FRICTION MEASUREMENT TECHNIQUES FOR SNOW AND ICE ROAD OPERATIONS

Prof. Dr. J. C. Wambold*, Prof. Dr. J. J. Henry* and Dr. Zóltan Radó**

*Professor Emeritus of Mechanical Engineering
** Research Associate
Pennsylvania Transportation Institute
Pennsylvania State University
University Park, PA 16802, USA
TEL: +1-814-865-1891/FAX: +1-814-865-3039
Email: jcw@psu.edu
Email: jjhenry123@aol.com
Email: z.rado@worldnet.att.net

1. Abstract

Maintenance agencies are in need of a relatively inexpensive device that can measure roadway friction under winter conditions and will tell the snowplow operator in real time whether there is sufficient friction or not. This method would assist the operator in determining when, where, and how much abrasive and/or chemicals are required to be applied during snow and ice control operations under all conditions. There have been studies that utilized braking action friction measurements as an indicator. However, this method cannot be used during high traffic volume conditions.

Field studies have been conducted at NASA Wallops flight facility and in Iowa, Minnesota, Michigan and Norway using Norsemeter's Roar and later SALTAR to determine applicability of the equipment to snow & ice operation, reliability, and durability. The measuring device is mounted on a snowplow and the measurement is achieved by employing wheel braking to 100% and then measuring the friction force that the road surface exerts against the wheel when the wheel spins up. Each measurement consists of a variable slip speed measurement and records peak friction, slip at peak friction and the friction verses slip shape factor. Data was collected concerning precipitation, pavement condition, pavement temperature, air temperature, speed of the measuring device and the friction values.

The equipment, measurement procedures, and findings are described in detail. This preliminary research study shows that the different contaminant conditions can be identified and the friction level can be evaluated to determine whether or not to salt, salt light or salt heavy. Also, a supervisor can evaluate the effectiveness of abrasives and/or chemicals applied.

2. Introduction

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 1994-1995. The study mapped maintenance guidelines and looked at current technology in friction measurements, as well as the PIARC friction and texture research project. Based on this study, Norsemeter developed ROAR (ROad Analyzer and Recorder). The unit was designed to be used as a stand-alone tester when mounted on a trailer or to allow mounting on a salt spreader truck. Field studies have been conducted in Minnesota and Norway during the 1995-96-winter season in a joint Minn DOT/Norsemeter project. This work was then carried over to a joint concept snowplow project to incorporate state of the art equipment on a snowplow. Iowa headed the project with participation by Minnesota and Michigan. Other States are now joining the group and a coordinated study is being carried out in Norway. This paper is a summary of these field studies describing the equipment, measuring procedures; the findings of this preliminary research study and include some of the data from the Norwegian study as well.

3. Test Apparatus-ROAR

The measuring device ROAR (Figure 1) is a “spot” measuring system with a variable slip test wheel. It was mounted on a two-wheel trailer and towed by a host vehicle. The test wheel is located in the left wheel track and mounted directly on the axle of a hydraulic wheel slip controller that is programmed to perform a desired braking action on the test wheel. One braking action is a linearly decreasing rotational wheel speed from free rolling to locked wheel. During this action the torque on the wheel axle is measured and converted to a friction coefficient by the digital computer of the device. A vertical static load of 1.2 kN (300 lbf) is applied on the test wheel which has a four bar suspension with no spring and no shock absorber. The ASTM E-1551 test tire [1] is used as the test tire with inflation pressure 207 kPa (30 psi). The instrumentation has provision for acquisition of the torque acting on the test wheel, which is converted to friction coefficients in a digital computer, and the rotational speed of the test wheel converted to a distance and distance traveled per unit time. The computer is programmed to calculate several friction process parameters, including peak friction coefficient, the slip speed at which the peak friction occurred, the slope of the friction coefficient curve as a variable of slip speed and more. The computer program uses the Rado Friction Model [2] for deriving these parameters. Friction coefficients for all slip speeds can be computed from each braking action, including friction at lower slip ratios like 15 or 18.5 % and at other speeds than the one at which measurements were taken. The measured values are stored in the computer and outputted as printout on a strip chart and recorded in files on diskette.

