CONTINUOUS SKID RESISTANCE TEST

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ABSTRACT

The performance of a mobile and continuous skid resistance meter for measuring friction and driving conditions is assessed by comparing friction readings to an independent discontinuous braking friction meter. The tested device “Road Condition Monitor RCM411” is an optical sensor capable of detecting ice and providing coefficient of friction based on an embedded algorithm of modeling friction. Data for the study were collected by driving extensively on main highways in alternating winter conditions and making 248 discrete reference measurements by the braking friction meter in winter 2011-2013. The overall standard deviation of the differences between the instruments was 0.10 units. In slippery conditions caused by snow events the standard deviation was 0.05. The tested meter detects different surface conditions on a short distance and clear systematic errors were not detected. The meter showed potential for the winter maintenance quality control purposes and enhanced maintenance operations by possibly unifying treatments, as well as for educational purposes. It might be feasible to use the instrument even for location based application of applying salting.

1. INTRODUCTION

It is a common winter maintenance practise to apply salt or other de-icing or anti-icing chemicals to keep coefficient of friction at an acceptable level and to provide safe driving conditions on highways. The effectiveness of de- or anti-icing treatments can be detected reliably with friction measurements. However, friction measuring instruments have so far been either fairly expensive or they have provided spot measurements making it challenging to cover large areas effectively [1], [2].

In this paper we report test results of a mobile optical instrument designed to measure winter surface conditions, coefficient of friction, water layer thickness and road surface temperature in an easy and effective way. Measurements were commissioned by a major Finnish winter maintenance contractor Destia Oy to study the reliability of the instrument as a tool for maintenance operations. Specifically we were interested in the accuracy of the modelled coefficient of friction on various surface conditions. An independent braking friction meter based on a mobile phone accelerometer was used for reference purposes [2]. Only point measurements can be conducted with this type of devices, but they have the advantage that the results are easily calibrated against the acceleration of gravity. While braking hard so that the tires start to slip, the measured acceleration can be directly converted to coefficient of friction by laws of physics [2]. Braking friction meters are used already nationally in Finland for quality control of winter maintenance [3] and it would be desirable to have available more effective means of measuring friction in winter conditions.

The test was carried out by driving a selected fixed test route or occasionally some other routes during the winter seasons 2011-2012 and 2012-2013. The test drives were carried out when expecting slippery conditions due to precipitation or icing. Nearly a distance of 2000 km consisting of 15 rounds of the preselected route and 8 rounds of other routes were driven and altogether 248 reference friction measurements were done. All the test routes were driven by the same car and the same driver. We analysed these measurements by comparing the obtained friction figures to those of the braking friction meter taking into account general weather information and subjective observations of the driver.

1.1. Road Condition Monitor RCM411

The tested instrument RCM411 is described in detail elsewhere [4] and thus only the main functionality is covered here. Measurement of friction is modelled on information about quantity of water and ice on the road surface and those are obtained by optical detection through spectroscopic absorption at near infrared wavelengths. Ice is detected by measuring the shift of the water absorption peak to longer wavelengths at freezing. Inclusion of surface temperature could improve the model in certain weather conditions, but temperature measurement was not implemented in the model at the time of testing. RCM411 was used in a mobile fashion to collect continuous data with location information. The instrument can be installed in few minutes to any passenger vehicle using either a trailer ball joint (Figure 1) or a back door adapter.

Figure 1. RCM411 installed by a trailer ball joint adapter.

A cell phone is used for a user interface, for a source of GPS data and for communicating the data to a selectable server through an internet connection. The same cell phone was used also for the braking friction measurements, which simplifies comparison of data from the two instruments. Data is communicated from RCM411 to the cell phone by a Bluetooth module and the trailer socket or the cigarette lighter is used for supplying power. RCM411 outputs a set of measurements once per second with a response time of a few seconds. Friction, surface temperature and water layer thickness are shown as lines on a graph and in numeric format. Surface condition is revealed by the colour of the friction line.

1.2. Test routes

In the first test winter 2011-2012 the purpose was to drive a fixed route prior to, during and after a weather episode to observe the effect of winter maintenance on the surface condition. In this way we could measure slippery conditions caused mainly by snow episodes and there were only few cases of freezing conditions. Thus the range of friction readings did not include the lower values of the scale.

In the next season the driving conditions were selected to cover all road surface conditions not tested earlier. This way we could cover surface conditions from very slippery and icy to snowy, slushy, wet, moist and dry conditions with friction values ranging from 0.15 to 0.80.There was one occasion of freezing rain on an icy surface with very low friction readings. Figure 2 shows a photograph taken on Kt-51 near Inkoo of Southern Finland prior to freezing rain.

Figure 2. Icy surface condition on Kt-51 near Inkoo on 28.01.2013.

2. TEST DRIVING

To concentrate on the most interesting cases of test driving we have selected only a few examples to demonstrate the collected information. The friction data collected during the winter 2011-2012 is presented on a map interface as colour coded lines, where hues of red, yellow and green cover the whole scale from 0.20 – 0.80. During the second season the map interface was changed to include thickness of water layer on road surface and road surface temperature data. The colour coding of friction data was changed to reveal also the state of surface by selecting colours as in Table 1. This presentation is similar to the user interface on the cell phone where a graph of lines is shown instead of a map.

