A MODEL FOR ADJUSTING SCRIM SKID RESISTANCE DATA TO REFLECT SEASONAL VARIATION

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ABSTRACT

The SCRIM (Sideway-force Coefficient Routine Investigation Machine) is the most common type of sideway-force device used to measure pavement skid resistance at network level. Countries in Europe currently using sideway force systems include the United Kingdom, Ireland, Belgium, France, Italy, Spain, Germany and Denmark. The SCRIM machine has been used in Ireland since 1985.

The skid resistance of a road pavement fluctuates throughout the year. This seasonal variation can have a significant effect on the level of frictional resistance provided by a pavement surface. Typically, "in season" (summer) testing is specified between May and September. For measurements made during the winter period from October to April, it is recommended that a standard seasonal correction factor is applied to adjust the data to the expected values during the summer period.

This paper presents a research study of skid resistance data collected throughout each year over a five year period using SCRIM. The variation in skid resistance was monitored in Ireland using a 7.2 kilometre control circuit for two different asphalt surfaces, a surface dressing and hot rolled asphalt. The data set comprises almost 55,000 data points (averaged over 50 metre intervals) collected from 2005 to 2010. The paper looks at the effect of seasonal variation (between years and during each year) on skid resistance for the six years of data and develops a model to correct for seasonal variation based on the influencing factors of surface type, temperature and accumulated rainfall rather than the calendar time of year.

Keywords: SCRIM, Skid resistance, Seasonal variation, Temperature, Accumulated rainfall

1. INTRODUCTION

The measurement of pavement skid resistance is of critical importance to highway agencies worldwide. The Sideway-force Coefficient Routine Investigation Machine (SCRIM) is the most common type of sideway-force device used to measure pavement skid resistance at network level. Countries currently using sideway force systems include the United Kingdom, Ireland, Belgium, France, Italy, Spain, Germany and Denmark in Europe, Australia and New Zealand, and Singapore and Malaysia in Asia. The SCRIM machine has been used in Ireland since 1985.

There are many factors that affect the skidding resistance of a pavement surface including wet or dry conditions; speed; seasonal variation, including temperature and rainfall; and age, type and contamination of the road surface [(1) (2)]. The skid resistance of a road pavement fluctuates throughout the year. As seasonal variation has a significant effect on the level of frictional resistance, typically, "in season" (summer) SCRIM testing is specified between May and September. For measurements made during the winter period from October to April, it is recommended that a seasonal correction factor be applied to adjust the data to the expected values for the summer period. This paper presents the findings of research based on six years of SCRIM data, for four different surface types, that account for the seasonal variation effects on skid resistance in terms of temperature and rainfall.

The variation in skid resistance was monitored on a 7.2 kilometre control circuit with two different asphalt surfaces, a surface dressing and hot rolled asphalt. The data set comprises almost 55,000 data points (averaged over 50 metre intervals) collected from 2005 to 2010.

2. SCRIM OPERATION IN IRELAND

The SCRIM machine operates by applying a freely rotating fifth wheel with a smooth tyre, at an angle of 20 degrees to the direction of travel, onto the wetted road surface under a known load. The sideway-force developed at right angles to the plane of the test wheel generated by the resistance to sliding is related to the wet road skid resistance of the surface. The ratio of the sideway-force to the vertical load on the wheel is the sideway-force coefficient (SFC), which is continuously measured with the average for each 10 metres section being recorded. In Ireland, the skid resistance is measured in the left-hand wheel path and the standard test speed is 50 km/hr.

The SCRIM data used in the study was collected by PMS Pavement Management Services Ltd. (PMS). The SCRIM was operated, calibrated and maintained by PMS in accordance with specified standard conditions [(3) (4) (5) (6) (7)]. The SCRIM machine was serviced annually by the manufacturer and had successfully passed the UK Highways Agency correlation trial at the TRL for each year of this study. Accordingly, the factors affecting SCRIM measurements, e.g. tyre wear, calibration, water flow and tracking, were minimised [(8)].

When the SCRIM returns from the annual UK correlation trial, it is used regularly for the rest of the year and the possibility of the apparatus going out of calibration prevails at all times. To overcome this possibility, the SCRIM is calibrated regularly on a control circuit throughout the year. Immediately on the return of the SCRIM machine from the UK correlation trial, a calibration run is carried out on the control circuit. Repeat runs on this circuit are carried out typically on a weekly basis that have established SFC values that would be expected at any time of year. When there is disagreement between the measured values and the expected values, it is possible to identify the source for the difference and to take remedial action.

3. CONTROL CIRCUIT

Figure 1 shows an overall view of the control circuit used in the study. The control circuit is located close to the west coast of Ireland just east of Galway City. The circuit is divided into four distinct segments as shown in Table 1. The circuit comprised: three sections of National Primary road, two sections on the N6 (reclassified the R446 in 2011) and one section on the N18, and one section on the R339 regional road. The SCRIM calibration runs were performed in an anti-clockwise direction.

The control circuit had two different asphalt surfaces: a surface dressing and hot rolled asphalt. The surface type on the N18 (Segment 1) and the R339 (Segment 2) sections was surface dressing, and the surface type on the two N6 sections (Segments 3 and 4) was hot rolled asphalt.

The prediction model in this study was developed using the five years of data from 2005 to 2009 using all four segments, and was tested on the data collected in 2010 on Segments 2 and 4, as the circuit was interrupted on Segments

1 and 3 during 2010 with the construction of the M6 motorway from Galway to Dublin. With the construction of the new motorway, the N6 was reclassified as a regional road (the R446) in 2011.

Figure 1: Overall View of the Control Circuit Showing Segments 1 to 4

Table 1: Segment Description

Segment	Road ID	Lane	Surface Type	Segment Type	Segment Length
1	N18	Northbound carriageway	Surface Dressing	SD1	1000 m
2	R339	Westbound carriageway	Surface Dressing	SD2	2750 m
3	N6 (reclassified R446)	Southbound carriageway	Hot Rolled Asphalt	HRA3	1150 m
4	N6 (reclassified R446)	Eastbound carriageway	Hot Rolled Asphalt	HRA4	2300 m

4. SEASONAL VARIATION

The skid resistance of a road pavement fluctuates throughout the year due to seasonal variation and is typically greater in winter than in summer. The magnitude of the seasonal variation and the time at which the maximum and more importantly minimum SFC values are reached vary from year to year [(1)]. Results for 11 years (1958 – 1968) of data collection in the south east of England have shown that not only is there within year variation but also that there is between year variation depending on whether or not the summer is wetter or drier than average and the severity of the previous winter [(1)].