Figure 1 ROAR Friction Trailer

The Norsemeter ROAR measures variable slip as shown in Figure 2 below.

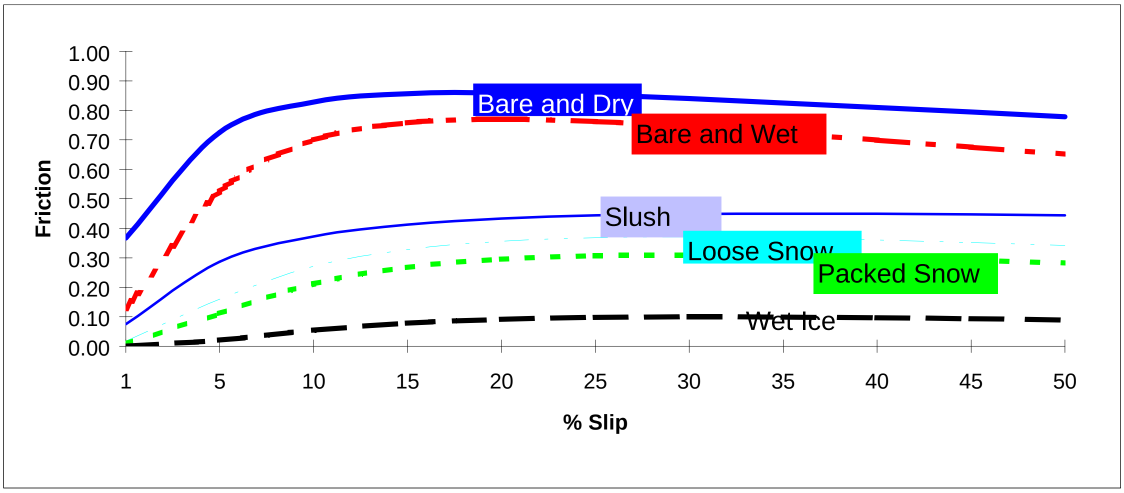

Figure 2. Sample friction verses percent slip for six conditions [3]

Figure 2 gives an example from the baseline dry tests and an example for wet, slush, loose and packed snow from the MinnDOT tests as well as an example on wet ice from the Norwegian tests. The data is fitted to the Rado 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). It is these values that were to be studied to see what is needed to determine the type of contamination and if salting is needed. Note that Figure 2 shows that the wet friction drops faster with speed and this has been shown to be correlated to macrotexture. Note that the percent slip at which the peak value occurs is around 18% on dry, 20% on wet, and near 30 % on the winter contaminated surfaces. This along with the drop in the peak value appears to provide important information. 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.

This preliminary project [4] was successful in establishing better values and showed that the Rado Model constants can be used to differentiate contaminates. The peak friction along with the slip speed at the peak distinguishes the ice and snow from dry or wet. The shape factor then separates loose snow and slush from packed snow and ice. The project showed that friction levels can be monitored in real time and salting control does appear to be feasible either with a go/no-go or perhaps with varying levels of salting. Since salting control does appear to be feasible, it was planned to continue the study in the US and Norway with more experiments. Iowa, MinnDOT and Michigan mounted units on a salt truck and evaluated its use this past winter season.

In the second year of testing ROAR, the three States brought their ROAR mounted units to the test track at St. Paul Minnesota [5]. The Michigan unit was mounted on a trailer, The Iowa unit was mounted just behind the cab on the left wheel track and the Minnesota unit was mounted on the front bumper in the left wheel track. In addition Minnesota and Iowa provided two KJ Law ASTM E-274 [6] skid trailers to be used for comparisons. Four sites were used at the test track to evaluate the units. Table 1 gives the Speed Gradient and MTD for the texture of the four sites.

