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Verification of Friction Index Prediction

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ABSTRACT

Friction on road and runway surface plays a very important role in the safety of road traffic and aircraft taking-off and landing. Loss of friction or skid resistance is closely related to incidents or accidents on the road and at the airport, especially in winter conditions when the surfaces are covered by ice, frost, snow or water. In theory, the friction coefficient (μ) is defined as the ratio of the resistive forces (Fr), a result of the movement between two opposing object surfaces, to the normal force (N) exerted on the surface. In reality, however, the coefficient is complicated and is affected by many factors, such as: tyre pressure, rubber composition, tyre tread configuration, pavement surface material composition, pavement micro- and macro-texture, pavement surface temperature and surface state etc. Such complexity was dealt with in this paper by introducing the concepts of surface texture and friction index (0.0-1.0).

In this paper, we present a numerical road weather and friction index forecast model and results of verification of that model. The data for verification was obtained from Helsinki International Airport. The model was run up to 3 hours ahead, in hourly automatic modes with forecasting output at 10-min intervals. Verification of the model considered both the meteorological variables (pavement surface temperature, water thickness on the surface, air temperature, dew point etc) and the friction index. The comparison between forecasts and measurements, with thousands of samples, showed that both bias and RMS errors of the meteorological variables and friction index forecasts were suitably small; with the overall friction forecasting bias being slightly negative and the RMS error falls in the range of 0.24 to 0.26 for the nowcasts of FI 1 to 3 hours ahead.

Keywords: Road surface, Temperature, Ice, Friction

1 INTRODUCTION

The Vaisala Friction Index (FI) is the friction measured at a speed of 60kmhour^{-1} on a concrete surface. It is given a value from 0 to 1.0 with 0 being no friction between tyres and the surface and 1 being the highest possible friction. The interval of most interest is between 0 and 0.3, as times of minimal friction are closely related to accidents on roads and at airports. This low friction is usually associated with the surface being covered in ice, frost, snow or water, but can equally be a result of oil or other chemical substances spilt on the surface.

The IceBreak model was developed in 1990's as an automated nowcasting (≤6 hours lead time) or non-automated forecasting (>6 hours lead time) model of surface temperature and state [1]. It is recently further developed to generate a forecast FI of a road or runway. In the recent study, the model used solely automatically collected sensor measurements of current weather and surface condition from the test site (i.e. no external meteorological forecast data to IceBreak), and produced nowcasts of up to three hours for the site. This paper shows the results of comparison between the nowcasts and measurements of the FI. It is hoped that the prediction of FI will give a quantitative measure of road slipperiness in order to improve road safety. It will also help Decision Support System (DSS) to decide optimum level of chemicals application and necessary action to take without compromise of safety and waste of valuable resources [2].

2 TEST SITE

The validation of the prediction model was carried out using past data from Helsinki-Vantaa Airport. The airport is a civil airport with three runways, the third being the latest addition to the airport in 2002. Runways 1 and 3 are parallel, 1350m apart. Runway 2 runs at an angle to the other runways and crosses Runway 1 at 2900m (see Figure 1). The airport is at 54.6m elevation and receives regular snowfall during the winter months.

Figure 1. Layout of Helsinki-Vantaa Airport with runways divided into sections and the approximate location of the ROSA weather station marked

2.1 Meteorological data

The data used in this study covered 55 days in total, during the months of February and March 2007, with a maximum of 22 days of consecutive data. The meteorological data needed to run the model came from a ROSA weather station located in the middle of runway three. The ROSA Weather station took readings every minute of air temperature, dew point temperature, freezing temperature, surface temperature, ground temperature at 6cm in depth, precipitation status and intensity, surface water thickness, chemicals on the surface and the state of the surface. The observations on surface state and surface and ground temperature were gained using a Vaisala runway surface and depth sensor, DRS511. The model used the data at 10 minute intervals, with the addition of calculated estimation of wind speed, visibility and cloud coverage and type by the model itself, in order to produce the nowcasts.

