Comparison of skid resistance evolution models

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ABSTRACT: This paper presents results of a research aiming at modeling the evolution of road surface skid resistance using statistical and phenomenological approaches. Data are provided by a database composed of measurements collected on French roads during ten years: skid resistance values (Sideway Force Coefficient measured by SCRIM machine), macrotexture values (Mean Profile Depth), road geometry, traffic and age. Principal component analyses determine the connection between relevant factors. Analyses of variance enable the selection of independent variables used in the evolution laws. Various types of evolution laws are explored: linear regressions with one to four parameters, non-linear regressions and logarithmic functions. In parallel, model based on the combination of the main factors that can explain the skid resistance evolution is developed. This model takes into account both mechanical effect like polishing under traffic and ageing effect (changes in asphalt mix properties due to the weather effect). In a last part of the study, results obtained with the two approaches on a specific database are compared.

1 INTRODUCTION

Road surface maintenance is mainly based on measurements of road surface characteristics in view of detecting deteriorated sections. These measurements are costly and cannot be done as often as needed. Thus, French road managers dispose of measurements conducted only every three years for the national road network to define their road maintenance policy. To complete these periodically collected data, the use of theoretical tools like evolution models presents a helpful alternative for road managers.

Regarding road surface skid resistance, two approaches are possible to develop an evolution model. On the one hand, statistical analyses can be performed on road databases to determine the main factors that can explain the friction evolution and the evolution law. On the other hand, phenomenological models, issued from consideration of physical phenomena involved in the friction evolution, can be used. Few results have been found on the comparison of the two model types.

This paper deals with a comparison between two models developed respectively by CETE Lyon and Ifsttar. Existing models found in the literature are first presented (section 2). Description of the statistical model and the phenomenological model is then given in respectively sections 3 and 4. In section 5, comparison of predictions obtained respectively with the two models is presented and discussed.

2 STATISTICAL APPROACH

2.1 *Data collection*

Evolution of skid resistance is assessed by means of a database containing data collected on 980 km – rural roads connecting cities or bypasses – of the French national network. The following information can be found:

- skid resistance (Sideway Force Coefficient);
- macrotexture (Mean Depth Profile, MPD) sampled every 10m;
- road geometry (radius of curvature, longitudinal and transversal slopes)sampled every 10m;
- traffic;
- pavement surface type (mix formulation) ;
- age of the pavement surface.

Sideway Force Coefficient (SFC) is provided by the SCRIM machine (Sideway force Coefficient Routine Investigation Machine) (Fig. 1) every 20m, at 60 km/h with a water thickness of 0.5 mm. A smooth standard tyre is used for the tests. SFC is measured in the right wheel path and ranges from 0 to 1. This parameter is used to estimate indirectly road surface microtexture.

Macrotexture is measured by means of the so-called RUGO laser sensor (Fig. 1). RUGO provides a Mean Profile Depth profile (MPD) every 20m, according to the ISO standard 13473-1 (ISO 2002).

Geometrical characteristics (i.e. radius, crossfall, longitudinal slope) are measured by means of the POMMAR device (Fig. 1) equipped with gyroscopic station and laser sensors. Measurements are realized at 90 km/h.

Traffic is provided by SIREDO stations. The SIREDO network consists of approximately 3000 stations SOL2, which have been installed since the early 1990's on the whole national road and motorway network. Using inductive loops embedded in the pavement and linked to a recorder, SIREDO stations detect metallic masses running on the road. Thus, the station can deduce the class of vehicles, the speed and the weight. The average daily traffic is calculated every year.

Figure 1 - SCRIM, POMMAR and RUGO devices.

2.2 *Database characteristics*

The database is first analyzed in terms of distribution of pavement surface (mix formulations, ages), geometry characteristics and traffic; graphs are presented in figures 2 to 4.

It can be noticed that the age of pavement surfaces ranges from 0 month to more than 10 years. The most represented mix formulation is high-modulus bituminous concretes; this statistics is coherent with the fact that data are collected on trafficked roads. Almost 2/3 of the data are collected on straight sections with a crossfall ranging between 1 and 3% (in accordance with the road construction guide). One third of the data are collected on flat areas, whereas 10% match areas with a longitudinal slope higher than 5% (ramps). Finally, 83% of the road sections of the database present an average daily traffic ranging between 15000 and 20000 vehicles/day.

