Skid resistance prediction for new two-lane roads

Author 1

Heriberto Pérez-Acebo, CEng

- Assistant Professor, Mechanical Engineering Department, University of the Basque Country UPV/EHU, Bilbao, Spain
- heriberto.perez@ehu.eus
- ORCID number: 0000-0003-0577-9597

Author 2

Hernán Gonzalo-Orden, PhD

- Professor, Civil Engineering Department, University of Burgos, Burgos, Spain.
- hgonzalo@ubu.es
- ORCID number: 0000-0003-1777-2333

Author 3

Eduardo Rojí, PhD

- Professor, Mechanical Engineering Department, University of the Basque Country UPV/EHU, Bilbao, Spain.
- eduardo.roji@ehu.eus
- ORCID number: 0000-0003-3322-5524

Corresponding author:

Heriberto Pérez-Acebo

Mechanical Engineering Department, University of the Basque Country UPV/EHU
Pº Rafael Moreno “Pitxitxi”, 2. 48013 Bilbao, Vizcaya, Spain.
Tel: +34 946017820. Email: heriberto.perez@ehu.eus

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Abstract

Skid resistance is a vital issue in pavement management, mainly regarding to road safety and, hence, road agencies must assure a minimum friction level at their road network. The Regional Government of Biscay (Spain) uses the Sideway force Coefficient Routine Investigation Machine (SCRIM) to know present pavement surface condition and to better allocate available funding. The aim of this paper is to develop a deterioration model to predict the minimum skid resistance in the rural two-lane bituminous roads of Biscay by means of the factors that affect it. Trying to include all possible variables that could influence the friction, 23 sections of new roads of Biscay, constructed in the last 25 years were selected, with different pavement structures (flexible and semi-rigid pavements), ages, surface layers and traffic volumes; and a multiple linear regression was performed. It was concluded that only Average Annual Daily Traffic of heavy vehicles and required minimum Polished Stone Value of aggregates reflect their importance and, consequently they are the only variables introduced in the model. Age of pavement, total thickness of bituminous layers and Average Annual Daily Traffic of all vehicles showed no influence and were discarded. Proposed model can forecast future skid resistance.

Keywords

Road & Highways, Pavement design, Infrastructure planning

List of notation

V	is the vehicle speed (km/h)
V_p	is the average peripheral speed of tyre (km/h)
S	slip speed, relative speed between the tyre circumference and pavement (km/h)
SR	is the slip ratio (%)
λ	is the wavelength of the deviations from a true planar pavement surface (mm)
A	is the amplitude of the deviations from a true planar pavement surface (mm)
IFI	is the International Friction Index, as defined by PIARC
SFC	is the Sideway-Force Coefficient
$MSSC$	is the Mean Summer SCRIM Coefficient
CSC	is the Characteristic SCRIM Coefficient
Q_{cv}	is the volume of commercial vehicles (cv) (> 1500 kg) [commercial vehicle/day/lane]
PSV	is the Polished Stone Value
N	is the number of polishing cycles
$AADT$	is the Annual Average Daily Traffic [vehicle/day]
$H.AADT$	is the Heavy Annual Average Daily Traffic [vehicle/day/lane)
Age	is the years since a road was constructed [year]
$Tot\ Bit$	is the total bituminous thickness of the pavement [cm]
VIF	is the Variance Influence Factor
R	is the Pearson coefficient
R^2	is the coefficient of regression

1. Introduction

The measurement and management of pavement friction or skid resistance is a key factor for highway administrations around the world with regard to road safety (Wang *et al*., 2013; Fernandes and Neves, 2014). If a higher friction is available at the pavement-tyre contact, drivers can control better their vehicle (Ongel *et al*., 2009; Buddhavarapu *et al*., 2013). Moreover, road accidents are normally due to more than one factor, usually classified as related to driver, vehicle and highway condition (Hall *et al*., 2009; Chen *et al*., 2016). One of the most significant factors that affects skid resistance, lateral and longitudinal positions of vehicles is road surface deformation (Aydin and Topal, 2016). Despite the fact that multiple factors are involved in highway crashes; researches have established a relationship between accidents and pavement surface conditions or characteristics, such as friction and texture (Hall *et al*., 2009). It was demonstrated that wet crashes rate increased when pavement friction values were low, generally in wet conditions (Araujo *et al*., 2015). Consequently, highway agencies must maintain an adequate friction level at their road network (Papageordiou and Mouratidis, 2015). Hence, a predictive model, able to estimate future skid resistance, is necessary (Kogbara *et al*., 2016).

Following this necessity, the Regional Government of Biscay (RGB) in Spain uses the Sideway force Coefficient Routine Investigation Machine (SCRIM), in order to measure the sideway force coefficient (*SFC*) in wet roads. The aim of this paper is to develop a deterioration model for predicting the available skid resistance on asphalt concrete roads of Biscay with no maintenance or rehabilitation by means of factors that have influence on it. Different factors that could affect friction are examined and the ones with real effect are included in the model. Consequently, the Road Agency of the RGB could anticipate available friction at its road network and act with prevision.

The paper is organized as follows. Section 2 describes skid resistance and its evolution according to some factors. In section 3, the Pavement Management System of the Regional Government of Biscay is explained and the applied methodology is detailed. Results are discussed in section 4 and section 5 presents the conclusions.

2. Skid resistance and its variation according to different factors

As defined in the AASHTO Guide for Pavement Friction, pavement friction is "*the force that resists the relative motion between a vehicle tyre and a pavement surface*" (Hall *et al*., 2009). The slip speed, *S*, is the relative speed between the tyre circumference and the pavement, as expressed in Equation 1.

$$S = V - V_p$$

1.