2.2 Friction measurements

The friction data needed for comparison came from the airports SNOWTAM system. SNOWTAM is a system used internationally by airports. It is a message describing the conditions of the runways, taxiways and apron at the airport. It consists of several different fields, each assigned a letter, and the information is almost entirely given in code. The SNOWTAM for Helsinki-Vantaa Airport records the braking action across the whole airport, measured at irregular intervals (average interval time around 25 minutes) using a high pressure tyred skiddometer. The SNOWTAM broke each runway down into thirds and gave the average braking action for each third of each runway. The breaking action, when measured with the skiddometer, was given as an integer from 1 to 100, with greater than 40 being good friction; 39 to 36, medium/good friction; 35 to 30 medium; 29 to 26 medium/poor and finally less than 25, poor friction. The breaking action integer recorded was simply one hundred times the FI that the IceBreak model outputs. In the cases where braking action was predicted rather than measured, a single digit was given for each section of the runway. The digits used for estimated friction were as follows: 5 – Good Friction; 4 – Medium/Good; 3 – Medium; 2 – Medium/Poor; 1 – Poor; 9 – Unreliable. If unreliable was recorded, the runway contamination was outside the approved range of whatever equipment was used to measure the braking action. The comparison for the model was limited because it could not process the measured and estimated friction as different values. So in cases where both the estimated and observed values of friction were good and the correlation between them have been strong, the comparison results are showed herewith. As well as recording friction the SNOWTAM file also contained information on runway contamination and the depth of this contamination.

3 THE MODEL

The IceBreak model used in this study is based on unsteady one-dimensional heat conduction within the road sublayers, together with calculation and projection of initial and boundary condition for the model. The governing equation of the model is

$$C\frac{\partial T}{\partial t} = \frac{\partial}{\partial z}(\kappa\frac{\partial T}{\partial z})$$

where, C is the heat capacity, κ is the thermal conductivity, and T(z, t) is the temperature at time t and depth z. It is assumed that the road surface and its underlying sublayers are horizontally homogeneous so that heat transfer in a lateral direction can be neglected.

To run the model, an initial condition, and upper and lower boundary conditions are needed. The initial thermal condition prescribes the temperature profile within the road sublayers. The lower boundary condition (usually at a 1 m depth) is treated as a climatological constant. The upper boundary condition is, however, described by a time-dependent energy balance equation

$$(1-\alpha)S + L + H + LE + G = 0$$

where, S is the solar irradiance, α is the surface albedo, L is the net longwave irradiance, H and LE are the sensible and latent heat flux densities, and G is the ground conductive heat flux density.

The model is run by ingesting sensor measurements in the past at the forecast site. One valuable feature of the model is that unlike many other models that require human intervention (e.g., for providing meteorological inputs), the model depends only on sensor measurements and is fully automatic. It will generate (three or six hours ahead) forecasts of road or runway surface temperature, surface state (dry, wet, icy, snow, etc.) and water thickness on the surface once sensor data are available or updated. The model can easily be re-run every time that new observations are available. Based on these forecasts, the FI is then calculated.

4 VERIFICATION RESULTS

4.1 Prediction of meteorological variables

The 3-hour ahead forecast surface temperature, air temperature, dew point and water thickness were compared against actual observations at the test sites. The bias and standard deviation of each forecast are displayed in Tables 1, broken down so they are available for each hour of the day. It is clear from the results that the model appeared to be performing best late at night and early morning, i.e. when the temperatures were coolest. As nowcasting period increases from 1 hour to 3 hour, there is increase in the bias and the standard deviation between the observed and predicted parameters. This is clearly seen in Table 2 which shows the absolute error, bias, standard deviation and root mean square as an average for the parameters during all hours of the day for the 1, 2 and 3 hour nowcasts. The bias and absolute error show the least increase as the nowcasting period increases, whereas there is a more obvious significant change in the standard deviation and RMS. The negative biases for each temperature show that the model forecast is colder than the actual observation. This may lead to the overprediction of the ice state of the surface in wet conditions and thus a lower FI forecast than is observed.

Generally it is seen from Table 2 that the biases of the forecasts of air temperature, dew point and water thickness are negligible, and the standard deviation from the observed is just over 1ºC for the final 3 hour nowcast of both temperatures, and is only 0.08mm for the water thickness. The surface temperature is less well forecast and shows a significant deterioration of accuracy as the now casting period increases.