Table 1. Colour coding of friction data.

Colour	Friction	Surface state
green	~ 0.80	dry
dark blue	~ 0.75	moist
light blue	~ 0.65	wet
violet	~ 0.50	slushy
white	~ 0.40	snowy
yellow	~ 0.35	icy, thin or breaking
red	< 0.30	icy, thick and hard

The data of water layer thickness and surface temperature are presented in a similar fashion. Hues of blue correspond to water layer (0 – 3 mm). Freezing surface temperatures are presented as well with hues of blue whereas hues of yellow to red are reserved for positive surface temperatures. The interface is available for a detailed study at the web link RCMDataViewer. Figure 3 shows a drive with friction and surface state including inserts of water layer (middle) and surface temperature (right).

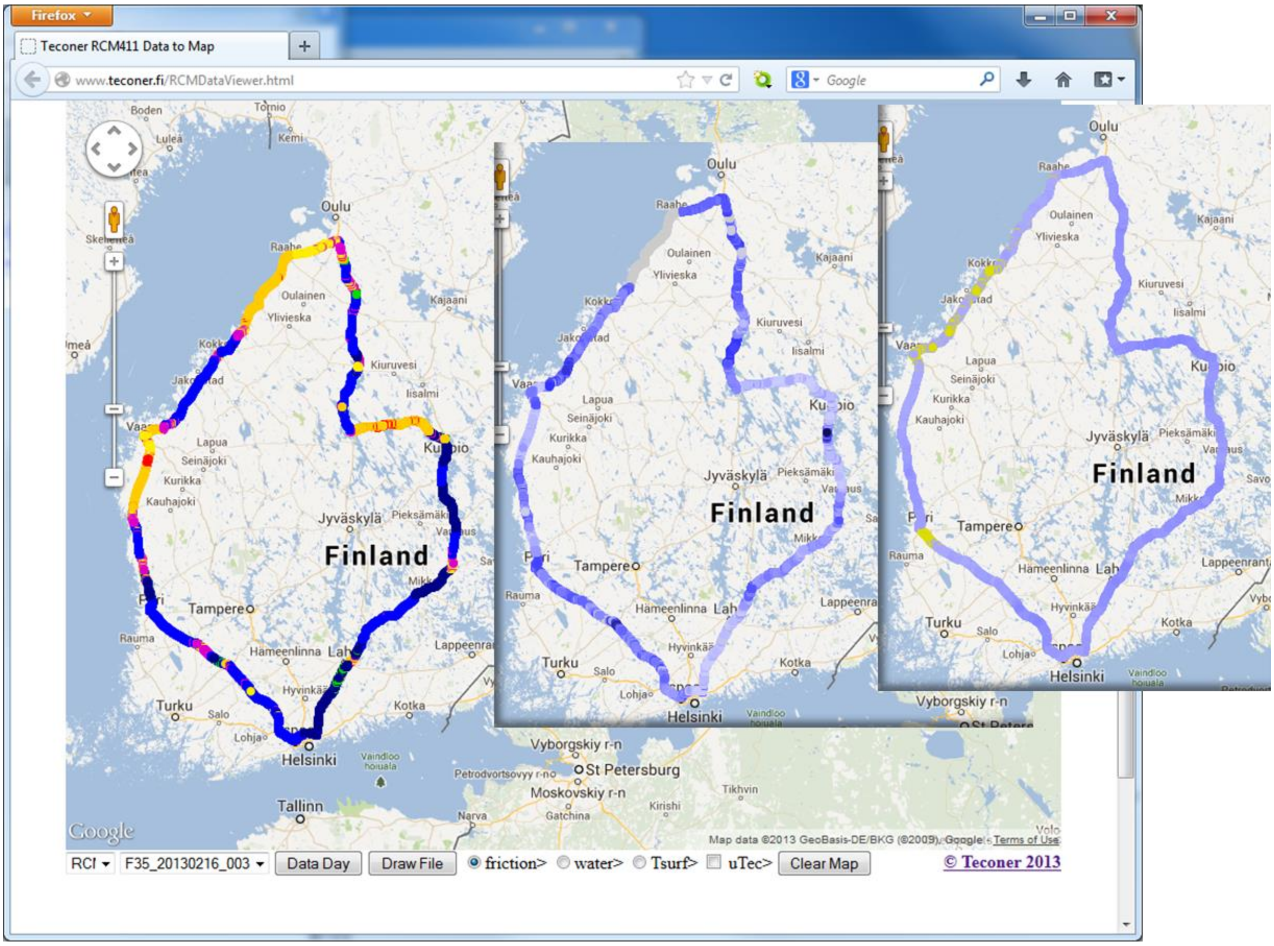

Figure 3. Friction, water layer and surface temperature during a demo drive on 15.-16.02.2013.

