# THE POTENTIAL OF FRICTION AS A TOOL FOR WINTER MAINTENANCE

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by

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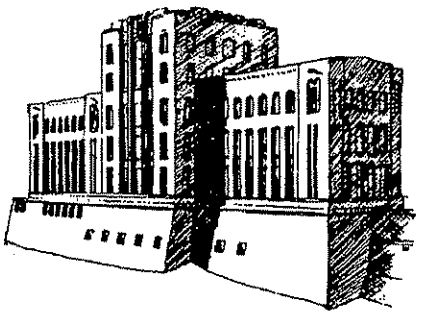

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## ABSTRACT

It is intuitively obvious that snow or ice on a road surface will make that surface more slippery and thus more hazardous. However, quantifying this slipperiness by measuring the friction between the road surface and a vehicle is rather difficult. If such friction readings could be easily made, they might provide a means to control winter maintenance activities more efficiently than at present.

This study is a preliminary examination of the possibility of using friction as an operational tool in winter maintenance. In particular, the relationship of friction to traffic volume and speed, and accident rates is examined, and the current lack of knowledge in this area is outlined. The state of the art of friction measuring techniques is reviewed. A series of experiments whereby greater knowledge of how friction deteriorates during a storm and is restored by treatment is proposed. The relationship between plowing forces and the ice-pavement bond strength is discussed. The challenge of integrating all these potential sources of information into a useful final product is presented together with a potential approach. A preliminary cost-benefit analysis of friction measuring devices is performed and suggests that considerable savings might be realized if certain assumptions should hold true. The steps required to bring friction from its current state as a research tool to full deployment as an operational tool are presented and discussed. While much remains to be done in this regard, it is apparent that friction could be an extremely effective operational tool in winter maintenance activities of the future.

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# THE POTENTIAL OF FRICTION AS A TOOL FOR WINTER MAINTENANCE

## I. INTRODUCTION

One major aim of winter highway maintenance is to bring the road surface to a safe condition for the motorist within a specified, and generally short, period of time. This statement, while seemingly somewhat innocuous and straightforward, in fact raises a host of questions. For example, what exactly is a "safe" road condition? Who is the motorist for whom the road is being maintained? Are they primarily commuters, or perhaps truckers, or the emergency services (or all three, but to differing degrees)? The time in which the road must be cleared is often specified in a maintenance policy document, but why are certain times chosen (2, 12 and 24 hours are popular choices for response times), and not others?

Answering these various diverse question is the task of the winter highway maintenance personnel within a given jurisdiction. The intent of this study is to examine the issue of a safe road condition in more detail. Currently, a maintenance policy may specify that a road be returned to a bare pavement condition or to a bare wheeltrack condition as part of the maintenance response to a storm. Thus safety is measured in terms of a visual judgment of the road surface. However, there are indications that such measurement may be subjective and very dependent on the experience of the observer. Further, it has been suggested that this approach may result in "overkill" - that is in chemicals being applied to the road surface in greater amounts than are actually needed to make the road safe.

In the ideal, there would exist some form of measurement which would quantify the safety of a (partially) snow/ice covered road in an objective manner. This measure would then (again, in the ideal) be used to determine how much chemical (and of what sort) should be applied to the road surface at that location in order to bring the road to a safe condition as efficiently as possible. This system would thus allow winter

maintenance to be conducted using a minimal quantity of de-icing chemical, while providing an improved level of service to the road user. It would also allow the optimum deployment of both personnel and equipment in response to a storm.

What appears to be needed, therefore, is some form of objective measurement that determines, or from which can be determined, the safety of the road surface, and the degree of additional treatment (chemical or mechanical) needed to bring the road surface to a pre-determined level of safety. One obvious candidate for this measurement is road surface friction. One major problem with winter weather for the road user is slipperiness (visibility, or lack thereof, is perhaps the other major problem). A slippery road surface can result in vehicles losing traction and skidding off the road, or being unable to brake in a timely manner and thus colliding with other vehicles. However, it is not clear precisely how friction relates to road user safety. Clearly, a lower value of friction means a greater likelihood of traction-loss accidents, but how the probability of such accidents relates to friction values has not been detailed in any way. Figure 1 indicates two possible curves of probability of accident versus friction level (note that these two curves are purely hypothetical - data do not exist to support either curve). These two curves probably mark extremes or bounds between which the actual friction/accident probability curve lies. It should be noted that other factors, such as traffic density, visibility, road type, and so forth will also affect these curves.

Friction then is clearly an important factor in road safety, but equally clearly, little is known about how exactly friction effects accident rates or vehicle travel speeds. As discussed below, there is a need for studies on the relationship between friction and a number of other parameters, which include road capacity, vehicle speeds, and accident rates. Until such time as these relationships are well established, friction cannot be considered the objective measure of road safety discussed above. However, such information once available will make friction one such measure.