Hour of Day	Number of Samples	Surface Temperature (ºC)		Air Temperature (ºC)		Dew Point (ºC)		Water thickness (mm)	
		Bias	SD	Bias	SD	Bias	SD	Bias	SD
0	359	-0.02	0.75	-0.02	0.84	-0.05	0.82	0.06	0.09
1	360	-0.04	0.88	-0.06	1.05	-0.09	1.06	0.07	0.09
2	360	0.00	0.92	-0.02	1.09	-0.08	1.18	0.07	0.08
3	358	0.02	0.84	0.04	1.00	-0.08	1.17	0.08	0.08
4	360	-0.19	0.89	0.03	1.04	-0.09	1.17	0.08	0.08
5	360	-1.05	1.56	-0.11	1.02	-0.22	1.03	0.08	0.08
6	360	-2.23	2.36	-0.13	1.07	-0.21	1.14	0.07	0.08
7	360	-3.15	2.75	-0.08	1.20	-0.03	1.49	0.06	0.09
8	360	-3.76	3.06	-0.02	1.22	-0.02	1.55	0.05	0.08
9	360	-4.10	3.37	-0.05	1.27	-0.07	1.55	0.03	0.08
10	360	-3.45	3.52	-0.10	1.31	0.03	1.63	0.02	0.07
11	360	-2.18	3.02	-0.06	1.14	-0.01	1.58	0.01	0.07
12	360	-0.76	2.51	-0.06	0.95	-0.02	1.46	0.00	0.07
13	360	0.67	2.02	-0.09	0.84	-0.04	1.33	0.00	0.06
14	360	1.69	1.74	-0.10	0.87	-0.09	1.29	0.00	0.07
15	360	1.99	1.60	0.02	1.05	-0.05	1.23	0.01	0.07
16	360	1.85	1.68	0.14	1.08	0.00	1.34	0.02	0.07
17	360	1.33	1.63	0.10	1.04	-0.21	1.43	0.03	0.08
18	360	0.71	1.35	-0.10	0.99	-0.27	1.25	0.03	0.08
19	360	0.31	1.13	-0.15	1.08	-0.17	1.05	0.04	0.08
20	360	0.14	0.91	-0.05	1.05	-0.07	1.02	0.04	0.08
21	367	0.11	0.75	0.02	1.01	-0.03	1.04	0.05	0.09
22	366	0.06	0.65	0.00	0.88	-0.08	0.92	0.05	0.09
23	366	0.01	0.74	0.04	0.85	0.01	0.77	0.06	0.09

Table 1. Comparison of 3 hour predicted surface temperature, air temperature, dew point and water thickness for all sections of all runways, for each hour of the day

	1 Hour				2 Hour				3 Hour			
	Absolute Error	Bias	SD	RMS	Absolute Error	Bias	SD	RMS	Absolute Error	Bias	SD	RMS
Surface Temperature (ºC)	1.04	-0.33	1.70	1.74	1.37	-0.43	2.19	2.23	1.64	-0.50	2.58	2.63
Air Temperature (ºC)	0.32	-0.02	0.49	0.49	0.50	-0.03	0.76	0.77	0.69	-0.03	1.05	1.05
Dew Point (ºC)	0.36	-0.03	0.61	0.61	0.57	-0.05	0.94	0.94	0.77	-0.08	1.25	1.26
Water thickness (mm)	0.07	0.04	0.08	0.09	0.08	0.04	0.08	0.09	0.07	0.04	0.08	0.09

Table 2. Comparison of predictions of meteorological inputs to sensor measurements for 1, 2 and 3 hour nowcasts

4.2 Prediction of FI

Forecast FI was compared to observed FI for each section of runway three where ROSA is located. The comparison covers 1, 2 and 3 hour nowcasting period. The model was run once every hour with a 10-minute output interval. Table 3a shows the comparison of forecasted friction against observed braking action, on each of the sections of runways three for the 1, 2 and 3 hour nowcasts. It is seen from the table that the absolute error, standard deviation and root mean square error increases slightly with increase of nowcasting period.