Where *V* is the vehicle speed and V_p is the average peripheral speed of tyre. The three variables of Equation 1 must be expressed in the same speed units, and are generally expressed in km/h. When a tyre is free rolling in a straight line, longitudinal frictional forces occur and the slip speed is zero. When breaking, breaking force increases until it approaches a peak coefficient of friction available, "peak friction". From this point, the tyre continues to slow down relative to the vehicle speed and to slip over the road. If the tyre is completely locked, the wheel stops rotating and it skids over the road surface. At this point, the slip speed, *S*, is equal to the vehicle speed and V_p is zero. Hence, the locked-wheel condition is usually referred as 100 % slip ratio, *SR*, defined in Equation 2.

$$SR = \left[\left(V - V_P \right) / V \right] \cdot 100 = \left(S / V \right) \cdot 100$$

2.

Tyre pavement friction is the result of adhesion and hysteresis (Lee and Chon, 2008). Adhesion is due to the molecular bonding between the tyre and the surface, related to the micro level asperities of the aggregates of the pavement (microtexture). Hysteresis is consequence of energy loss because of tyre deformation and it is due to macro level asperities of the surface (macrotexture). Pavement surface texture is the deviation of the pavement from a true planar surface. The scales of surface texture were defined by PIARC according to the wavelength, λ, and amplitude, A, of the deviations (PIARC, 1987), and are shown in Table 1.

Microtexture influences the magnitude of tyre friction, interacting with it on a molecular scale and provides adhesion. Macrotexture depends on the shape and size of aggregates in the pavement surface, affects the friction-speed gradient. Whereas microtexture and macrotexture are indispensable for pavement friction, megatexture and unevenness should be avoided.

Factors influencing pavement friction can be classified as shown in Table 2. For measuring it, there are several devices available. They can be classified according to three main operating principles: the longitudinal friction coefficient, the sideway force coefficient and sliders or stationary or slow-moving measurement principles (Kogbara *et al*., 2016). Each device measures under specified conditions, like tyre properties, vehicle speed, slip ratio, water display, etc. However, when a highway administration chooses a device and carries out a measurement with it, only road surface characteristics vary and the rest of variables exposed in Table 2 remain constant.

Speaking about pavement characteristics, the friction is mainly influenced by the aggregate gradation of the bituminous mixtures, reflected in the macrotexture (Zhang *et al*., 2014) and the polish resistance of aggregates. The polish resistance of aggregates defines the ability to maintain their microtexture after having been grinded and sheared by repeated traffic loadings. The Polished Stone Value (PSV) and Acid Insoluble Residue (AIR) are the most employed tests for polish resistance. Other properties of aggregates that affect friction are hardness and mineralogy (usually evaluated by the Mohs hardness scale), abrasion resistance (measured by Micro-Deval and Los Angeles tests), shape, texture and angularity (Sengoz *et al.,* 2014). Asphalt binder may influence microtexture after placement but aggregates are the main medium of contact with tyres (Hall *et al*., 2009).

With regard to age, due to the elimination of the bituminous film that covers the aggregates, the maximum skid resistance is achieved few weeks after being opened to traffic (Foster, 1989).

Immediately after the peak, the surface is said to be polished quickly, with a high rate loss of skid resistance, followed by a slower rate until an equilibrium point is achieved, as shown in Figure 1(a) (Kokkalis, 1998). This is a different behaviour to other pavement characteristics, which get worse as pavements get older (Ferreira *et al*., 2009).

Furthermore, seasonal variation in skid resistance has been documented for decades, obtaining higher values in wet road surfaces in winter than in summer, and it has been modelled by different approaches (Burchett and Rizenbergs, 1980; Echaveguren and de Solminihac, 2011). Hence, it is usual to collect data in summer, when the lowest values are measured, critical for safety design. This is explained because rubber resilience increases and hysteresis losses become smaller with higher temperatures, resulting in a lower value of skid resistance.

The SCRIM, a sideway-force measuring device developed by the Transport and Road Research Laboratory (TRRL) in the United Kingdom, has a standardized test wheel mounted on the nearside of the vehicle (to test the wheel-track), with an independent load and suspension system, inclined at an angle of 20 degrees to the direction of travel and connected to a water supply. The standard test speed for SCRIM is 50 km/h in the UK, also employed in Biscay (Spain). The ratio of sideway force to vertical reaction between the tyre and the pavement surface is referred to as the Sideway-Force Coefficient, *SFC*, with a value from 0 to 1. A SCRIM Reading is the output for each subsection (usually 5, 10 or 20 m) and it is the average *SFC* value over the subsection length, multiplied by 100, hence, expressed as percentage. As in other friction measuring devices, the *SFC* values obtained by means of SCRIM may depend on both the present road slipperiness (depending on pavement characteristics) and factor affecting the SCRIM measurement itself (Table 3) (Hosking and Woodford, 1976a).

As seen in Table 3, factors affecting the SCRIM measurement itself represent less than 2% of the possible variation in the value. Nevertheless, factors related to road slipperiness have a greater influence. In dry conditions, a constant *SFC* around 0.90 is obtained (Hosking and Woodford, 1976a). Therefore, tests are made in wet conditions. As other measuring techniques, the type of the surface layer, the traffic, age and emplacement of the road represent the main reasons for its variation. Similarly, within the year, it has also been known since 1931 that the lowest values were registered in summer (Bird and Scott, 1936). A sinusoidal variation of *SFC* is estimated along the year, with the lowest values in summer (Figure 1(b)). Therefore, British Highway Agency has employed the Mean Summer SCRIM coefficient, *MSSC*, which is obtained from the mean of 3 *SFC* values registered in summer. The *MSSC* is obtained at its lowest and also when variation is the least, with measurements every 3 years (Hosking and Woodford, 1976b). Nowadays, in UK the Characteristic SCRIM Coefficient, *CSC*, is proposed as standardized value obtained in a month from May to September, every year in a different month and adjusted according to the observed variation in the previous 3 years in that area (Brittain, 2015).

