Variable Slip Friction Measurement Techniques for Snow and Ice Operations

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Maintenance agencies seek a relatively inexpensive device that can measure roadway friction under winter conditions and tell the operator in real time whether friction is present. This method would assist the operator in determining when and where abrasives or chemicals should be applied during snow and ice control operations under all conditions. Past studies have used braking action friction measurements as an indicator, but this method cannot be used under high-traffic-volume conditions. Field studies have been conducted in Minnesota and Norway using Norsemeter's road analyzer and recorder to determine the applicability of the equipment to snow and ice operations and its reliability and durability. The measuring device, mounted on a smaller trailer, uses an industry-standard pavement friction measuring tire. The measurement is made by employing wheel braking on the road surface and measuring the braking friction force that the road surface exerts against the braking wheel. Each measurement uses a variable slip speed measurement and records peak friction, slip at peak friction, and the friction versus slip shape factor. Data were collected for precipitation, pavement condition, pavement temperature, air temperature, speed of the measuring device, and friction values. The equipment, measurement procedures, and findings are described in detail. This preliminary research study shows that the contaminant conditions can be separated and the friction level can be evaluated to determine whether to salt and whether to salt lightly or heavily. Also, with this method a supervisor can evaluate the effectiveness of applied abrasives and chemicals.

A joint project on winter road friction measurement with Norsemeter, the Norwegian Road Administration, the Norwegian Director, and the Norwegian Road Research Laboratory was carried out in 1994 and 1995 (*1*). The study mapped maintenance guidelines and looked at current technology in friction measurements and the friction and texture research project of the Permanent International Association of Road Congresses (PIARC). On the basis of this study, Norsemeter developed its road analyzer and recorder (ROAR). The unit was designed to be used as a stand-alone tester mounted on a trailer, or to be mounted on a salt spreader truck. Field studies were conducted in Norway and Minnesota during the 1995–1996 winter season in a joint Norsemeter–Minnesota Department of Transportation (MinnDOT) project. This report summarizes these field studies; describes the equipment, measuring procedures, and findings of the preliminary research study; and includes some of the data from the Norwegian study as well.

Test Site

The roadway selected for the test site is a western segment of the beltway around the twin cities of Minneapolis and St. Paul (I-494) (Figure 1). This segment of I-494 (both the southbound and the northbound roadways) is located between Trunk Highway 7 and Trunk Highway 55. The site consisted of four test areas: two concrete surfaces, south-

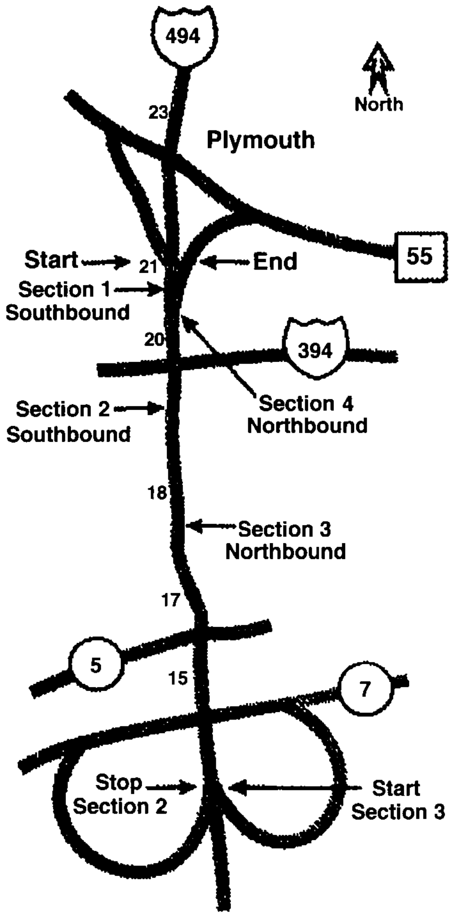

FIGURE 1 Test sections, west of Minneapolis–St. Paul.

bound and northbound, and two bituminous surfaces, southbound and northbound. This segment of I-494 is approximately 9.6 km (6 mi) long and has three bridges that cross another Interstate route, a county road, and railroad tracks. The hourly average weekday and weekend traffic for each roadway is 43,015 and 31,953 vehicles in the southbound lane, respectively, and 43,447 and 30,575 in the northbound lane, respectively. Located near the county road overpass is a road weather information system site that monitors atmospheric parameters and pavement temperatures every 15 min; wind speed and direction, relative humidity, air temperature, and precipitation are measured. The pavement sensor is located in the southbound roadway of I-494, in the bituminous section.

The test site was entered on the southbound roadway of I-494 at the ramp for Route 55. The friction measurements were begun at the nose of the on-ramp and continued to the nose of the off-loop to eastbound Route 7. The friction measurements were suspended, the vehicle continued through the interchange loop, and measurements were begun again on northbound I-494 at the nose of the entrance loop from the Route 7 eastbound roadway. The measurements were continued to the nose of the off-ramp for Route 55 and then were stopped.