The main difference between summer and winter conditions relates to changes in microtexture. During dry summer conditions, SFC values increase as traffic polishes the aggregate faces using road surface detritus ground to a fine powder that acts as a polishing medium. The opposite effect results in the winter months when, under wet conditions, the surface rainwater washes away the dust and facilitates larger particles to scratch the polished surface after the summer and, thereby, restore the skidding resistance [(9)]. In addition, the presence of salt and grit works to improve and roughen the microtexture in wet winter conditions [(10) (11)].

To overcome the problem of seasonal variation, it has been the practice in the UK and elsewhere to measure SFC in the summer months only (May to September) [(7) (12)]. For measurements made during the winter period from October to April, it is recommended that seasonal correction factors be applied to adjust the data to the expected values during the summer period. However, in Ireland as with many other countries, whether due to global warming or other factors, there is no longer a simple cyclical pattern of warm dry summers followed by cold wet winters; there are increasingly wetter summers and drier winter periods, and significant changes in weather patterns with greater variation of rainfall and temperature occurring from year to year. In practice, the minimum skid resistance varies from year to year and occurs during different periods, depending on the prevailing weather conditions [(7)].

The data recorded in this study have shown that the minimum SFC value can be attained early or late in the year, outside of the May to September summer season, depending on weather conditions. Evidence of this for the data collected on the control circuit from 2005 to 2010 is shown in Figures 2 and 3 for Segments 1 and 4, respectively. For example, the SFC values recorded for the surface dressing on Segment 1 in the Spring and Autumn of 2007 were 0.61 in March and April, 0.57 in October and 0.59 in November, where the mean summer SFC was 0.61. For the hot rolled asphalt on Segment 4, the SFC values recorded in the Spring and Autumn of 2007 were 0.52 in April, 0.49 in October and 0.51 in November where the mean summer SFC was 0.51. The occurrence of lower skid resistance in the earlier and later part of the year was also noted in a previous study [(13)]. In these circumstances, the use of a seasonal adjustment based on time of year would lead to erroneous estimates of the SFC values. The object of the study was to develop a model to adjust SFC based on the influencing factors of surface type, rainfall and temperature rather than calendar time of year.

5. DEVELOPMENT OF THE MODEL

In the study, multiple linear regression [(14)] was used to perform the statistical analysis of the data matrix to construct a prediction model to relate the response variable (SFC) to the input variables of surface type, temperature and accumulated rainfall. The response variable SFC is quantitative in nature. The input variables (regressors) of temperature and rainfall are quantitative input variables. The input variable, surface type, is a qualitative input variable or factor. The factor segment type is treated as a fixed effect factor. The four different segments types SD1, SD2, HRA3 and HRA4, as designated in Table 1, are converted into indicator variables, using 1, 0 for the presence or absence of each surface type.

The regression model developed to take account of the effects of the different variables can be expressed in the standard form, $SFC = \beta_1 x_1 + \beta_2 x_2 \ldots \beta_n x_n$, as

Speed Corrected SFC = β_1Segment-Type_SD1 + β_2Segment-Type_SD2 + β_3Segment-Type_HRA3 + β_4Segment-Type_HRA4 + β_5Avg._Temp + β_6Accum._Rainfall,

where:
β - the effects of the regression coefficients of the corresponding variables
and using the indicator variables of 1 and 0 for the presence or absence of each surface type.
Segment-Type_SD1= 1 if an observation is taken with SD1 and is 0 otherwise;
Segment-Type_SD2 = 1 if an observation is taken with SD2 and is 0 otherwise;
Segment-Type_HRA3 = 1 if an observation is taken with HRA3 and is 0 otherwise, and
Segment-Type_HRA4 = 1 if an observation is taken with HRA4 and is 0 otherwise.

There was no evidence of interactions between segment type, temperature and accumulated rainfall. For this study, hypothesis testing with a level of significance, α , equal to 0.05, corresponding to a 95% confidence interval, was used to determine whether a P-value was significant or not [(14)]. The coefficient of determination, R^2, was used to report the percentage of variation in the data of the response variable that can be explained by the regression equation fitted to the data [(14)]. The PRESS (predicted residual sums of squares) statistic [(14) (15)] was used in regression analyses to summarise the fit of a particular model to a sample of observations that were not used to estimate the model parameters.

