Liikennevirasto

2013

MIKKO MALMIVUO

# Comparison study of mobile optical friction and temperature meters 2013

# Foreword

This is a long English abstract of the study "Optisten kitka- ja lämpömittarien vertailututkimus 2013", financed by Finnish Transport Agency and carried out by Mikko Malmivuo, Innomikko Ltd.

The original report (in Finnish) can be found
http://www2.liikennevirasto.fi/julkaisut/pdf3/lts_2013-52_optisten_kitka_web.pdf

This translation is not verified by professional translators.

# Contents

# 1 Introduction

The friction measurements of winter roads are an essential part of public roads winter maintenance control in Finland. There can be seen different purposes for the measurements:

A: **Measurements to check if the quality requirements are met**. The friction requirements are essential part of the winter maintenance quality requirements in public roads in Finland. The idea behind these frictions requirements is that all the main roads don't need to be bare, as far as the friction on the road surface is sufficient. This policy minimizes the need of various environmentally unfriendly anti-icing materials and chemicals.

These measurements are done as spot check measurements and are usually carried out in most demanding weather conditions.

B: **Measurements to assess the overall service level of winter roads.** These measurements are done using fixed schedule, despite of the weather conditions. This data can be used when comparing the service level of different winters, areas or road classes. This is a tool for authorities to assess the effectiveness and success of winter maintenance operations. These kinds of measurements started in Finland in 1990's and have been carried until 2011. Today Finnish Transport Agency is looking for cheaper procedures to gather this kind of information. The traditional method required to pay both the driver and the vehicle costs.

C: **Measurements for winter maintenance management.** These measurements are done by maintenance entrepreneurs and help them to schedule maintenance operations.

In Finland, during last 25 years, our road friction measurements are based on the method, where there needs to brake a vehicle in order to get friction value. These meters are small electrical in-car accessory, and they determine the deceleration during braking and therefore estimate the friction. Those accessories are intended to be used in ordinary passenger cars or SUV's (Sport Utility Vehicle). When measuring friction, driver brakes the car with full force about 1-2 seconds and then releases the pedal. During the braking, the car speed decreases, but the car won't stop. The measuring cars have been equipped with studded tyres and they have ABS-brakes. The measurements should be taken on the flat road section and driver should carefully be aware, that no one is behind the car, neither driving from the opposite direction.

The optical friction meters offer certain benefits compared to these "braking friction meters":

- They offer continuous friction data
- They can be used anywhere and also in places where you can't use braking friction meters: on sharp curves, on hills, in the congestion
- They are more safe to use in traffic (no need for braking)

When compared to special friction trailers, they have two benefits:

- They don't have any wearing parts (no need to change any friction measurement tyres).
- They are more affordable.

Thus optical friction meters seem to be quite ideal for mobile friction measurements. There are still a couple of open questions:

- Are optical meters accurate enough?
- How maintenance free are they, will the optics get dirty easily?

These are the question this study is seeking for the answers.

The compared optical friction meters offer also other kind of information. They also give road weather condition classification, road surface and air temperature, dew point and humidity. Also the accuracy of this extra information is analyzed.

# 2 The meters compared

## 2.1 Optical friction meters

The object of the study was two optical friction meters: Vaisala's DSP310 and Teconer's RCM411. The main measuring principle, to assess the friction based on the reflection of the light from the road surface, is the same on both devices. But when studying other features of the devices, you can see remarkable differences. The detachment into a vehicle has been illustrated in figure 1. Both meters use mobile phone display as a real time user interface (figure 2). The differences and equalities of the meters has been compared in table 1.


*Figure 1.* *Optical friction meter DSP310 (in the blue circle above) analyses the road surface farther and should be detached on the roof stand. Optical friction meter RCM411 analyses the surface nearer and is here detached on the towing hook. Both meters are focused on the left wheel path.*

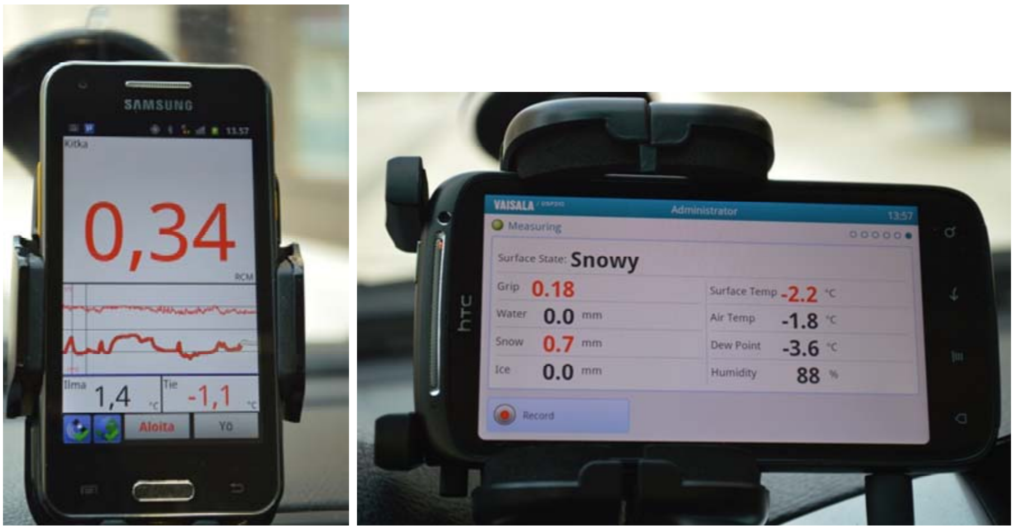



*Figure 2. The user interface of the meters is a mobile phone. RCM411 interface on left and DSP310 interface on the right.*

*Table 1. The differences and equalities of RCM411 and DSP310*

| | **RCM411** | **DSP310** |
|---|---|---|
| **Technology of optical measurement** | Diode | Laser |
| **Detachment** | To the vehicle towing hook or to the special fastener adaptable to the vehicle tailgate | To the vehicle roof stand. Humidity and air temperature sensors to the towing hitch (in front of the car) |
| **Position and calibration** | Should be installed in certain angle and certain distance from to road surface. After that, ready to be used. | The angle and the distance from to road surface is not so accurate, but the meter should be calibrated on bare asphalt before use. |
| **The heating of the optics in order to prevent frost** | Not in the basic version, but available as an option | Yes |
| **Power input** | With wire from trailer socket or from vehicle cigarette lighter | With wire from vehicle cigarette lighter |
| **Data transmission** | Wireless from meter to the in-cabin mobile phone. | With wire to the in-cabin central unit and wireless from central unit to the mobile phone |
| **Sampling rate in the data** | Every 1 second | Every 3 seconds |
| **Friction measurement** | Optical friction measurement. The same data includes also µTEC-braking friction measurement values, if also µTEC purchased. | Optical friction measurement. |
| **Road weather classification** | Yes (dry, moist, wet, slush, ice and snow or frost) | Yes (dry, moist, wet, snow, ice and slush) |
| **The material thickness on the road surface** | One variable for the layer thickness | 3 separate variables (layer thickness separately for water, snow and ice) |
| **Air temperature** | If the separate optical temperature meter RTS411 has been purchased, the air temperature in the same data. | Yes. |
| **Road surface temperature** | If the separate optical temperature meter RTS411 has been purchased, the road surface temperature in the same data. | Yes, optically. |
| **Dew point** | No | Yes |
| **Humidity** | No | Yes |
| **GPS-coordinates, altitude** | Yes, uses GPS in the phone | Yes, uses GPS in the phone |
| **Speed, direction, distance** | Yes, uses GPS in the phone | Total distance in separate measuring report |
| **Price** | RCM411 ≈ 5500 €, RTS411 ≈ 1000 €, µTEC 500 € | ≈ 10 000 € |

## 2.2 Braking friction meters

Three different braking friction meters where used as a reference meter in the study. When using braking friction meters, the heavy braking of the vehicle is used in a 60 km/h speed. The meter measures the deceleration and calculates the friction between vehicle and road surface. The braking friction meters used (all meters in the same vehicle) were:

- Eltrip-45n, which calculates the friction in the basis of wheel spinning speed before and after the braking. The meter was calibrated according to Finnish transport agency quidelines (the friction was 0.29 on the packed snow in -5°C)

- Gripman, which calculates the friction in the basis of own acceleration sensor

- μTEC, which is a mobile phone friction measurement software. The software is applicable with phones having own acceleration sensor. Also μTEC calculates the friction in the basis of the acceleration sensor.