Test Apparatus

ROAR is a continuous measuring device with a variable slip test wheel. It was mounted on a two-wheel trailer and towed by a host vehicle. The test wheel was located in the left wheel track and mounted directly on the axle of a hydraulic wheel slip controller, which was programmed to perform a desired braking action on the test wheel. The braking action was a linearly decreasing rotational wheel speed from free-rolling to locked wheel. During this action the torque on the wheel axle was measured and converted to a friction coefficient by the digital computer of the device. A vertical static load of 1.5 kN (300 lbf) was applied on the test wheel, which had a four-bar suspension with no spring and no shock absorber. ASTM E1551 was used as the test tire with an inflation pressure of 207 kPa (30 psi). The instrumentation could measure the torque acting on the test wheel, which was converted to friction coefficients in a digital computer, and the rotational speed of the test wheel, which was converted to a distance and a distance-traveled-per-unit time. The computer was programmed to calculate several friction process parameters including peak friction co-efficient, the slip speed at which the peak friction occurred, the slope of the friction coefficient curve as a variable of slip speed, and others. The computer program used the Radó friction model for deriving these parameters (2). Friction coefficients for all slip speeds could be computed from each braking action, including friction at lower slip ratios like 15 or 18.5 percent and at traveling speeds other than the one at which measurements were taken. The measured values were stored in the computer and output as a strip chart and data files on diskette.

Test Procedures

A baseline test was made of the test sections when bare and dry and when bare and wet. The actual tests were made whenever there was a significant snow or ice storm. The test procedure was to measure right after the first salting, 30 min after salting, and just before salting a second time. For the same period, the weather conditions (precipitation type, pavement condition and contaminate, time since plowed, and chemical type used) were recorded by the driver. From the remote weather station, an office report was created for the time period including the time, air and pavement temperature, pavement condition, dew point and relative humidity, and beginning and end of precipitation.

Data Reduction and Analysis

The ROAR measures variable slip as shown in Figure 2, which gives an example from the baseline dry tests and