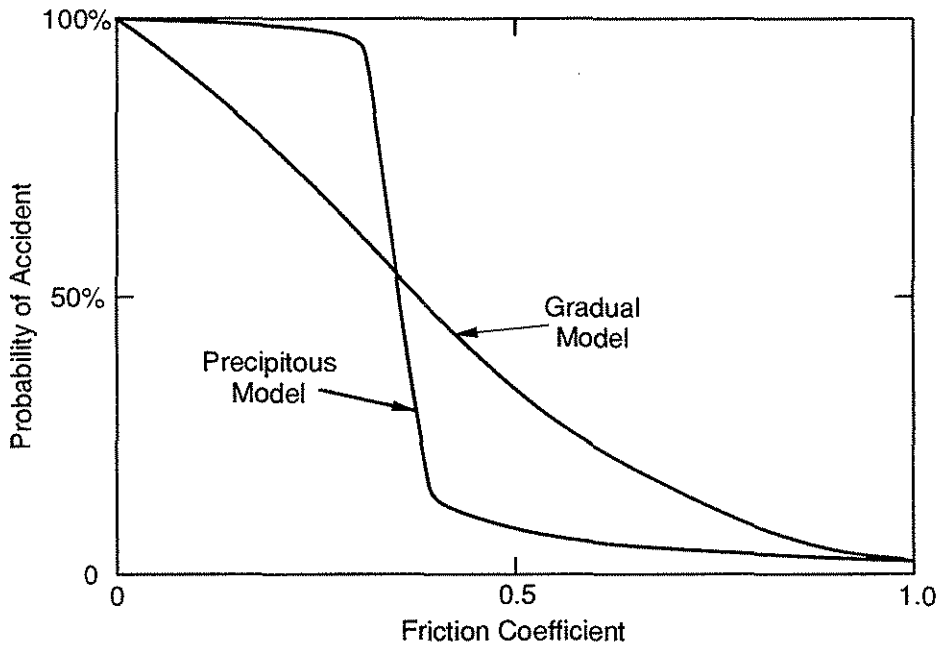


Figure 1. Hypothetical models of the relationship between friction and the probability of an accident.

While friction clearly has the potential to be an objective measure of road safety, the question remains as to whether friction can be measured with sufficient ease to allow it to become a real-time tool for winter maintenance. Work by Fleege et al. (1996) suggests that it may be possible to use friction information to make salt-no salt decisions in real-time, but also indicates that there was much scatter in the data. This scatter is problematic, because it suggests that considerable judgment skill may be needed to use friction data for chemical application decisions. Such a need would perhaps negate the benefits of friction as a winter maintenance tool (although expert system techniques might allow development of automated systems). Even with an expert system to interpret the friction readings, there is still no well defined knowledge base of how friction deteriorates during a storm, and how friction levels change with chemical application rates and other maintenance treatments. Such information (as discussed below) would be needed before friction could be a controlling parameter in any automated winter maintenance system.

However, friction alone cannot be the controlling parameter in a system that determines winter maintenance treatment. Clearly, a low friction level indicates a need for treatment, but the type of treatment cannot be determined by the friction reading alone. For example, suppose a friction readings indicates that the road surface is icy. It could be that snow has been compressed onto the road and a slippery surface has thus been formed which is well bonded to the pavement. However, it might also be that (due perhaps to an anti-icing treatment) while there is ice on the road surface, it is not well bonded to the pavement. The first situation calls for a chemical treatment, while in the second case, chemicals may not be needed, and the ice might be removable simply by plowing (most likely with an underbody plow). Thus additional information is needed to determine the type of winter maintenance needed to address a low friction situation. Again, the nature of this information, and how it might best be obtained, is discussed below.

The aim of this study is to develop a concept for a system that could automatically determine the state of the road surface, choose the right treatment for that surface, and deliver that treatment in a timely fashion. The system should be truck mountable, and should be capable of working in real-time, to the degree that the truck on which the system is mounted could perform all three functions described above. There are a number of other desirable features for such a system, that include a suitable cost, and an appropriate level of ruggedness. This project has not attempted to address any such issues at this time, since they go far beyond what has been determined to date. However, they will be critical in deciding whether such a system should be pursued. The gaps in current knowledge that must be filled before friction measurement can be implemented as a standard tool of winter maintenance are clearly identified along with plans for how the knowledge might be obtained. Current research in these areas is reviewed and discussed in this context also. Such a system is clearly feasible, and appears from this preliminary viewpoint to be desirable also. However, much further work is needed to bring this system from its current position on a piece of paper, to reality.

## II. FRICTION AND TRAFFIC

The notion that snow and other winter precipitation will effect traffic is by no means novel. It might even be considered obvious. However, there have not been many attempts to quantify the relationship. Recently, Hanbali and Kuemmel (1993) noted the effect of snow on traffic volume for a number of locations under different storm conditions. While they were able to provide some quantifiable results, it is difficult to develop statistically meaningful models from the data they obtained.

Part of this difficulty arises from the inherent variability of traffic patterns. Comparing travel on a given day with an average value for the year at a certain location can have some value, but if travel is lower anyway during wintertime, is an annual average appropriate? Comparing travel on a storm affected day in January with a January average is also suspect, because the January average is affected by storms. The previous year's data may have limited value because traffic levels may be increasing over time. Clearly there are a number of difficult issues (that are well acknowledged in the literature) with such measures.

Nonetheless, in order to develop quantifiable measures of how winter storms affect travel, some attempt at comparisons must be made. Figure 2 shows one such comparison. This shows data taken from an automated traffic recorder (ATR) located on I-29/80 1.0 km West of IA 192 in Council Bluffs. The "storm" data were gathered on February 3 and 4, 1997. They are compared with data from the following week (February 10 and 11, 1997). Snow began at 10:00 am on February 3, stopped at 1:00 p.m. that day, but started again at around 5:00 p.m. on February 3 and continued until about 9:30 am February 4. A total of about 10 cm (4 in) of snow fell during this period. The snowfall appears to have had a significant effect on traffic through the period, and that effect did not cease with the end of snowfall, but continued for at least 14 hours afterwards.