2.1. Test Drive on 03.02.2012

Friday, 3rd of February 2012 was a snowy and frosty day with temperature below −12 °C in Southern Finland. There was a heavy snowfall from noon until late afternoon. The driving conditions were exceptionally bad already in the morning, which caused later a traffic chaos and pileups due to poor visibility and skidding as seen in a video link [5]. Also the test drive had to be cancelled due to the disastrous conditions, and thus only a part of the day’s route was measured. Anyway we show the collected results in Figure 4 to demonstrate how much there can be variation in surface conditions already in the beginning of a heavy snowfall at low temperatures. Measured friction was ranging from 0.30 to 0.70, low values were measured at around 9 in the morning and about one hour later measurements were terminated due to a traffic chaos in the Metropolitan area of Helsinki.

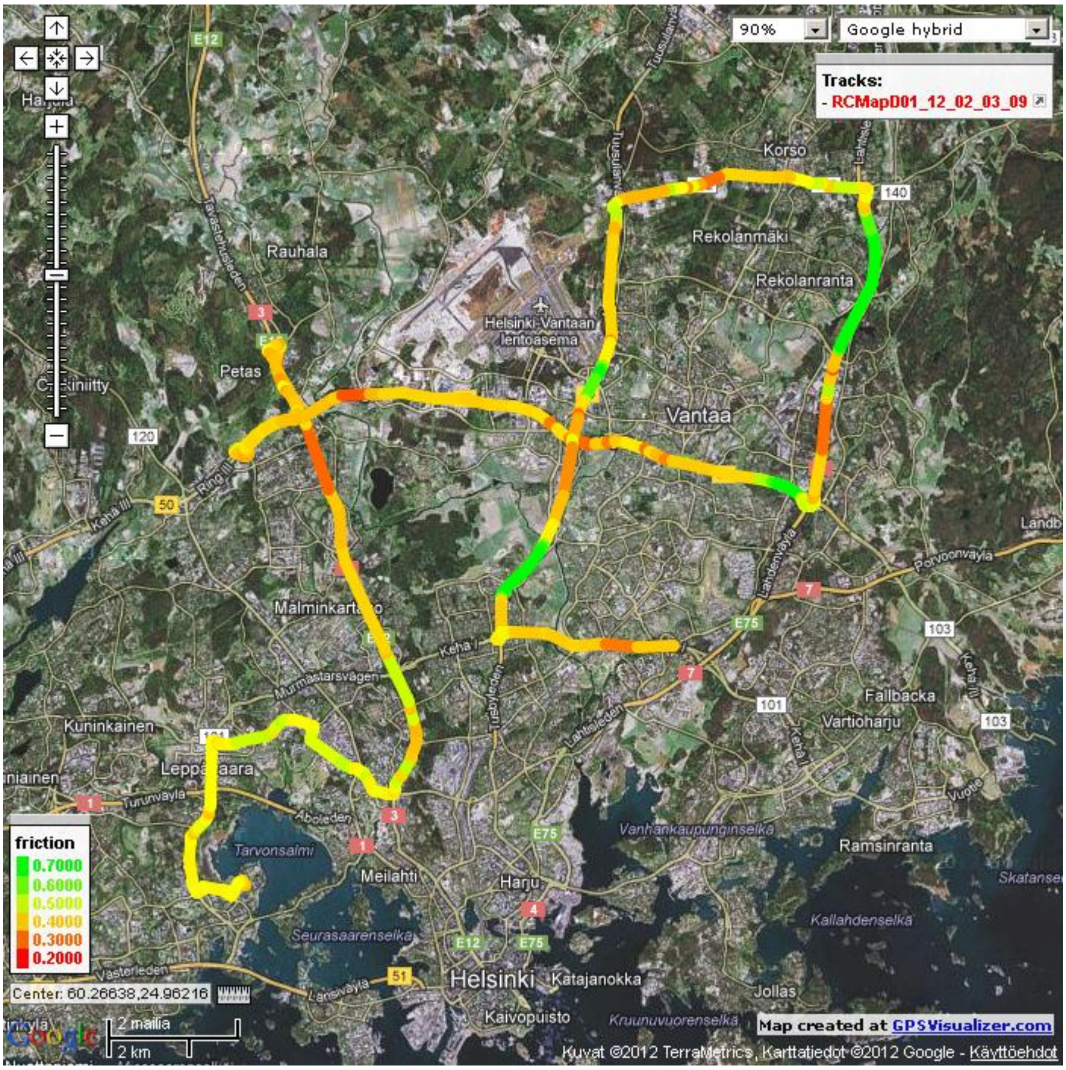

Figure 4. Test Drive 03.02.2012.

2.2. Test Drive on 11.03.2012

On 11th of March 2012 day time temperatures were a few degrees above freezing. This caused the snow to melt by the road sides resulting in increased moisture in the driving lanes. According to the local weather stations, the road surface temperature decreased below freezing at late afternoon. The surface did not have time to dry before reaching subfreezing temperatures according to one of the local road weather stations, whereas another weather station reported drying out. Therefore, moist surfaces may have frozen here and there depending on residual or freshly applied salt in that night.