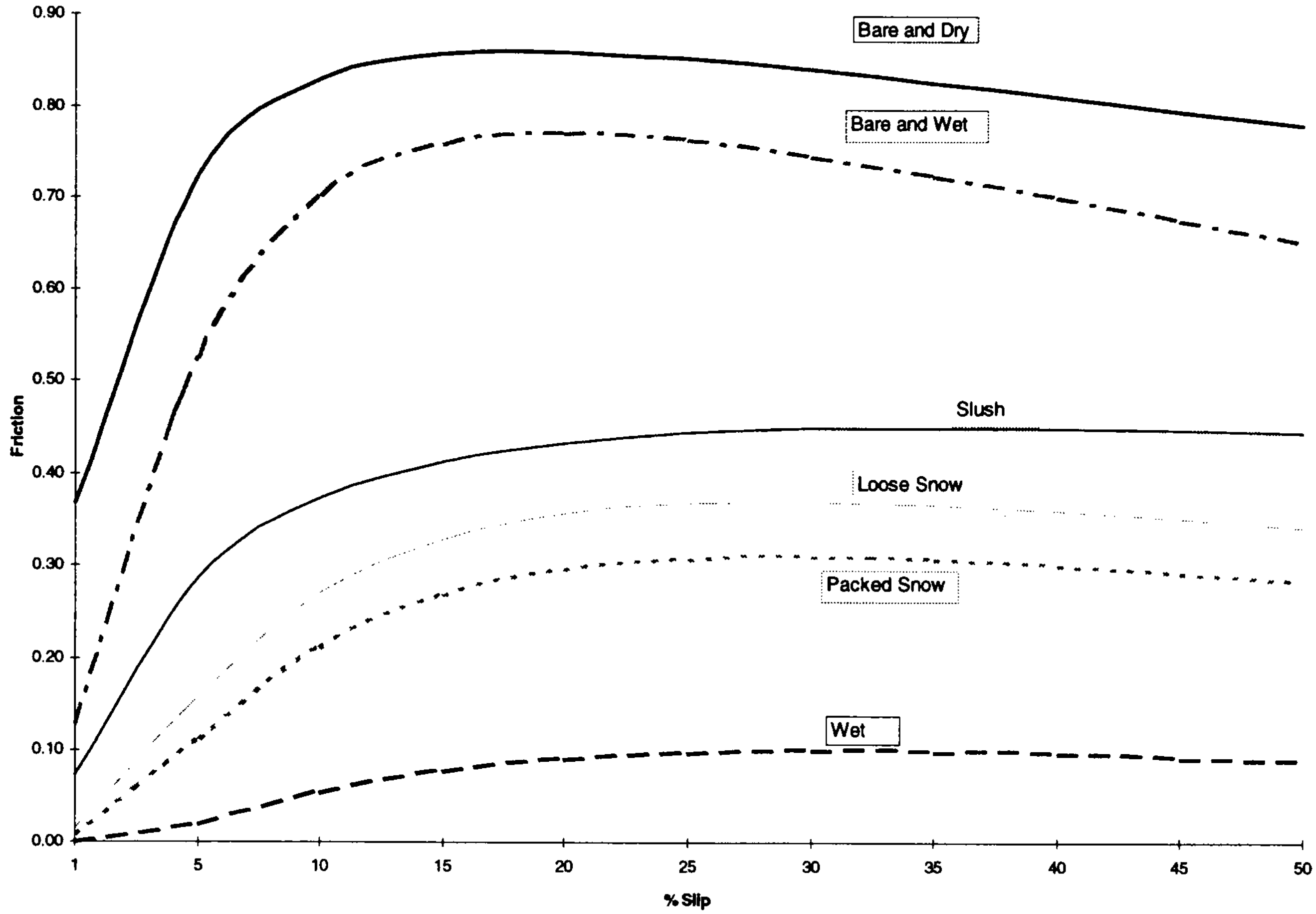

FIGURE 2 **Sample friction versus percent slip for six conditions.**

an example for wet, slush, loose, and packed snow from the MinnDOT tests, as well as an example on ice from the Norwegian tests. The data are fitted to the Radó model to provide the three coefficients required to produce the friction-slip speed curve. The three coefficients are μ_{peak} (value of the peak friction), S_{peak} (value of slip speed at which the peak friction occurred), and C (a value that gives the shape of the curve, called the shape factor). These values are studied to determine the type of contamination and whether salting is needed. Figure 2 shows that the wet friction drops faster with speed, and this has been shown to be correlated to macrotexture (*3*). The slip at which the peak value occurs is around 18 percent on dry, 20 percent on wet, and nearly 30 percent on the winter contaminated surfaces. This, along with the drop in the peak value, appears to be a clear sign. The shape factor also separates the loose snow and slush from the packed snow and ice, and the ice is separated from the packed snow by the low friction.

Peak Slip Distributions

Figure 3 is a continuous plot of the peak friction verses position for the baseline (dry) of the test site. Real-time Bayesian statistics are applied to the μ_{peak} values. A research goal was to determine proper Bayesian values so that the data could be used for decision making. In these plots of peak friction, the dots are the individual data points and the line represents the applied second-generation Bayesian statistics applied. Figure 4 shows the average peak value for each section as well as the most frequent peak friction value. There is a difference between the average and most frequent values although less for the dry baseline than for later plots for winter conditions. All sections run between .84 and .87 in the dry condition. Figure 5 gives the baseline values for the test site under wet conditions. Both the peak friction and the friction at a slip velocity of 60 kmh (37.5 mph) (FR60) of the PIARC international friction index are reported. FR60 is near the value of a locked wheel test per ASTM E274 with a blank tire.

Figure 6 is a sample plot of the peak friction value on packed snow, and Figure 7 shows the average and most frequent peak values for the different sections. The sections are fairly uniform near 0.3, and there is more difference between the average and most frequent values. Figure 8 shows the peak variations for each section for four periods on January 28 and 29. The first period de-

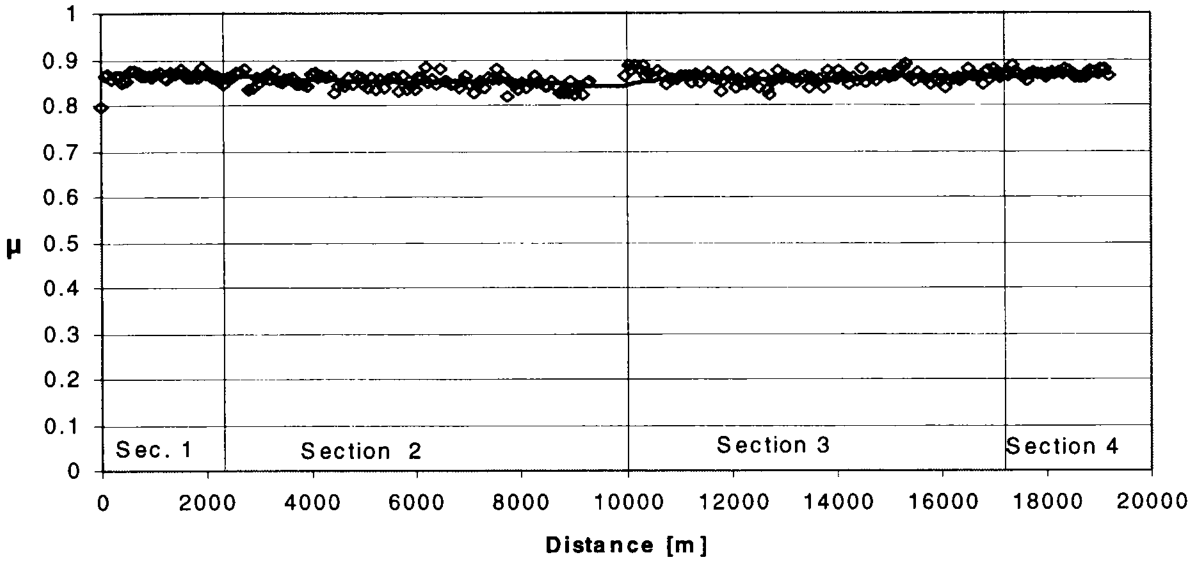

FIGURE 3 Peak friction on dry pavement.

picted is for black pavement showing (bare); and the second, 30 min later after sanding of the bridges, shows that all sections are now even. The next period, 18 hr later, shows that the friction level drops from .6 to .4 when drifting snow spots the roadway. The last period is 30 min later while following a plow truck; although there is some improvement, it is not significant. During this time the temperature dropped from −10°C to −20°C (15°F to −5°F).