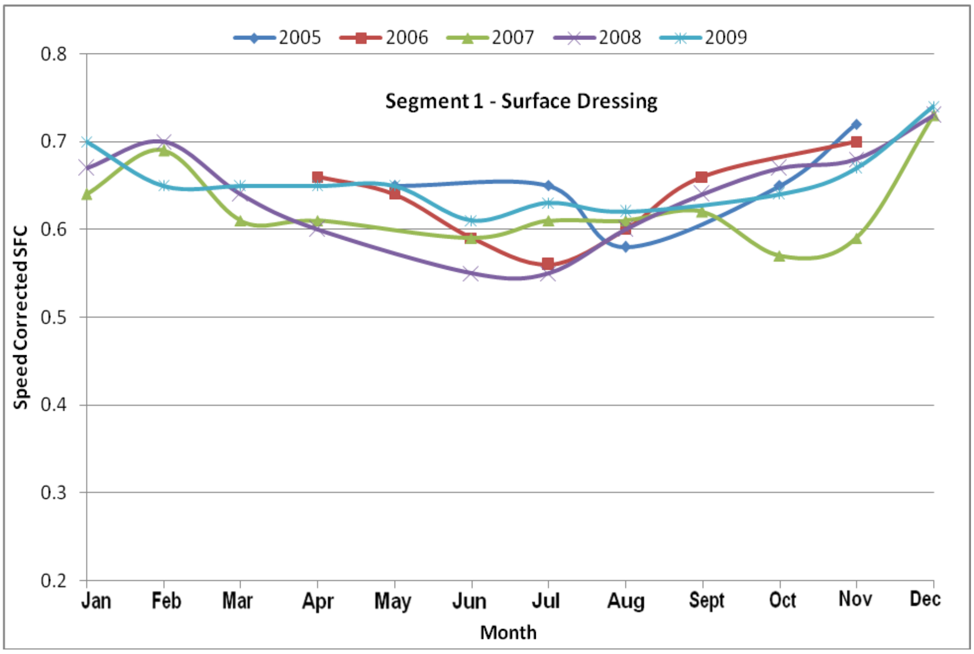

Figure 2: Monthly Average SFC for Segment 1 (Surface Dressing) from 2005 to 2009

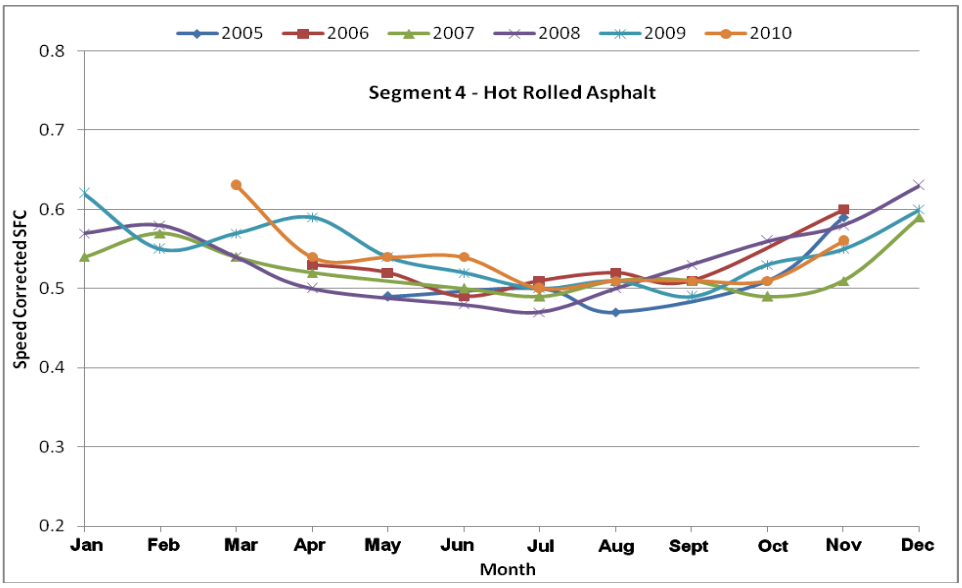

Figure 3: Monthly Average SFC for Segment 4 (Hot Rolled Asphalt) from 2005 to 2010

6. RESEARCH DATA USED IN THE STUDY

6.1. TEMPERATURE AND RAINFALL DATA

The daily weather data for the study were provided from a weather station located at the National University of Ireland, Galway, which is 5km west of the SCRIM control circuit. The average air temperatures were the averages of the daily minima and maxima recorded using thermometers placed in a Stevenson Screen. In general, this level of information is not available to the SCRIM operator; current international specifications [3, 4] do not specific how weather data, which are required, should be recorded under actual measuring conditions.

Temperature affects the stiffness of the asphalt surfacing and the resilience of the rubber test tyre on the SCRIM machine [1]. The record of the daily minima, maxima and average temperature from 2005 to 2010 is shown in Figure 4.

The pattern is similar from year to year excepting the very cold winters experienced in 2009 and 2010. From 2005 to 2010, the maximum temperature reached was 30°C, the minimum temperature was -15°C and the overall average air temperature was 10.4°C.

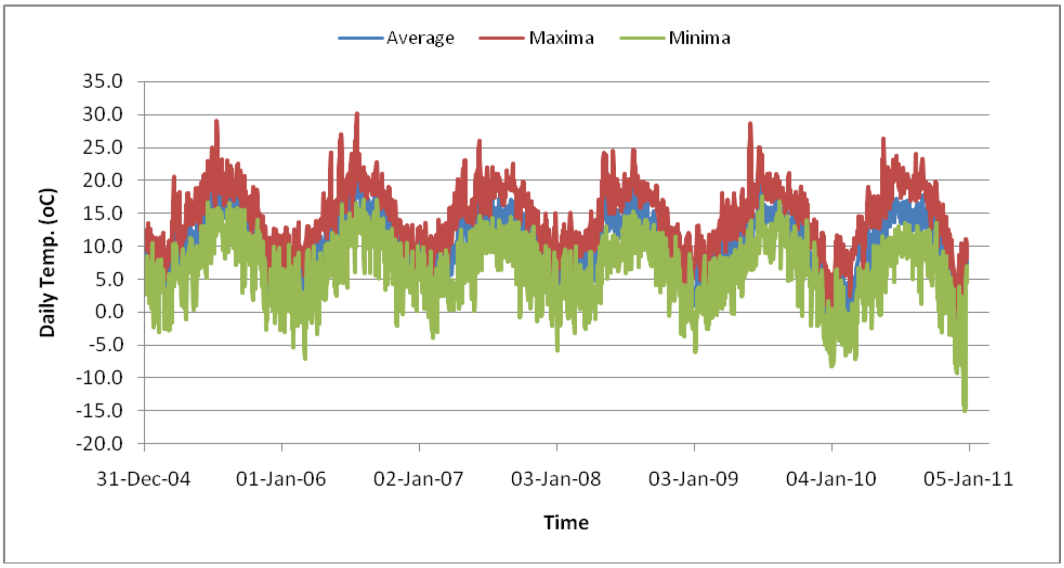

Figure 4: Daily Minima, Maxima and Average Temperature from 2005 to 2010

Figure 5 shows a plot of the accumulative rainfall for each month for the six-year period. This figure illustrates the fluctuations in monthly rainfall both within and between years. Moreover, it illustrates the events of particularly wet summers occurring in 2008 and 2009 and how the rainfall intensity can vary over the winter. From the daily rainfall data, the accumulated rainfalls were calculated for from 1 to 60 days prior to measuring the SFC. The accumulated daily rainfalls for 1 day, 10 days, 30 days and 60 days that are shown in Figure 6 illustrate the significant fluctuations and unusual combinations that occurred over the six-year period. The lowest accumulated rainfall does not necessary occur during the summer months and it depends on the number of days rainfall over which it has accumulated. The daily rainfall from Figure 6 is magnified in Figure 7 to illustrate the daily extremes that can occur.