Differences between years are related to climate changes but are less important than the previous ones. For temperature, some regression models have been obtained to correlate SCRIM values at different temperatures (Hosking and Woodford, 1976b). As other friction indices, SCRIM values become higher during first weeks, too. Later, through a quick polishing, approximately after 12 month skid resistance tends to settled down to an asymptotic value (Figure 1(a)).

Without considering seasonal and annual variations, the value of *MSSC* is said to be maintained unless surfacing deteriorates or traffic volumes change. Hence, traffic volume, especially heavy traffic volume is stated to be the main factor for prediction of the *MSSC* asymptotic value (Figure 2(a)). On this basis, Szatkowski and Hosking (1972) proposed a formula relating the *SFC*, the volume of commercial vehicles, Q_{cv}, expressed in commercial vehicles, cv, (vehicles over 1500 kg) per lane and per day and the Polished Stone Value, *PSV*, of the aggregates used in the surface layer, with a correlation coefficient of 0.91, Equation 3.

$$SFC = 0.024 + 0.063 \cdot 10^{-4} \cdot Q_{CV} + 0.01 \cdot PSV$$

3.

Equation 3 was used as the basis for the standards for construction of new roads in the UK. Further research showed that the equation 3 underestimated the *MSSC* value obtained in practice at higher traffic volumes, while at lower traffic levels predicted higher values (Roe and Hartshone, 1998). Consequently, new formulae of the form of Equation 4 were proposed, where *A*, *B* and *K* are coefficients related to the corresponding investigatory level used in the UK (Roe and Hartshone, 1998). These equations obtained an average R^2 coefficient of 0.10.

$$SFC = A \cdot PSV - B \cdot \ln(Q_{CV}) + K$$

4.

Therefore, heavy traffic volume is said to be the key factor of skid resistance values. Moreover, it has observed that if heavy traffic is reduced in a road, due to an alternative itinerary, the available friction increases (Figure 2(b)) (Szatkowski and Hosking, 1972).

Other researches attempted to develop models correlating skid resistance with mixture gradation, aggregate and traffic level. Rezaei and Masad (2013) developed an expression to quantify the variation on the International Friction Index, *IFI,* according to polishing cycles, Equation 5. The International Friction Index was created in order to develop an international index for friction and is based on the PIARC Friction Model, as a function of slip speed and macrotexture (Wambold *et al*., 1995).

$$IFI(N) = a_{mix} + b_{mix} \cdot \exp(-c_{mix} \cdot N)$$

5.

Where a_{mix}, b_{mix}, c_{mix} are the terminal, initial and rate of *IFI* change and *N* is the number of polishing cycles (in thousands) using the polisher. The paper indicates formulae to obtain aforementioned coefficients. Moreover, Kassem *et al.* (2013) proposed new expressions to calculate coefficients a_{mix}, b_{mix}, and c_{mix}. In any case, these models and other from other authors (Wang *et al*., 2013) show that the loss of skid resistance depends on the aggregate characteristics, but all of them tend to an asymptotical value after several polishing cycles. Those cycles can be identified as traffic on a real road and, hence, certifying the tendency shown in Figure 1(a).

Nonetheless, although laboratory test can reproduce polishing effect of heavy vehicles, it may be objected that laboratory tests do not represent the real evolution in field, where other factors like environmental factors could interfere. On the contrary, the formulae with in situ data proposed by Roe and Hartshone (1998) (Equation 3) showed low correlation. Consequently, this study aims to develop a friction evolution model for real roads as a function of different factors that could affect it, such traffic, age, thickness of bituminous layers, mixture type, pavement structure or PSV.

3. Pavement Management System of the RGB and methodology

Biscay is one of the 3 provinces of the autonomous region of the Basque Country in the north of Spain. It has an extension of 2217 km^2, and a population of 1159639 inhabitants in 2014. The oceanic climate is homogeneous in the entire province, with high precipitation all year round and moderate temperatures. Due to the special status of the region, each province has the competence about roads, allowing the Regional Government of Biscay (RGB) to plan, project, construct, maintain, finance, use and manage all the roads in its territory. Therefore, the RGB manages a road network of more than 1200 km. Asphalt concrete pavements are employed in the entire network, combining flexible and semi-rigid structures.

The Pavement Management System (PMS) of the RGB, called “State Agenda”, includes all the information related to road geometry (such as lane widths, number of lanes, sight distances, etc.), structures, traffic volumes and pavement structures. The RGB collected pavement condition data in 2000, 2004, 2007 and 2011, including indices like the International Roughness Index (*IRI*), SCRIM, texture and deflection values. These data are analyzed to know the current pavement condition and to forecast future performance, eliminating subjective decisions on maintenance works.

In order to avoid interferences from previous road structures, 16 new rural highway stretches, constructed in the last 25 years, were selected to be analyzed (Table 4), with no rehabilitation or maintenance works until 2011. Some stretches, with the same transversal section, are divided in various sub-stretches according to traffic volumes, due to some connections along their layout. As a result, 23 different sections with different traffic volumes are studied.

There are 3 types of surface bituminous layers: discontinuous (BBTM 11A), semi-dense (AC surf S) and porous (PA-11). With regard to pavement structure, flexible and semi-rigid pavements are included. Each road was constructed in a different moment and, hence, each data collections were carried out at a different pavement age. The total thickness of the bituminous layers of the section is available. Annual Average Daily Traffic [vehicles/day], *AADT*, is registered in all section. Heavy Annual Average Daily Traffic, *H.AADT*, the traffic volume of heavy vehicles, is also available. In Spain, a heavy vehicle is considered when its weight is over 3500 kg (MFOM, 2003). Each stretch is classified by means of *H.AADT* [heavy vehicle/day/lane] in the project lane when the road is opened to the traffic (Table 5) (MFOM, 2003).