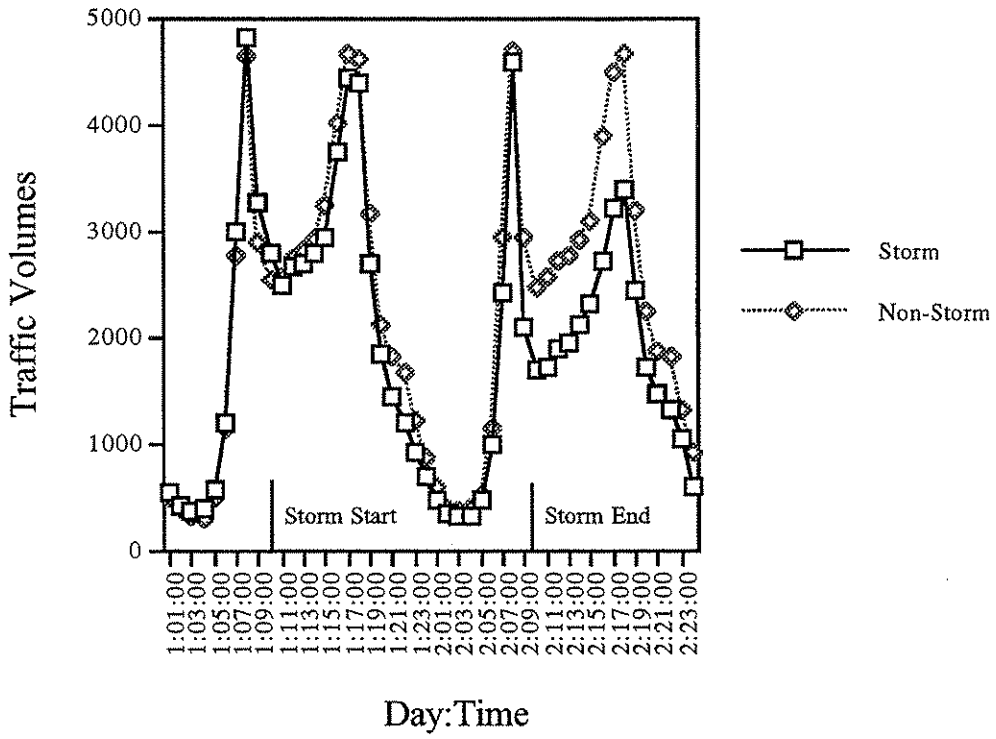


Figure 2: Storm Data from I-29/I-80. Hourly Traffic Counts over Two Days for Storm Event and for one Week later (non-storm)

While such data are interesting, they represent only a beginning step in the process of understanding how snow effects traffic. A number of additional steps are needed. The traffic volume data should be supplemented with traffic velocity data, so that an estimate can be made not only of reduction in the number of trips, but also of the increase in transit time. Further, it is critical, from the point of view of this study, to know exactly why the traffic volume decreased (and presumably also why the traffic speed decreased). It is a reasonable hypothesis that this occurred because of a reduction in road surface friction, but a direct comparison between friction data and traffic data is needed before this hypothesis can be proved.

Accordingly, in order to develop an appropriate Roadway Condition System model, a clear relationship must be established (if possible) between road surface friction,

traffic volume, and mean traffic speed. If such a relationship exists and can be found, then it will allow the setting of appropriate road surface friction goals as part of a winter maintenance strategy. Thus, for example, if it is found that there is little effect on traffic provided friction levels stay above 0.4, but that as friction drops below that level there is a marked decrease in traffic levels (Figure 3 shows this schematically) then a friction value of 0.4 becomes a goal for maintenance operations. The actual value may of course be very different from 0.4. Clearly the effect on traffic volume and speed is somewhat analogous to the hypothesized effect on accidents (see Figure 1).

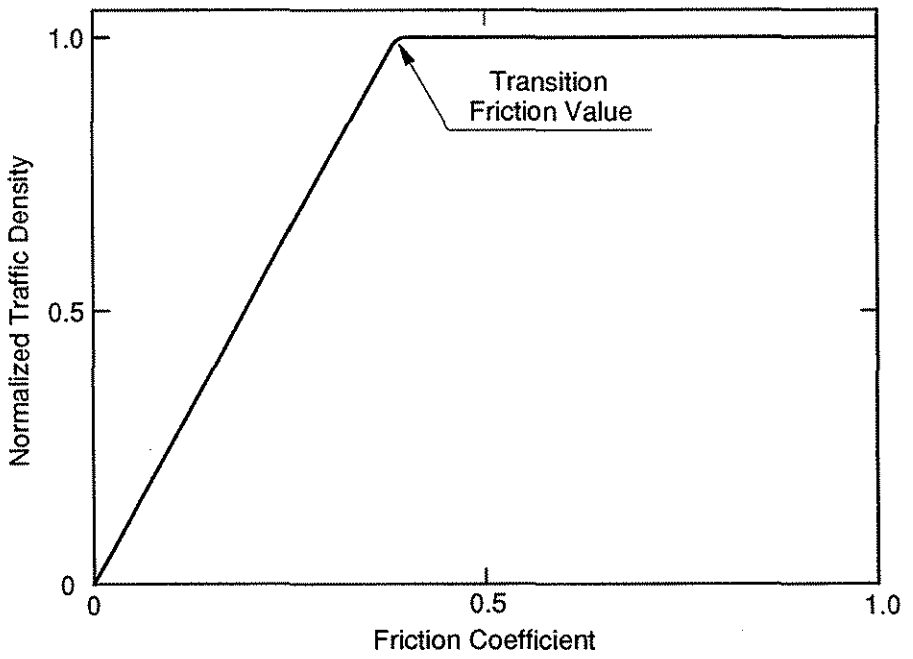


Figure 3. Relationship between friction coefficient and normalized traffic density.

In order to test these hypotheses and establish the models (if they do, in fact, exist), it will be necessary to choose sites in the State to conduct friction measurements during storms (perhaps using the Concept Maintenance Vehicle) and to correlate those data with traffic volume and speed data from ATRs, and with accident data. A primary finding of this preliminary work is that such a study should be undertaken.