Figure 9, which depicts results for slush and wet pavement, is of more interest. It is apparent that parts of the site have a good friction value compared with the dry and wet baseline. However, other sections within the site have very poor showings. Clearly, a protocol could have been

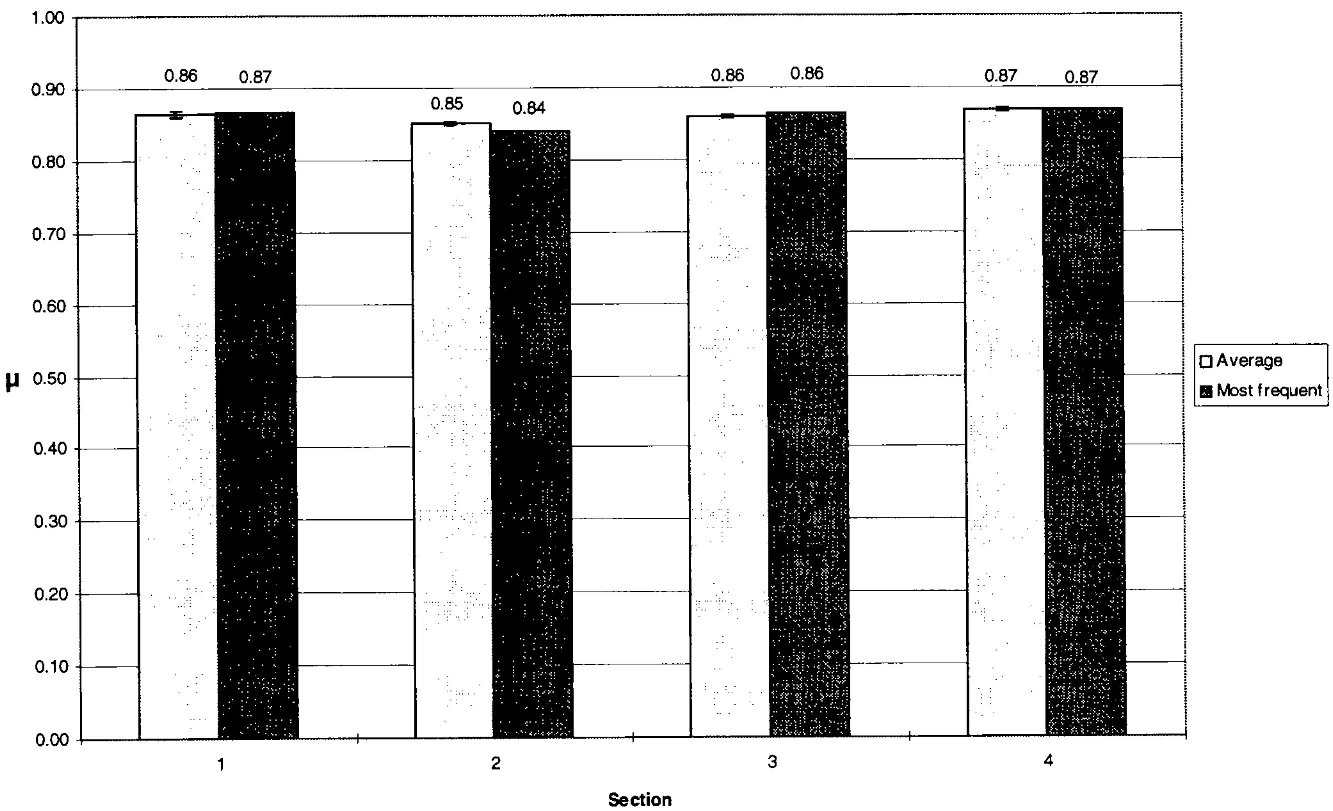

FIGURE 4 Peak average and most frequent for dry pavement.

