Economic Factors Related to Raising Levels of Skid Resistance and Texture

DON L. IVEY AND W. FRANK McFARLAND

An evaluation of the requirements for skid resistance and pavement texture is presented. Economic factors other than accident costs are considered for the first time. The primary economic factors recognized at this time, in addition to accident costs, are fuel cost and tire wear. The study indicates that significantly increasing levels of skid resistance and texture will result in decreases in fuel economy and tire life. These losses will have a major economic impact. The extent of this impact is estimated. A method of calculating the comparative cost of using polish-resistance aggregates and polish-susceptible aggregates for surface treatments is presented. A method to determine the increase in cost that is economically justified to acquire polish-resistant aggregates is developed.

The relation between the level of available friction on highway surfaces and accident rates has been well established. Perhaps the cleanest relation was established by the Dutch (1) in 1977. These relations, illustrated by Figure 1 (1), show a clear interdependence of traffic volume and accident sensitivity as influenced by different levels of skid resistance.

Recent work on this subject was done at Texas A&M University (2). Equations 1 and 2 give the new relations that were developed. The degree of accuracy of these equations is illustrated by Figure 2.

For low speed (urban), speed limit > 50 mph,

$$WAR_{LS} = -21.7 + 0.0009ADT + 2.34ACC - 0.40SN + 286\,TW + 1.32LN \quad (1)$$

For high speed (rural), speed limit = 55 mph,

$$WAR_{HS} = -0.75 + 0.0001ADT - 0.053VM + 0.54\Delta V + 0.69ACC - 0.025SN \quad (2)$$

where

ADT = average daily traffic,
ACC = access,
SN = skid number at 40 mph,
TW = proportion of time wet,
VM = mean traffic speed,
ΔV = variation in traffic speed, and
LN = lanes of traffic.

Figure 1. Accident sensitivity to volume of traffic as influenced by friction.

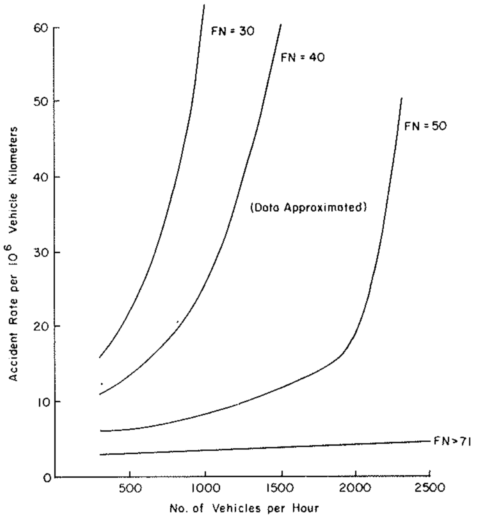


Figure 3 illustrates the relative insensitivity of accident rate to skid number on rural highways and the high sensitivity on urban highways. The obvious conclusion is that major accident, and thus economic savings, can be realized predominantly in urban areas (i.e., areas where speeds are posted at less than 55 mph).

There is much more to the problem of maintaining adequate levels of skid resistance than simply building surfaces with a high value of SN. Davis and Epps (3) have treated the problem of aggregate polishing, attrition of surface aggregate, and fat spots on the surface caused by overasphalting.

OVERVIEW OF ECONOMIC ASPECTS

Increases in tire-pavement friction have a variety of economic influences. The most sought-after influence is accident reduction, but several other in-

Figure 2. Observed versus predicted wet-accident rate.

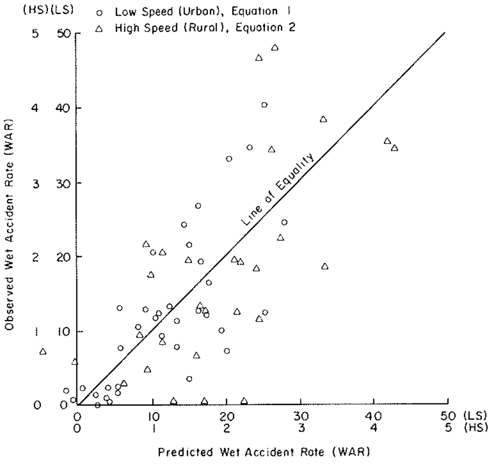
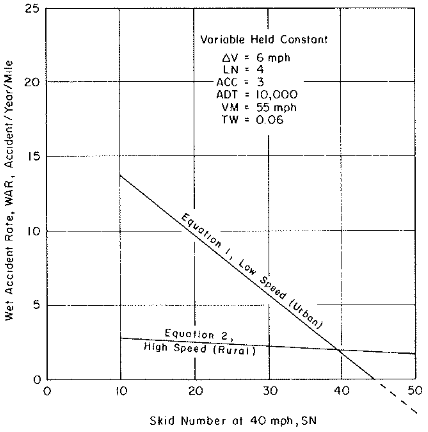