The Gripman and μTEC were calibrated to use physical friction scale, which is broader than the Transport Agency scale and also more near to the scale, which is used by optical friction meters. The difference between these scales has been described in figure 3.

**TRANSPORT AGENCY FRICTION SCALE**

**- More condensed scale**
**- The meter shall be calibrated to measure 0.29 on packed snow at -5 °C**
**- The scale was concluded at 1980's, when the reference meter was BV-11 (friction meter designed for runway friction measurements)**

**PHYSICAL FRICTION SCALE**

**- Broader scale**
**- Transport agency scale value 0.29 equals 0.37 in physical scale**
**- The scale is based on the physical formula for friction**

$$\tfrac{1}{2} m (v_0)^2 - \tfrac{1}{2} m (v_i)^2 = \mu m g L$$

where:
$m$ = vehicle mass
$v_0$ = initial speed before braking
$v_i$ = end speed after braking
$\mu$ = friction coefficient
$g$ = gravity, 9,82 $m/s^2$
$L$ = braking distance

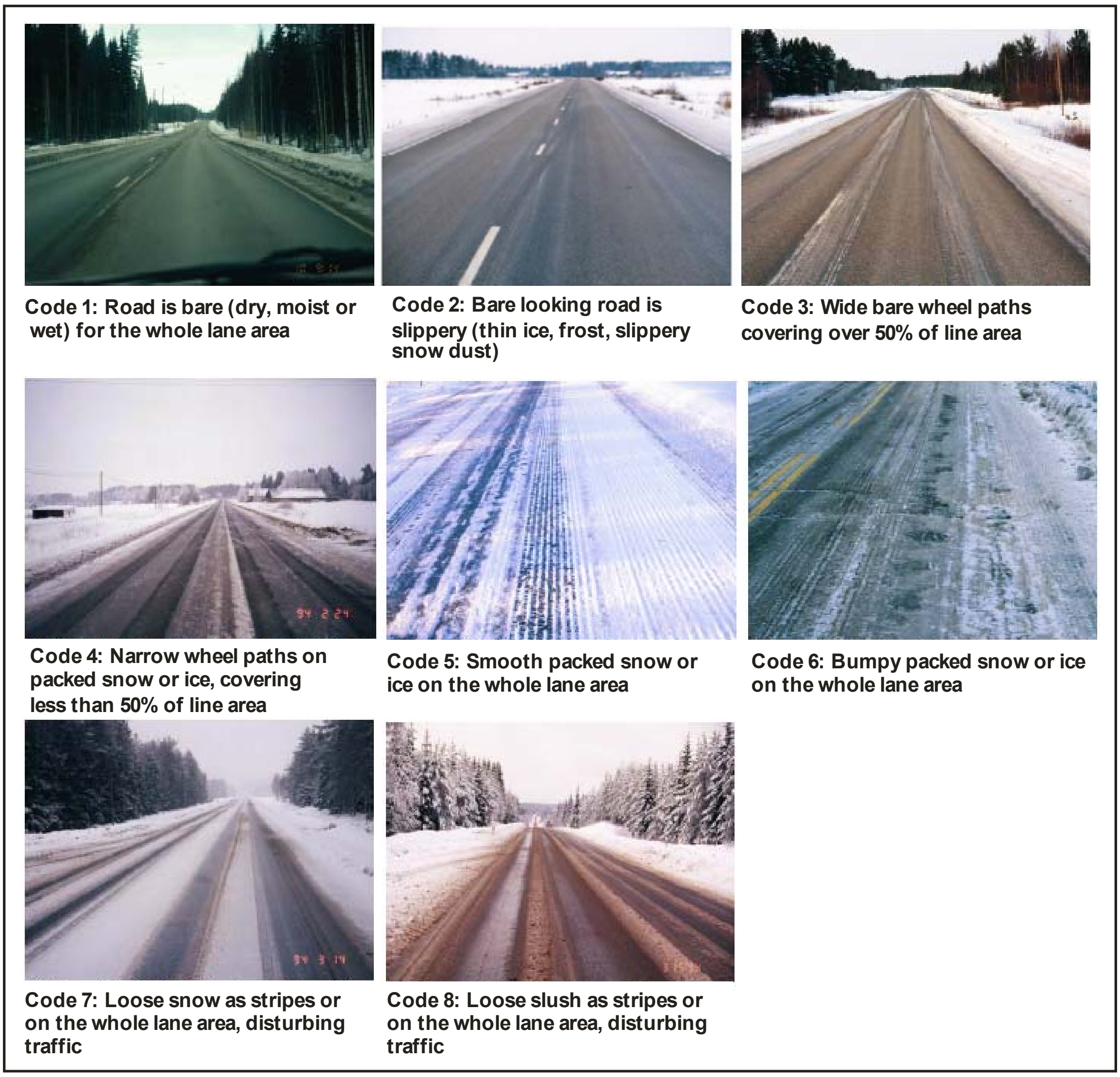
$$\Rightarrow \mu = ((v_0)^2 - (v_i)^2) / 2 g L$$

*Figure 3. Finnish transport agency friction scale and physical friction scale.*

# 3 Research method

The comparisons were made on different kind of roads in southern Finland. Most on measurements were made on one-carriageway main roads. The total amount of measurements was over 2500 kilometres, including over 700 braking friction measurements.

During the measurements, the road weather type was classified, just based on how the road weather type was looking like. The classification was based on so called "road weather codes", which were initially created for "centralized winter maintenance control" (type B friction measurements mentioned in the Introduction). This classification was very natural for the measurement person, who has used this classification for years.



**Code 1:** Road is bare (dry, moist or wet) for the whole lane area

**Code 2:** Bare looking road is slippery (thin ice, frost, slippery snow dust)

**Code 3:** Wide bare wheel paths covering over 50% of line area

**Code 4:** Narrow wheel paths on packed snow or ice, covering less than 50% of line area

**Code 5:** Smooth packed snow or ice on the whole lane area

**Code 6:** Bumpy packed snow or ice on the whole lane area

**Code 7:** Loose snow as stripes or on the whole lane area, disturbing traffic

**Code 8:** Loose slush as stripes or on the whole lane area, disturbing traffic

*Figure 4. Road weather classification used in this study. Based on the "centralized winter maintenance control" classification.*

When measuring friction on the road, the road weather and friction can vary significantly, even on a short distance. Therefore it's very important, that both the optical friction meters and the reference meters (braking friction meters) measure the same spot. In the results presented, the optical friction is always an average of the friction measured within ± 5 seconds of the braking friction measurement time stamp. There is couple of reasons for the time window selected:

- Because the precise alignment of the two methods is impossible, we wanted to be sure, that the braking friction measurement is in the same window as the optical friction measurement.

- Because the sample interval of DSP310 is 3 seconds, much smaller time window would not be appropriate.