Table 1. Texture of test sites at St. Cloud, MN, test track

Track Site	Speed Gradient [7] (Km/hr)	Mean Texture Depth [8] (MTD in mm)
1	74.0	0.75
2	16.2	0.24
3	46.3	0.51
4	182.2	1.71

The tests were conducted under both wet and dry pavement conditions at speeds of 32, 48, 64, and 80 km/hr. It was found that the units did compare favorably in their measurement of μ_{peak} and the friction level at 65 km/h with correlations of R^2 of 0.8 and 0.75. However the Iowa unit gave a different slope than the others for μ_{peak}. The units where later tested in each state individually by the states under winter conditions. The Iowa unit did not do well structurally and in general it was found that the units measured satisfactorily, but that they were not durable. The environment associated with snowplows is extremely harsh and demanding. Durability and cost of the ROAR [9] units led Norsemeter to then develop a less expensive unit that incorporated ruggedness in their design of a unit for snowplows and called the unit SALTAR.

4. Test Apparatus-SALTAR

The measuring device (SALTAR) is a spot measuring type with a variable slip test wheel. It was mounted on the snowplow frame behind the driver in the left wheel track. The unit uses an electric brake to bring the test wheel to a stop. The braking action is released and the rotational wheel speed goes from locked wheel to free rolling. During this action the wheel speed is measured and the torque on the wheel is calculated and converted to a friction coefficient. A vertical static load of 70kg (155 lbs) is applied on the test wheel. A Bridgestone 8F-228 135R X 12 tire is used as the test tire with inflation pressure 207 kPa (30 psi). The computer is programmed to calculate the average friction which is used to provide the operator with a one to five levels of friction, one being poor and 5 being the best. For evaluation and research, the actual friction calculated can be reported.

The main mechanical component in the SALTAR device is the measuring wheel system. The measuring wheel mechanism is designed as an extendable ladder frame. The frame consists of three horizontal crossbars and two vertical cylinders (see Figure 3 and 4.)

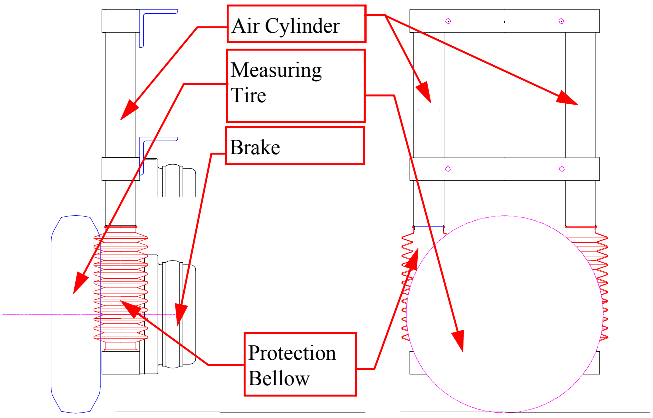

Figure 3. SALTAR Friction Meter

Figure 4. SALTAR Friction Measuring Device Mounted on a Salt/plow Truck

A keyboard operates the computer system with a display for operator guidance. The keyboard operator panel is a palm size "hard wired remote control" unit of the measurement system that also displays in real time the measurement results. The control buttons indicators and LED's are arranged to give the operator maximum flexibility and easy observation. Because of the small size the operator panel can be placed anywhere in the driver's cabin of the host vehicle.

The SALTAR friction meter was designed with mobility and versatility in mind. The symmetrical layout of the mounting frame and the in-line design of the whole unit make the SALTAR device very modular. The extremely slim design perpendicular to the direction of travel/measurement gives the possibility of mounting the device virtually anywhere on a large plow truck or winter maintenance vehicle. The unit was designed to be mounted in the left or right wheel track or in the middle of the vehicle. SALTAR's unique and simplified design makes it possible to operate the unit in forward or reverse direction without any difficulty. Thus, the unit can be turned 180° if mounting it to the vehicle makes that decision necessary.

5. Evaluation of SALTAR at NASA Wallops Flight Center

Annually, NASA holds a runway friction workshop at their Wallops Flight Facility. There are presently some 19 different friction sites, ranging in wet friction from .01 to nearly 1.0. In 1999 there were some 10 different friction-measuring devices, however at this time data is available for only the following six devices.