On the other hand, it is unknown the exact *PSV* of aggregates in each highway, but Spanish regulations (PG-3) indicate the minimum *PSV* required for each asphalt concrete and traffic category. In the time of projects of selected roads, it was indicated for AC 16 surf S mixes a minimum value of 0.50 for T0 and T1 categories; 0.45 for T2 and 0.40 for T31-T42 categories. For discontinuous and porous mixes, 0.50 was established for T0-T2 range and 0.45 for T31-T42 (MOPU, 1989; MFOM, 2001; MFOM 2004). At present, as the last regulation indicates (MFOM, 2004), the *PSV* is expressed in a scale from 0 to 100.

The date of the data collections of 2000, 2004 and 2007 is not registered, but it is recorded that data from 2011 were collected in February or March. Due to the general low values, data in 2004 seem to be collected in summer. Data from winter 2011 are the only one that can be used to calculate the *MSSC*. Supposed that data in 2000, 2004 and 2007 were obtained in different seasons, the seasonal variation for each surface layer type can be calculated (Table 6). These range variation (from winter to summer) were compared to the values obtained in a research carried out in Gipuzkoa (Spain), where SCRIM values were collected in previously rehabilitated roads during 2 years every 3 month (Navarro *et al*., 2011). Gipuzkoa is another province of the Basque Country, also located at the seaside, with similar extension and oceanic climate as Biscay. Navarro *et al*. (2011) observed the initial decrease during first 12 months and subsequent seasonal variations with lowest values in June (there were no data in July or August) (Table 6).

As observed, the average range variation registered in Biscay is approximate to those obtained in Gipuzkoa (Navarro *et al*., 2011). There is not a perfect correspondence because not all the stretches have been measured in all data collections (2000, 2004 and 2007), and values from 2011, with higher values, are predominant. These seasonal variations are within the range obtained by Echaveguren and de Solminihac (2011) for asphalt concrete, between 8 and 25. The reduction proposed for each surface from winter value to mean summer minimum value, is shown in the last column of the Table 6. It is 3/4 of the registered variation of Gipuzkoa, as these data include the initial decrease of friction value (Figure 1(a)), because they were recorded from the beginning of their service. Therefore, average value of selected road stretches in winter 2011 is reduced the quantity indicated in Table 6, according to surface layer, to obtain the Mean Summer SCRIM Coefficient.

A multiple linear regression was performed between the *MSSC*, dependent variable, VD, (predicted value) and the possible independent variables, VI, (predictors) that can affect the value: *ADDT*, *H.ADDT*, *Age* (years since it was constructed), Total bituminous thickness (*Tot Bit*) in cm, and required Polished Stone Value (*PSV*). Influence of each variable was assessed using forward stepwise regression analysis, by means of the Version 24 of the SPSS software. When performing a regression analysis some assumptions are made:

- The relationship between VD and VI is linear. This can be evaluated by means of the Pearson coefficient, *R*. If there is non-linearity between some variables, they can be transformed. Although there is linearity between *MSSC* and *AADT* and *H.AADT* (Table 7), the last ones were transformed applying natural logarithm, square root, and inverse, following ideas from previous expressions, Equation 3 and 4, and applying similar techniques of other authors analysing friction data (Ongel *et al*., 2009), in order to obtain a normal distribution of the data.

- Each observation is drawn independently from the population, meaning that the errors are independent from other. This can be checked with the Durbin-Watson test, which ranges from 0 to 4. A value of 2 means total independence, and a range between 1.5 to 2.5 is assumed to represent independence of errors.

- Variance of errors must be equal across all levels, which is call homoscedasticity. It is verified by means of a plot of obtained standardized residuals versus predicted standardized residuals and observing that there is no patron on it.

- Errors are normally distributed. This is certified observing if residuals lie along a straight line in the normal probability plot.

- There is little or no multicolinearity in the data. It can be checked by means of the Variance Inflation Factor, VIF. A value greater than 10 indicates a serious multicolinearity problem.

4. Results and discussion

A multi-variable regression analysis was performed to find an empirical equation to relate average *MSSC* in roads of Biscay as a function of different factors that may affect it. Some transformations were carried out to obtain a normal distribution of the variables. Table 7 shows the Pearson coefficient, R, between variables, indicating those with a high level of significance.

After the multiple regression analysis, it appears that the best result could be obtained excluding *AADT*, *Age* and *Tot Bit*. As a result, Equation 6 is proposed for skid resistance prediction with a 95 % of confidence level:

$$MSSC = 30.19 - 0.82 \cdot \sqrt{H.AADT} + 0.76 \cdot PSV$$

6.

Where *H.AADT* is expressed in heavy vehicles/day/line and *PSV* is expressed in a scale from 0 to 100. *MSSC* is also expressed in a scale from 0 to 100.

The only parameters employed in the model are the square root of *H.AADT* and required *PSV*. As shown in Table 8, the regression coefficient (R^2) of the model is 0.696, indicating that the formula can explain the 70 % of the total variance of the 23 sections. The Durbin-Watson statistic is 1.499, indicating the independence of errors. Figure 3(a) shows that residuals follow a normal distribution and Figure 3(b) shows that residuals do not follow any patron, certifying the homoscedasticity. *VIF* has a value of 1.17, indicating no problem of colinearity. A *F* test shows that the correlation is true ($p < 0.01$) and an analysis of *t* of Student of the coefficients show that they are real, different from 0 (Table 8).