## III. FRICTION AND ROAD TREATMENT

One of the factors which makes driving hazardous during a winter storm event is reduced road surface friction. This reduced friction makes vehicle handling harder and braking takes longer than on dry roads. Ideally, real time measurements of road surface friction could be used to determine treatment of the road surface, thus leading to enhanced winter maintenance with minimal cost and environmental effects. It is possible to conceive of the friction reading determining how much de-icing chemical should be applied to a particular part of the road. However, before such futuristic scenarios can be developed, a more complete picture of friction in winter conditions must be developed. There are a number of questions which must be addressed if this complete picture is to emerge. These are listed here:

1: What value of friction coefficient, $\mu$, corresponds to a safe road condition?

2: What effect do various winter weather situations have on $\mu$?

3: Can friction readings be used (in conjunction with other data) to determine highway treatment methods for a given storm situation?

4: Can real-time friction measurements be used to control chemical delivery (via expert systems or otherwise)?

5: Can friction readings be used to form the basis of a winter maintenance policy?

6: What might such specifications look like?

7: What changes in "culture" and management approach are needed to move friction measurement forward as a winter maintenance tool?

8: Can friction measurements be used to monitor contract performance, and if so, how?

9: How would friction information be used operationally? What would the purpose of using friction measurements be?

10: How complex is the relationship between a measured friction value and the action which should be taken to improve that value? What other factors (e.g. temperature) effect this relationship?

11: How many samples of "low friction" would be needed before spreading began? How many "high friction" readings would be needed before chemical application rates were reduced/discontinued?

12: Can friction readings be used to control spot sanding applications?

13: What correlation is there between a friction reading and the operator's recommended treatment for the road?

Answering these questions goes far beyond a single project, but they can serve to delineate the parameters of any studies of friction. In conjunction with these questions, it is useful to identify what uses might be made of friction readings. Undoubtedly, should such a system be in place and effective, a variety of novel uses would develop, but five fairly obvious uses can be noted:

* Verify and refine chemical treatment strategy
* Develop new strategies based on particular locations
* Control spreader output so as to optimize chemical application
* Inform customers (road users) of the "true" road condition
* Collect data for refinement of RWIS models

One purpose of this study is to examine how well the above questions can be answered. In addition, this study suggests a series of experiments that might be used to address any unanswered questions.

**3.1 Friction Measurement.** There are a number of devices that measure road surface friction. In essence, two approaches are taken. The first makes use of an instrumented wheel mounted to a vehicle. The second uses accelerometer devices to measure the deceleration of a vehicle under braking. These two device types are reviewed below.

3.1.1 Instrumented Wheel Devices. In this method, an instrumented wheel is attached to the measuring vehicle. The wheel may be independently driven, or may be

free rolling. When friction is to be measured, the wheel is locked and force measurements are made. Some devices measure friction only in a locked wheel condition, while others (e.g. the Norsemeter ROAR device mounted on the Concept Maintenance Vehicle) measure friction as a function of slip between the wheel and the road surface. The manufacturers of these devices claim (Norsemeter, 1996) that since peak friction does not occur at the locked wheel condition but at some intermediate level of differential slip (see Figure 4) that a locked wheel device is insufficient for road surface friction measurements. This may well be true, but it should be noted that locked wheel devices are considerably cheaper than full slip measuring devices. For research purposes, no doubt a full slip differential device is appropriate, but in field deployment something simpler may suffice.

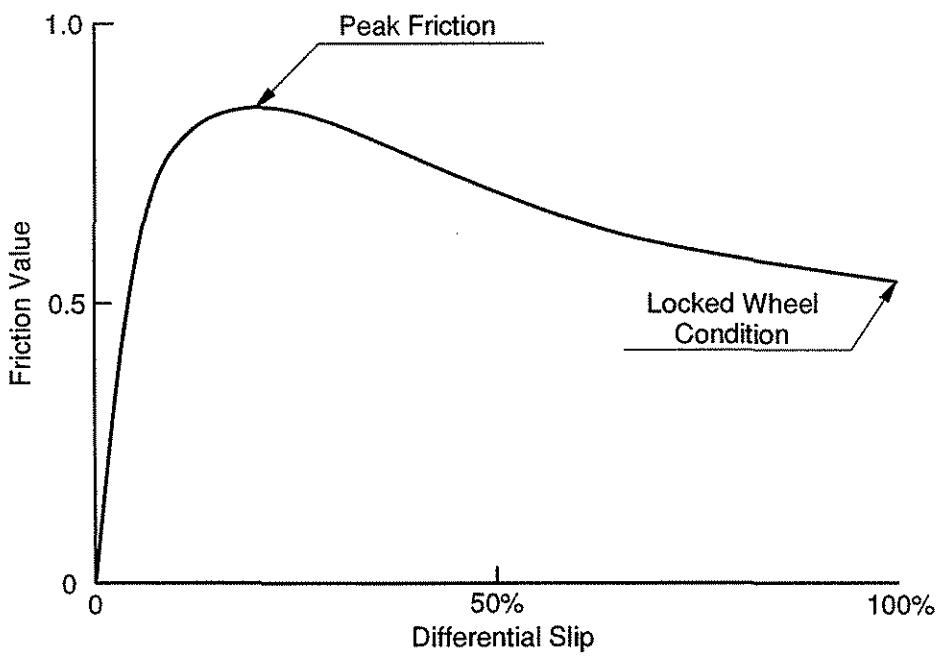


Figure 4. Variation of friction with differential slip.

3.1.2 Deceleration Devices. The second method of measuring road surface friction is by measuring the deceleration of a vehicle under full braking. One such device is the

Coralba meter, which is simply placed in a vehicle, and switched on. When a braking maneuver is made, the Coralba meter (by means of accelerometers) determines the coefficient of friction between the vehicle and road surface. To be useful, the Coralba meter must be mounted in a vehicle equipped with anti-lock brakes, and the braking action must be sufficiently severe to engage the anti-lock braking system. Such devices were used with some success in the SHRP and FHWA projects on anti-icing techniques. One obvious drawback is that they require the measuring vehicle to make a sudden stop on the road. Clearly such a technique is neither safe nor desirable in a heavy traffic situation.