USFT US version of the Airport Surface Friction Tester from Sweden with two different tires
SALTAR A friction tester designed by Norsemeter for Salt trucks.
SFT79 A 1997 Saab Friction Tester owned by Transport Canada.
BV11 A Swedish designed friction Tester owned by FAA.
RFT Runway Friction Tester by K.J. Law owned by FAA.
E274 An ASTM E274 skid tester from VADOT

All of the testers were run on some or all of the 19 sites in a self-watering mode. Values of the different testers show as much as 50% difference in their measured friction values. SALTAR always gives values within the range of the other testers; however, it measured higher friction values with increased speed in all but a few cases (see appendix). All of the other testers generally gave lower values with increasing speed. Investigation into the SALTAR showed that the computation done by Norsemeter should be somewhat speed sensitive, however, it was designed for speeds of plow and salt trucks and indeed at the 50 km/hr (32 mph) speed the SALTAR measured in the middle of the range of the rest of the testers. Also when the SALTAR results were plotted versus the E-274 trailer at 30 km/h, they both give the same friction values. Thus, it would be expected that at low friction and low speeds the SALTAR should give good friction measurements.

The results of the SALTAR tests on wet pavement are graphically displayed in Figure 5. This graph shows the friction versus speed of the SALTAR as compared to other friction measuring devices. The trend lines were added to the trend between the SALTAR measurements and the ASTM E-274 skid trailer. In these series of tests the SALTAR trend line shows an effect of friction increasing as speed increases. As the investigation showed, this increase in friction was due, at least in part, to constant water flow to the tire. Thus, the water film thickness decreased as the speed of the vehicle increased, providing an increase in friction. Accordingly, the tests showed that the SALTAR does consistently measure friction, however, more testing was needed to specifically determine if the speed of the vehicle also played a factor in the "reverse" trend line.

Since the SALTAR was designed with winter maintenance operations in mind, the study team decided to conduct more field-testing in winter conditions. As the past winter in the Midwest was unusually mild, the consortium decided to send the concept vehicle to an additional NASA-sponsored friction workshop in North Bay Ontario, Canada. The workshop was held January 17 –31, 2000 at the Jack Garland Airport in North Bay, ON. The Highway Maintenance Concept Vehicle participated during the second week of the workshop, in which the ground friction-vehicle tests were run. The purpose of this workshop was to field test the SALTAR in winter conditions on ice and snow packed roadway surfaces.