Figure 3. Sensitivity of Equations 1 and 2 to SN.



fluences are not positive. These influences are summarized below.

Consequence of Increased Tire-Pavement Friction	Economic Influence
Positive	Reduction in accidents in wet weather, resurfacing required less frequently
Negative	Increased fuel consumption, increased tire wear, increased costs for surfacing
Other	Increased noise and vibration levels imposed on vehicle occupants

Of the two positive influences, the second is actually somewhat dependent on the first and reflects the requirement of maintaining generally adequate levels of pavement skid resistance. The first two negative influences (increased fuel consumption and increased tire wear rates) may prove of some significance, at least in imposing some upper limit on the amount of macrotexture that will be tolerated by the public. Increased traffic noise, although not necessarily of economic importance, may also impose a practical upper limit on macrotexture.

Arbitrarily increasing the pavement macrotexture to produce increases in friction and reduce hydroplaning tendencies must be subject to some compromise to prevent the negative influences from growing intolerable.

Methods Available to Increase Friction

Many methods are available to increase tire pavement friction. They have been discussed in detail by Davis and Epps (3). Seventeen methods are described by Davis and Epps, including acid etching, scabbing, grooving, portland cement concrete (PCC) overlays, chip seals, open-graded friction courses, epoxy seals, heater-planer treatment, and milling. Discussions of the practicality of each method are given as well as costs and estimates of surface life. A relatively new innovation is the pavement-milling method.

Pavement Milling

One of the most innovative methods of achieving high values of pavement texture, and thus tire-pavement friction, is cold milling. Several companies now perform this service and others are building equipment for cold milling. The resulting surface is an extremely highly textured, longitudinally striated surface that should provide excellent skid resistance. In apparent conflict with this expectation is that early determinations of SN do not show high values. It may be that a texture has been achieved that has a directional geometry so pronounced that the reduction of contact area in the tire contact zone generates lower values of locked wheel-braking friction force. If this is true, the value of SN may even increase as the most extreme textured projections are abraded and worn, although this must be considered unlikely. It seems obvious that the pattern will greatly improve directional stability as does pavement grooving. Also apparent is the high-speed insensitivity to friction reduction of a texture so pronounced. Although this is a hypothesis, if verified, it will prove an excellent characteristic.

There seem to be only two drawbacks to the cold-milling process. First, these newly completed sections have drawn criticism from motorcyclists and drivers of small cars. They complain that the surface may produce stability problems. Another way of interpreting this is that the surface provides too much directional stability. A human factors study conducted by Martinez (4) showed that early surfaces milled in Texas posed some problem to the riders of some motorcycles, but as the technology has matured, the problem has receded.

The second drawback is a negative economic influence. Elevated pavement textures add to rolling resistance and thus to decreased fuel economy. Although this seems to have been appreciated only intuitively until now, recent tests indicate that the difference in the rolling resistance for a full-sized vehicle between a pavement that has low textural value (approximately 10-20/1000 in) and one that exhibits a very high cold-milled texture (approximately 70-80/1000 in) is approximately 85 lbs. (Pavement texture is normally expressed as the average depth of the depressions between aggregate particles. Another way to view it is the average height of the pavement surface asperities.) Based on limited data, the curves shown in Figure 4 are hypothesized.

As an example, consider the possibility that the Federal Highway Administration (FHWA) is successful over a period of the next four years in increasing the average macrotexture of the federal and state highway systems from the currently assumed average of about 30/1000 to a level of 50/1000.