3.1.3 Factors Affecting Friction Measurement. As might be expected, a number of factors can affect the value of friction obtained from a testing device. Ideally, the only factor affecting the measurement would be the interaction between the wheel and the traveling surface, but unfortunately reality is somewhat more complex. One extraneous factor (as noted above) is the degree of slip between the wheel and the road surface. The tread upon the tire itself and the tire material are both of critical importance in determining the friction measurement (Conant et al., 1949; Niven, 1955, 1958; Nordstrom and Samuelsson, 1990). There is also some evidence that the texture of the (snow or ice covered) road surface has some effect on the friction measurement (Norsemeter, 1996). Clearly, then, one would not expect one friction device to give the same reading as another device, and this is found to be the case (see, e.g. Shoop, 1993). There then exists a need to relate all the measurements to a standard, and this has been done.

3.1.4 The PIARC Standard. PIARC conducted a series of tests on Public Roads and Runways in 1992, from which were developed an average friction curve (World Road Association, 1995). This has been termed a Golden Value Curve, and with appropriate calibration testing any friction device can be related to the curve. Clearly this provides a sort of "gold standard" for friction values and means that some degree of uniformity can be obtained between different testing devices. However, it should be noted that the Golden Value Curve was developed in the absence of snow or ice on the road surface and

for fixed slip devices only. This raises issues about the applicability of this calibration to winter friction measurement.

Thus, while the PIARC standard may well be useful in winter maintenance applications, its applicability in that area has not yet been demonstrated. Some work may thus be needed to extend the PIARC standards into the winter maintenance arena.

**3.2 Friction Studies.** There have been a number of studies on various winter maintenance topics in which friction has been measured. Not all of these have used or attempted to use friction as the primary determinant of performance. This section will concentrate on those studies in which measuring friction was a primary goal.

One such study was conducted by Fleege et al. (1996). They report data from one winter's testing on Interstate 494, to the west of the Twin Cities in Minnesota. They found that the ROAR Norsemeter device was able to measure friction effectively, but that there was considerable scatter in the values obtained in the test section. In one run that they present, measured under conditions of slush and wet pavement, friction values ranged between 0.9 as a high and below 0.2 as a low, over a distance of 20 km (12.5 miles). This variability may well be due to variable road conditions, and highlights the possible usefulness of such information. The authors suggest that the use of friction limits to determine salt application could limit the quantity of salt applied. In this case, using their suggested standard (heavy salt for values below 0.4, light salt for values below 0.6 and above 0.4) heavy salting would have been required for 8 km, light salting for a further 6 km, and no salting for 6 km (note: these are calculated from the work of Fleege et al., by the author of this study. Fleege et al. did not report such calculations). Current practice would require the whole 20 km segment to receive heavy salting. Assuming heavy salting to be 110 kg/lane kilometer (400 lb/lane mile), and light salting to be 55 kg/lane kilometer (200 lb/lane mile), a saving of about 990 kg of salt (for each lane) would have resulted from the current standard of 2200 kg per lane through the segment. This

represents a 45% reduction in salt use, which is a considerable saving. However, it is not clear that such high levels of savings would always be attainable. Nor, as the authors note, are the levels of friction for different chemical treatments based on any valid data - they are merely suggested as seeming suitable by the authors.

Fleege et al. (1996) also note that friction values increase substantially over a five hour period after salting. This finding is based on friction values obtained in Norway. In all cases reported the friction increased over this period. The amount of increase varied between 15% and 70%. they additionally noted that while sanding produces a short term increase in friction (a gain of maybe 30% maximum half an hour after sanding), those friction gains diminished over the next four hours, finally disappearing altogether.

These results are supported by a study conducted by the Ministry of Transport of Ontario (MTO). In a field study extending over the 1995 and 1996 winters, tests were conducted to measure the increase in friction associated with the application of sand (Comfort and Dinovitzer, 1997; Comfort et al., 1996). The relationship between friction and stopping distance was also determined. Friction was measured using a deceleration type device, since (Comfort and Dinovitzer, 1995) this gave better correlation with stopping distance than a differential slip wheel on a towed trailer. The tests were conducted on roads that were either closed, or had very low traffic volumes (of order ten to twenty vehicles per day).

They found that friction and stopping distance could be related directly by a simple equation:

$$d = \frac{v^2}{2g\mu} \qquad \text{(Eqn 3.1)}$$

where: d = stopping distance (m)

v = initial velocity of the vehicle (m/s)

$g$ = acceleration due to gravity (9.81 $m/s^2$)

$\mu$ = friction factor (as measured by the decelerometer device)

Measurements were conducted on both packed snow and bare ice. Table 3.1 shows the measured friction factors (an average for untreated roads) and the stopping distance (in meters, for a vehicle with an initial speed of 80 kilometers per hour [about 50 mph]) for three conditions: bare pavement, packed snow, and bare ice. Clearly bare ice is the most serious condition. The significant variability in friction readings for the packed snow between 1995 and 1996 is not discussed in the report.

Table 3.1: Friction Factors and Stopping Distances from MTO Field Tests

| Road Condition | Measured Friction Factor | Stopping Distance (meters) |
|---|---|---|
| Bare Pavement | 0.7 | 35.9 |
| Packed Snow (1995) | 0.276 | 91.2 |
| Packed Snow (1996) | 0.184 | 136.8 |
| Bare Ice (1995) | 0.128 | 196.6 |
| Bare Ice (1996) | 0.125 | 201.4 |

A primary finding of the report showed that post-sanding friction values declined rapidly after only one or two truck passes. They also found that friction for packed snow surfaces could be increased by about 10 to 20% by applications of between 200 and 250 kg/lane km. Above this application rate, no further significant improvement in friction was observed. On ice, in contrast, friction continued to improve as the application rate increased (up to a maximum rate tested of about 450 kg/lane km). At the highest application rate, friction was measured to be about 50% higher than bare (untreated) ice values of friction. This corresponds to a decrease in stopping distance from about 200 m at an initial velocity of 80 kph, to a distance of 130 m. This study clearly shows how friction can be useful research tool in developing new winter maintenance treatments. The issue of friction measurements as operational tools must still be addressed.