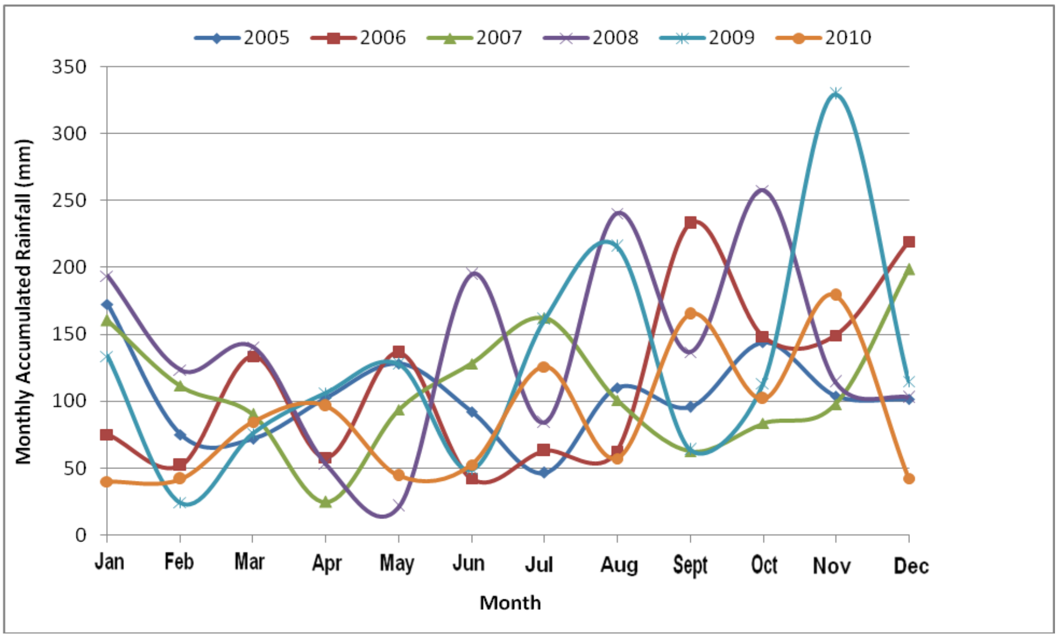

Figure 5: Monthly Accumulated Rainfall from 2005 to 2010

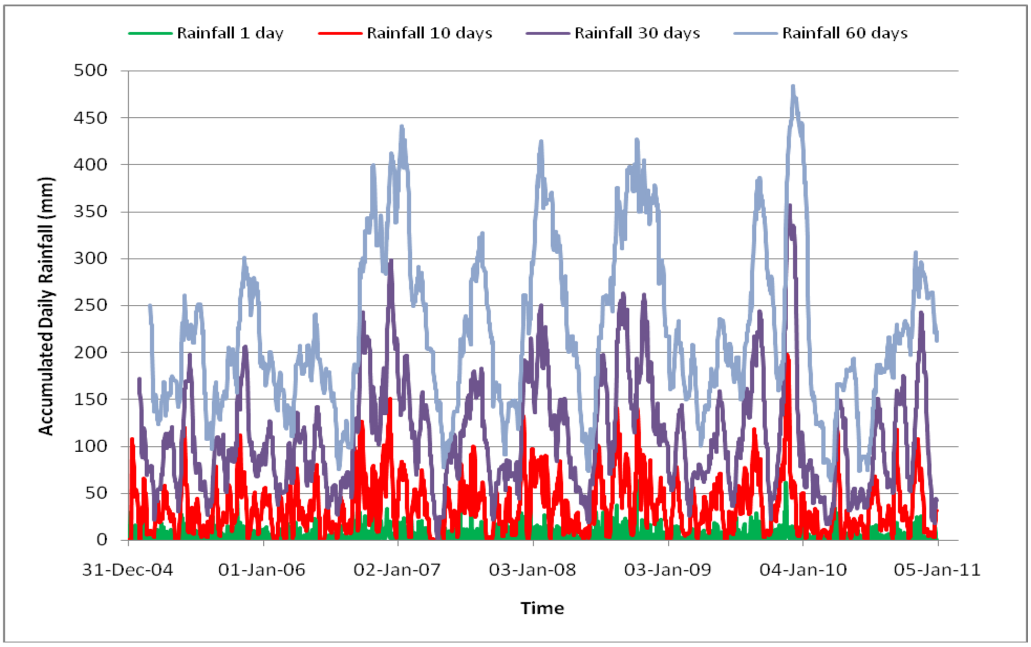

Figure 6: Fluctuations in Accumulated Rainfall from 2005 to 2010

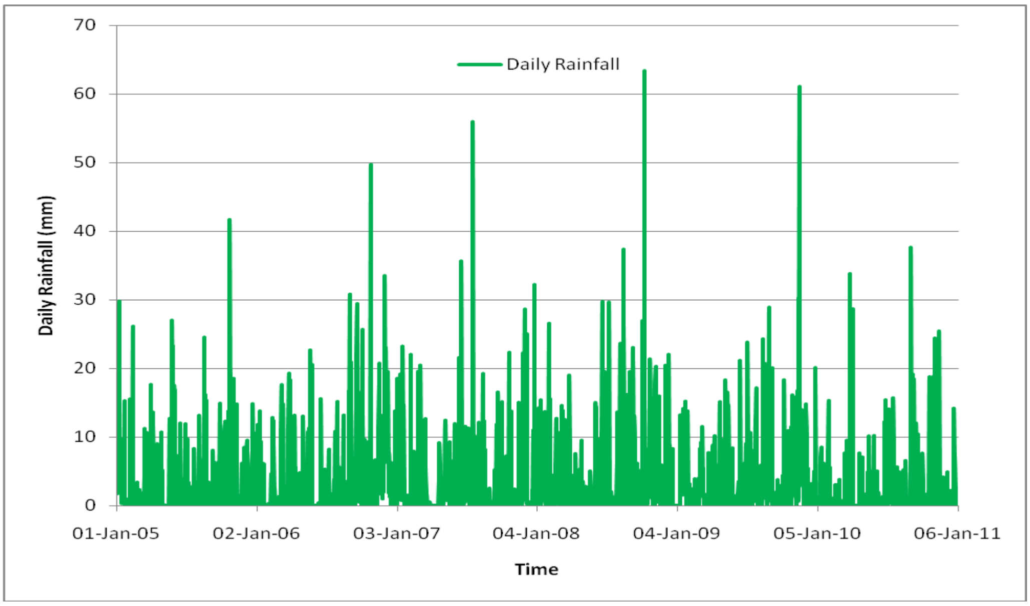

Figure 7: Fluctuations in Daily Rainfall from 2005 to 2010

6.2. TRAFFIC DATA

The effect of traffic fluctuations and the extent of the commercial traffic flow is a major factor affecting the polishing of a road surface (1). The four segments of the control circuit are situated close to Galway City and cater for significant commuter traffic travelling to and from the city on a daily basis. Galway Airport is also located within the control circuit. Whereas no traffic counts were conducted over the test circuit, it was possible to obtain daily traffic data from the National Roads Authority (NRA) official traffic counting stations for the N6 (now the R446) at Kilreekill, Co. Galway and for the N18 at Gort, Co. Galway. These locations were the closest official traffic count locations to the control circuit and were on the roads that formed part of the control circuit closer to Galway city. There were no significant fluctuations in traffic over the six-year period. The traffic counts showed an overall average estimated traffic of 2400 AADT (annual average daily traffic) with 9% HCV (heavy commercial vehicles) for the surface dressing segments, and 8900 AADT with 10% HCV for the hot rolled asphalt segments. Accordingly the surface dressed segments were lightly trafficked and the hot rolled asphalt segments were more heavily traffic.