In practice, the road section measured by two methods is not exactly the same, because:

- when the measuring speed is 60 km/h, the road section measured by optical meters is 170 meters and the section measured by braking friction meters is 20 meters

- the optical meters are analyzing the left wheel path, but braking friction meters both wheel paths (four wheel braking).

The differences of the two methods are illustrated on the figure 5.

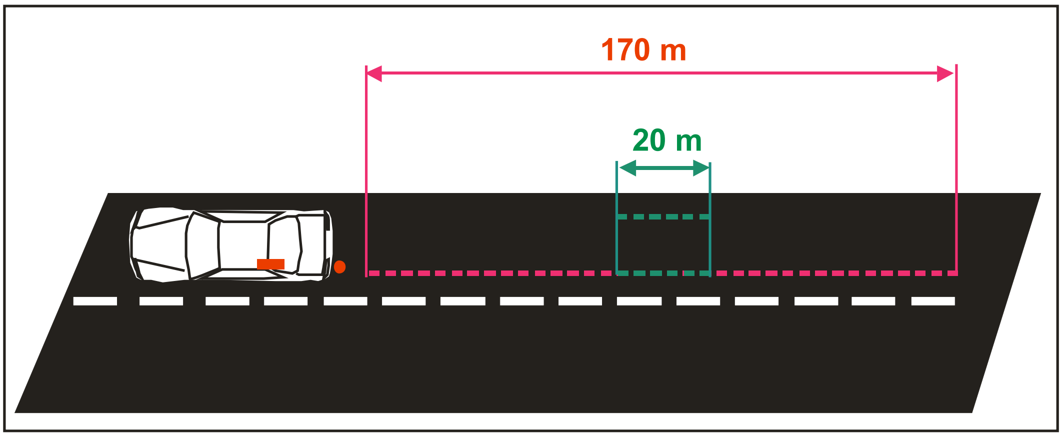



*Figure 5. The road area measured by optical meters (red dashed line) and area measured by braking friction meters (green dashed lines).*

# 4 The results

## 4.1 The dispersion between different meters

When analyzing the results, it was realized, that the greatest differences between optical and braking friction meters happened in situations, where the dispersion between various braking friction meters was the biggest. The big dispersion between various braking friction meters presumably occurs on those situations when the real friction has had big variations during braking, because the meters utilize different time gap during the braking. It is also possible, that measurement has not been successful for other reasons, for example because of demanding traffic condition (a large portion of the measurements were made in the high traffic volume roads).

To improve the reliability of the study, the braking friction measurements with largest mutual deviations were excluded from the data. The figures 6 and 7 illustrates the initial dispersion between braking friction meters. The red dots represent the measurements, which were excluded. The dispersion between Eltrip and μTEC is slightly bigger than expected and as in earlier studies. The reason why there is red dots in figure 7 even in the middle of the picture is, that there was a big dispersion between Eltrip and μTEC in the same measurement (if the correlation of any of the two braking friction measurement meters was weak, all three braking friction meter results were excluded).

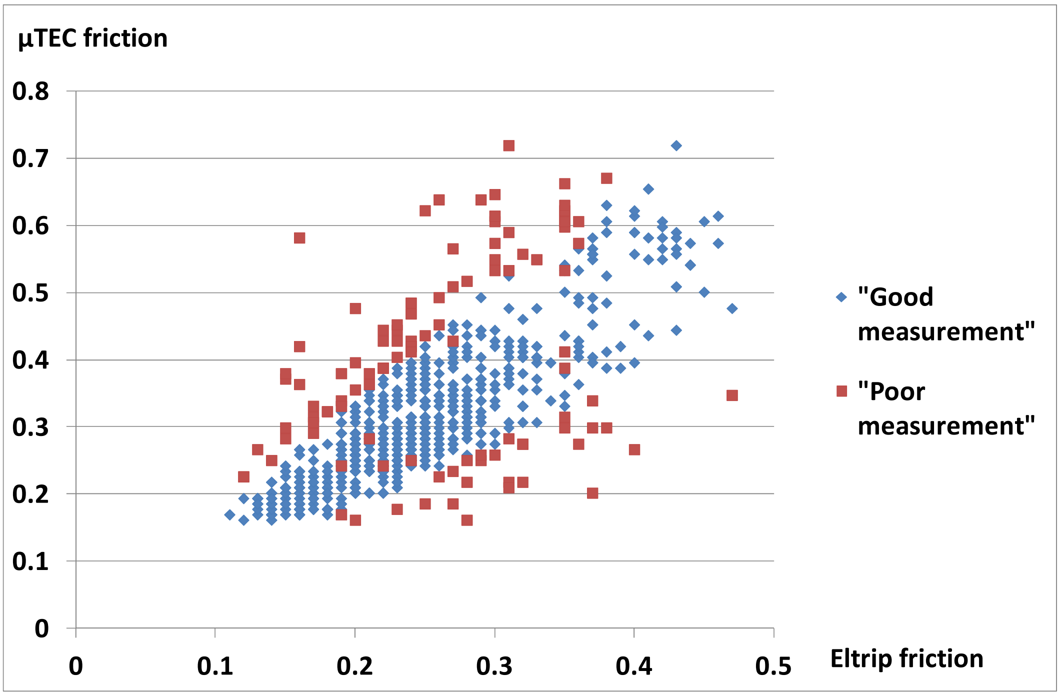



*Figure 6. The dispersion between the friction results of the μTEC (physical scale) and Eltrip (traffic agency scale). "Good measurement" means results, were all three braking friction meters (μTEC, Gripman and Eltrip) showed comparable results.*

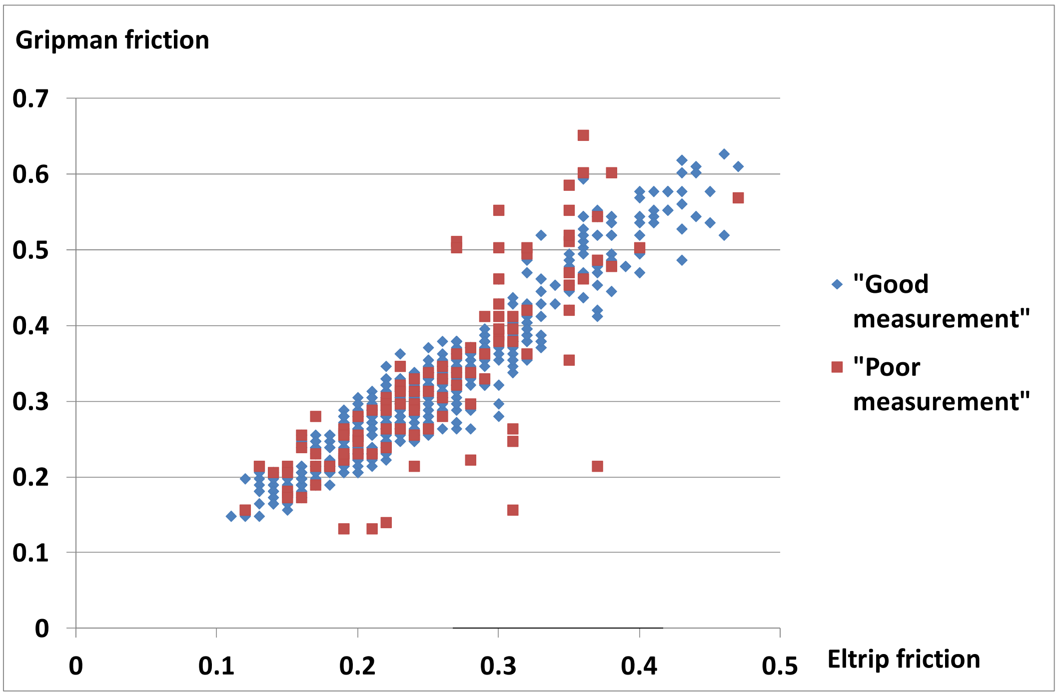



*Figure 7.* *The dispersion between the friction results of the Gripman (physical scale) and Eltrip (traffic agency scale). "Good measurement" means results, were all three braking friction meters (µTEC, Gripman and Eltrip) showed comparable results.*

#### 4.1.1 RCM411

When comparing RCM411 to various braking friction meters, the best correlation could be found with µTEC (figure 8), althougth there were not major differences when comparing with Eltrip and Gripman. The correlation line between RCM411 and µTEC had a formula RCM411 = 1.02 * µTEC, which means, that RCM411 friction scale is very near to the physical friction scale.