The two test drives with RCM411 are shown on a map in Figure 5. The RCM indicated that the road was mainly moist or wet, with the exception of a few short stretches. The single most interesting observation in Figure 5 is the road condition on a junction between Hämeenlinnanväylä and Kehä III, the leftmost part of the drive. On the first trip, the junction was passed at 18:20 when the surface temperature was about to drop subfreezing. The RCM reported partial freezing at the junction, and on the following trip two hours later, the same road stretch was already clearly frozen although the other slippery sections were improving due to maintenance and applied salting. It turned out that this junction was not on the contractor’s list of required maintenance operations and was not treated, which may have caused the freezing.

Figure 5. Test drives on 11.03.2012 revealing freezing of a junction.

2.3. Test Drive on 31.03.2012

The measuring day in the Tampere region on 31st of March 2012 began with a nightly snow fall that caused approximately five centimetres of snow accumulation by the morning hours. The road temperature had been above zero in the previous day, which caused partial melting of the snow and made surface condition slushy. Still, a significant amount of snow stayed on the roads while the temperature decreased as much as four degrees below zero. The weather warmed up by noon, and some sections of the road dried out.

Figure 6 shows the friction measurements on 31.03.2012. On the left of Figure 6 there is the data from Tampere to north of national road 65 and on the right the same road back a few hours later. While driving north a plowing and salting truck passed. This caused the slippery snowy surface to turn to slushy or wet with high friction (green color), while driving back to Tampere.

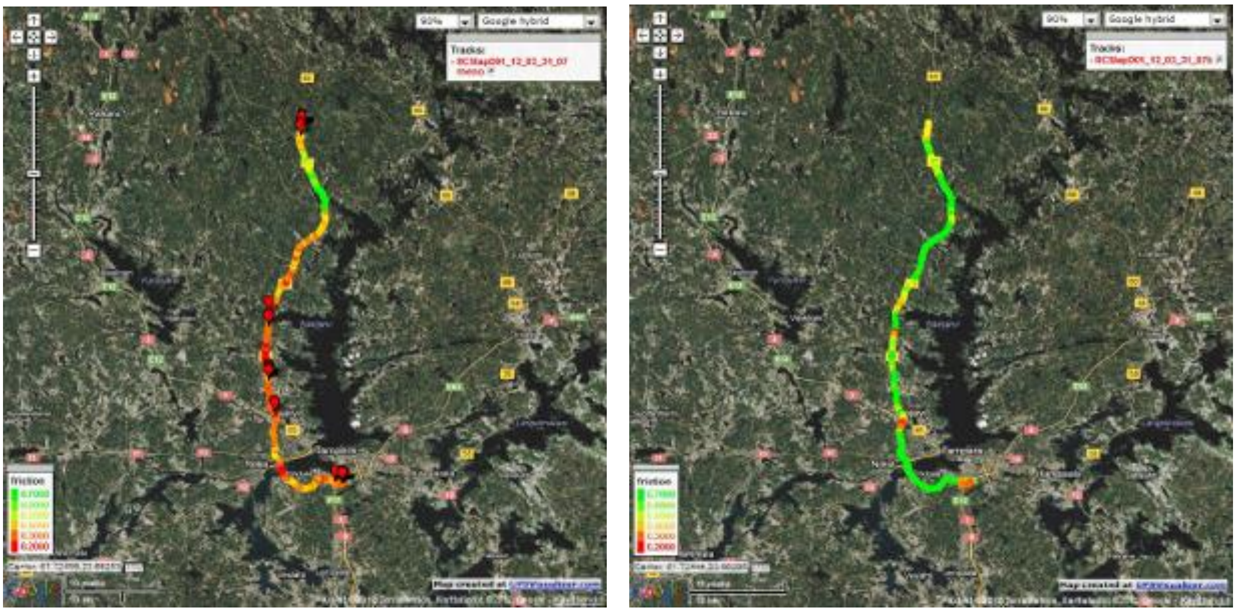

Figure 6. Test drive in Tampere region on 31.03.2012.

Table 2 presents comparison of measurements with the two units showing single-point friction measurements from national road 65, including averages and standard deviations. The average results of the braking friction meter (µTEC) yielded a slight rise of friction from 0.33 to 0.38 when heading north on national road 65. With RCM the rise has been even more obvious, from 0.29 to 0.45. In the first series of measurements, RCM was reporting ice or snow, whereas the snow condition was more stable in the second and third series. The low standard deviation values indicate that the continuous meter can yield stable results systematically when conditions remain uniform.

Table 2. Friction measurements on national road 65.

Nr 65 **Location 1**			**Nr 65** **Location 2**			**Nr 65** **Location 3**		
Time	**µTEC**	**RCM**	**Time**	**µTEC**	**RCM**	**Time**	**µTEC**	**RCM**
7:57:51	0.34	0.31	8:06:46	0.38	0.37	8:43:49	0.38	0.44
7:58:09	0.30	0.23	8:07:07	0.35	0.39	8:45:00	0.38	0.44
7:58:24	0.35	0.29				8:45:13	0.37	0.46
7:59:21	0.33	0.36				8:45:50	0.42	0.44
7:59:35	0.33	0.26				8:47:06	0.38	0.44
						8:47:18	0.38	0.46
						8:50:34	0.35	0.44
						8:50:48	0.36	0.46
Minimum:	0.30	0.23		0.35	0.37		0.35	0.44
Maximum:	0.35	0.36		0.38	0.39		0.42	0.46
Average:	0.33	0.29		0.37	0.38		0.38	0.45
Std. Deviation:	0.02	0.04		0.02	0.01		0.02	0.01

2.4. Test Drive on 28.01.2013

The test drive on 28th January 2013 was from Helsinki to Tammisaari. Air temperature was varying between -6 and -2 °C during the daytime and surface condition was mostly icy or snowy as shown in Figure 2. Snow fall was approaching from west and southern wind was warming the air. Near Tammisaari there was freezing rain causing very low friction. The road was plowed and salted on the afternoon.