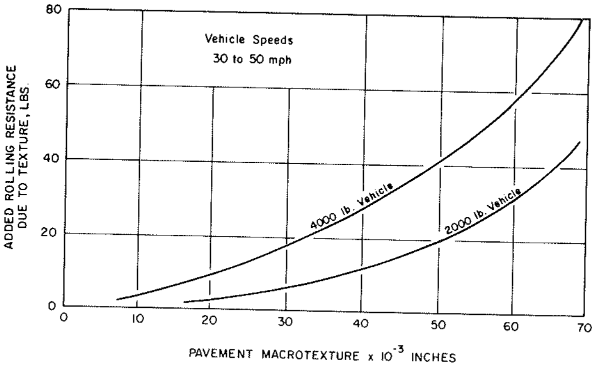
According to Winfrey (5, p. 292), total rolling resistance for a 4000-lb automobile is about 65-70 lb at speeds of 55-60 mph. If the added rolling resistance from increasing macrotexture from 30/1000 to 50/1000 increased total rolling resistance, by 20 lb (from 60 to 80 lb), this is an increase in rolling resistance of 33 percent. Since about 36 percent of total horsepower used is for rolling resistance at speeds of 55-60 mph (5, p. 292), the 20 lb of added rolling resistance would increase horsepower required by about 10 percent.

Thus, for a full-size automobile that achieves 20 mile/gal with a macrotexture of 30/1000, fuel efficiency would drop to about 18 miles/gal with a macrotexture of 50/1000. Assuming that 1.8 trillion miles are driven per year in 1984 and fuel costs are $1.30/gal (assumed 1981 cost), this translates to a difference in cost of about $13 billion/year for this increase in macrotexture. If fuel increases in price by 7 percent/year between 1981 and 1984, this would amount to an increase of about $16 billion/year.

Effect on Rates of Tire Wear

A corollary to the increased rolling resistance is the increase in tire wear. It has been estimated

Figure 4. Influence of macrotexture on rolling resistance.



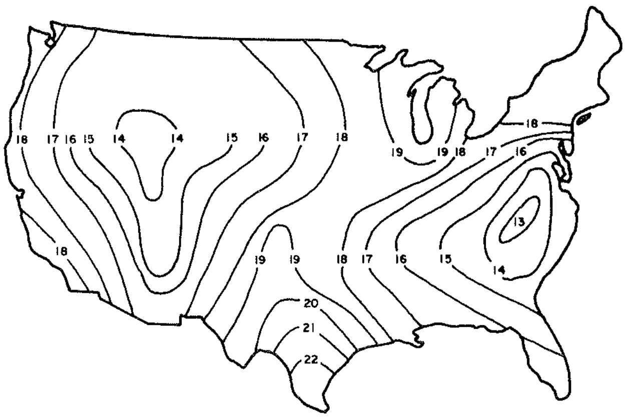
that tire life is inversely related to pavement texture.

Although there is no direct verification of the influence of pavement texture on tire wear rates, the contour map of tread wear in the United States by Snyder (6) provides strong indirect evidence [Figure 5 (6)]. In the highest wear areas of Utah and North Carolina, angular polish-resistant, igneous aggregates, such as crushed granite, are predominantly used. In the lowest wear area of Texas, relatively soft rocks, such as crushed limestone and well-rounded gravels, have been widely used. Note, however, that no quantitative relations have been derived from this information. An obvious factor--the influence of microtexture--is involved in the Snyder contour map and is neglected in current considerations of the effect of macrotexture. Further complicating this relation is the research that shows that most tire wear occurs when pavements are wet (7). This seems somewhat in conflict with the Snyder contour map, where states such as Washington and Louisiana have relatively low wear rates (i.e., high values of mileage to wear out a tire).

In spite of this lack of quantitative evidence, in consultation with Bob M. Gallaway, we have intuitively derived the graph shown in Figure 6. Certain end points of this curve have been roughly quantified by tread life values occurring at the main automotive proving ground (APG) tire wear track and the El Camino track. Even so, the graph is somewhat speculative.