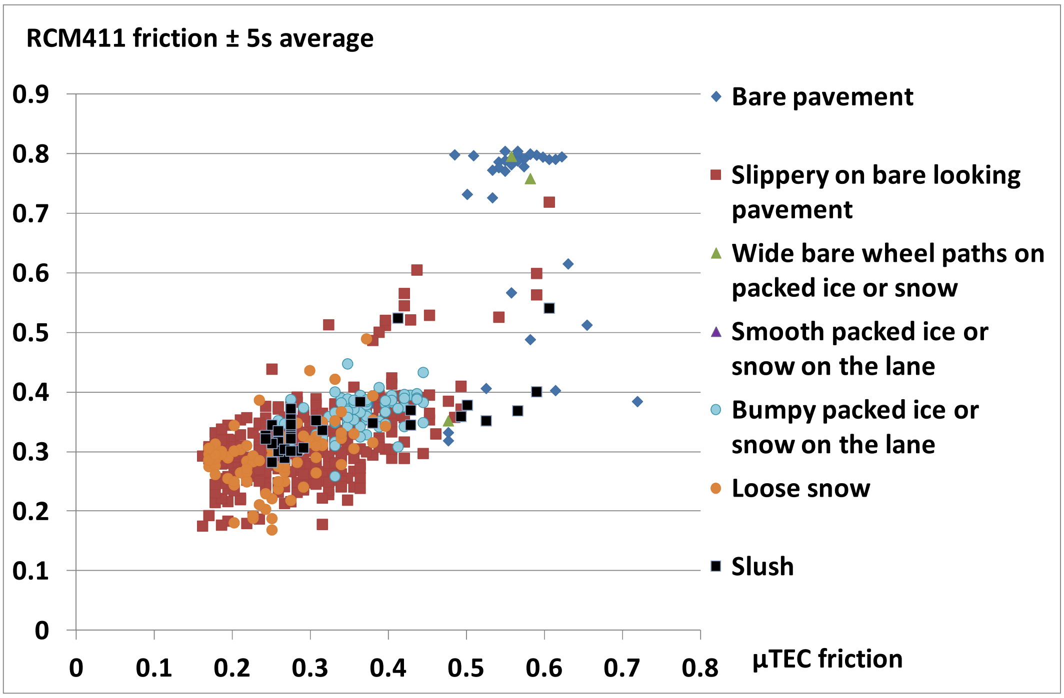



*Figure 8. The comparison between RCM411 and µTEC friction. Road weather classification according to the measurement person.*

### 4.1.2 DSP310

The dispersion of the DSP310 results seem to be wider than with RCM411. The friction scale of the DSP310 is significantly bigger than the scale of DSP310. A broad scale is a desirable feature, but directly creates bigger dispersion. The correlation line formula between DSP310 and µTEC is: DSP310 = 1.3*µTEC.

Vaisala has announced that DSP310 works better on highways. It's easy to sea from the figure 9, that the figure would seem much nicer, if the road weather type "bumpy packed ice or snow on the lane" would have been excluded from the results. And as we now, "bumpy packed ice or snow on the lane" happens rarely on highways, but more typically on minor roads. In figure 10, only the highway measurements have been included in the comparison.

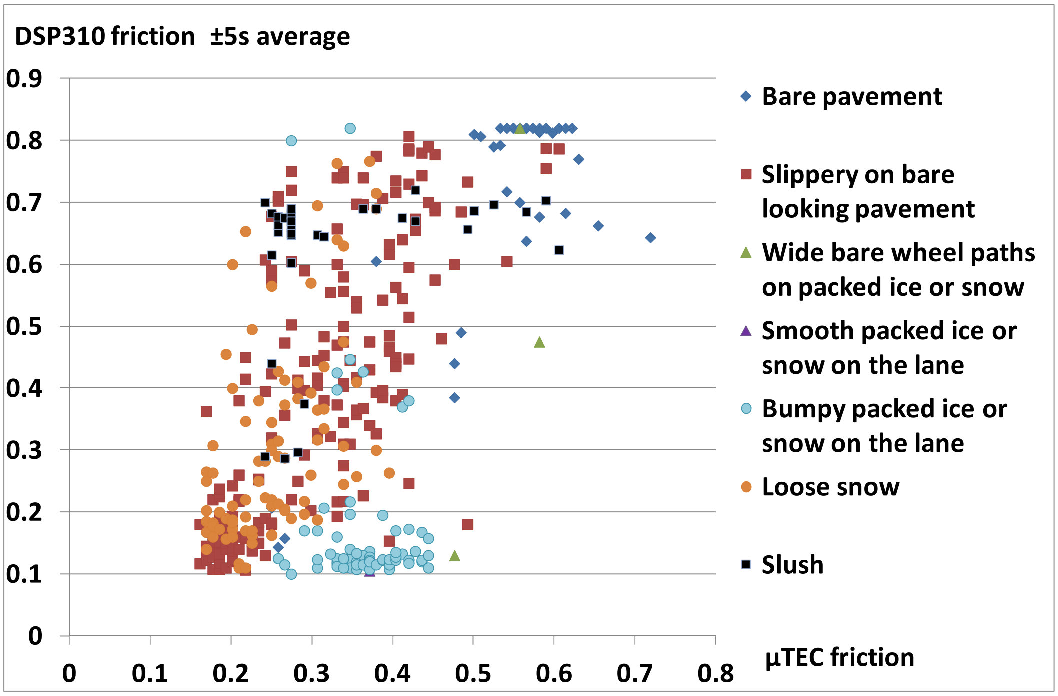



*Figure 9.* *The comparison between DSP310 and µTEC friction. Road weather classification according to the measurement person.*