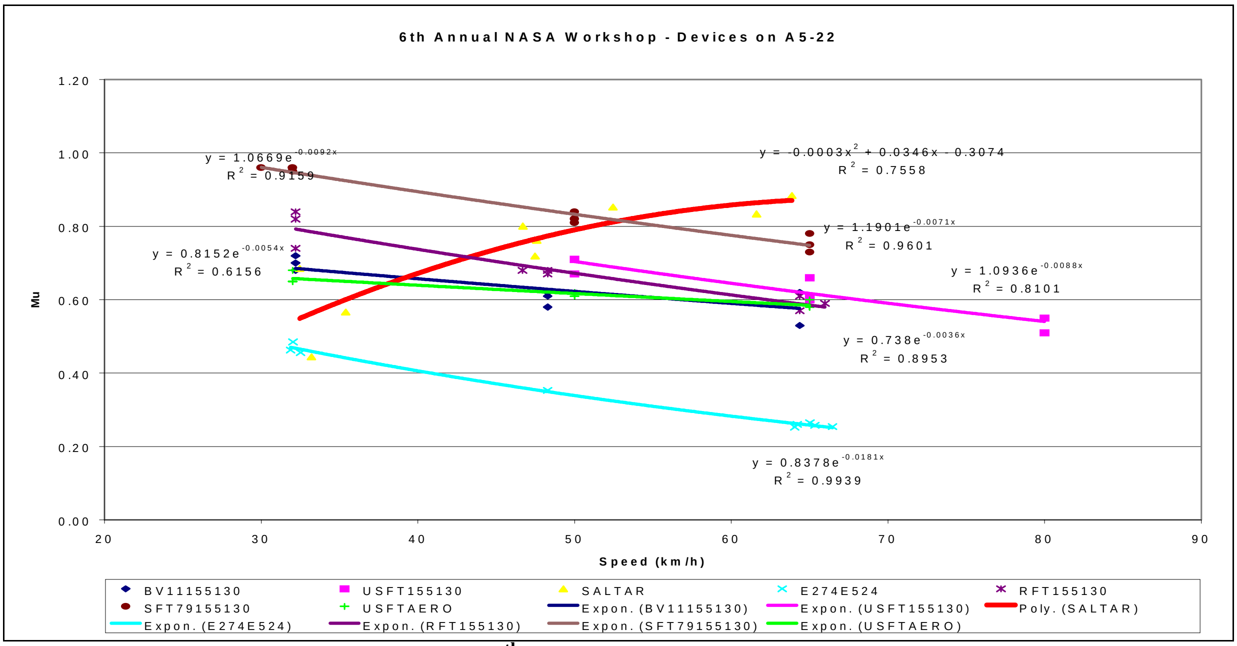

Figure 5. A Sample Comparison from 6th Annual NASA Runway Friction Workshop, SALTAR v. ASTM E-274 Friction Measurements May 1999

6. North Bay, Canada

The Iowa SALTAR unit was taken, mounted on their snowplow, to North Bay, Canada in January 2000 and was tested along with the other devices in the Joint Winter Runway Friction Measurement Program. Testing showed that at very low temperatures, -30^{O}C that the air lines needed better winterization as any water in the lines froze causing low normal load on the test tire. Overall results did not show a speed effect, but rather a scatter at very low friction level. The scatter is due to the varying normal load caused by the air line.

Over all comparisons of the SALTAR measurements showed that the friction values were low when compared to the reference device. However, no calibrations were carried out since it could not be determined when the low reading was due to low contact pressure or if it was a low reading with the proper contact pressure. Since the data from Norway was without these problems, that data was used to make comparisons.

The following Figure 6 shows SALTAR running tests at the workshop.

Figure 6. Iowa DOT Concept Vehicle at North Bay ON

7. SALTAR Data From Norway

Similar testing was conducted in Norway by the Road Administration were SALTAR and ROAR were run together to make comparisons. Figure 7 shows that SALTAR measures low when compared to ROAR; however, SALTAR does appear to increase or decrease in a similar manner as ROAR. Hot sand was applied to the same section, followed by cold sand placed on the middle half and the measurements were then repeated. Figure 8 shows these results that clearly show that SALTAR does change with friction level, but reads low. Based on this a calibration was made and the results are shown in Figure 9. This calibration was then applied to the data from Figures 8 and 9 and they were repotted as Figures 10 and 11. It is felt that with the calibration, SALTAR reads satisfactory.