The friction data is shown on a map presentation in Figure 7. Only five reference measurements were made by the braking friction meter (µTEC) in this run. However, the reference meter itself was compared to another similar meter installed to a second car. When the readings were calibrated against each other to take care of differences in tires and other possible factors, the results agreed within 5 % of reading in this case of very low friction with lowest readings being below 0.20. This result suggests that the braking friction meter provides repeatable means of making comparison measurements.

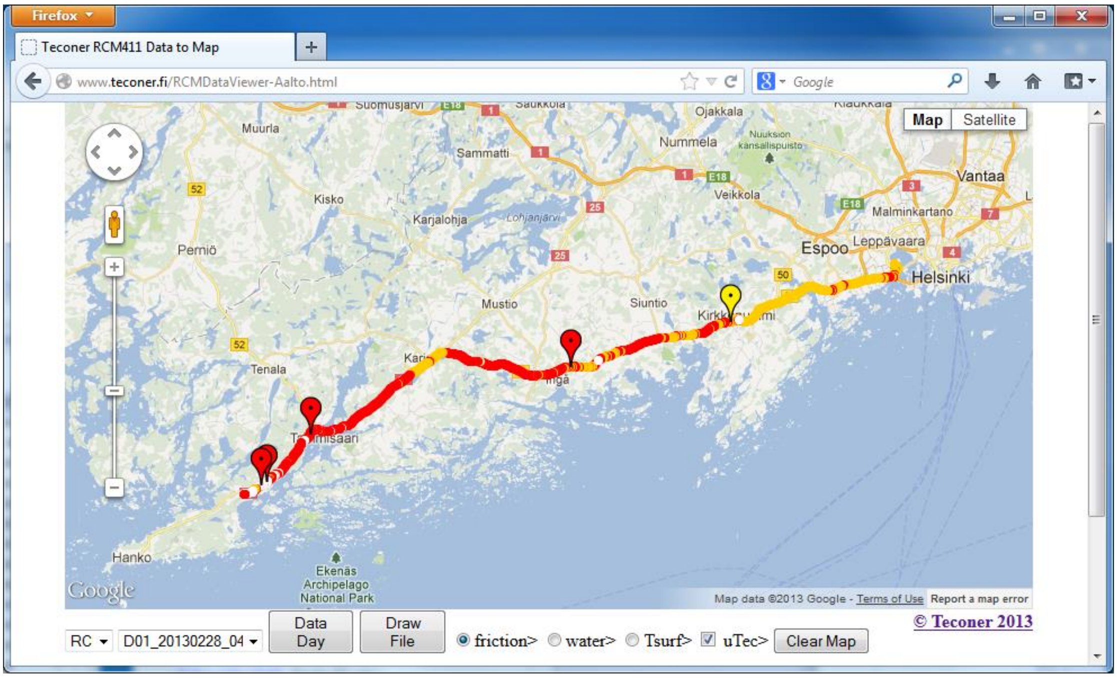

Figure 7. Test drive on 28.01.2013 Helsinki-Tammisaari.

Figure 8 shows the results of the continuous friction meter as a graph on traveled distance and the yellow points represent braking friction measurements. The standard deviation of the difference in results in this test drive was 0.14 units.