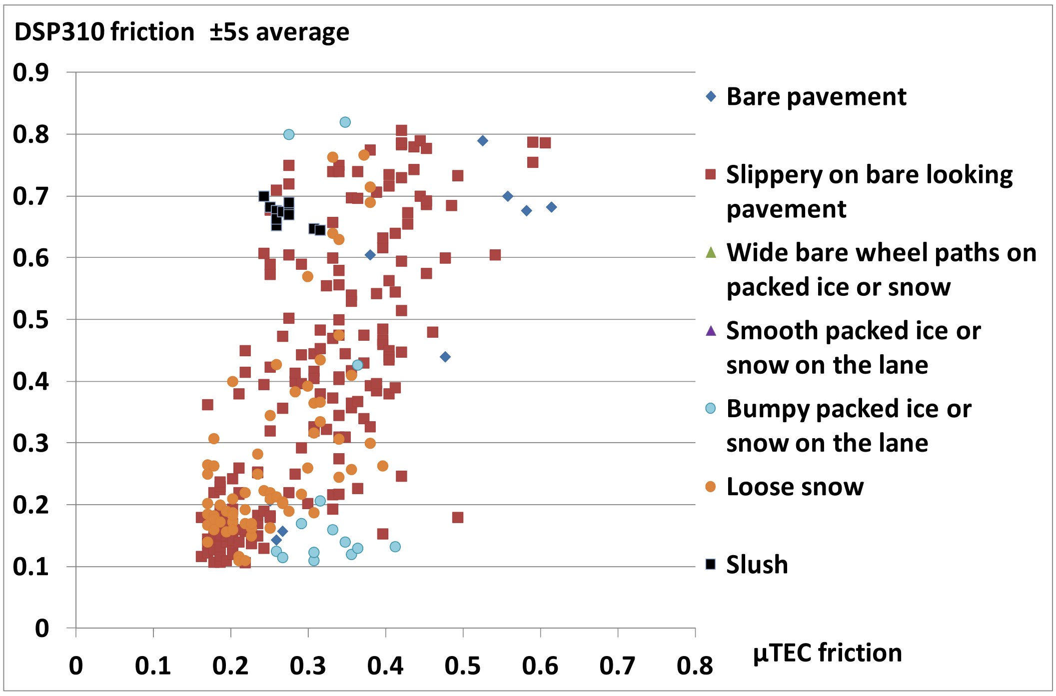



*Figure 10.* *The comparison between DSP310 and µTEC friction. Only highways. Road weather classification according to the measurement person.*

# 4.2 Analyzing the friction scale and dispersion of the optical meters

The data for the next figures is again the data, where the most inconsistent braking friction measurements have been excluded. After the clean up, the total amount of braking friction measurements was 600. In the next analysis, the data has first been sorted to an ascending order according braking friction measurements. After that, the data was divided into 12 pieces, were each piece consisted of 50 measurements. Finally, the average of 50 braking friction measurements and corresponding optical friction measurements were calculated. As a result, a friction profile of optical friction meters against different braking friction meters could be drawn.

Additionally, it was analyzed, how much dispersion optical meters have around their own averages. Line "± 0.05" describes, what is the percentage of the optical meter results, which are inside 5 hundredth part from the average. Correspondingly, line "± 0.10" describes, what is the percentage of the optical meter results, which are inside 10 hundredth part from the average.

### 4.2.1 RCM411

Figure 11 describes the RCM411 friction profile against µTEC. Let's look once again how this figure has been created:

– The thick blue line describes RCM411 friction profile against µTEC. The first dot on the line (dot "A"), presents the average of 50 lowest µTEC friction values (0.180) and the average of RCM411 results (0.287) in same occasions. The second dot (dot "B") presents 50 second lowest µTEC values and corresponding RCM411 results.

– The red and green lines describe the RCM411 dispersion. The dot "C" describes the percentage of the RCM411 results , which are inside ± 0.05 units from the RCM411 average in the dot A. In other words, according to dot "C", 84% of the RCM411 results in Dot A are between 0.237 (0.287 - 0.05) and 0.337 (0.287+0.05).

– Accordingly, Point "D" describes the percentage of the RCM411 results which are inside ± 0.10 units from the RCM411 average in the dot A. In other words, according to dot "D", 96% of the RCM411 results in Dot A are between 0.187 (0.287 - 0.10) and 0.387 (0.287+0.10).

When looking at figure 11, you can see that the red and green dispersion lines shows quite high percentages, which means that the dispersion is quite narrow. The friction profile (the blue line) is still quite gently sloping when looking lower friction values, which means that the resolution in lower friction levels is weaker.

The figure 12 shows same analysis against Gripman. There you can see that there is a little bit better resolution in lower friction levels, but the dispersion lines show slightly weaker dispersion than with µTEC.

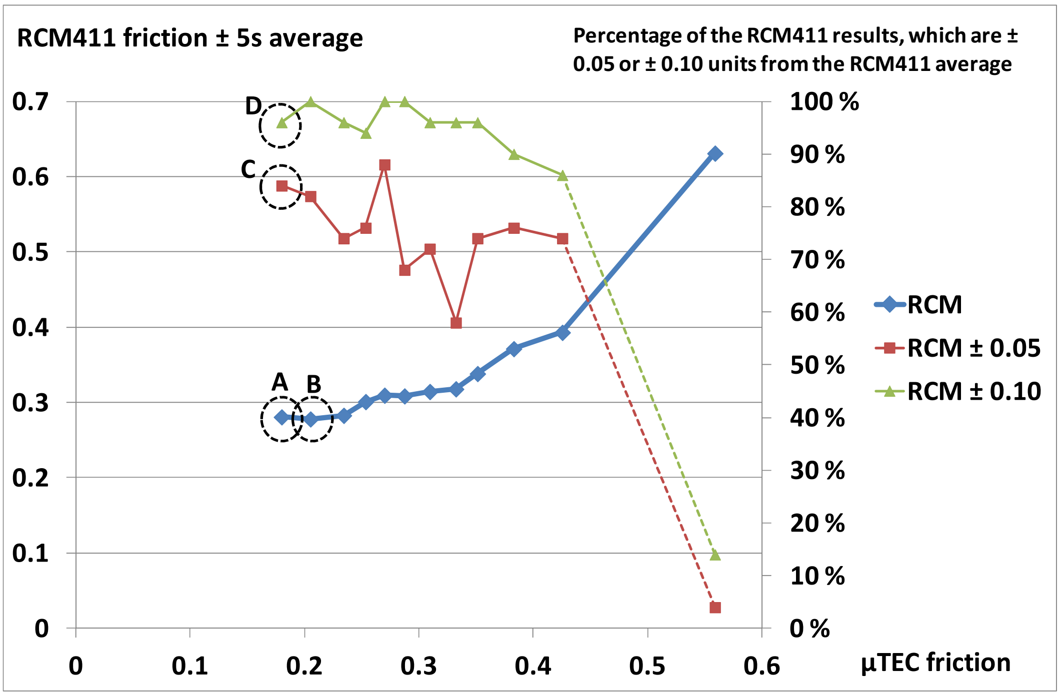



*Figure 11.* *RCM411 friction profile against µTEC. Also percentage of the RCM411 results, which are ± 0.05 or ± 0.10 units from the RCM411 average. This dispersion number is misleading in the highest friction level, because there the µTEC dispersion is already big, because of the small sample size.*

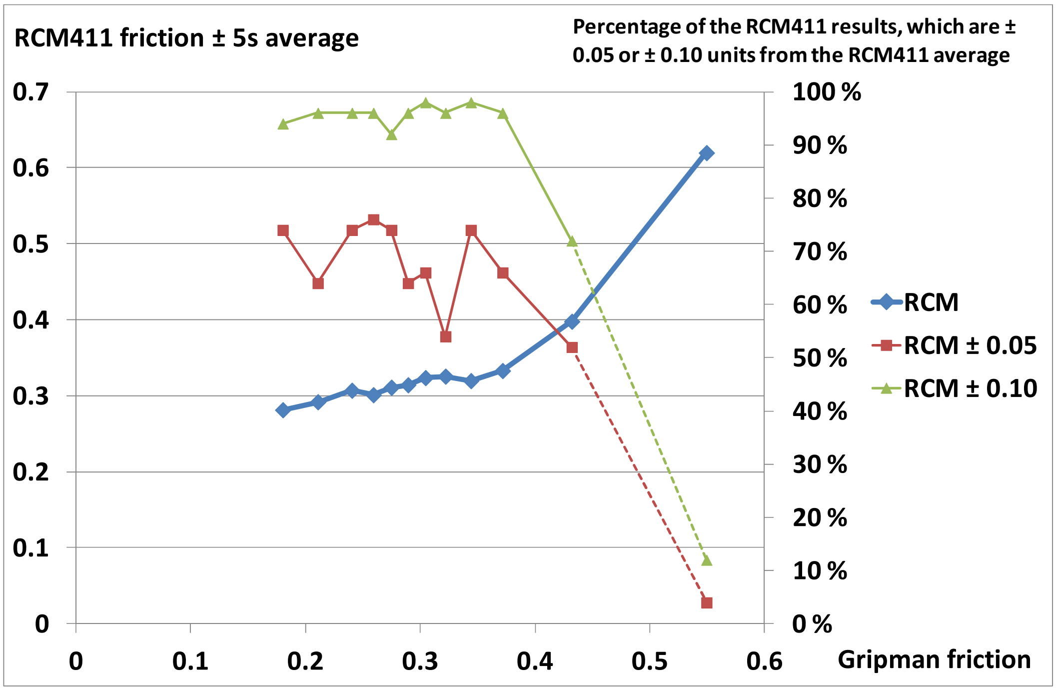



*Figure 12.* *RCM411 friction profile against Gripman. Also percentage of the RCM411 results, which are ± 0.05 or ± 0.10 units from the RCM411 average. This dispersion number is misleading in the highest friction level, because there the Gripman dispersion is already big, because of the small sample size.*