The proposed model does not take into account the age of the pavement, which showed a low correlation with MSSC ($R = -0.06$), so it corroborates the ideas from the TRL (Hosking and Woodford, 1976b), and the shape of Figure 1(a) is verified. After a quick polishing cycle, the only variations are seasonal, and the minimum value remains constant along years. Therefore, it certifies the expressions developed by Rezaei and Masad (2013) and Kassem *et al*. (2013), underlining that after a number of polishing cycles, an asymptotical value was reached. If pavement surface is more than 2 years old, age must not be regarded as an interfering factor.

Moreover, the total thickness of the bituminous layers does not influence the skid resistance, a surface characteristic. The correlation with MSSC could be considered not so low ($R = -0.33$), but the reason is that pavements with higher heavy traffic are designed with thicker bituminous layers and the regression analysis excluded this variable from the model. Additionally, the mixing graduation (porous, discontinuous and semi-dense) does not reflect a great importance. It must be considered to estimate the difference between the peak value and the equilibrium value, but not to define the equilibrium value, which has been demonstrated to be only dependent on heavy traffic and PSV. The pavement structure type, flexible or semi-rigid, did not show variation on the proposed model. When gathering pavement structures according to their type, similar models were obtained.

Using the developed regression model, Equation 6 it can be predicted the minimum Sideway Force Coefficient obtained in required *PSV*. If the RGB establishes a higher threshold for skid-resistance than the one predicted for that heavy traffic volume, it must require a higher value of *PSV* in the aggregates employed in the surface layer (Figure 4). The model is only valid for *H.ADDT* values under 1400 heavy vehicle/day/lane, approximate maximum figure for two-lane roads.

5. Conclusions

A skid-resistance prediction model is proposed for new rural two-lane roads of Biscay (Spain), constructed in the last 2 decades, with no rehabilitation or maintenance treatments. The equation is able to forecast the minimum friction available on the road in long term, expressed as the SCRIM coefficient. Regression analysis shows that only Heavy Annual Average Daily Traffic (*H.AADT*) and required Polished Stone Value *(PSV)* are the only factors that significantly influence the SCRIM coefficient in summer, when it reaches its minimum value. Moreover, results confirmed that the Annual Average Daily Traffic (AADT) of all vehicles, the age, the total thickness of bituminous layers, the pavement structure and mixing type have no incidence in the prediction and, hence, they must be discarded.

Therefore, as the traffic demand of a road cannot be modified by the Road Administrations, they can only manage the required minimum *PSV* of the aggregates deployed in the surface layer to maintain a skid-resistance value over established thresholds.

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Figure 1. Side-force Coefficient (*SFC*) variation; a) Variation from the beginning, b) Seasonal variations

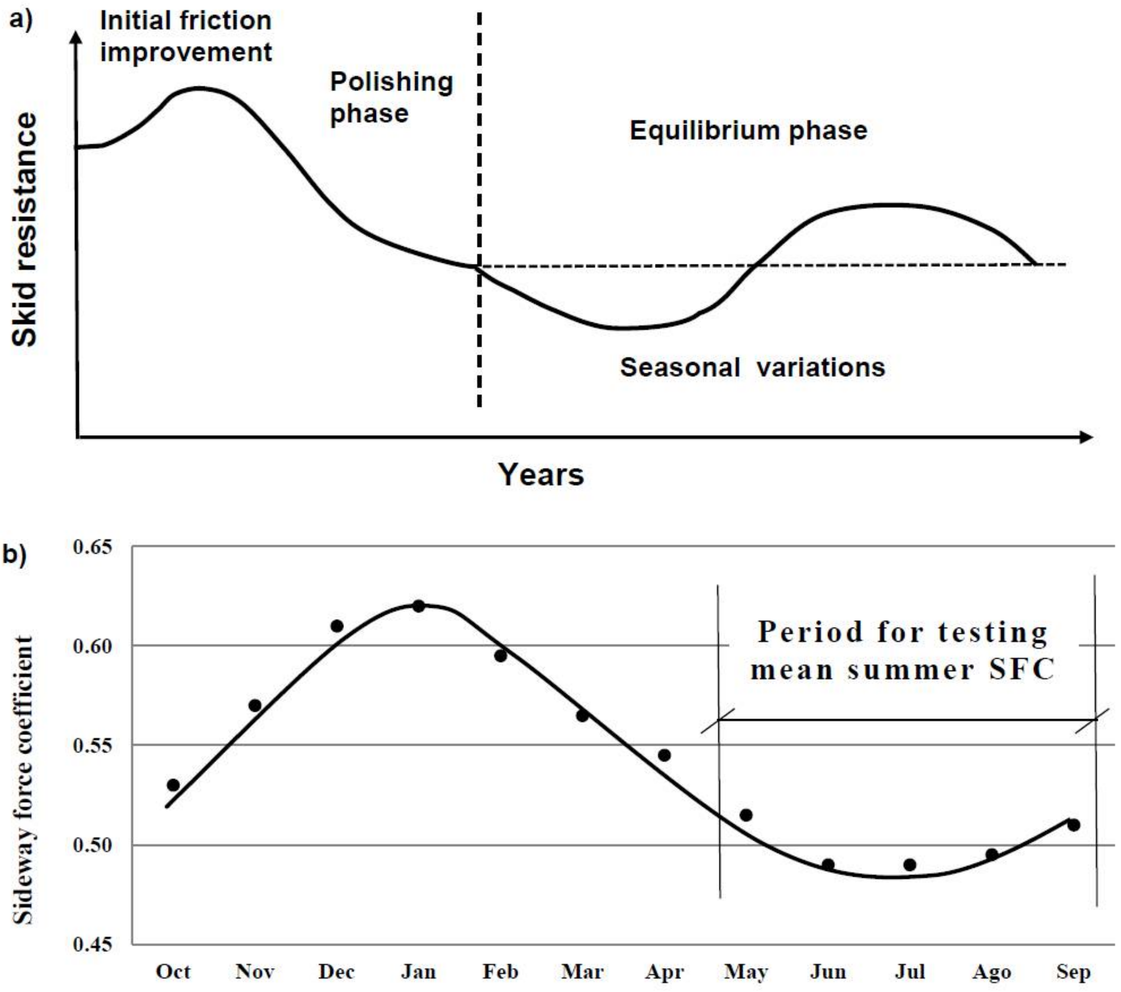


Figure 2. Mean Summer SCRIM Coefficient (*MSSC*) performance, a) with constant Heavy Traffic Volume, b) with changing Heavy Traffic Volume