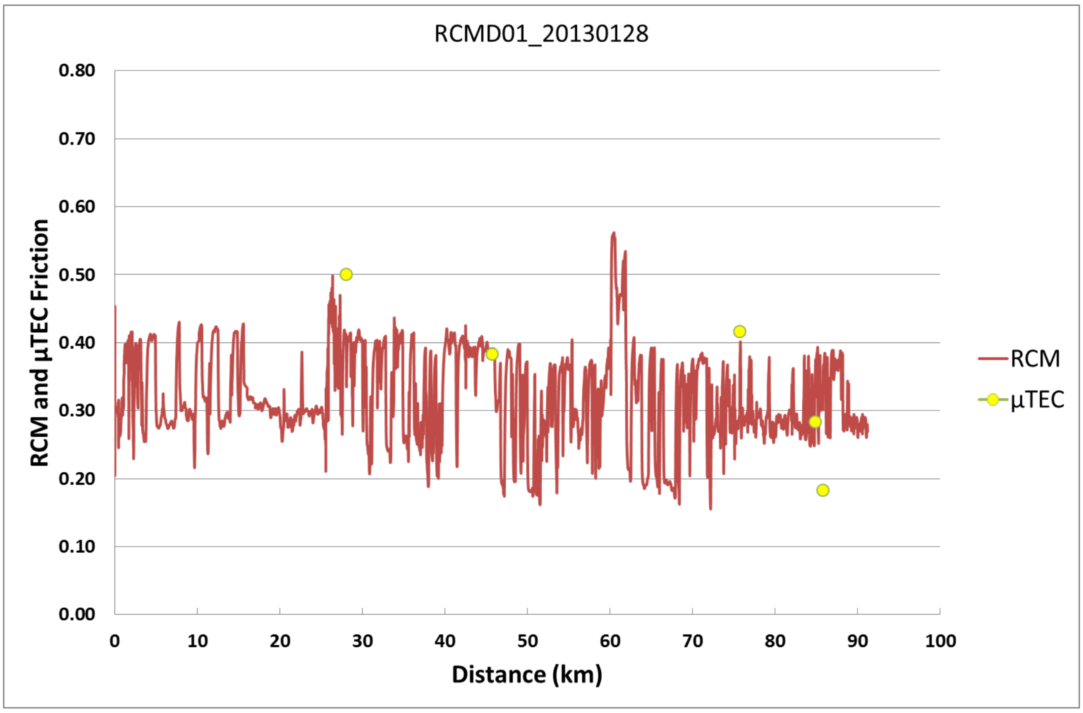

Figure 8. Test drive 28.01.2013 as a function of distance.

2.5. Observations by the test driver

The driver observed that for µTEC measurements, the phone holder has to be installed securely not to allow the holder to shake and cause additional noise in the braking measurement. When there was moist snow on the road, it could pile up on the protection tube of the RCM meter. Therefore, the tube must be checked and cleaned on longer trips, if necessary. The meter seemed to sort out different surface conditions well even on a short trip and did not make obvious errors. The user interface in the cell phone was easy to use and the graphics was clear.

3. FRICTION COMPARISON

When comparing two friction meters in accuracy it is important to consider the limitations coming from the surfaces of interest. In our case we are interested in friction experienced by typical vehicle tires on an asphalt pavement surface. There are various factors effecting but we are limiting our studies to the slipperiness caused by presence of ice and snow on highways. Even with this limitation there are considerable differences between car tires. However, in practise it turns out that the coefficient of friction varies within a reasonably narrow range for a dry and clean surface being ca. 0.80 ± 0.10 [1][2]. When there is a thick and hard layer of ice on the surface, the friction value drops to ca. 0.20 or less even with best quality of tires [6]. It is this wide range of friction variation from a dry to an icy surface, which we are interested to tackle. The purpose of the comparison is to find out, how well the continuous meter can replicate the friction experienced by a braking friction meter with typical winter tires.

The results for the first winter season 2011 - 2012 measurements are summarized in Table 3, which includes all the results from Helsinki metropolitan area and Tampere region. The total of comparison measurements for this period counts to 142, but we have averaged out those measurements taken in immediate vicinity to each other, which reduces the total number to measurement pairs to 79 in Table 3.

Table 3. Summary of results for the 2011-2012 season as a Pivot table.

Count of RCM **uTEC**	**<0.2**	**0.2-0.25**	**0.25-0.3**	**0.3-0.35**	**0.35-0.4**	**0.4-0.45**	**0.45-0.5**	**0.65-0.7**	**0.75-0.8**	**>0.8**	**Grand Total**
<0.25											
0.25-0.3		1	1	6	4	3	2				17
0.3-0.35		1	7	7	8	6			1		30
0.35-0.4			2	4	1	4	1		2		14
0.4-0.45			1	1	1	1				2	6
0.45-0.5								1	4		5
0.5-0.55									3		3
0.55-0.6									3		3
0.7-0.75						1					1
Grand Total		**2**	**11**	**18**	**14**	**15**	**3**	**1**	**13**	**2**	**79**

The count of RCM411 results belonging to a braking friction (uTEC) class of range 0.05 units is presented in Table 3. Green colour denotes the number of points belonging to the same or the neighbouring class, and there are 41 of these pairs. When analyzing the cases where both of the friction figures have been 0.45 or less, 69.5 percent of the results are consistent. When considering that the results of the Helsinki Metropolitan Area can include occasional incomplete braking actions resulting from the traffic situation, this result is surprisingly good.

The RCM results are presented as a function of the braking friction meter in Figure 9. This presentation shows clearly the deviation of the points from each other. Points above the blue line show higher friction for the RCM and points below show higher friction for the µTEC. Approximately one-fifth of the results are obviously deviating (difference > 0.20). There are clearly less of these divergent spots below the straight line. They have been caused in situations where the RCM model has determined the surface state as icy or slushy, or it has not yet had enough time to turn to wet conditions due to recently-appeared icy, snowy or slushy conditions.