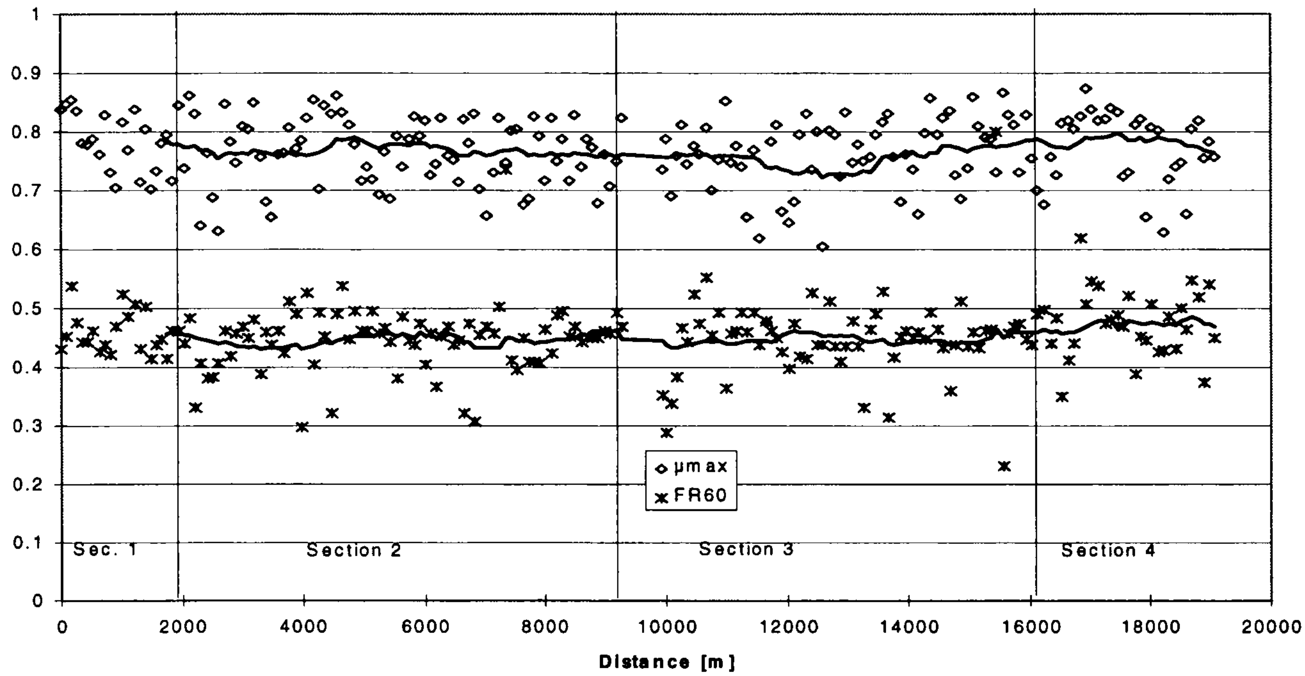

FIGURE 5 Peak friction and FR60 for wet pavement.

set requiring no salting for some parts, light salting for others, and heavy salting for still others. Suggested levels are given, but these would be subject to the roadway's baseline values, the average daily traffic, and the type of roadway, and should also consider whether the temperature is rising, falling, or holding steady. On this day the temperature had dropped from above freezing to below and had later risen again. Figure 9 also shows the improvement of the newer Bayesian values now being used as a result of this study. Because ROAR is under computer control, all of these factors can be programmed for control of salting. Figure 10 shows the distribution for Section 1. Although this would not be useful in real time for salting control, it is useful to the field engineer for evaluating the effectiveness of salting or sanding by comparing conditions before and after maintenance is performed. Note that in Section 1 most of the friction points are satisfactory and only a few need salting in this section.

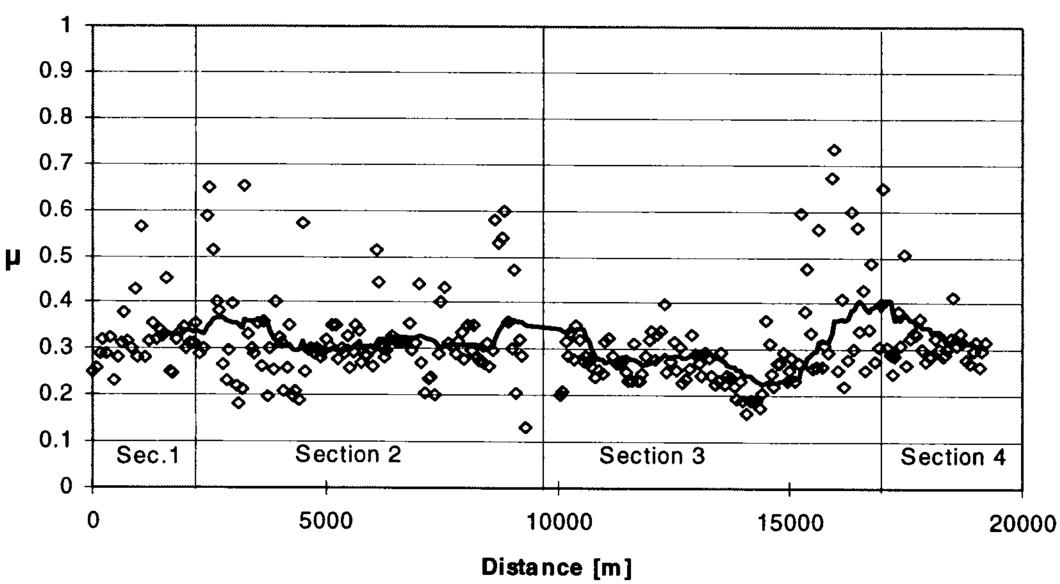

FIGURE 6 Peak friction for packed snow.