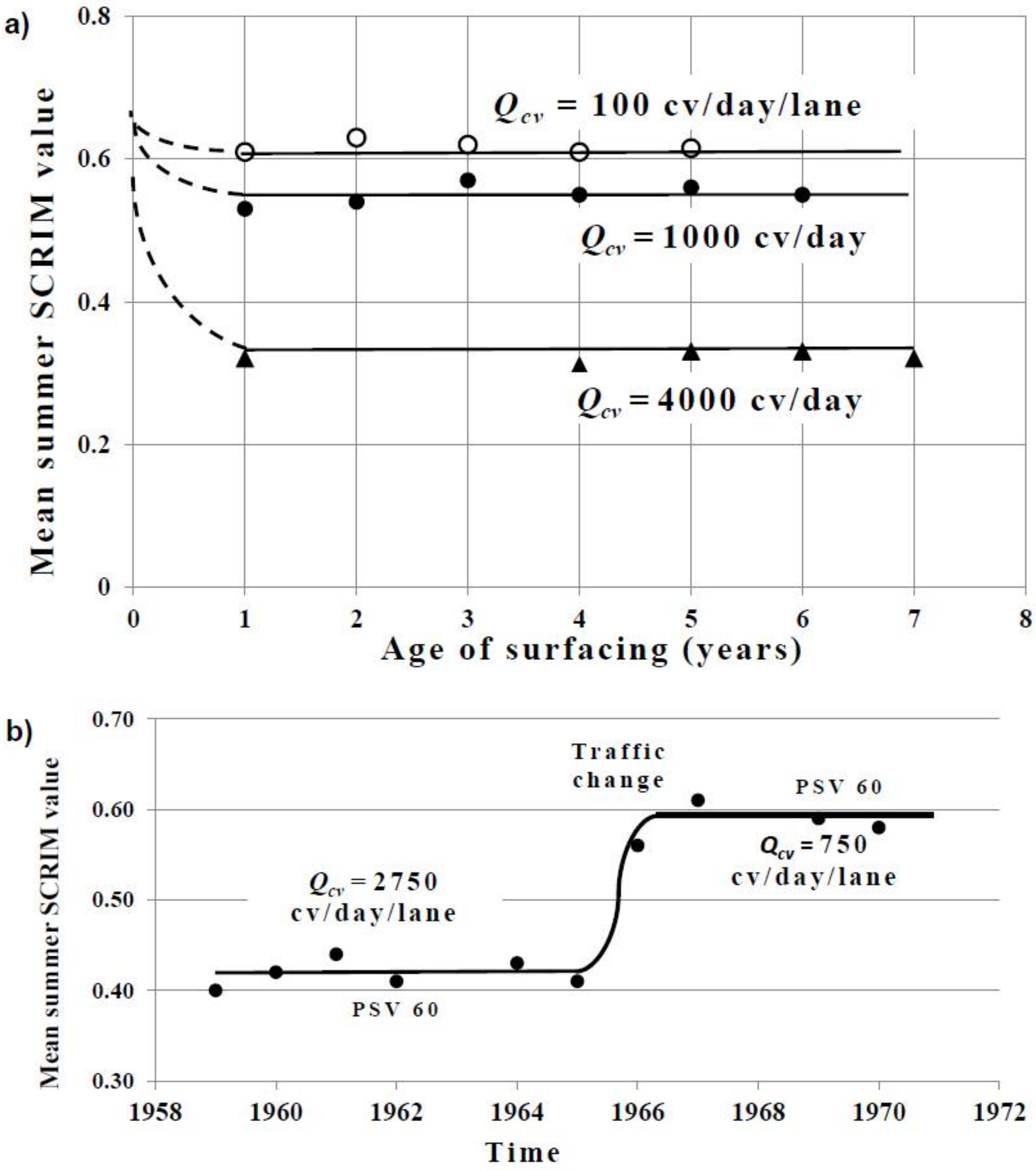


Figure 3. Analysis of the residuals of the proposed model; a) Adjustment of residuals to standardized normal distribution, b) Observed standardized residuals vs. Predicted standardized residuals