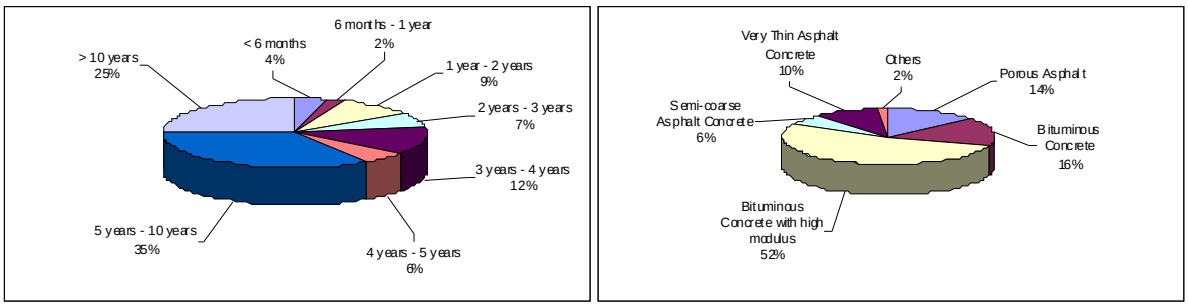


Figure 2 – Distribution of age and type of pavement surface.

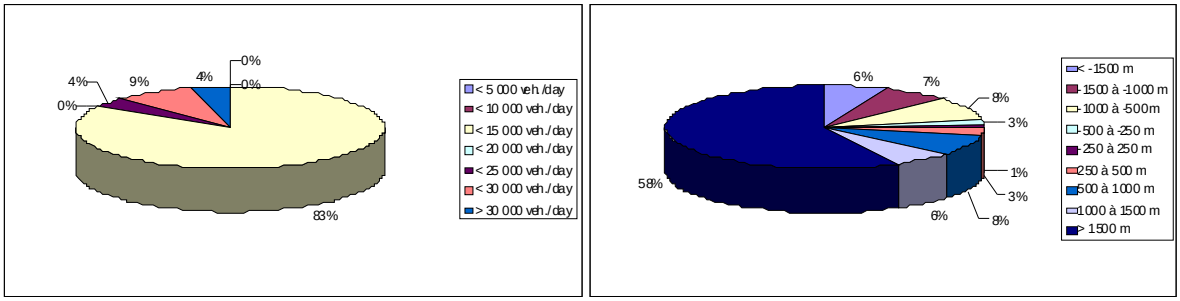


Figure 3 – Distribution of average daily traffic and radius of curvature.

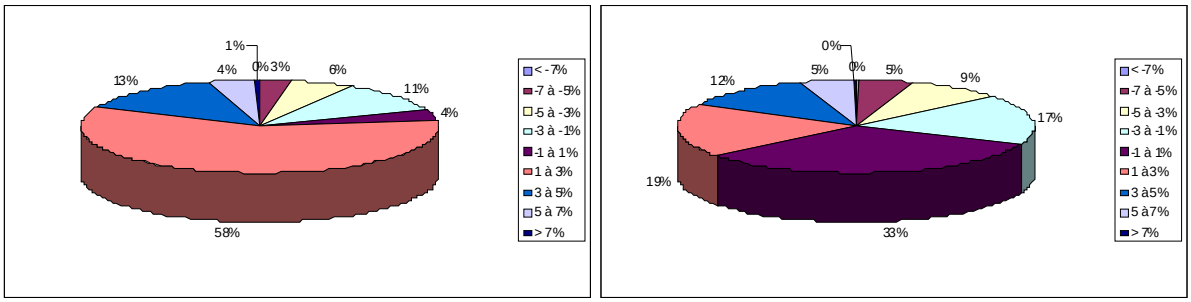


Figure 4 – Distribution of crossfall and longitudinal slope.

2.3 *Determination of the main factors*

The determination of factors influencing the skid resistance evolution is conducted by means of the Principal Component Analysis (PCA). The principle of this statistical method consists in transforming the so-called “correlated” variables into “uncorrelated” variables – they become independent after the transformation. The new – uncorrelated – variables are called “principal component” (or axles). The number (n) of principal components is lower than the initial number (N) of correlated variables. The choice of (n) depends on the fraction of the variance to be explained. In the frame of this study, the Pearson PCA is employed (Bouyer et al. 2009).