### 4.2.2 DSP310

Figure 13 shows the DSP310 friction profile and dispersion against Gripman. You can see much steeper friction profile than with RCM411, which gives good resolution especially in lower friction levels. On the other hand, the dispersion lines show much weaker dispersion. Still it's important to remember, that wide friction scale affects weaker diespersion.

When you look only highways (figure 14), you can see even sharper friction profile, but the dispersion doesn't get much better.

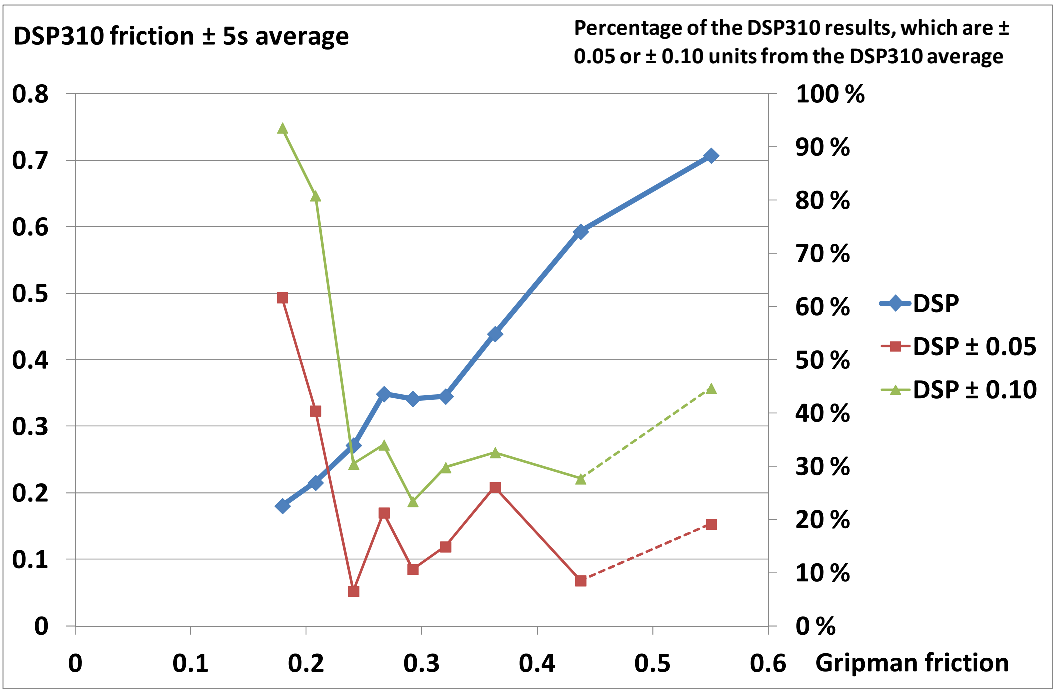



*Figure 13.* *DSP310 friction profile against Gripman. Also percentage of the DSP310 results, which are ± 0.05 or ± 0.10 units from the DSP310 average. This dispersion number is misleading in the highest friction level, because there the Gripman dispersion is already big, because of the small sample size.*

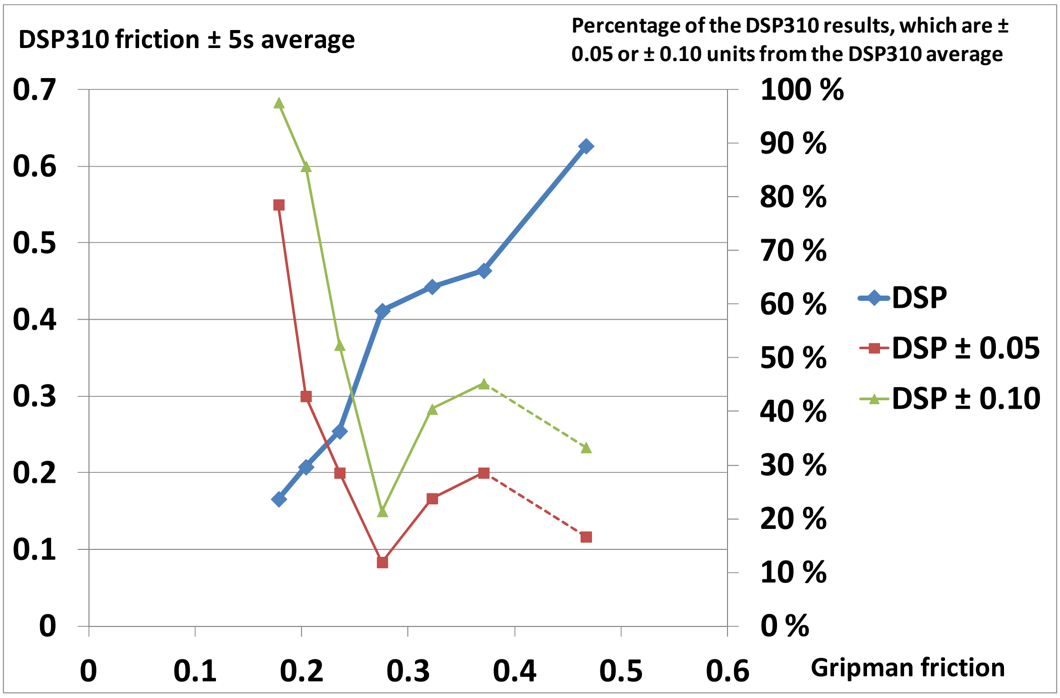



*Figure 14.* *DSP310 friction profile against Gripman. Only highways. Also percentage of the DSP310 results, which are ± 0.05 or ± 0.10 units from the DSP310 average. This dispersion number is misleading in the highest friction level, because there the Gripman dispersion is already big, because of the small sample size.*

## 4.3 Looking at running meter data

Figures 15 and 16 give a glimpse of running meter data. It's easy to see, how the friction variations are bigger with DSP310, but DSP310 shows also larger friction scale. When looking at braking friction meter results, it's important to remember, that Eltrip has been calibrated for Traffic Agency friction scale, and Gripman and µTEC for Physical friction scale (scale explanations in chapter 2.2).

Figure 15 shows the situation when there is clear friction level change. Both optical meters show the level change, but DSP310 shows higher friction values than RCM411 after the level change. According to braking friction meters, correct friction level lies somewhere between DSP310 and RCM411 values.

Figure 16 shows an interesting black ice situation. In the end the friction level arises, most with DSP310.