**3.3 Friction as a Standard of Winter Maintenance.** There is a growing trend in the Scandinavian countries toward using friction measurements as a way to set standards for winter maintenance. Finland is moving strongly in this direction (Lampinen, 1998) and is conducting continuous friction monitoring of the European Road 18 from Turku, via Helsinki to the Finnish Russian Border en route to St. Petersburg. They are also building friction levels into standards that may be used when they privatize parts of their winter maintenance activities (Raukola, 1997). The trend in this direction is also strong in Norway (Dahlen, 1998). Their high volume roads (which comprise about 20% of their road system) must be brought to a friction level of 0.4 or higher within a certain time that is dependent on the road's AADT. Thus a road with an AADT of between 3001 and 5000 vehicles must be brought to a friction level of 0.4 within 4 hours of the end of a storm.

Norway also uses friction to determine treatment levels on lower volume roads (Dahlen, 1998). Two friction levels (0.15 and 0.25) are used in these lower volume roads. It should be noted that they do not attempt to bring these roads to bare pavement, but rather to what might be termed a groomed surface condition. Again, time limits to attain the friction levels are set and strategies to follow (sanding or plowing) are determined based on the friction level.

It must be said that traffic volumes in Norway and Finland are significantly lower than in many parts of the United States. However, the studies referenced in section 3.2 show that significant savings can be attained by using friction as a measure of road condition. The challenge is to develop simple, cheap and effective methods of measuring friction, and also to develop a very clear understanding of how friction affects traffic, and how it deteriorates under certain weather conditions. The issue of friction and traffic was discussed in Chapter 2. The next section discusses how knowledge about friction changes during a storm might be developed.

**3.4 Possible Future Friction Studies.** The aim of future friction studies described in this section would be to develop a clear understanding of how friction deteriorates during a storm, and how friction improves as the road is treated. Because these test would require the road surface to remain untreated during a storm, they can only safely be conducted using some sort of test facility. Two excellent facilities exist in the MN Road facility in Minnesota, and the Smart Road facility, soon to be completed in Virginia. The tests proposed herein could make use of the Maintenance Concept Vehicles, as well as any other friction measuring devices which can be made available at that time

3.4.1 Proposed Test Series. The following suggests three test series that could be conducted to develop a comprehensive understanding of friction changes in storm conditions.

Test Series One: No Treatment

Initial tests would be conducted simply by running the test trucks along the facility without making any attempt to remove the precipitation from the road surface. By conducting such "runs" continuously throughout a storm, it is possible to develop an accurate picture of how the friction of the road surface deteriorates with the progress of a winter storm if left untreated. Also, by means of subjective measures (the operators' expressed opinions of the "slipperiness" of the road surface) it should be possible to develop a reasonably clear idea of what friction values correspond to a dangerous driving condition. Tests could also be conducted to measure stopping distances at set initial velocities. It should be noted that these tests are somewhat hazardous for the truck operators, and they will need to be careful while driving the routes, especially if freezing rain conditions should develop.

Ideally such tests should be run for at least three types of storm: heavy snowfall, light snowfall, and frozen precipitation. Also, more than one storm of each type should be measured in this way.

Test Series Two: Plowing Only

The second series of tests would involve the trucks treating the road only through plowing. It is suggested that two different approaches be used here. In the first approach, the trucks plow continuously through the storm. In the second approach, they pause so that each plowing "run" begins two hours after the previous run started. A third approach, with a four hour interval could also be used.

This test series will show how much friction can be regained solely by plowing. This knowledge will develop a "zero tolerance" baseline for chemical treatment, against which the effectiveness of various chemical and abrasive treatments can be judged.

Test Series Three: Standard Treatment

This test series will apply to the test facility exactly the treatment which would be used were it an Interstate in actual operation. Since this effort will likely involve several states, it may be necessary to use several different treatment regimes. This series will establish a current practice baseline.

Once these first three series have been accomplished, three conditions on what might be termed the "friction graph" will have been established. These points will determine what happens if no treatment is used, if only plowing is used, and if standard treatment is used. In addition, and perhaps of equal importance, these tests will allow for development of considerable experience using friction measuring devices, from which a detailed evaluation of their potential usefulness can be developed. It must be noted that current friction measuring devices were not necessarily developed solely (or even primarily) with winter conditions in mind.

A second phase of testing could be considered for a second winter in the project. In this winter, a variety of different treatments, including anti-icing, use of abrasives only, use of alternative de-icing chemicals, and different levels of salt usage, could be tested exhaustively, again making use of the test facilities.

3.4.2 Conclusion. A series of tests are proposed making use of either the MN Road facility or the Virginia Smart Road Facility. The Maintenance Minnesota's Concept Vehicles would also be used. These tests would measure road surface friction during winter storms with different treatments being applied to the road surface. Such a test program would develop three critical benchmark conditions for friction measurements, and will also allow for an extensive evaluation of the capabilities of current friction measuring instrumentation.