The road surface on the control circuit sections had been in place for many years and could reasonably be accepted as having reached an equilibrium state of polishing. Over the period of 2005 to 2010, the traffic on each section had remained relatively constant, with the skid resistance fluctuating through seasonal weathering and polishing cycles. The mean summer SFC and the equilibrium SFC for each section are shown in Table 2. Supporting this argument, the annual SFC values for each segment are shown in Figure 8 to be fairly consistent. Therefore, it is reasonably assumed that an equilibrium level of skid resistance was maintained over the study period as the level of traffic flow remained reasonably constant.

Traffic flow was not included as an input variable in the model, partly because it did not vary substantially, but mainly because it is confounded with the Segment-Type input variable. This confounding occurred because the two surface dressed sections carried the low traffic flows and the two hot rolled asphalt sections happened to carry the high traffic flow. This confounding meant that it was not possible to disentangle the Segment-Type effect from that of the Traffic effect and, since the former is trivially easier to measure than the latter, the former was included in the model.

Figure 9 shows the monthly fluctuation in SFC for the four segments over the six years. The typical cyclical pattern of lower skid resistance values in summer and higher values in winter is evident. However, it can also be seen that lower skid resistance does occur during the Spring and Autumn, for example 2007 and 2010.

Table 2: Mean Summer SFC and Equilibrium SFC for Each Section

Segment Type	Mean Summer SFC						Equilibrium SFC
	2005	**2006**	**2007**	**2008**	**2009**	**2010**	
SD1	0.63	0.61	0.61	0.59	0.63	n/a	0.61
SD2	0.63	0.62	0.64	0.62	0.68	0.66	0.64
HRA3	0.55	0.55	0.55	0.54	0.56	n/a	0.55
HRA4	0.49	0.51	0.51	0.50	0.51	0.52	0.51

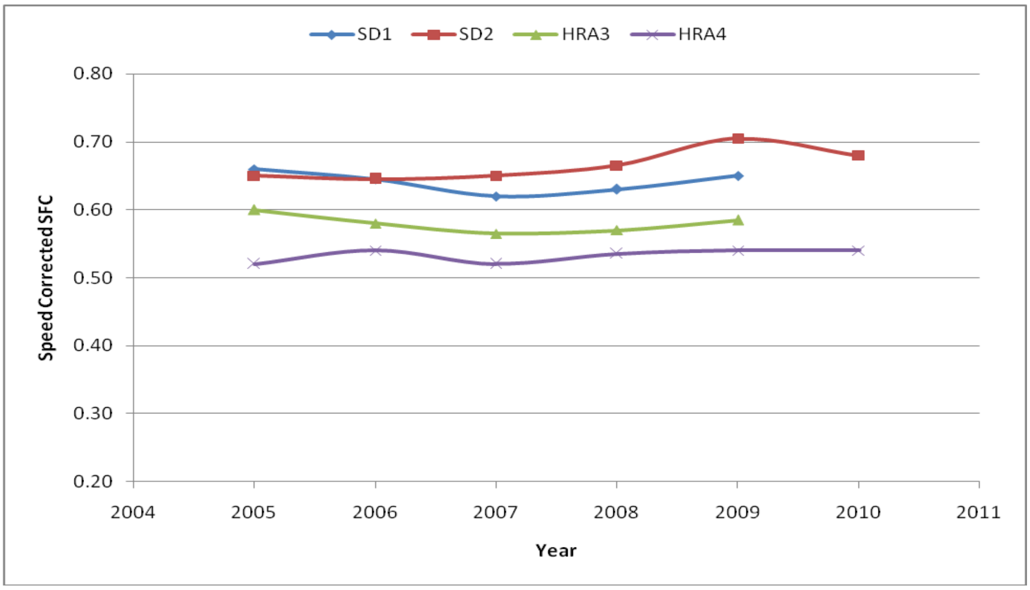

Figure 8: Overall Average SFC by Year and Segment Type

6.3. SCRIM DATA

The study comprised 378 individual SCRIM runs on the 7.2 km control circuit from 2005 to 2010. The data for the study comprised over 272,000 data points for 10-metre intervals, or almost 55,000 50-metre data segments for 50-metre intervals (10 metre measurements averaged over 50 metre intervals). Due to the extremely large number of data points, the data were averaged for each run on each segment of the control circuit resulting in 1,276 segment SFC points for the regression analysis.

The test speed for the SCRIM runs on the control circuit was the standard test speed of 50km/hr. Whilst the test speed of 50 km/h was targeted, the actual speeds recorded were analysed with the deviations from the targeted speed observed to be very small. The overall average test speed for all runs was 50km/hr with a standard deviation of 1 km/hr. For consistency, the recorded SFC values were speed-corrected to 50km/hr in accordance with UKDMRB HD28/04 [7].

7. PERFORMANCE MODEL

The model was developed using 1064 data points for the five years from 2005 to 2009, and was tested using 212 data points for 2010. The data analysis was carried out using SPSS (Statistical Package for the Social Sciences), now called IBM-SPSS, and MINITAB, both widely used statistical packages for analysing data. There was no evidence of correlation between the input variable of average temperature and accumulated rainfall.

In the analysis of speed corrected SFC against segment type, average temperature and accumulated rainfall for up to 60 days, the same values were obtained for the regression coefficients for segment type and average temperature, but the coefficient for accumulated rainfall depended on the number of days rainfall that were counted. Moreover, the P-values for the coefficients for segment type and temperature were consistently equal to 0.00+ (effectively zero), indicating they were highly significant; and the P-values for the different regression coefficients for the days of accumulated rainfall fluctuated for the first 30 days but remained consistently significant with a P-value of 0.00+ for accumulated rainfall greater than 30 days. A plot of the P-values obtained for each day of accumulated rainfall up to 60 days is shown in Figure 10 with a P-value of 0.00+ evident for greater than 30 days rainfall. The fluctuations in the P-values for the accumulative rainfall up to 30 days would indicate that there are other factors, possibly the number or sequence of days with and without rainfall, affecting the outcome.