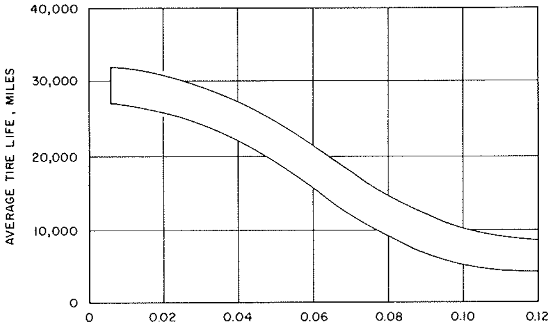
As Figure 6 illustrates, the construction of surface textures much greater than 0.50 in on highways could result in precipitous wear rates. By using the previous example of increases from 30 to 50/1000 in of macrotexture, it might be possible to decrease the average life of a tire by 10-20 percent. If we assume that 250 million tires are consumed per year with average macrotexture at 30/1000 (this includes retreads), the decreased tire life of 10-20 percent with macrotexture at 50/1000 would increase tire consumption by 25-50 million tires/year. If we assume that tires cost $50 each in 1984, this would amount to an increase in tire cost of $1.25-5 billion/year.

Figure 5. Contour map of tread wear for United States, showing equal tire mileage lines.



Note: Contours designate the average number of miles in thousands driven by vehicles where one tire rib has been worn to the 2/32 s-in wear line.

Figure 6. Influence of pavement macrotexture on tire life.



Overall, the increase in fuel and tire costs, from increasing macrotexture from 30 to 50/1000, would approach $20 billion/year in 1984.

Accident Savings

The major economic gain due to increasing pavement texture-friction is that of accident reduction. Table 1 illustrates the savings achievable by increasing average tire pavement friction from 35 to 45, an increase that might be considered achievable [see the following table (8-10) and Table 2 (2) for assumptions.]

Accident Type	Estimated Cost to Society of Accidents ($)	Estimated Distribution of Accidents (%)
Fatality	500 000	0.26
Disability injury	18 000	7.67
Property damage only and nondisability injury	1 000	92.07

The total estimated societal savings computed amounts to slightly more than $2 billion/year by 1984. It may seem inappropriate to estimate the cost of these accidents in terms of dollars. The prevention of more than 0.5 million accidents is a worthy societal goal unless the costs incurred by

Table 1. Estimate of accident cost savings in 1984 if average SN is raised from 35 to 45.

Road Type	1984 Total Mileage[a]	1984 Vehicle Miles[a] (000 000 000s)	Estimated No. of Accidents Prevented	Estimated Accident Cost Savings ($000 000s)
Interstate				
Urban	10 000	185	2 500	9
Rural	35 000	173	8 750	32
Other highways				
Urban	115 000	513	460 000	1657
Rural	450 000	470	112 500	405
Total			583 750	2103

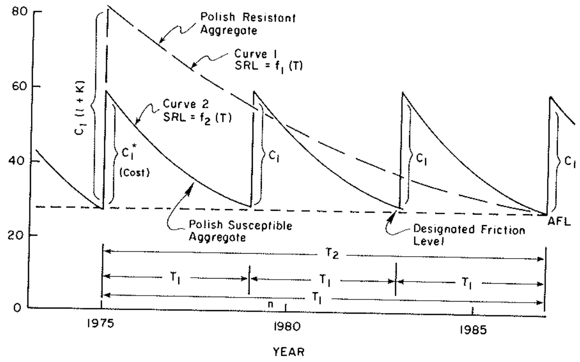
[a] From FHWA (7).

Table 2. Values assumed for accident reduction computations.

	Interstate		Other Highway	
Item	Urban[a]	Rural[a]	Urban[b]	Rural[a]
ADT	50 000	13 500	12 200	2860
ACC	2	1	4	2
TW	0.05	0.05	0.05	
LN	6	4	4	
VM				60
ΔV				6
SN	35, 45	35, 45	35, 45	35, 45

[a] Use Equation 2. [b] Use Equation 1.

Figure 7. Comparison of renewal frequency for polish-resistant and polish-susceptible aggregates.



*C_1 is the cost required to achieve the change in skid resistance shown.

such prevention detract from more productive preventative methods.

Direct Economic Effects on State Transportation Departments

Considering those factors of direct economic influence on state transportation departments, the problem translates into a comparison of the costs of specific treatments with the cost of maintenance and the frequency of resurfacing.