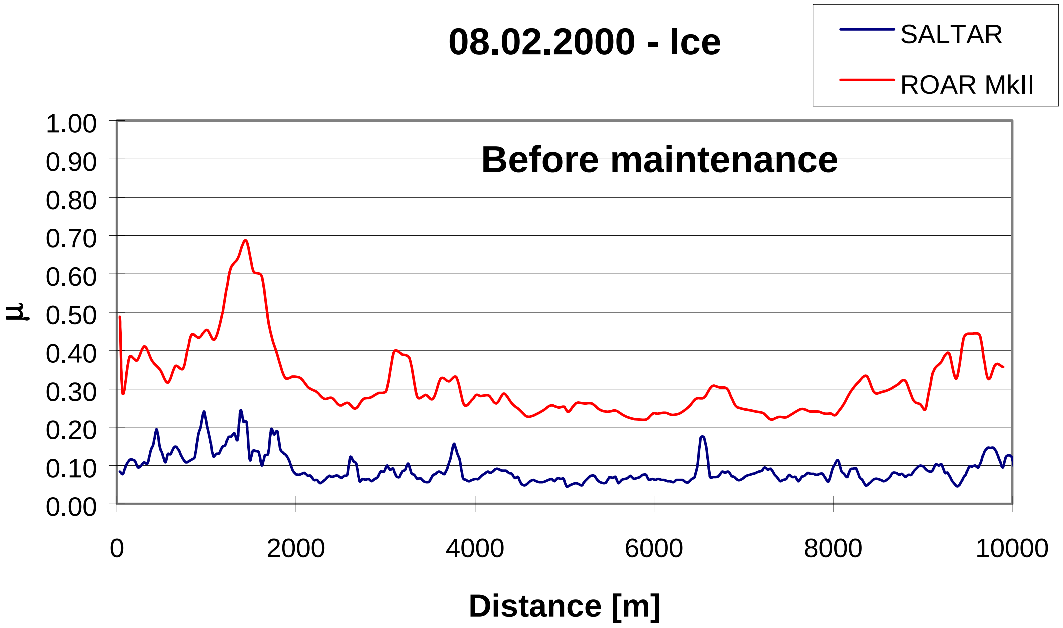

Figure 7. Friction by SALTAR and ROAR on a section of road covered with ice.

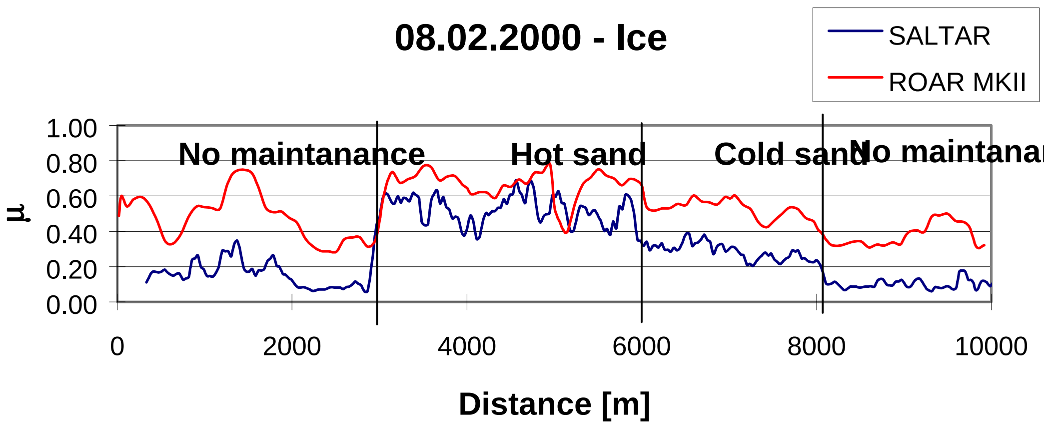

Figure 8. Ice covered road given in figure 7 with hot and cold sand applied to the mid-section.