Table 3b demonstrates the results of comparison of observed FI when it is less than 0.3. It can be seen from the table that the trend in the pattern of the errors is very similar to the overall results for all forecasted FI. Noticeably, he errors associated with the <0.3 FI threshold are much smaller than those related to larger FI. However, number of samples available for the comparison when measured FI<0.3 is much smaller than the number in overall comparison. This distinct lack of data is due to the fact that skidometer did not measure the braking action when there is lying snow on the runway, and thus did not give many measurements of low FI. Even so, the near zero errors and biases presented in Table 3b are encouraging, as this is the threshold of particular interest as this is where the driving, landing and taking off conditions became risky and winter road maintenance is crucial. Comparison of forecast and measured FI when FI=0.3 to 1.0 is shown in Table 3c. Because of dominant number of samples in the FI band, the results are very similar to those in Table 3a.

		1 Hour					2 Hour					3 Hour				
		Samples	Absolute Error	Bias	SD	RMS	Samples	Absolute Error	Bias	SD	RMS	Samples	Absolute Error	Bias	SD	RMS
RWY 3	S1	1978	0.18	-0.07	0.23	0.24	3623	0.20	-0.08	0.24	0.25	5293	0.20	-0.08	0.24	0.26
	S2	1978	0.18	-0.07	0.23	0.24	3623	0.20	-0.07	0.24	0.25	5293	0.20	-0.07	0.25	0.26
	S3	1978	0.18	-0.07	0.22	0.24	3623	0.20	-0.08	0.24	0.25	5293	0.20	-0.08	0.24	0.26

Table 3a. Comparison of forecasted friction against all observed braking action, on three individual sections of runway three, for 1, 2 and 3 hour nowcasts

		1 Hour					2 Hour					3 Hour				
		Samples	Absolute Error	Bias	SD	RMS	Samples	Absolute Error	Bias	SD	RMS	Samples	Absolute Error	Bias	SD	RMS
RWY 3	S1	15	0.02	-0.01	0.02	0.02	33	0.03	-0.02	0.02	0.03	53	0.04	-0.02	0.04	0.05
	S2	13	0.03	-0.02	0.02	0.03	29	0.03	-0.02	0.02	0.03	47	0.03	-0.01	0.04	0.04
	S3	20	0.06	0.02	0.11	0.12	38	0.05	0.02	0.09	0.09	56	0.05	0.03	0.08	0.08

Table 3b. Same as Table 3a, but for the cases when the observed friction <0.3

		1 Hour					2 Hour					3 Hour				
		Samples	Absolute Error	Bias	SD	RMS	Samples	Absolute Error	Bias	SD	RMS	Samples	Absolute Error	Bias	SD	RMS
RWY 3	S1	1963	0.18	-0.07	0.23	0.24	3590	0.20	-0.08	0.24	0.25	5240	0.20	-0.08	0.25	0.26
	S2	1965	0.19	-0.07	0.23	0.24	3594	0.20	-0.07	0.24	0.25	5246	0.21	-0.07	0.25	0.26
	S3	1958	0.18	-0.07	0.22	0.24	3585	0.20	-0.08	0.24	0.25	5237	0.20	-0.08	0.24	0.26

Table 3c. Same as Table 3a, but for the cases when the observed friction is 0.3 – 1.0

Figure 2 takes a more general look at the correlation between the observed and predicted values of the FI for 3-hours respectively on section 1 of runway 3. Here the observed braking action from the skidometer is plotted against the forecast FI from the IceBreak model. The observed friction data is reasonably well spread between the values of 0.2 and 1.0, but we are lacking of data in the crucial 0 to 0.3 threshold for the reason we explained before. The forecasted FI shows a noticeable step like function, particularly in the higher values of friction. Also, there is a very significant gap between the forecasted FI 0.55 and 0.79, where the model appears unable to predict in this particular interval. The step like function and the reasons for the gap lie in the model using the surface state to calculate the FI. The surface state outputs of the model are confined to: dry, wet (no present precipitation), wet (with precipitation), light dew, heavy dew, light frost, heavy frost, ice and snow. The gap in the model relates to surface state changing from wet to dry. As the model is unable to predict a surface state where a little moisture is present but a reasonably good level of friction remains, the surface state is restricted to either being classified as "wet" or "dry" depending on the level of water present on the original ROSA sensor, and thus the forecasted FI is restricted to a certain set of values depending on the surface state.