A simplified approach to this economic problem is illustrated by Figure 7. This figure compares the difference in several resurfacing operations over a period of years with a polish-susceptible aggregate to the cost of a single surfacing operation that has a more costly polish-resistant aggregate.

The total cost over a period of T_2 years is nC_1 (for the polishing aggregate) and C_1 (1 + K) (for the polish-resistant aggregate)

where

T_1 = the time the polish-susceptible aggregate surface treatment will last,
T_2 = the time the polish-resistant aggregate surface treatment will last,
$n = T_2/T_1$,
C_1 = the cost of a surface treatment using the cheaper polish-susceptible aggregate, and
K = the decimal increase in cost of the polish-resistant aggregate surface treatment relative to the cost of the polish-susceptible aggregate surface treatment.

If the total costs over the period T_2 are equated, then a value of K derived from the equation

$$nC_1 = C_1 (1 + K) \tag{3a}$$

can be justified

$$K = n - 1 \tag{3b}$$

This is an obviously oversimplified economic treatment, but one that may be roughly justified on the basis of comparing the value of money originally invested in the surface at time zero to the escalation of all material costs over the period T_2.

This simple equation shows that the amount of cost differential justified is linearly related to n, the ratio of the respective treatment lives, if a discount rate of zero is used.

There is a distinct advantage, however, to this apparent equalization of costs. The average level of friction provided to the public over the period T_2 is significantly greater for the polish-resistant than for polishing aggregates, even though they both approach the same low value during the period. In the example of Figure 7, the polishing-aggregate surface approaches the minimum level three times during the period T_2, but the polish-resistant surface approaches the minimum level only once.

In the hypothetical example shown by Figure 7, the value selected arbitrarily is approximately 30. The average level of friction provided by the polishing aggregate is the integration of curve 2,

$$SRL_{avg} = \int_0^{T_1} f_2(T)dT/T_1 \tag{4}$$

In the hypothetical example this value is approximately 40.

The average level of friction provided by the polish-resistant aggregate is the integration of curve 1,

$$\underset{\text{(Curve 1)}}{SRL_{avg}} = \int_0^{T_2} f_1(T)dT/T_2 \tag{5}$$

This value is approximately 52. This demonstrates that the average value provided over the period T_2 by the polish-resistant aggregate is roughly 30 percent greater than that provided by the polishing aggregate.

This difference in the average skid resistance provided has a modest influence on accident costs. For example, if T_2 is 9 years and the highway parameters are described as follows, for 5 miles of highway,

ADT = 10 000,
ACC = 4, and
Speed limit = 45.

The application of Equation 1 for the average friction levels of 52 and 40 will yield a predicted reduction in wet-weather accidents of 180 over the 9-year period, if the cost of the average accident is \$3600 (a weighted average of property-damage only, injury, and fatal accidents) (7). This is a direct savings of \$648 000, not to mention the humanitarian contribution.

In the previous economic comparison, no discount rate has been used for the polishing aggregate to discount future costs to present terms. Use of a positive discount rate (r) results in the following analogous cost comparison. If we assume that T_2 is some multiple (n) of T_1, as before,

$$C_1 + [C_1/(1+r)^{T_1}] + [C_1/(1+r)^{2T_1}] + \ldots + [C_1/(1+r)^{(n-1)T_1}]$$
$$= C_1(1+k) \tag{6a}$$

or

$$C_1 \sum_{j=0}^{n-1} 1/(+r)^{jT_1} = C_1(1+k) \tag{6b}$$

or the premium k that can be justifiably paid for the nonpolishing aggregate based on cost alone is

$$k = \sum_{j=0}^{n-1} [1/(1+r)^{jT_1}] - 1 = \sum_{j=1}^{n-1} 1/(1+r)^{jT_1} \tag{7}$$

which equals n-1 with r equals 0. With n equal to 3, T_1 equal to five years, and r equal to 0.05 (i.e., with a discount rate of 5 percent/year), we get the following results:

$$k = [1/(1+0.05)^5] + [1/(1+0.05)^{(2\times5)}] = (1/1.276) + (1/1.629)$$
$$= 0.784 + 0.614 = 1.398 \tag{8}$$