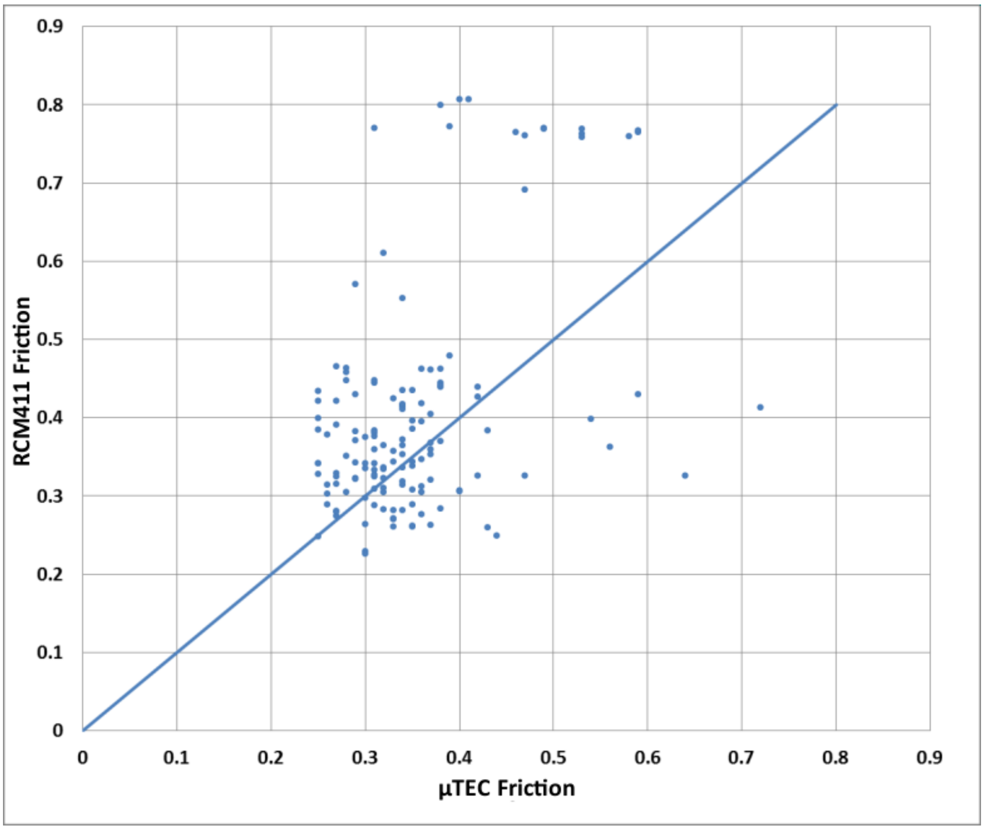

Figure 9. Continuous meter vs. braking friction meter for the season 2011-2012.

In Figure 9 the clearly deviating cases above the line of equality are caused by situations where braking has not been, for one reason or another, effective enough, or the RCM has seen a wet condition instead of the real slushy or icy one. Previous experience has shown that when the road is free of ice, the RCM yields a correct friction value reliably [4]. Ice-free and wet situations occurred on the measuring trip to the extent that some of the braking measurements can be assumed to have taken place at these points. However, braking results of good conditions are hardly found in the set of measurements. The braking actions in antiskid conditions may have been insufficient when it comes to acceleration. For instance, even if the car's ABS system is activated while braking, the rear wheels may not have the time to brake using their full power in a short braking. Then the measured acceleration remains lower than the one corresponding to the coefficient of friction. In slippery conditions, the power required from the brakes is notably lower, which is why, against all odds, the results may be close to the correct numbers with low friction figures.

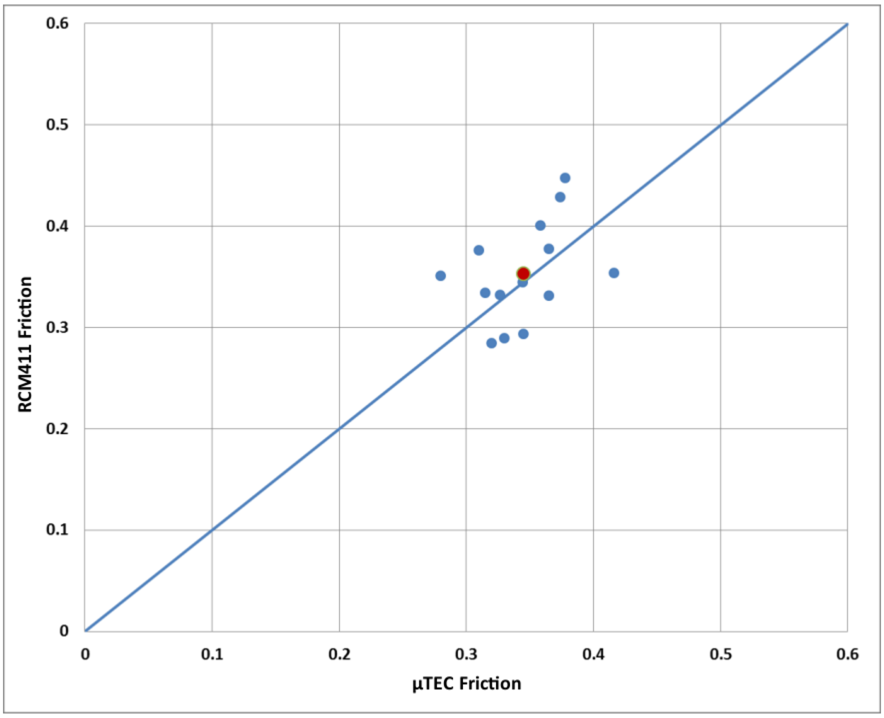

Figure 10. Average results of all single-point measurements in 2011-2012.