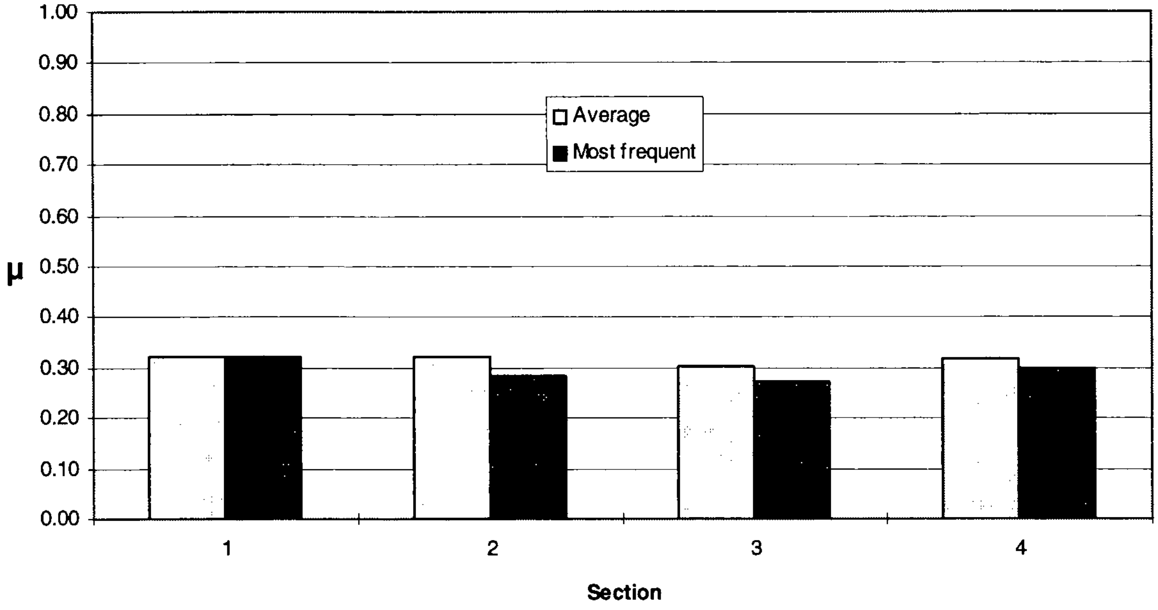

FIGURE 7 Average and most frequent for packed snow.

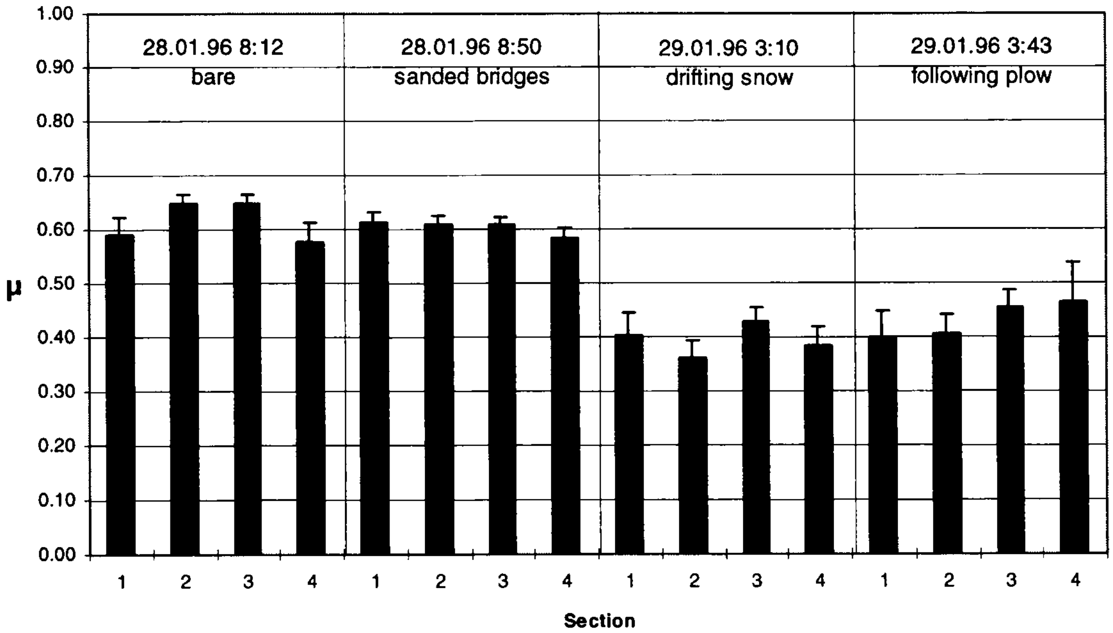

FIGURE 8 Distribution of peak friction on loose snow.

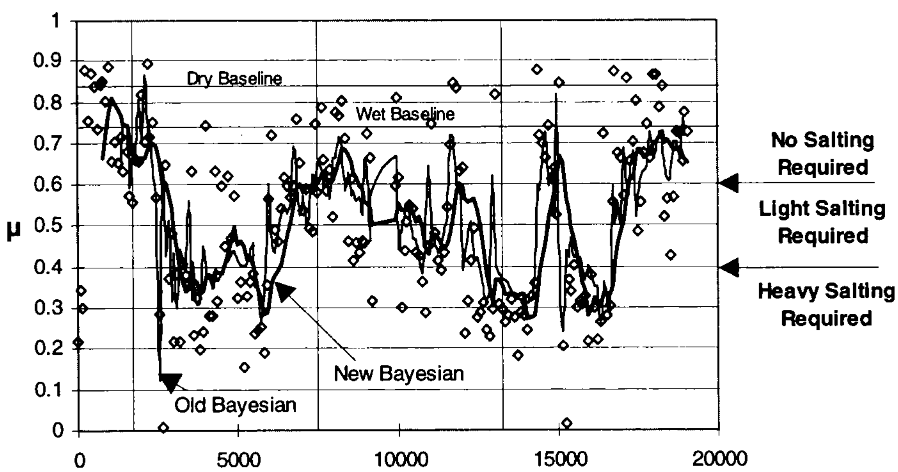

FIGURE 9 Peak friction in slush and wet pavement.