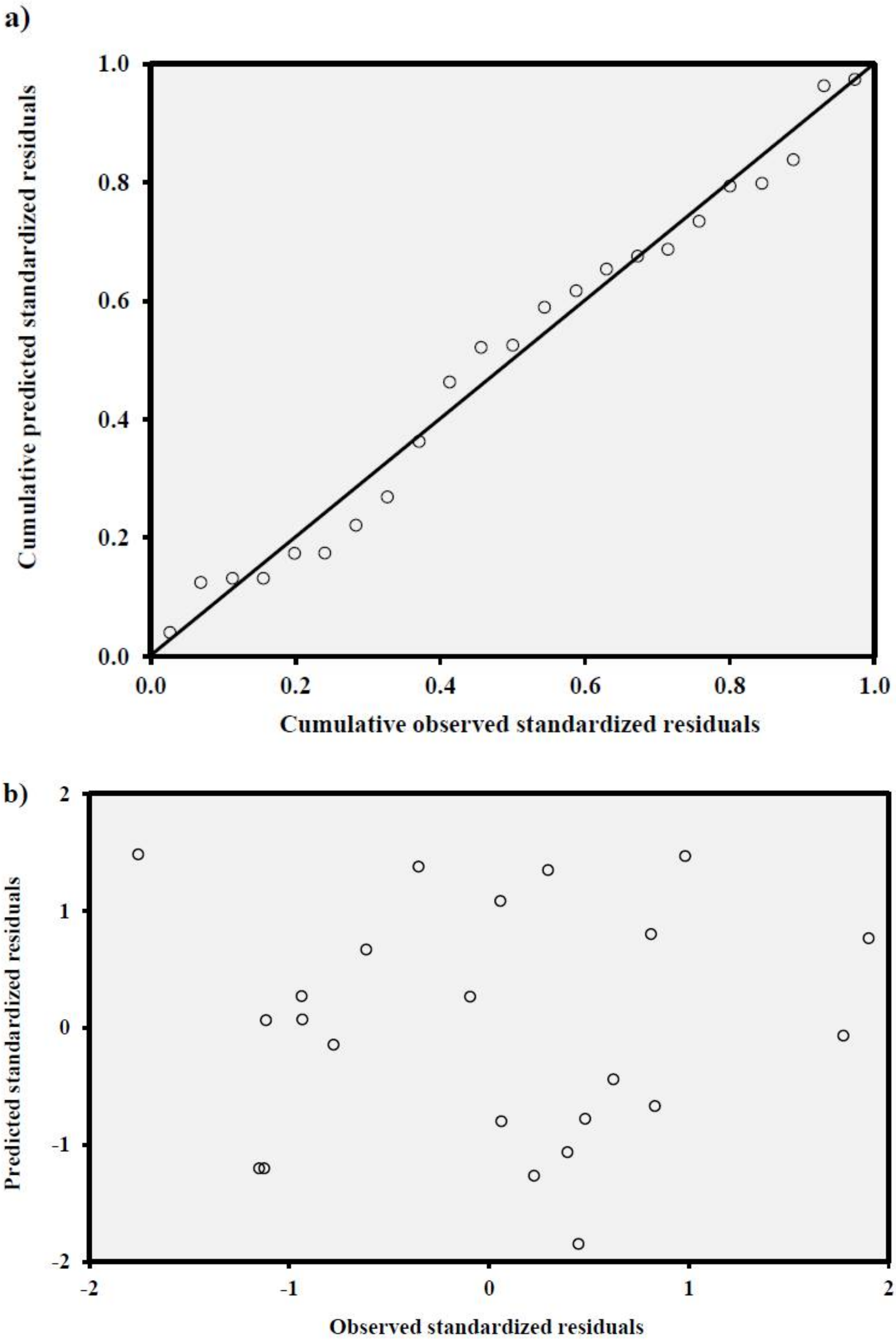
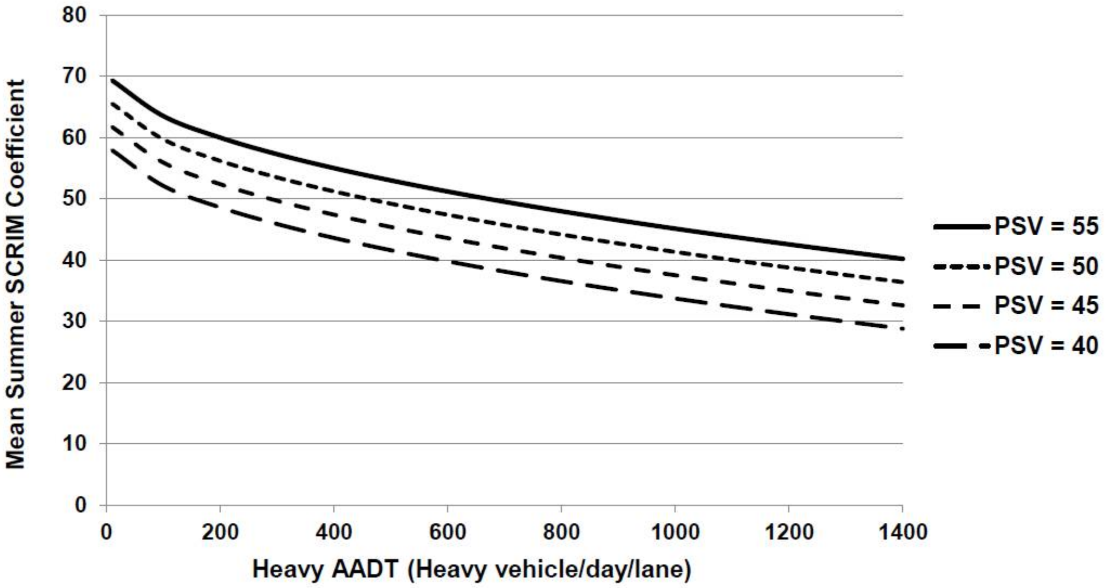


Figure 4. Prediction of Mean Summer SCRIM Coefficient (*MSSC*) by means of Heavy Annual Average Daily Traffic (*H.AADT*) and Polished Stone Value (*PSV*)



List of tables

Table 1. Levels of texture according to PIARC (1987)

Level of texture	Wavelength, λ (mm)	Amplitude, A (mm)
Micro-texture	$0.5 < \lambda$	0.01 – 0.5
Macro-texture	0.5 – 50	0.1 - 20
Mega-texture	50 - 500	0.1 - 50
Roughness or unevenness	> 500	1 - 200