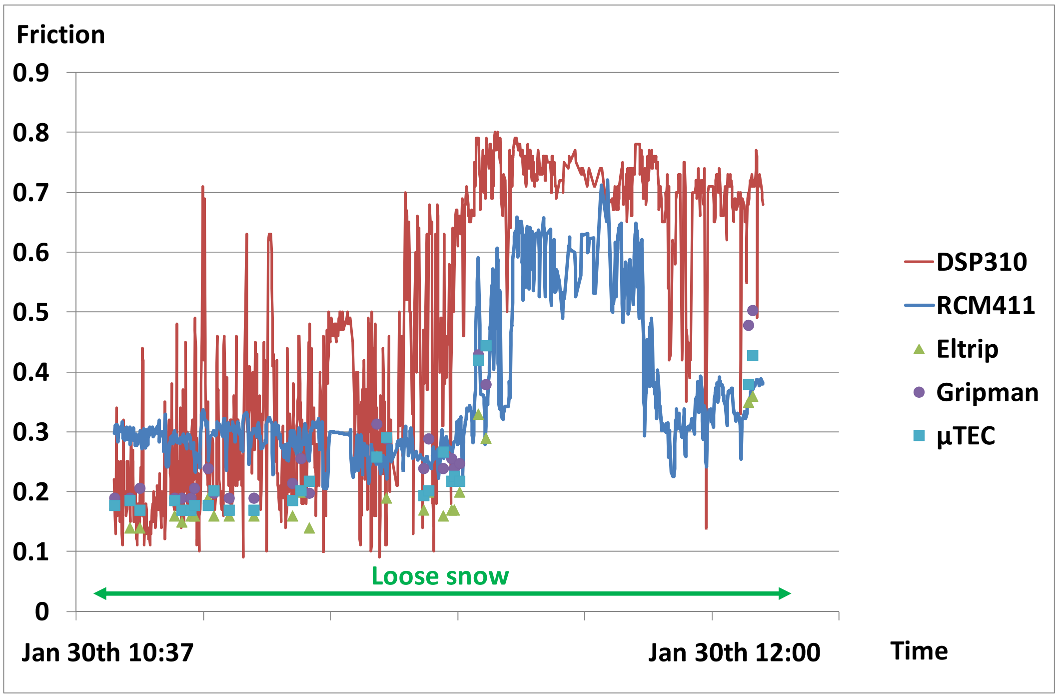



*Figure 15.* *Running meter data between January 30th 10:37 and January 30th 12:00. According to the measurement person, there were loose snow on the road surface.*

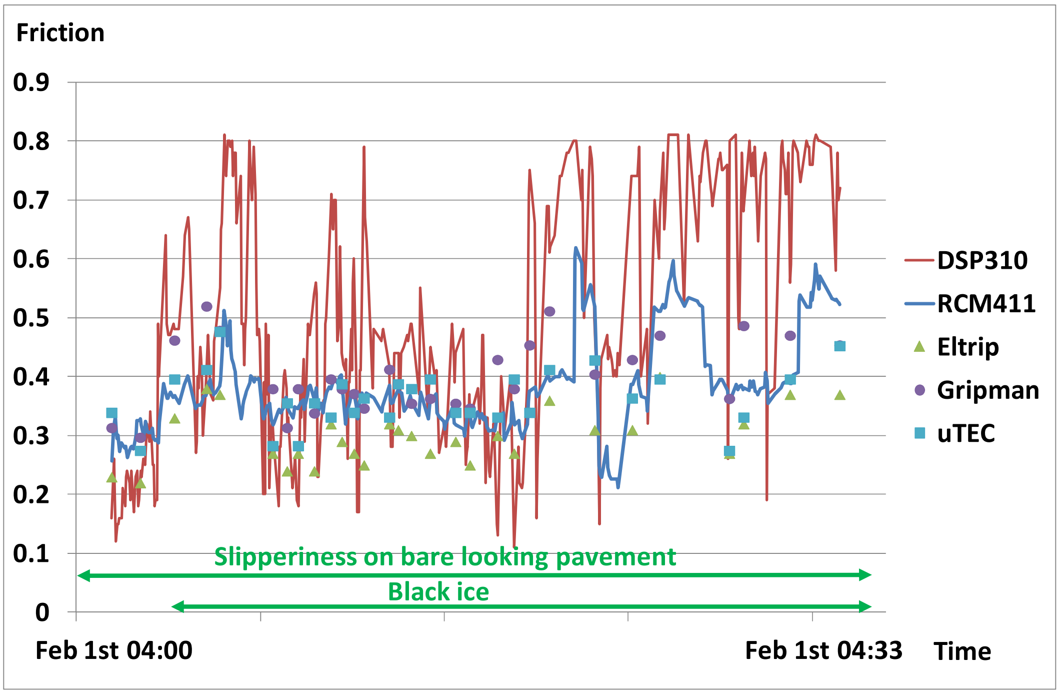



*Figure 16.* *Running meter data between February 1st 04:00 and February 1st 12:00. According to the measurement person, there were black ice almost all time.*

# 4.4 Examining other variables

### 4.4.1 Road weather condition

Both RCM411 and DSP310 record road weather condition all the time. Also the measuring person wrote down the weather condition, but the classification principles were not exactly the same (look chapter 3). In tables 2 and 3 there is comparison between measurement person road weather classification and RCM411 and DSP310 road weather classification.

The correlation between measurement person road weather classification and RCM411 road weather classification is otherwise quite good, but when measurement person classifies "loose snow" or "slush", RCM411 classifies quite often "ice" (table 2).

DSP310 records much less ice than RCM411 (table 3). There were also some occasions where DSP310 could not record the road weather at all. But when looking the big picture, correlation between measurement person classification is somewhat stronger with DSP310 than RCM411. It should still be taking into account, that

– there is no standard and no official reference for correct road weather classification

– measurement person was only able to classify road weather for long road sections, RCM411 and DSP310 give classification for every 1 or 3 seconds

– some older studies have demonstrated, that there could be even major differences in results, if there is two trained persons trying to classify road weather at the same time at the same spot.

*Table 2. Comparison between road weather classification by measurement person and by RCM411. Comparisons has been made in those moments, when also the braking friction measurements was made.*

| | RCM411 road weather | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Road weather by measurement person** | **Dry** | **Moist** | **Wet** | **Slush** | **Ice** | **Snow or frost** | **Total** | **Sample size** |
| Bumby packed snow or ice on the lane | 1 % | | | 1 % | 5 % | 93 % | 100 % | 96 |
| Loose snow | | | | 3 % | 58 % | 38 % | 100 % | 91 |
| Wide bare wheel paths on packed snow or ice | 50 % | 13 % | | | 13 % | 25 % | 100 % | 8 |
| Slipperiness on bare looking pavement | | | | 5 % | 74 % | 21 % | 100 % | 371 |
| Bare pavement | 62 % | 5 % | 5 % | 9 % | 18 % | | 100 % | 55 |
| Slush | | | | 14 % | 78 % | 8 % | 100 % | 36 |
| Smooth packed ice or snow on the lane | | | | | | 100 % | 100 % | 2 |

*Table 3. Comparison between road weather classification by measurement person and by DSP310. Comparisons has been made in those moments, when also the braking friction measurements was made.*

| | DSP310 road weather | | | | | | | | Sample |
|---|---|---|---|---|---|---|---|---|---|
| **Road weather by measurement person** | **Dry** | **Moist** | **Wet** | **Snow** | **Ice** | **Slush** | **Not known** | **Total** | **size** |
| Bumby packed snow or ice on the lane | 2 % | 0 % | 4 % | 89 % | 0 % | 0 % | 5 % | 100 % | 96 |
| Loose snow | 0 % | 1 % | 10 % | 68 % | 4 % | 5 % | 11 % | 100 % | 91 |
| Wide bare wheel paths on packed snow or ice | 57 % | 0 % | 0 % | 43 % | 0 % | 0 % | 0 % | 100 % | 7 |
| Slipperiness on bare looking pavement | 10 % | 5 % | 14 % | 50 % | 7 % | 3 % | 11 % | 100 % | 228 |
| Bare pavement | 69 % | 7 % | 9 % | 6 % | 6 % | 0 % | 4 % | 100 % | 54 |
| Slush | 0 % | 0 % | 53 % | 3 % | 0 % | 28 % | 17 % | 100 % | 36 |
| Smooth packed ice or snow on the lane | 0 % | 0 % | 0 % | 100 % | 0 % | 0 % | 0 % | 100 % | 2 |

### 4.4.2 Other road weather variables

The other road weather variables (road surface temperature, air temperature, dew point and humidity) were analyzed by comparing these measurements to road weather stations, in those occasions, when the measuring vehicle bypassed the weather station.