Looking back at Figure 2 again, there is a positive correlation between forecast and observed data. Wide scattering of sample points in the figure means that the model appears to predict lower values than necessary for the friction when actual FI was high (under-prediction), and higher values when actual friction is low (over-prediction). The under-prediction can be attributed in part to the forecast FI relying on the predicted surface state in its calculation. The IceBreak model is unable to forecast the treatment or amount of chemicals on the runway that would lower the freezing temperature and thus prevent the build up of ice or frost on the surface. As a result of this, the model will predict the treated surface to be in an icy condition and assign a low FI accordingly, where the actual state is wet with a reasonably high FI due to chemicals. The over-prediction is an area that requires further improvement.

The average frequency distribution of the differences between forecast and observed FI for all runways and all sections are displayed on Figure 3. The largest portion of prediction errors is in the -0.15 to 0.00 range, although there is also a band of large errors, particularly in the 2 and 3 hour nowcasts, in the 0.10 to 0.25 range, and another smaller peak between -0.55 and -0.40. Generally, the percentage of errors recorded for the 1 hour nowcasts is greatest in the -0.15 to 0.00 range and falls away at both sides, and the pattern is similar to 2 and 3 hour nowcasts. In the -0.15 to 0.00 band, 36.0% of FI for the 1 hour nowcast, 33.9% of FI for the 2 hour nowcast, and 32.3% of FI for the 3 hour nowcast fall into this band. At the other peaks in the graph, 18.9%, 19.9% and 20.9% of forecast FI fall into the 0.10 to 0.25 range respectively for 1-, 2- and 3-hour nowcasts. Finally, for the -0.55 to -0.40 range, the percentages are 9.6%, 10.9% and 10.9% respectively. This shows again that the differences between forecast and observed increase as the nowcasting period increases.