The premium that can be paid for the skid-resistant aggregate, in decimal terms, thus is 1.398 or, in percentage terms, would be 139.8 percent. In this example, 139.8 percent is the amount extra that can be paid for the skid-resistant aggregate and still have the same cost per year, assuming the factors of fuel efficiency and tire wear are roughly equivalent under the two situations. In the case where T_2 is not an even multiple of T_1, probably the preferable way to compare alternatives is to determine the equivalent uniform annual cost (EUAC) for each alternative and compare these. For example, if T_1 is 5 years and T_2 is 14 years, EUAC associated with the polishing aggregate would be obtained by multiplying the uniform series capital recovery factor for an interest rate of 0.05 and a life of 5 years, denoted by crf(r=0.05, t=5), by C_1. Similarly, for the nonpolishing aggregate, EUAC would be obtained by multiplying crf(r=0.05, t=14) by $C_1(1 + k)$, and k can be obtained by solving:

$$C_1 \times \mathrm{crf}(0.05, 5) = C_1(1 + k) \times \mathrm{crf}(0.05, 14)$$
$$\mathrm{crf}(0.05, 5) = \mathrm{crf}(0.05, 14) + k \times \mathrm{crf}(0.05, 14)$$
$$k = [\mathrm{crf}(0.05, 4)/\mathrm{crf}(0.05, 14)] - 1 \qquad (9)$$

where $\mathrm{crf}(r,t) = [r(1 + r)^t/(1 + r)^t - 1]$ and, crf(0.05, 5) = 0.230 97 and, crf(0.05, 14) = 0.101 02 and thus, k = (0.230 97/1.101 02) - 1 = 2.286 - 1 = 1.286

This same approach can be used, of course, even if T_2 is an even multiple of T_1; for example, in the case previously considered where $T_1 = 5$ years and $T_2 = 15$ years: k = [crf(0.05, 5)/crf(0.05, 15)] - 1 = (0.230 97/0.096 34) - 1 = 2.397 - 1 = 1.397

which is the same answer as obtained previously (except for the small rounding error).

SUMMARY

There are direct economic benefits to state transportation departments and to the public from increasing friction on road surfaces. Judgment must be exercised to prevent unacceptably high levels of macrotexture from alienating the public through the negative influences of noise, vibration, reduced fuel economy, and high levels of tire wear. Many proven methods of accomplishing this goal are available and new methods are becoming available. Careful economic analyses of alternative aggregate sources must be prepared relative to specific natural resources in different parts of the country to accurately determine the benefits that can be realized, but they are significant and should be pursued.

REFERENCES

1. L.H.M. Schlosser. Traffic Accidents and Road Surface Skidding Resistance. TRB, Transportation Research Record 623, 1976, pp. 11-20.
2. D.L. Ivey, L.I. Griffin III, T.M. Newton, K.C. Hankins, C.W. Blumentritt, and R.L. Lytton. Development of a Wet Weather Safety Index. Texas Transportation Institute, Texas A&M Univ., College Station, Res. Rept. 221-1F, Nov. 1977.
3. M.M. Davis and J.A. Epps. Skid Resistant Surfaces. Texas Transportation Institute, Texas A&M Univ., College Station, Res. Rept. 214-7, Dec. 1975.
4. J.E. Martinez and others. Effects of Milled Pavement Surfaces on Motorcycle Rideability. Texas Transportation Institute, Texas A&M Univ., College Station, Res. Rept. 237-1F, 1968 (unpublished).
5. R. Winfrey. Economic Analysis for Highways. International Textbook Co., Scranton, PA, 1969.
6. R.H. Snyder. Environmental Effects on Tire Treadwear. Tire Science and Technology, Vol. 1, No. 2, May 1973.
7. Roadway Report. In 1975 Highway Statistics, Section 4, FHWA, FHWA-HP-HS-75-04, 1975.
8. W.F. McFarland and J.B. Rollins. Discussion of Concepts, Principles, and Objectives of Economic Analysis Applicable to Traffic Accidents. TRB, Transportation Research Record 680, 1978, pp. 50-52.
9. R. Winfrey. Concepts, Principles, and Objectives of Economic Analysis Applicable to Traffic Accidents. TRB, Transportation Research Record 680, 1978, pp. 40-50.
10. Accident Facts. National Safety Council, Chicago, 1975.

Publication of this paper sponsored by Committee on Surface Properties-Vehicle Interaction.