## IV. SCRAPING LOADS AND ROAD TREATMENT

A friction reading on its own cannot be the only factor used to determine whether to apply chemical to a road surface. Sometimes friction may be low, because the surface of a road is covered in snow and/or ice, but no additional chemical may be needed, because the snow or ice is only loosely bonded to the surface and thus will be easily removed by plowing. While such a situation may seem unlikely, it is in fact fairly likely to occur if anti-icing strategies (applying chemical just before the onset of precipitation) are used. Since such strategies appear to be gaining in popularity (Ketcham, 1998), it would be prudent to take the results of such strategies into consideration when developing automated chemical application systems.

It should be possible, at least in theory, to determine the strength of the bond between the snow/ice and the pavement on which the snow/ice rests by observing the force required to plow the road surface. Recent developments have made it possible not only to measure ice scraping forces on underbody plows (Nixon and Potter, 1997) but also to measure them on front mounted plows (Nixon et al., 1997). A review of the underbody forces measured from in-service trucks by Nixon and Potter, 1997, suggests that the shape of the load trace does change somewhat from event to event. The trace changes in the slope of the rise and fall of the loads, and in the observed frequency spectra. However, at this time the meaning of these changes is unclear. It is possible that these changes are mere random variations, but the it is also possible that they reflect the nature of the snow and ice being scraped at the time. To determine precisely what the trace variations mean, full information on the snow conditions under which the scraping occurred would be needed, and such is not available for the tests previously done. Also, additional data are needed to develop statistically meaningful models of what exactly governs these variations. To date only about ten hours of scraping data have been gathered and analyzed, and that is insufficient to generate anything close to a meaningful understanding of the processes involved. Accordingly, further data collection should be

done so as to ensure that more complete data sets for different weather conditions are established. This is probably best done as a long term data collection and analysis program.

Once models that relate scraping loads with bond strength are developed, it should be possible to integrate this information into a control system. This is shown schematically in Figure 5. Clearly development of such a system should not be considered a trivial step. This is considered further in Chapter 5.

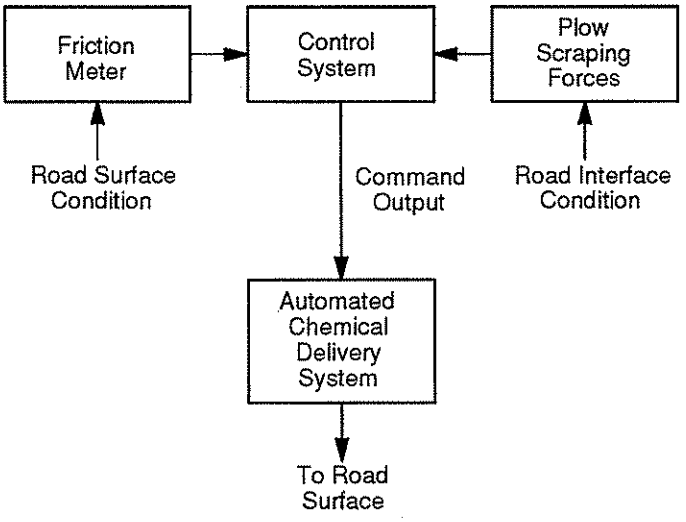


Figure 5. Schematic of RCS control process.

## V. SYSTEM INTEGRATION AND DEVELOPMENT

The notion of incorporating real-time friction measurements into winter maintenance activities is appealing insofar as it appears to show considerable promise in terms of increased efficiency of operation. However, it is important to consider the problems that such high tech equipment can bring. This chapter reviews some of those problems and suggests approaches that can be taken to address these problems.

**5.1 System Cost and Cost-Benefit Analysis.** At present the cost of continuously measuring friction meters that use a wheel type device is prohibitive. The Norsemeter ROAR system (the most sophisticated device on the market at present) costs somewhere between $75,000 and $100,000. Clearly such a system is far too expensive for general deployment on all trucks within a winter maintenance fleet, regardless of the efficiencies gained thereby. The cheapest devices (at about $2,000 each) are the deceleration type devices, but these cannot be used continuously, and furthermore, their operation on heavily traveled roads must be considered hazardous at best.

In defense of the high cost of the ROAR system, this cost reflects the fact that it is a low volume development type device, not engineered for widespread deployment. If sufficient demand for such devices could be foreseen then costs would likely drop considerably. Further, a widely deployed friction meter of this general type would not have all the "bells and whistles" of the current ROAR system, and would thus be cheaper on that account also. Nonetheless a strong cost-benefit argument must be developed for such a device if it is ever to be widely deployed as a standard service piece of equipment.

A simple cost benefit analysis can be conducted, but it should be noted that this analysis makes a number of assumptions that are not currently justifiable. These assumptions are identified explicitly in the following:

Assume that the use of friction devices results in a reduction in the use of chemical de-icers of R%. This reduction is from a base level of de-icer usage (i.e. the amount of de-

icer used now, without friction devices) of D tons per year, at a cost of $C per ton. Thus the potential savings of friction devices ($S per year) can be expressed as:

$$S = \left(\frac{R}{100}\right)DC \qquad \text{Eqn. 5.1}$$

Thus if 70,000 tons of salt per year are used now, at a cost of $25 per ton, and a full fleet of friction devices in use results in a reduction of salt usage of 25%, then annual savings are $437,500. Note that the assumption of a reduction in salt usage of 25% is HIGHLY speculative. However, this represents the direct material benefits of using friction devices. There may also be labor cost savings, and there will likely be indirect savings, due to less salt damage of the pavement, and fewer accidents and delays (because of a higher level of service). At present, these additional savings are not considered.

