle performance (friction factor). (The friction factor model assumes that mobility is directly proportional to friction factor.)

The results in Table 2 indicate that, except for steel chains and anti-lock brakes, the sliding accident and probability function mobility models give comparable results. The reason for the anti-lock-brake configuration having a very high cost-effectiveness in the probability model is that the terms for traction on ice and snow in this model have a dominant effect on the overall mobility rating when highway tires are fitted. The probability function used in the model was derived from braking data, and a function appropriate to traction would probably give a significantly different result. Similarly, the result for steel chains is probably biased, because this aid performs very well in traction on both ice and snow whereas the base vehicle performs very poorly. Thus, increasing the mobility rating for the base vehicle in traction will have a large effect on its overall mobility rating. A further increase in mobility rating as a result of fitting chains will then give a smaller added effectiveness than is indicated in the table. The steel and plastic chain mobility ratings are heavily biased in all three cases because of the assumption that the chains are always fitted. Their true operational characteristics are not accurately represented, and the model requires modification to give a realistic measure of their true effectiveness.

The friction factor model gave significantly lower cost-effectiveness ratios for plastic chains, four-wheel drive, and anti-lock brakes than did the other two models. The reason is that the model does not attenuate mobility rating as coefficient of friction increases, and the high friction terms contribute an unrealistically large proportion of the overall mobility rating. Steel chains are only slightly more effective than plastic chains in this model, but it is not known whether this reflects the true relationship because the operational characteristics are not correctly modeled.

Because the worked examples of driving-aid cost effectiveness consider only a simple hypothetical highway system in which one or two aids are in operation at the same time, many factors affecting the use and operation of driving aids on a real highway system are not taken into account. The results of the cost-effectiveness evaluation should therefore be interpreted as providing a guide to the relative worth of the aids considered rather than as a definitive ranking.

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