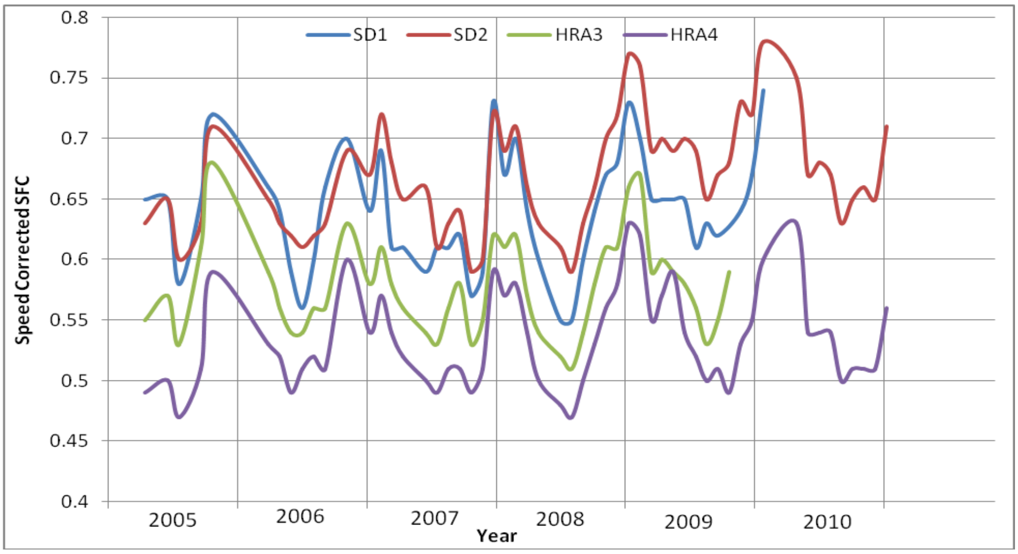

Figure 9: Monthly Average SFC by Year and Segment Type

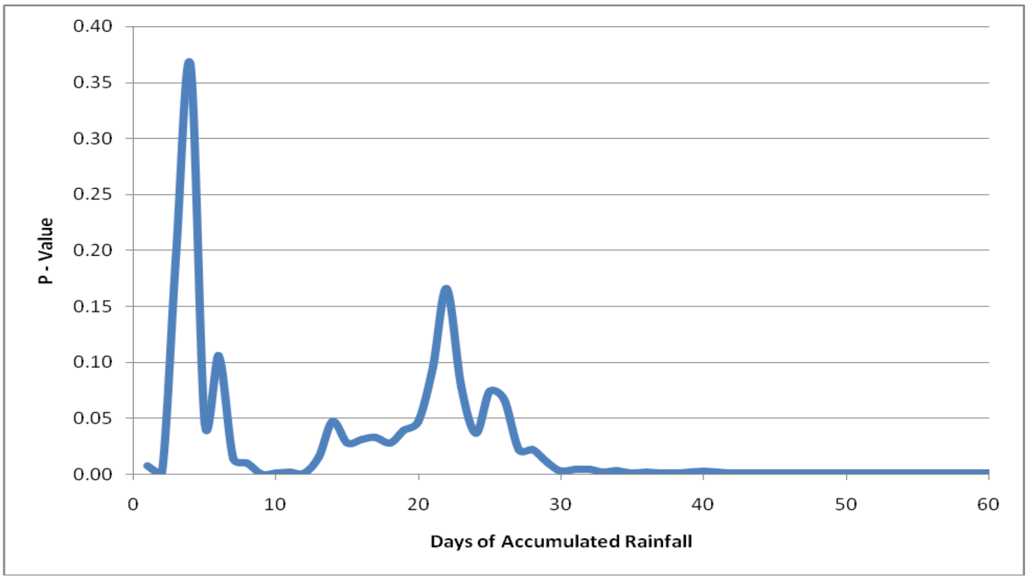

Figure 10: P-Values for Each Day of Accumulated Rainfall up to 60 Days

Consequently, the accumulated rainfall for the 30 days prior to making the SFC measurement was included in the regression model. Accordingly, the best model was:

Speed Corrected SFC = 0.720xSegment-Type_SD1 + 0.751xSegment-Type_SD2 + 0.659xSegment-Type_HRA3 + 0.620xSegment-Type_HRA4 - 0.00815xAvg._Temp + 0.000057xAccum._Rainfall_30

where:
Segment-Type_SD1= 1 if an observation is taken with SD1 and is 0 otherwise;
Segment-Type_SD2 = 1 if an observation is taken with SD2 and is 0 otherwise;
Segment-Type_HRA3 = 1 if an observation is taken with HRA3 and is 0 otherwise,
and Segment-Type_HRA4 = 1 if an observation is taken with HRA4 and is 0 otherwise.

The model has an R^2 of 72.1% and a PRESS statistic of 1.499. The results of the diagnostic tests are shown in Figure 11. The P-values associated with segment type and average temperature were 0.000+. The P-value for accumulated rainfall of 30 days was 0.003. Therefore, all the input variables were significant.

The appropriate model for testing the control circuit data for 2010 was:
Speed Corrected SFC = 0.751xSegment-Type_SD2 + 0.620xSegment-Type_HRA4 - 0.00815xAvg._Temp + 0.000057xAccum._Rainfall_30

The correlation between the predicted speed corrected SFC and the measured speed corrected SFC is shown in Figure 12. The correlation equation is: Predicted Speed Corrected SFC = 0.0843 + 0.850xMeasured Speed Corrected SFC. The R^2 is 84.8% with a PRESS statistic of 0.179. The P-value associated with the intercept and slope is 0.000+. The diagnostic plots for this predicted versus measured analysis are shown in Figure 13. The R^2 and PRESS statistic indicate that the developed regression model is a very good model for predicting the outcome for 2010.

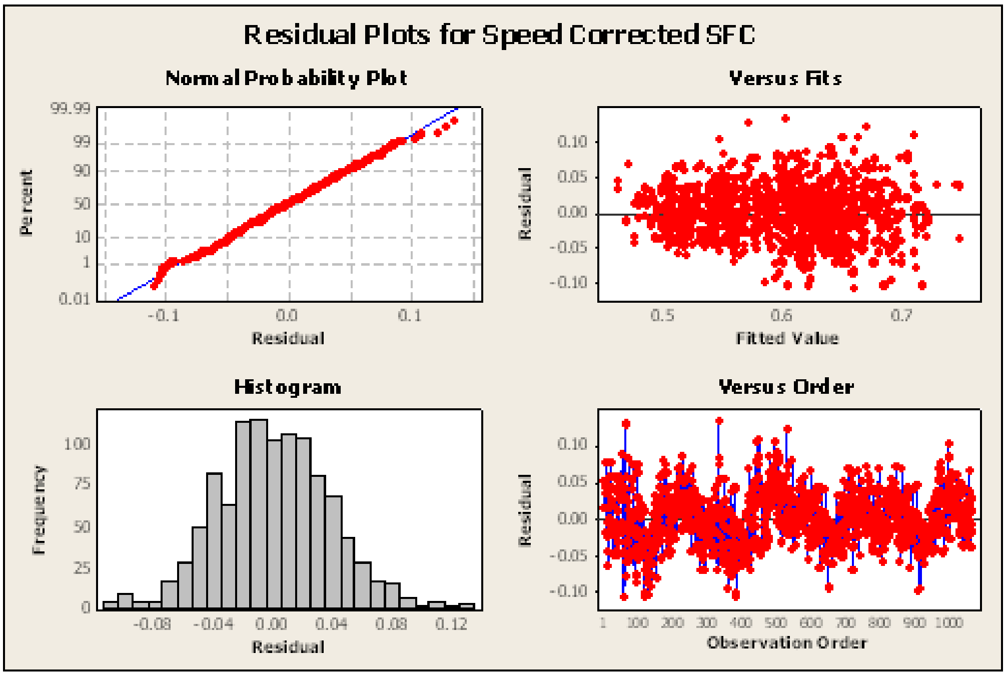

Figure 11: Residual Plots for Regression Analysis Using Segment Type, Average Temperature and Accumulated Rainfall_30