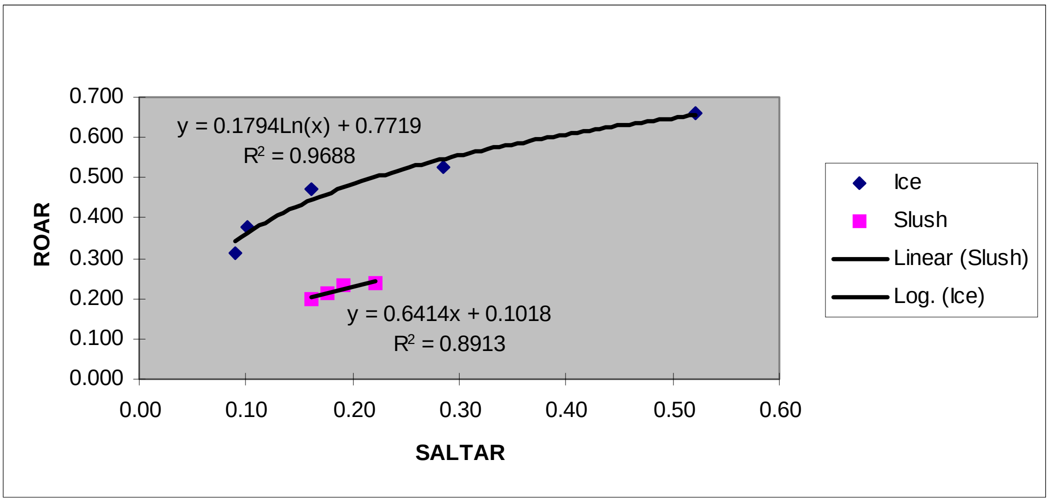

Figure 9. Correlation of SALTAR and ROAR

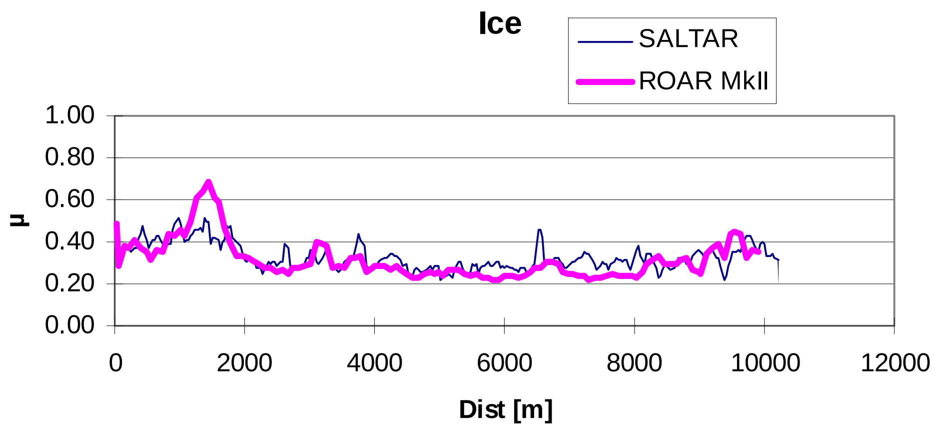

Figure 10. Data from Figure 9 with correlations applied.

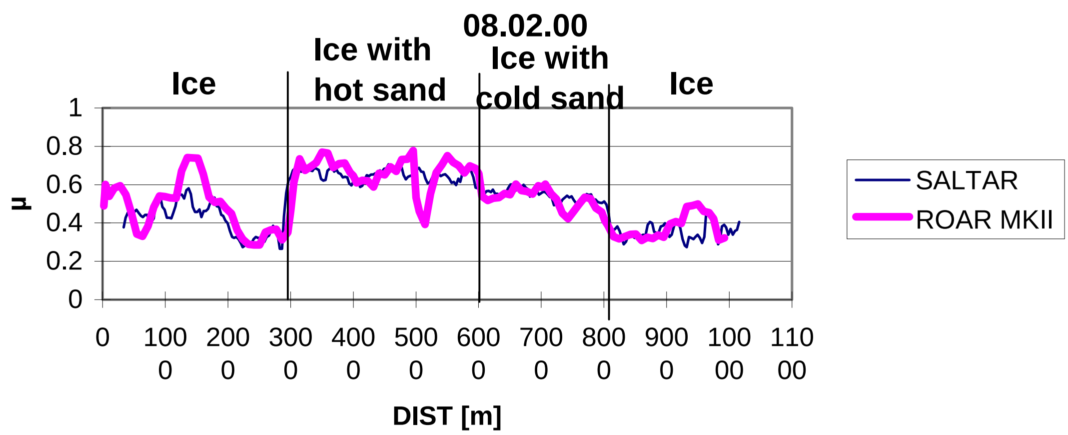

Figure 11. Figure 10 with Correlations applied.

From tests at different speeds on hard-packed snow, it can be seen in Figure 12 that there is a very slight increase in friction with speed, but not nearly as much as in the NASA Wallops tests.