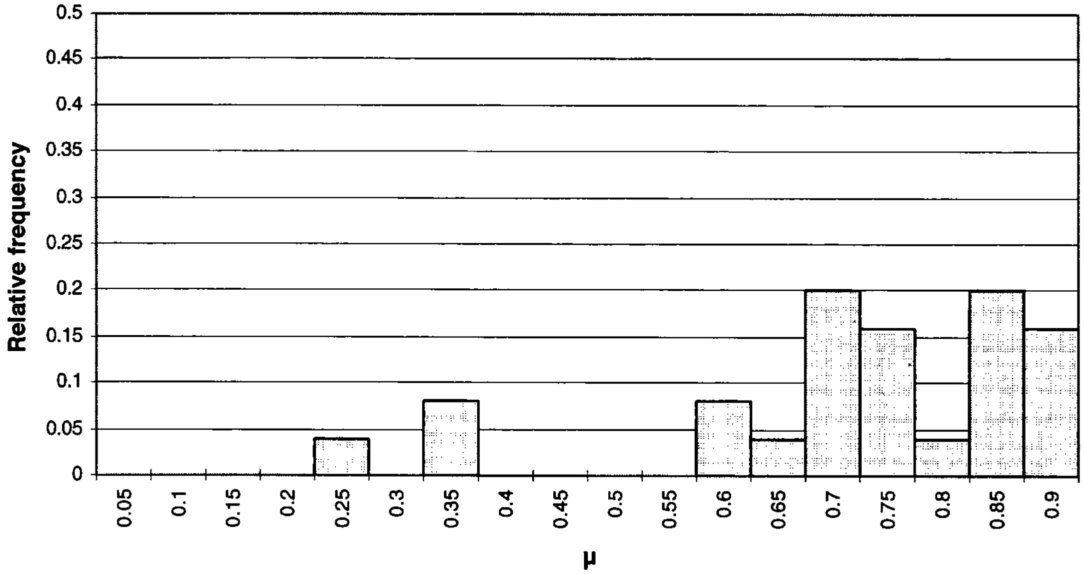

FIGURE 10 Relative frequency of peak values for Section 1 on slush and wet pavement.

Norwegian Data

The remaining figures present Norwegian data. Figure 11 shows the effect of speed on hard-packed snow; friction appears to increase with increased speed. However, it has been found that most of this increase is due to increased rolling resistance caused by snow plowing in front of the tire. Figure 12 shows the time effect of sanding for four periods—before sanding, 30 min after sanding, 2.5 hr after sanding, and 4.5 hr after sanding. As found in other studies, there is an initial 15 to 25 percent improvement, but much of this is then lost with time and traffic, and sand must be reapplied if salt is not also applied.

Figure 13 shows the time effect after salting on five sites. In each case improvement occurs as the salt has time to work; the increasing temperature also helps. Figure 14 shows the values for loose snow and hard-packed snow on ice. These are followed by values just before salting, then 30 min, 2.5 hr, and 4.5 hr later. At 30 min slush is forming; at 2.5 hr there is slush and

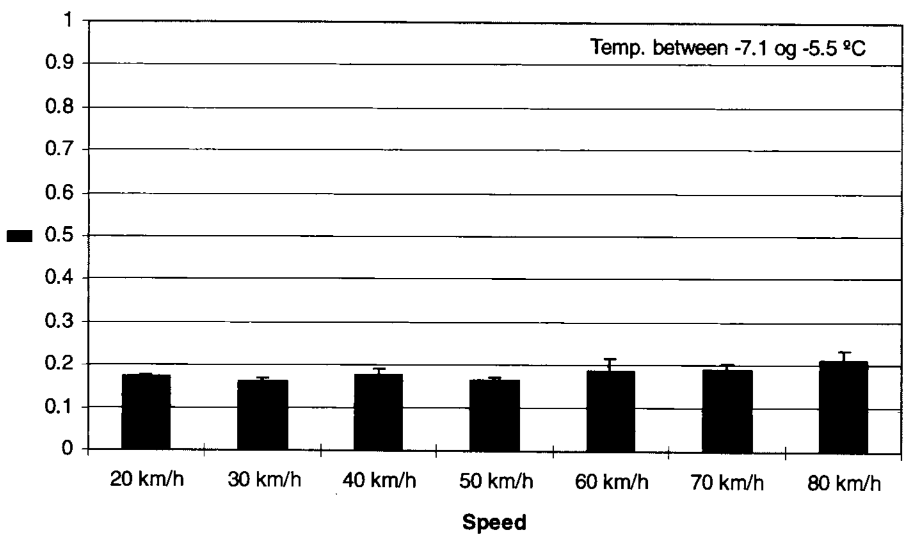

FIGURE 11 Effect of speed on hard snow and ice.

wet; at 4.5 hr ice again starts to form and the recovery is lost.

CONCLUSIONS

This preliminary study was successful in establishing better Bayesian values, and it showed that the Radó model constants can be used to differentiate contaminates. The peak friction and the slip speed at the peak separates the ice and snow from dry or wet. The shape factor then separates loose snow and slush from packed snow and ice. The study showed that friction levels can

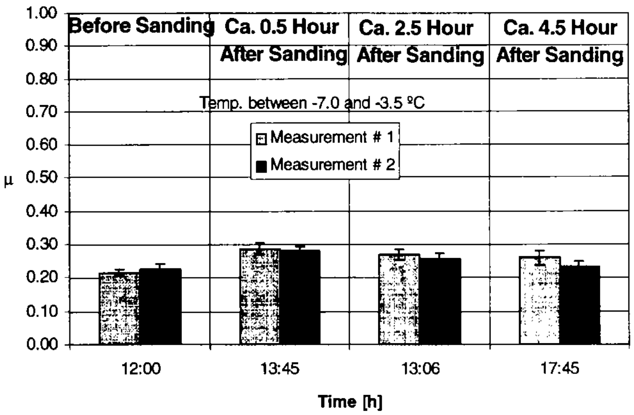

FIGURE 12 Effect of sanding on hard-packed snow.