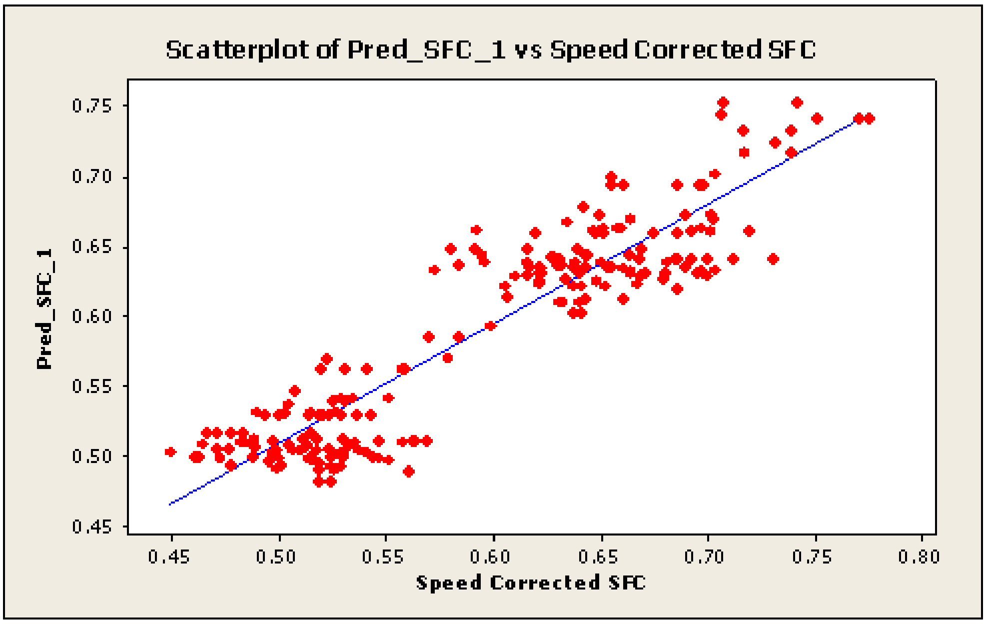

Figure 12: Plot of Predicted Speed Corrected SFC Versus Measured Speed Corrected SFC for 2010

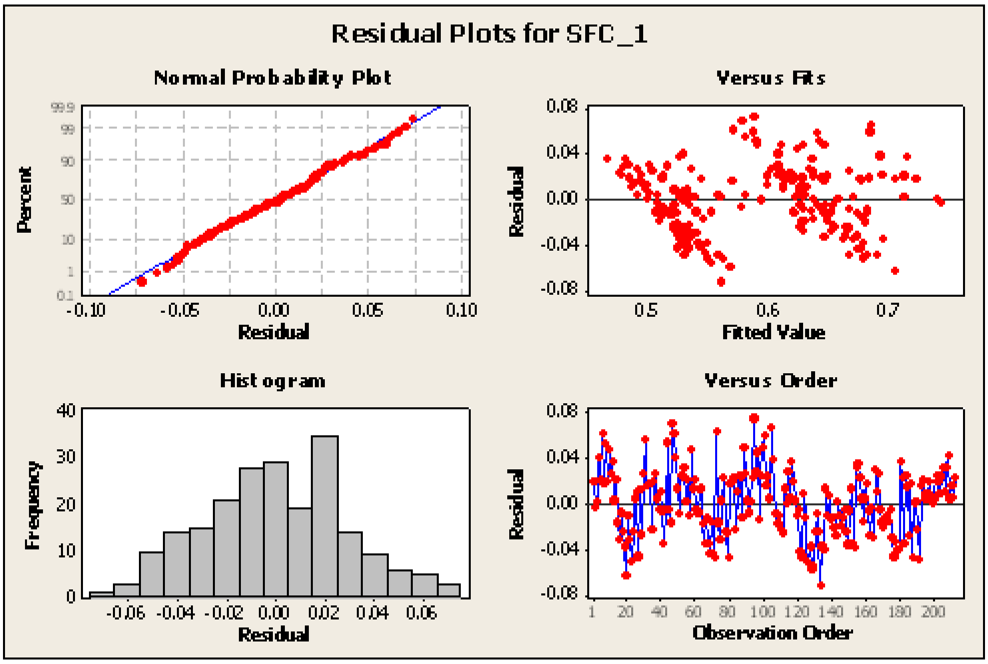

Figure 13: Residual Plots for Predicted Speed Corrected SFC Using Model Containing Segment Type, Average Temperature and Accumulated Rainfall_30

Without accumulative rainfall as an input variable, the regression model was given by:

Speed Corrected SFC = 0.728xSegment-Type_SD1 + 0.759xSegment-Type_SD2 + 0.667xSegment-Type_HRA3 + 0.628xSegment-Type_HRA4 - 0.00824xAvg._Temp

This model has an R^2 of 71.9% and a PRESS statistic of 1.509. The P-values were all 0.000+ indicating that the input variables were all significant. This model could be used in the event that rainfall data were not available.

For the regression model developed using segment type and average temperature, without accumulated rainfall, the correlation between the predicted speed corrected SFC and the measure speed corrected SFC was:
Predicted Speed Corrected SFC = 0.0816 + 0.856xMeasured Speed Corrected SFC.

The R^2 is 85.4% with a PRESS statistic of 0.173. The R^2 and PRESS statistic values indicate that the developed regression model without rainfall would also be a very good model for predicting the outcome for the extra year of 2010. It is equally arguable that this simpler behavioral model could be used to correct for seasonal effects. These findings would indicate that temperature may be the major factor affecting the SFC. Evidence of the effect of temperature as a possible major factor affecting seasonal variation was noted in a previous study by the Transport and Road Research Laboratory [(13)].