When measuring road surface temperature, the sun direction and shadows may have big effect to the correlation. If the road section is mainly on shadow, but the sun is just warming up the weather station spot, presumably you don't get very good correlation, because the fast moving vehicle (with optical surface temperature measurement) can't register the local difference on the warm spot.

RCM411 doesn't measure any of these road weather variables, but if you purchase road temperature sensor RTS411 with RCM411, you get both road and air temperature. The air temperature sensor of RTS411 could be placed in front of the vehicle, but unfortunately the air sensor was situated in proximity with the RTS411 behind the vehicle during the test (because the initial goal of the test wasn't air temperature testing). When the air sensor was behind the vehicle, the vehicle was warming up the air so much, that the RTS411 air temperature result were 3-5 degrees Celsius too high. Therefore the results of RTS411 air temperature measurements have not been included in the table 4.

According to table 4, RTS411 shows typically 1.2°C degrees higher road temperatures than road weather stations, but the measurements are quite consistent, because the standard deviation is 0.8°C. The DSP310 air and dew point measurements seem to have even better correlation, because standard deviation is 0.4 °C.

*Table 4. The difference between the road weather variables measured by optical devices and weather stations.*

| | **Road surface temperature** | | **Air temperat ure** | **Dew point** | **Air humidity** |
|---|---|---|---|---|---|
| | **RTS411** | **DSP310** | **DSP310** | **DSP310** | **DSP310** |
| **The median of the difference between optical devices and road weather station** | 1.2 °C | 0.2 °C | 0.2 °C | -0.5 °C | -5 % |
| **Standard deviation** | 0.8 °C | 0.8 °C | 0.4 °C | 0.4 °C | 3 % |

# 5 The measurement person's experiences of the optical meters

The measurement person (Juha-Matti Vainio from West Coast Road Masters Ltd) has over 20 years of experience of friction measurements on roads. Vainio presented following opinions after driving over 2500 kilometers with optical meters:

- Both optical devices had good technical performance and they produced data without major interruptions. The memory of Vaisala phone became full at the end of the season and I was forced to gather information from Vaisala server. It would be nice, if the user interface would inform me, when there is lack off memory space.

- The need for lens clean up was minor with both devices. I checked the lenses occasionally, and couldn't see any major dirtiness in either meters.

- Both devices were quite user-friendly, easy to use.

- I think RCM411 could have even more rigid attachment to the towing hook, because it's important that the distance between RCM411 and road surface don't vary.

- From my point of view, it's difficult to say which one of the meters is better. In some occasions RCM411 was better observing slipperiness, in some other occasions DSP310 was the better device.

- When using meters during winter maintenance spot check control, I felt, that meters helped me to find black ice situations. Therefore I think the optical meter is a great tool for quality control. But I still consider, that's it's important to verify the friction level with braking friction meter, when you are near or below the quality requirement level

- The importance of the road surface temperature measurement is, that it is possible to assess, if we are still on the road salting temperatures (if it's too cold, salt doesn't work and lower friction levels are acceptable). The accuracy of the road surface temperature measurement is still difficult for me to assess.

# 6 Summary and conclusions

The aim of the study was to assess the accuracy and functionality of the optical friction meters as the support tool for winter maintenance quality control. Additionally, the accuracy of the other road weather variables (road weather type, road and air temperature, dew point, air humidity) was analyzed.

The object of the study was Teconer Ltd's optical friction meter RCM411 and Vaisala's optical friction meter DSP310. The optical meters were compared to three different braking friction meters: Eltrip-45n, μTEC and Gripman. The measurement were carried out during 2500 road kilometers, including over 700 braking friction measurements.

According to these measurements, the accuracy of the optical meters has been improved since the tests made 2 years earlier (Malmivuo 2011). RCM411 had clearly more narrow dispersion of the friction results than DSP310. On the other hand, the friction profile of DSP310 was steeper, which is a desirable feature and helps to separate different friction levels. It should be taking into account, that steep and wide friction scale of DSP310 also automatically increases the dispersion of DSP310 results.

The accuracy of DSP310 was better on highways than minor roads. Usually DSP works better when there was less thick snow or ice layers. On the other hand, the RCM411 seemed to work on minor roads as well as on highways.

According to test person, the optical meters helped to observe black ice situations and therefore meters can be recommended as support tool for winter maintenance quality control. The accuracy demands for winter maintenance quality control are extremely high, because measured friction level could be an argument for a sanction. Therefore braking friction meters should always be used to verify optical measurements in situations, where optical devices show friction near or below the friction demands.

The accuracy testing of optical meters is extremely challenging, because comparisons to other meters should be made on roads, where road weather and friction level can vary remarkably even on short road sections. It's very difficult to position the braking friction measurements into same spot, where optical meter has measured friction. In addition, the braking friction meters measure two wheel paths, optical meters only one. Finally it must be taken into account, that there is always certain dispersion between two braking friction meters and this dispersion is increasing in nonhomogeneous road environment.

The above described problems could be minimized, if optical meters could be tested on special test tracks, where it is possible to have broad and homogeneous ice and snow surfaces. This was in fact tested two years earlier, but the optical meters were not suitable for test tracks, because the artificial circumstances of test tracks were optically highly different from real road circumstances.

There were not observed any significant dirtiness of optical meters during tests. The freedom of constant meter maintenance could mean, that meters could be attached to any vehicle traveling on road network without the need to pay for the driver for carrying the meter. This gives tremendous possibilities to use meters in winter maintenance service level measurements (chapter 1, point B), road weather information, control of variable road signs etc. It should be still noted, that in vehicles, which will be stored in warm garages, the frost and vaporization in the optics is risk when driving from cold to warm. To prevent this, DSP310 have optics warm up, and the warm up is an option for RCM411.

In the study, the road weather class reported by optical meters was compared to the class registered by measurement person. These classes seemed to correlate quite logically. RCM411 reported more often ice than DSP310. RCM411 reported ice quite often in those situations, where the measurement person registered the condition as snow or slush. It should still be noted, that there is no objective reference method for road condition classification.

Also the other road weather variables (road and air temperature, dew point, air humidity) reported by optical meters, were analyzed in the study. When comparing these measurements to the road weather stations, the biggest differences could be found with road surface temperature (about ± 1°C). But it must be noted, that road weather station is only reporting the temperature in one spot, which may be in the sun or in the shadow despite of the road section around. The DSP310 air temperature, dew point and humidity measurements seemed to be quite accurate. An accurate dew point information gives important support for the winter maintenance management.

# References

Malmivuo, Mikko 2011: Kitkamittarien vertailututkimus 2011 (Comparison study of friction meters 2011). Liikenneviraston tutkimuksia ja selvityksiä 48/2011. 80 s. + 2 liitt.