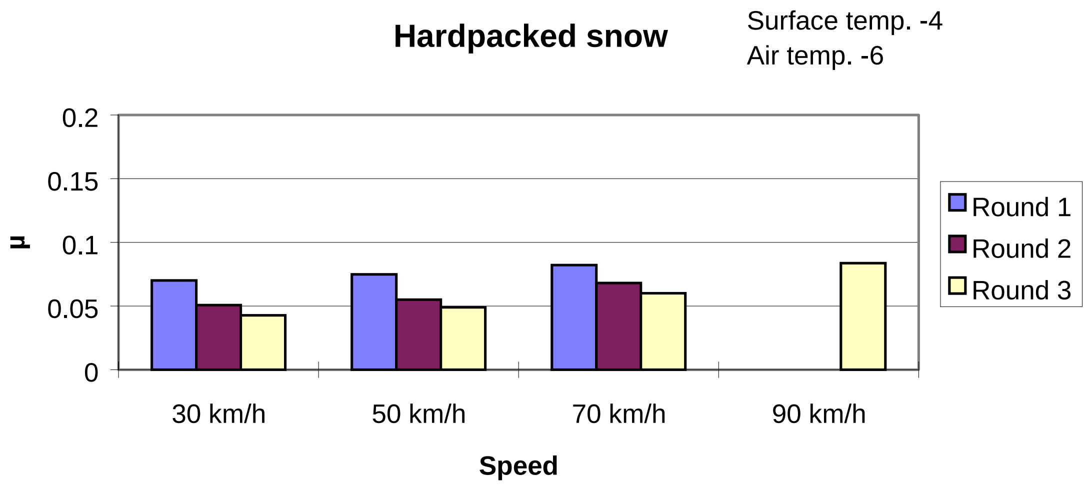

Figure 12. Different speeds on hard-packed snow

8. Conclusions

Although SALTAR is a prototype, it was shown to be able to report reliable friction levels and shows great promise for measuring road friction under winter conditions. The brake system works according to its specifications and the overall principle works well. Further development is required and the following is recommended:

- An ASTM standard be developed for SALTAR.
- A standard tire and manufacturer be found.
- The air system must be fully winterized.
- A calibration procedure needs to be developed.
- The reason for the low readings be eliminated.
- Further reliability be added in future models.

References

1. ASTM (1993): "Standard Specification for Special Purpose Smooth-tread Tire, operated on Fixed Braking Slip Continuous Friction Measuring Equipment", Standard No. E1551-93, *American Society for Testing and Materials Book of Standards Part 04.03,* Philadelphia, PA.
2. Zoltán Radó, A *Study of Road Surface Texture and Its Relationship to Friction*, PhD Thesis, 1994, Penn State University.
3. Wambold et al, Evaluation *of Ground Test Friction Measuring Equipment on Runways and Taxiways Under Winter Conditions*, A Joint Transport Canada/Norsemeter Winter Runway Friction Program Report, January 1996.
4. Fleege, E.J., Wambold, J.C. and Rado, Z., Variable Slip Friction Measurement for Snow and Ice Operations, 4th International Symposium Snow and Ice Control Technology, TRB, Aug. 11-16, 1996 Reno, Nevada.
5. *Concept Highway Maintenance Vehicle, Final Report: Phase One*, April 1997, Center for Transportation Research and Education, Iowa State University.
6. ASTM (1997): "Standard Test Method for Skid Resistance of Paved Surfaces Using a Full-Scale Tire, Standard No. E274-97, *American Society for Testing and Materials Book of Standards Part 04.03,* Philadelphia, PA.
7. Wambold, J. C., Antle, C. E., Henry, J. J., Rado, Z. (1995), "International PIARC Experiment to Compare and Harmonize Texture and Skid Resistance Measurements", *Final Report, PIARC* Paris, France.
8. ASTM (1996): "Standard Test Method of Measuring Surface Macrotexture Depth using a Volumetric Technique", Standard No. E965-96, *American Society for Testing and Materials Book of Standards Part 04.03,* Philadelphia, PA.
9. *Concept Highway Maintenance Vehicle, Final Report: Phase Two*, December 1998, Center for Transportation Research and Education, Iowa State University.

.