Because it is recognised that rainfall has a significant effect in the polishing mechanism that takes place under traffic, the best model with accumulated rainfall only and without including temperature was:
Speed Corrected SFC = 0.616xSegment-Type_SD1 + 0.647xSegment-Type_SD2 + 0.554xSegment-Type_HRA3 +0.515xSegment-Type_HRA4 + 0.000104xAccum._Rainfall_30

This model has an R^2 of 54.5% and a PRESS statistic of 2.440. The P-values were 0.000+, but the poor R^2 indicates that fitting a model involving segment type and accumulated rainfall for 30 days but not including average temperature to the speed corrected SFC data does not lead to good predictions for the actual 2010 data.

8. CONCLUSIONS

The skid resistance of a road pavement fluctuates throughout the year due to seasonal variation. Records have shown that the use of a simple seasonal correction factor to adjust measured SFC values could lead to erroneous estimates of the SFC values, and that climatic conditions would focus more attention on taking the prevailing temperature and accumulated rainfall at the time of testing into account.

This study has produced a linear regression model for relating skid resistance to the input variables of surface type, average temperature on the day of testing and 30-day accumulated rainfall based on five years of SFC data. The research included regression analyses of speed corrected SFC against segment type, average temperature and accumulated rainfall for up to 60 days. The analysis consistently obtained the same values of the regression coefficients for the segment type and average temperature, but the coefficient for accumulated rainfall depended on the number of days rainfall that were counted. Moreover, the P-values for the coefficients for segment type and temperature were consistently equal to 0.00+ (effectively zero) indicating they were highly significant. The P-values for the regression coefficients for the days of accumulated rainfall fluctuated for the first 30 days but remained consistently significant with a P-value of 0.00+ for accumulated rainfall greater than 30 days. The fluctuating P-values would indicate that other factors, such as possibly the number or sequence of dry and wet days, were influencing the SFC for up to 30 days prior to making the measurement. Consequently, the accumulated rainfall for the 30 days prior to making the SFC measurement was included in the regression model. The regression model for temperature and accumulated rainfall is presented within the paper. The resulting R^2 value was 0.721, indicating that the model explained 72.1% of the variation in the data. In addition to surface type, temperature and rainfall, the suspected causes of unexplained variation include factors associated with the machine itself (e.g. tyre wear, calibration, water flow) and factors associated with the operation of the machine (e.g. tracking, road evenness) [8].

With an R^2 value equal to 84.8%, the resulting regression model performed very well in predicting the SFC data for a sixth year of data for the same control circuit. It is arguable that this behavioral model could be used to correct for seasonal effects throughout the year using the regression coefficients of -0.00815 for average temperature (ºC) and 0.000057 for accumulated 30 days rainfall (mm).

The regression model for surface type and average daily temperature, without accumulated rainfall, is also presented. The resulting R^2 value was 0.719, indicating that the model explained 71.9% of the variation in the data. This regression model also performed very well in predicting the SFC data for a sixth year of data with R^2 value of 85.4%. Accordingly, it is equally arguable that this simpler behavioral model could be used to correct for seasonal effects using the regression coefficient of -0.00824 for average temperature (ºC) alone. These findings would indicate that temperature may be the major factor affecting seasonal variation of skid resistance.

In view of the significance of the temperature that was highlighted in this study, it might be beneficial to record surface temperature at the time of measurement; however, it would be difficult to record rainfall without having to resort to the nearest meteorological station. At present, the prevailing weather conditions and whether the road surface is dry, damp or wet at the time of testing are recorded.

9. ACKNOWLEDGEMENTS

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10. REFERENCES

(1) Measurement of skidding resistance Part II: Factors affecting the slipperiness of a road surface, Hosking J R and Woodford G C, TRRL Laboratory Report LR738, Transport and Road Research Laboratory, Crowthorne, United Kingdom, 1976.
(2) The polished stone value of aggregates and in-service skidding resistance, Roe P G and Hartshorne, S A, TRL Report 322, Transport Research Laboratory, Crowthorne, United Kingdom, 1998.
(3) BS7941-1: 2006 Methods for measuring the skid resistance of pavement surfaces - Part 1: Sideway-force coefficient routine investigation machine, British Standards Institution, London, England, 2006.
(4) Standard Recommendation SR CEN/TS 15901-6: 2009 Road and airfield surface characteristics – Part 6: Procedure for determining the skid resistance of a pavement surface by measurement of the sideway force coefficient (SFCS): SCRIM, National Standards Association of Ireland (NSAI), Dublin, Ireland, 2009.
(5) Description of Duties and Services to be Provided in Respect of Term Contract for the Collection of Road Condition and Skid Resistance Data – Project Specification, National Roads Authority (NRA), Ireland, April 2010.
(6) SCRIM Operating and Maintenance Manual, W.D.M. Limited, North View, Staple Hill, Bristol, England, February 2011

(7) Design Manual for Roads and Bridges, Volume 7: Pavement Design and Maintenance, Section 3, Part 1 – Skid Resistance, HD28/04, Stationery Office, London, England, 2004.
(8) Measurement of skidding resistance Part III: Factors affecting SCRIM measurements, Hosking J R and Woodford G C, TRRL Laboratory Report LR739, Transport and Road Research Laboratory, Crowthorne, United Kingdom, 1976.
(9) A Study of the Mechanism of Polishing of Roadstones by Traffic, Neville, G., TRRL Laboratory Report LR621, Department of the Environment, Transport and Road Research Laboratory, Crowthorne, United Kingdom, 1974.
(10) Pavement Skid Resistance Management, Feighan, K., Chapter in The Handbook of Highway Engineering, Taylor & Francis, Florida, 2006.
(11) Measurement of skidding resistance Part I: Guide to the use of SCRIM, Hosking J R and Woodford G C, TRRL Laboratory Report LR737, Transport and Road Research Laboratory, Crowthorne, United Kingdom, 1976.
(12) Design Manual for Roads and Bridges, Volume 7: Pavement Design and Maintenance, Skidding Resistance, Section 3, Part 1, HD28/94, Stationery Office, London, England, 1994.
(13) Relationship Between Skidding resistance and accident frequency – Estimates based on seasonal variation, Hosking J R, TRRL Research Report 76, Transport and Road Research Laboratory, Crowthorne, Berkshire, United Kingdom, 1986.
(14) Applied Linear Statistical Models, Michael H. Kutner, John Neter, Christopher J. Nachtsheim, William Li, McGraw-Hill College, January 2004.
(15) Electronic Statistics Textbook, Statsoft:StatSoft.com, http://www.statsoft.com/textbook/statistics-glossary