Of course, the friction devices come with a cost. If each device costs $M to purchase and install, and there are F vehicles in the fleet, then the total cost of installing devices in the fleet ($P) is given simply as $MF. Typically, however, such costs are annualized over the lifetime (n years) of the device, by assuming a percentage cost of money of i% per year. This is a standard equation from economic analysis, and it gives the annual cost ($A) as:

$$A = P\left(\frac{i(1+i)^n}{(1+i)^n - 1}\right) \qquad \text{Eqn. 5.2}$$

Thus, if a ten year life is assumed for the equipment, with a percentage cost of money of 5%, a fleet size of 1,000 vehicles and a device cost of $1,000 per device, the annualized cost (A) is $129,500. The cost-benefit ratio (B) of the installation is then calculated as:

$$B = \frac{S}{A} \qquad \text{Eqn. 5.3}$$

The worked example above gives a ratio of 3.38. That is, every dollar spent on friction devices would result in somewhat more than three dollars in savings. However, note that costs assumed a unit cost of $1,000 per device installed, a very low figure given current costs, and that no account was taken of training costs for use of the new equipment. Nonetheless, the example does show a simple methodology for considering the benefits of such a system. It also indicates the sensitivity of such analyses to a variety of different factors.

**5.2 Development of an Integrated System.** One concern that is sometimes raised when novel technology for winter maintenance is discussed is that vehicle operators already have their hands full operating the trucks. Adding additional tasks may merely result in degraded operator performance. Some of this may be addressed by a more careful consideration of cab ergonomics than is typically the case in the United States at present. As noted by Scharffbillig (1997), the Finnish winter maintenance trucks have cabs that are far superior ergonomically to most US cabs.

Although there is much room for improvement in cab ergonomics, any inclusion of friction measuring devices must be done in such a way as to add no significant extra load to the operator. Indeed, if care is taken it should be possible to reduce the load, by automating some of the processes currently performed by the operator. Chief among those tasks that could be operated would be the distribution of chemicals and abrasives.

If friction is to be used to determine how much chemical and abrasive is to be applied to the road, and if the friction readings must be analyzed by a computer prior to being displayable (currently the case for more sophisticated devices - even simple devices use dedicated microprocessors), then in many ways it makes no sense for that information to have to be processed by the truck operator. A change in friction would have to be noticed by the operator, she would have to then determine that it was significant, and adjust the output of chemicals accordingly. It would be much more efficient to have the chemical and abrasive output handled by a computer based expert

system. The system could take in data from plow loads, on-board temperature sensors, and RWIS systems also, to determine the appropriate chemical delivery response, as shown schematically in Figure 5. Although computer control of chemical delivery is available as an option on some chemical spreaders, the expert system described above does not yet exist and would need to be developed. As indicated in Chapter 4, for plowing loads, part of that development involves obtaining a suitably broad database on which to construct an expert system.

**5.3 Proposed Future Work.** The need for two possible studies is evident from the above material. First, there is a clear need to refine the cost-benefit analysis given above, in the context of specific storms and activities that might really occur. The numbers used above were for example only. This study might best be conducted in conjunction with the study on traffic patterns and friction suggested in Chapter 2. Individual storms in specific locations can be analyzed for potential cost savings, and a clear benefit model can be developed.

The second area in which additional work is needed is that of systems integration. At present the use of expert systems in winter maintenance is limited, but it is clearly a growth area. A study that started the process of developing a suitable expert system (perhaps linked with TR 412) would be an obvious first step in this direction.

## VI. CONCLUSIONS AND RECOMMENDED FUTURE STUDIES

The primary conclusions from this preliminary study may be stated as follows:

1. Friction measuring devices exist but their current nature and cost is such as to make them best suited as research and development tools, rather than as an integrated part of winter maintenance activities.

2. On the basis of current work, it appears possible to develop friction devices in such a way that they could become an integrated part of winter maintenance activities. Such integration would likely be via expert systems control, so that operator overload is not an issue.

3. To make friction devices integrable into winter maintenance actions in such a way as indicated by 2 above, a number of issues must be addressed by way of research. A series of research projects are indicated below.

4. Some fundamental questions remain in regard to friction. These include, but are not limited to, the following:

   How does the level of friction effect traffic volume and speed, and the accident rate?

   How does friction deteriorate during a storm?

   How is friction improved by various winter maintenance treatments?

   What combination of price and features would make a friction measuring device cost effective for winter maintenance?

   How can a friction measuring device be most effectively integrated with other novel computer controlled devices on future plows?

In an attempt to address these and other questions, it is suggested that the following research projects (or similar activities) would need to be pursued:

1. A study should be conducted at three different sites within the State of Iowa at which traffic volume and speed can be continuously recorded, along with appropriate RWIS data. At these sites, friction readings should be gathered during storms and correlated with traffic and accident data to determine the levels of friction that appear to create problems for motorists under different weather conditions. The information obtained from such a study would provide clear indications as to appropriate friction standards to be aimed at in different winter storm conditions. the project should also, to the extent possible, conduct a cost-benefit analysis of potential savings associated with the integrated use of friction data for winter maintenance and chemical application control during each storm.

2. A long term data gathering effort should be instituted to obtain plowing loads (from both front mounted and underbody plows) from different locations and in differing weather conditions. To the extent possible, the load data should be correlated with storm conditions and road surface type, so as to allow for a development of models relating observed scraping load traces with the strength of the bond between snow and pavement. It may be possible (and would be desirable) to correlate this effort with the project described in 1 above.

3. A study should be undertaken, using a closed road test facility (such as MN Road or the Virginia Smart Road), in which friction values are measured as a storm progresses under a variety of different treatment conditions, ranging from zero treatment through full standard treatment as currently practiced. This study would provide clear information of how friction values are effected both by winter weather and by the treatments used to combat winter weather. The National nature of such a study suggests a pooled-fund type approach as being most appropriate.

4. A preliminary study should be undertaken to develop a framework within which the systems integration of a friction controlled chemical spreader could be performed. such a system would be based around an expert system, and might well be linked with the ongoing TR 412 project.

With regard to technology transfer, it is hoped that the results of this study will be presented at the Crossroads 2000 Conference to be held in Ames in 1998.

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