Table 2. Main factors affecting available pavement friction

Pavement surface characteristics	Factors related to the vehicle	Tyre properties	Environment
Micro-texture	Vehicle speed	Rubber composition and hardness	Wind and temperature
Macro-texture	Yield angle	Inflation pressure, load	Water
Mega-texture		Foot print	Snow and ice
Material properties		Tread design and condition	Contaminants

Table 3. Factors affecting the slipperiness of SCRIM measurements and the SCRIM measurement itself (Hosking and Woodford, 1976a)

Factors affecting the slipperiness	Maximum likely difference in SFC
Type and composition of the surfacing, traffic, age, road-site and climate	From under 0.05 to over 1.00
Contamination of surface	about 0.10
Wet or dry conditions	-
Between years (in same season)	0.04
Within year	0.12
Within summer season	0.04
Temperature	0.03
Factors affecting SCRIM measurements	**Maximum likely difference in SFC**
Machine variability (repeatability)	0.02
Tire resilience	0.01
Tire wear, tire pressure	negligible
Calibration	0.01
Tracking	0 to +0.05
Speed	0.005
Water film thickness	0.005
Unevenness	unknown

Table 4. Selected roads for the research

Road denomination	Road category	Surface layer	Length (km)	Open to traffic
N-240 (I)	National	AC 16 surf S	0.70	24/05/2002
BI-625	Preferential	AC 16 surf S	1.04	01/10/1994
BI-633 (I)	Preferential	AC 16 surf S	1.34	08/01/2003
BI-633 (II)	Preferential	AC 16 surf S	2.535	07/08/2002
BI-647	Preferential	AC 16 surf S	1.40	01/06/2007
BI-2121	Provincial	AC 16 surf S	0.975	01/07/2000
BI-2238 (I)	Provincial	AC 16 surf S	1.02	01/06/2009
BI-2238 (II)	Provincial	AC 16 surf S	1.55	23/10/2009
BI-2224	Provincial	AC 16 surf S	0.08	01/06/2007
BI-2405	Provincial	AC 16 surf S	1.570	23/10/2009
BI-2522	Provincial	AC 16 surf S	1.300	01/06/1997
BI-2713 (I)	Provincial	AC 16 surf S	0.08	01/11/2003
BI-732	Complementary	BBTM 11A	0.70	01/10/2005
BI-2713 (II)	Provincial	BBTM 11A	2.260	03/08/2005
N-240 (II)	National	PA-11	1.71	19/07/2002
BI-633 (III)	Preferential	PA-11	1.42	18/09/2000

Table 5. Heavy traffic categories in Spain (MFOM, 2013)

Traffic category	H.AADT [heavy veh./km/lane]	Traffic category	H.AADT [heavy veh./km/lane]
T00	H.AADT ≥ 4000	T31	200 < H.AADT ≤ 100
T0	4000 < H.AADT ≤ 2000	T32	100 < H.AADT ≤ 50
T1	2000 < H.AADT ≤ 800	T41	50 < H.AADT ≤ 25
T2	800 < H.AADT ≤ 200	T42	25 < H.AADT

Table 6. SFC variation range in Biscay and in Gipuzkoa (Navarro *et al*., 2011)

Surface layer	Variation range in Gipuzkoa	Average SFC in Gipuzkoa	Variation range in Biscay	Average SFC in Biscay	Proposed reduction
BBTM 11A	18	55	14,7	65	13,5
PA-11	17	54	11,3	60,1	13
AC16 surf S	12,5	50	17,1	54,7	9

Table 7. Correlations among variables (Coefficient of Pearson, *R*)

	MSSC	AADT	H.AADT	Ln(AADT)	Ln(H.AADT)	Inv (AADT)	Inv (H.AADT)	Sqrt (AADT)	Sqrt (H.AADT)	PSV	Age	Tot Bit
MSSC	1.00											
AADT	-0.66**	1.00										
H.AADT	-0.75**	0.70**	1.00									
Ln(AADT)	-0.63**	0.90**	0.65**	1.00								
Ln(H.AADT)	-0.73**	0.75**	0.89**	0.86**	1.00							
Inv(AADT)	0.47*	-0.63**	-0.48*	-0.89**	-0.79**	1.00						
Inv(H.AADT)	0.49*	-0.59**	-0.56**	-0.86**	-0.85**	0.98**	1.00					
sqrt(AADT)	-0.66**	0.98**	0.69**	0.97**	0.82**	-0.76**	-0.726**	1.00				
sqrt(H.AADT)	-0.77**	0.74**	0.98**	0.75**	0.96**	-0.62**	-0.693**	0.77**	1.00			
PSV	0.02	0.22	0.41	0.25	0.37	-0.37	-0.409	0.22	0.38	1.00		
Age	-0.06	-0.13	0.05	0.00	0.16	-0.12	-0.225	-0.07	0.10	-0.12	1.00	
Tot Bit	-0.33	0.09	0.47**	0.29	0.59**	-0.41	-0.527**	0.18	0.55**	0.20	0.18	1.00

Table 8. Analysis of Variance of the model

Analysis of variance						
Source	Degrees of freedom	Sum of squares	Mean Square	*F* value	*p*	Durbin-Watson
Model	2	985.122	492.561	22.932	< 0.001	1.499
Error	20	429.581	21.479			
Corrected total	22	1414.704				
Root MSE	Dependent mean	Coeff. var.	*R*	R^2	Adj. R^2	*VIF*
6.69166	51.1484	13.08	0.834	0.696	0.666	1.172
Parameters estimates						
Variable	Parameter estimate	Standard error	*t* Value	*p*	95 % confidence limits	
Intercept	30.188	12.394	2.436	0.024	4.335	56.042
Sqrt(H.AADT)	-0.824	0.122	-6.771	< 0.001	-1.077	-0.570
PSV	0.759	0.280	2.713	0.013	0.175	1.342