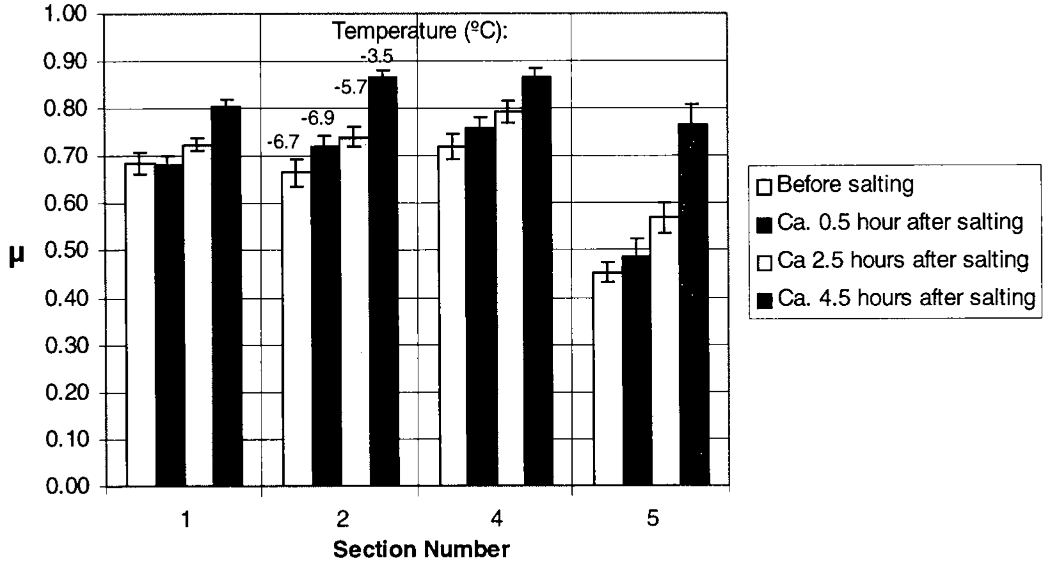

FIGURE 13 Time effect of salting on four sections.

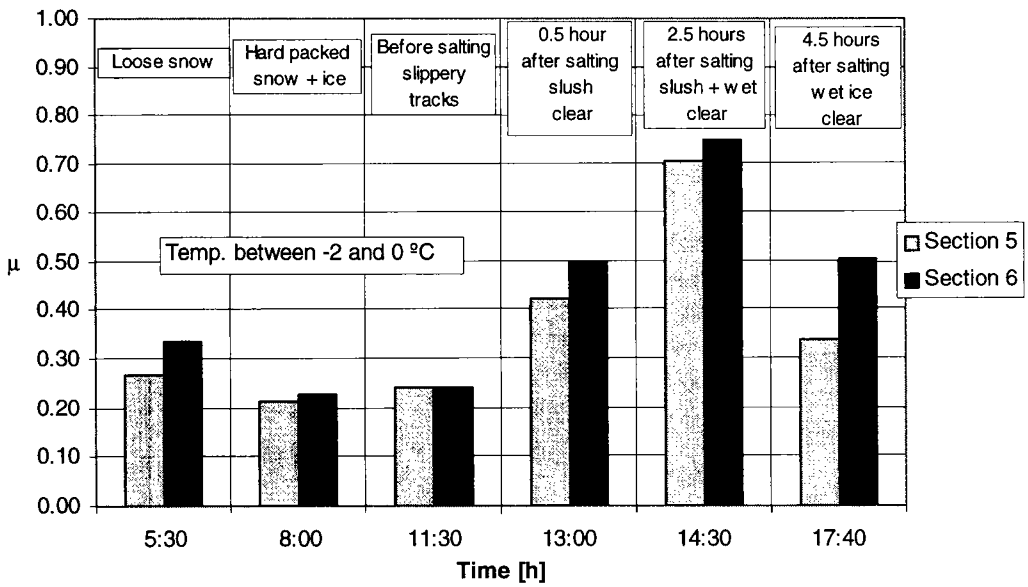

FIGURE 14 Time effect of salting on two sections.

be monitored in real time and salting control does appear to be feasible, either with a go–no-go approach or perhaps with varying levels of salting.

More sites should be tested next season to finalize how the three Radó constants can be used to differentiate the contaminate. Also, because salting control appears to be feasible, continued study in the United States and Norway with more experiments is planned. MinnDOT plans to mount a unit on a salting truck and will evaluate its use during the coming winter season.

References

1. Norsemeter. *Winter Testing Reports.* Norwegian Road Administration, 1995.
2. Radó, Z. *A Study of Road Surface Texture and Its Relationship to Friction.* Ph.D. dissertation. Pennsylvania State University, University Park, 1994.
3. Navin, F., M. Macnabb, and C. Nicolleti. *Vehicle Traction Experiments on Snow and Ice.* SAE 960652.2-96, SAE, Warrendale, Pa.