The average results of all the measurements at fixed preselected locations from the Helsinki Metropolitan Area and Tampere region have been collected into Figure 10. These results do not include unintentional incomplete braking measurements. The red spot represents the average of these results. The average difference between the instruments is only 0.01 friction units. Also the standard deviation of the differences is very low, only 0.046 units, and the results from the Helsinki Metropolitan Area and the Tampere region are very similar.

Table 4. Summary of comparison for the season 2012-2013.

Date	µTEC	Test	Deviation	Average
08.01.2013	7	Test route	0.11	0.05
09.01.2013	15	Lahti-Vierumaki-Vaaksy-Lahti	0.11	-0.12
09.01.2013	37	Test route	0.10	-0.04
28.01.2013	5	Helsinki-Tammisaari	0.14	-0.02
29.01.2013	9	Otaniemi-Maantiekyla	0.12	-0.17
28.02.2013	33	Test route and Otaniemi-Salo	0.09	0.00
	106	µTEC brakings altogether		
		Weighted Standard Deviation	0.104	
		Weighted Average		-0.043

Obviously the surface conditions did not include very low friction or intermediate and high friction cases in the season 2011-2012 as revealed by Figure 10. To better cover these friction ranges the testing was continued on the same test route and some other routes during 2012-2013. The results of the latter measurements are summarized in Table 4 as standard deviation and average of differences. This data has a better coverage of very low friction near 0.20 and also of the range of 0.40 to 0.70.

Based on the results of the season 2011-2012 and taking into account poor presentation of all surface states for this season we estimated that the continuous friction meter and the braking friction meter agree within 0.10 units measured as a standard deviation of differences. This result seems to be supported also by the data of the season 2012-2013 as seen in Table 4. RCM411 and µTEC meters agreed in most surface conditions according to expectations and the standard deviation of the differences weighted by the count of measurements was 0.104 whereas the average set to -0.043.

4. DISCUSSION

There is a need to assess the validity of the braking friction meter as a reference device. By definition the braking friction meter measures accurately the friction of the vehicle on the given surface assuming that the accelerometer functions correctly and the measurement is done such a way that all tires slip for a brief time [2]. The validity of these assumptions is easy to check by inspecting the accelerometer response against the earth gravity and checking the result against the time of braking. Comparison of two different braking friction meters installed in separate vehicles showed a good reproducibility of results, which suggests that the braking friction meter can be used reliably as a reference device in this study. There is still left the question of type and quality of tires. In this testing we used new studded winter tires as required by the Finnish Transport Agency [3]. There is a clear difference in friction experienced by studded and non-studded tires in certain icy conditions. However, this difference is largest at the extreme low end of friction (<0.20), which cannot change much the observed figure of agreement of the two meters. From the point of view of winter maintenance, this difference is anyway unavoidable in regions, where both types of tires are legal.

When a friction meter produces a result within about 0.10 of the actual value, it means that we can divide highway friction to about 6 classes which represent all surface conditions from icy and snowy to moist or dry. This level of precision may first sound being not adequate. However, for winter maintenance purposes reaching a higher absolute accuracy is difficult for a couple of reasons. First, friction is often varying even within a few meters in driving direction and across the road the change can be from a completely dry surface to an icy one within fractions of a meter. Small variations in salt spreading will have dramatic effects on apparent friction [6]. Therefore an accurate number for a given location can be misleading at worst. Secondly, all other factors in the braking process, e.g. tires and braking assistance, cause different vehicles experience the same surface more or less slippery. Thus repeatability of measurement may turn out more important than absolute accuracy.

There are several ways of utilizing the friction information in the winter maintenance. All information can be used for the general quality control of winter maintenance operations. Although the accuracy may not be high enough for penalizing contractors for not reaching the required level of friction, continuous measurements are very effective way of identifying road sections of low friction. Then it is fairly straightforward to validate the result by a braking friction meter or by other means. Continuous friction measurement can also be used for training purposes by comparing maintenance operations, weather parameters and observed friction. Direct on-board information to drivers about slippery road sections is also an interesting future application.

In future, presumably the most significant application of continuous friction data would be precision control of spreading salts and anti-icers. It has been shown that required concentrations of salt to keep friction at acceptable levels are only a few percent and the layer thickness of water or ice is typically less than 0.2 mm [6]. Theoretically it would be feasible to measure friction and thickness of water/ice layer and calculate the right amount of salt to keep friction high enough for the next few hours by taking into account local weather forecast. Currently the process of estimating the required amount of anti-icer is very rough. Precision type automated spreading of anti-icers has thus potential for more economical maintenance operations with positive ecological impacts.

5. SUMMARY

A continuous skid resistance meter has been tested against a discontinuous braking friction meter. The continuous meter is intended for measuring friction on highways to reveal slippery road sections caused by ice and snow. The results of the two instruments agree within about 0.10 units in friction. The accuracy allows various applications in winter maintenance, e.g. in quality control and in optimization process, and also in communicating information of slippery road sections to drivers. Precision based spreading of salts and de- or anti-icing chemicals may turn out to be feasible.

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