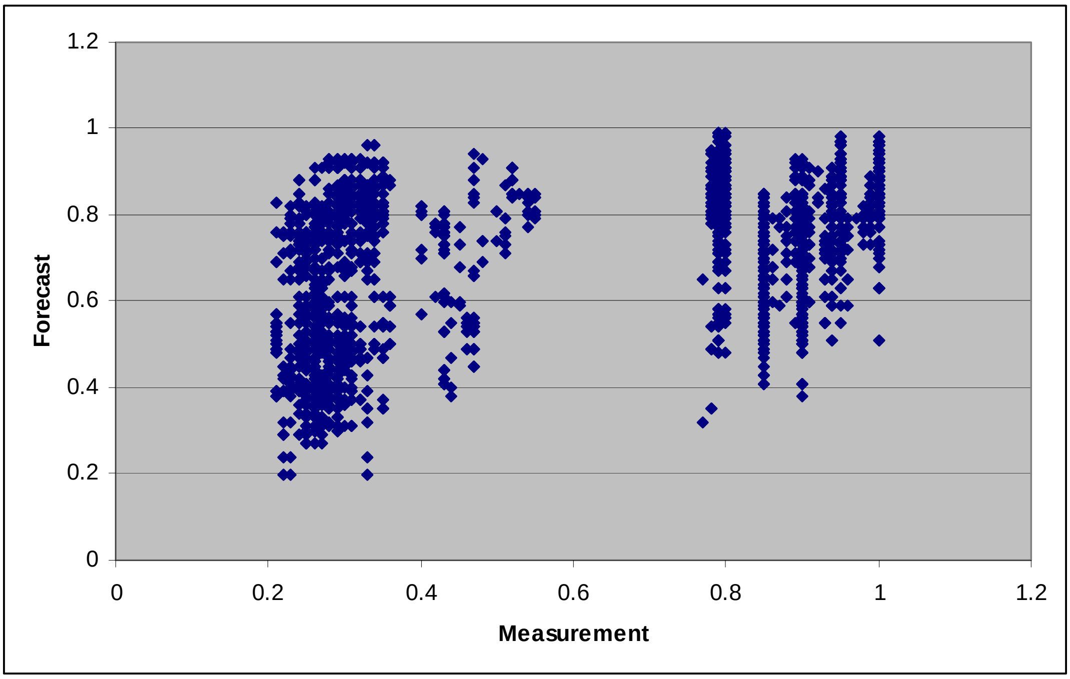

Figure 2. Forecasts of FI 3-hour ahead against measurements

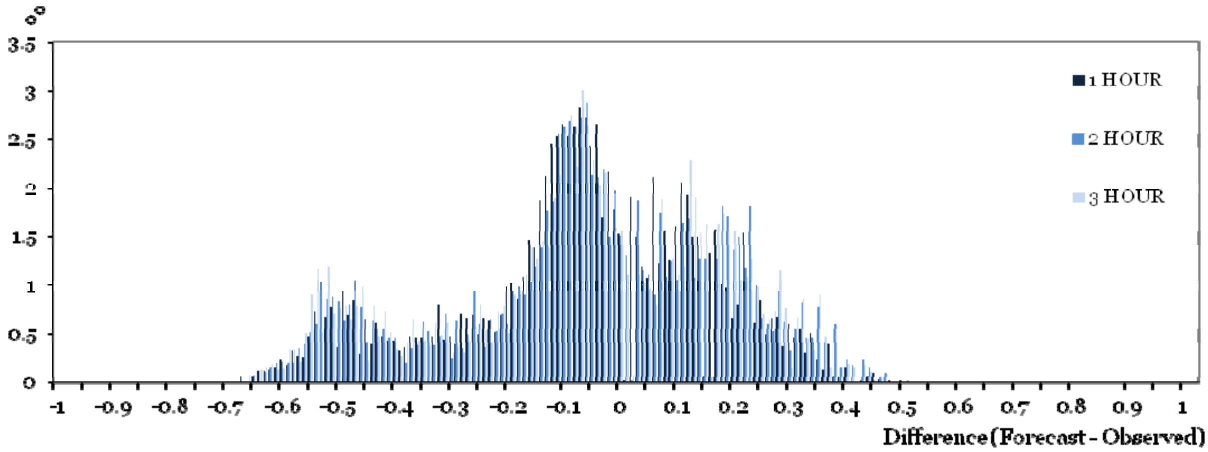

Figure 3. Distribution of difference between the forecast FI and observed friction for 1, 2 and 3 hour nowcasts

5. SUMMERY AND DISCUSSION

Tests carried out at Helsinki-Vantaa Airport showed that the IceBreak model produced near zero biased and acceptable standard deviations for 1 to 3 hour nowcasts of runway surface temperature, air temperature, dew point, and water thickness. The nowcasts of FI were slightly negative biased and standard deviation varies between 0.22 and 0.26. Although the accuracy of FI nowcasts appears impressive when the observed index fell below 0.3, the number of samples for the comparison may be too small to be statistically significant. More data are needed to enhance the comparison and to improve accuracy of the prediction.

One particular error in the forecast arises as a result of it dependency on the forecast surface state, particularly on the inability of the model to forecast a surface state between 'dry' and 'wet'. If a surface state is midway between these two categories, the model may not be able to predict the surface friction with a FI between 0.55 and 0.79. Another situation to consider is when chemicals have been used to prevent build-up of ice on the runway. The model is unable to predict the existence of chemicals on the runway, and as such, it is obviously unable to forecast their presence and the effect that may have on surface state on runways. These two situations lead to poor FI prediction when surface state is between dry and wet, and when chemicals exist on runway.

Overall, the prediction FI by the IceBreak model will be a useful aid to winter runway and road maintenance decision making. If the model is able to take into account the amount of chemicals already present on the runway, it will reduce the number of cases where low FI were predicted and the observed were much higher and therefore reduce the amount of waste resources caused by treating a surface that was not in danger of producing poor surface conditions.

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