Tests show that 4 axles are necessary to explain 80% of the variation of skid resistance with the relevant parameters (Figure 1 and Figure 2). They are listed below by increasing order of importance:

- Radius and crossfall;
- Slope, macrotexture and age;
- Slope, macrotexture and traffic;
- Traffic and age.

The connection between radius and crossfall can be explained by the infrastructure conception rules, which propose crossfall values depending on the radius of curvature. Moreover, the polishing effect is more important in curves than in straight sections, which entails a decrease

of SFC values. The strong interaction between traffic and age can be explained by the fact that the higher is the traffic; the lower is the road surface life due to polishing effect.

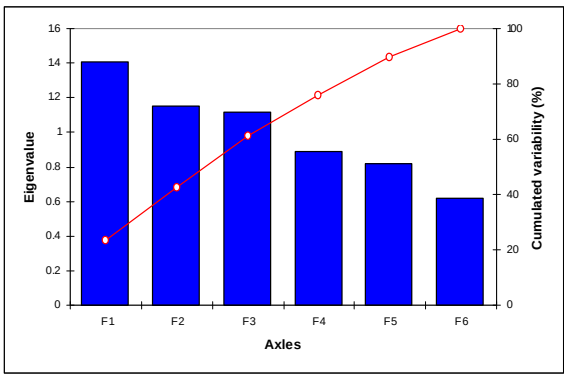


Figure 1 - Eigenvectors (or axles) and eigenvalues (PCA).

	F1	F2	F3	F4	F5	F6
Slope	1.4	**31.9**	8.9	**54.8**	2.8	0.0
Radius	**46.6**	0.5	0.4	1.3	3.5	**47.7**
Crossfall	**47.2**	0.2	0.2	3.0	0.0	**49.4**
Average daily trafic	0.4	8.9	**47.6**	14.1	**27.8**	1.2
Age	2.4	16.2	**39.4**	0.5	**39.9**	1.7
MPD	2.1	**42.2**	3.4	**26.4**	**25.9**	0.0

Figure 2 - Contribution of the relevant parameters to the axles (in percent).

In a second step, analyse of the variance is performed. This analysis, widely known as ANOVA, shows how the variation of given parameters (skid resistance or its evolution for instance), called dependent variables, can be explained by influencing factors (road geometry or traffic for instance), called independent variables. The objective is to reduce to the minimum the number of variables that should be introduced in the evolution models. A F-test (Fisher) is used to evaluate the relevant factors with an error of 0.01%.

Table 1 - Results of ANOVA.

Source	Value	Standard deviation	t	Pr > |t|	Borne inf. (95%)	Borne sup. (95%)
AGE	-0.224	0.006	-36.385	< 0,0001	-0.236	-0.212
MPD	0.260	0.006	42.315	< 0,0001	0.248	0.272
SLOPE	-0.014	0.006	-2.362	0.018	-0.026	-0.002
RADIUS	0.085	0.007	13.030	< 0,0001	0.073	0.098
CROSSFALL	-0.027	0.007	-4.125	< 0,0001	-0.040	-0.014
TRAFFIC	0.011	0.006	1.848	0.065	-0.001	0.023

The ANOVA performed for all types of road surface shows that only 13% of the variation of SFC can be explained by the considered variables. This percentage can be improved significantly when the analysis is formulation specific. In the following sections, evolution laws are then proposed separately for each family of asphalt formulation.

Results are summarized in Table 1. The p-value of the traffic variable is high (0.065), meaning that this variable has a negligible impact. The p-values of the other variables (age, MPD, slope, radius and crossfall) show that their respective effects are statistically significant with 95% confidence.

To conclude, only age, radius of curvature, macrotexture and crossfall will be considered in the evolution laws.

2.4 *Evolution laws for bituminous mix*

First, simple linear regressions were tested. The results were obviously not satisfying at all considering the interactions between the relevant factors.

Then, multiple linear regressions are tested. The best results are obtained by considering evolution laws with two parameters (age and MPD). Figures 7 and 8 present the evolution of SFC obtained respectively for very thin asphalt concrete and, semi-coarse asphalt concrete and porous asphalt concrete.

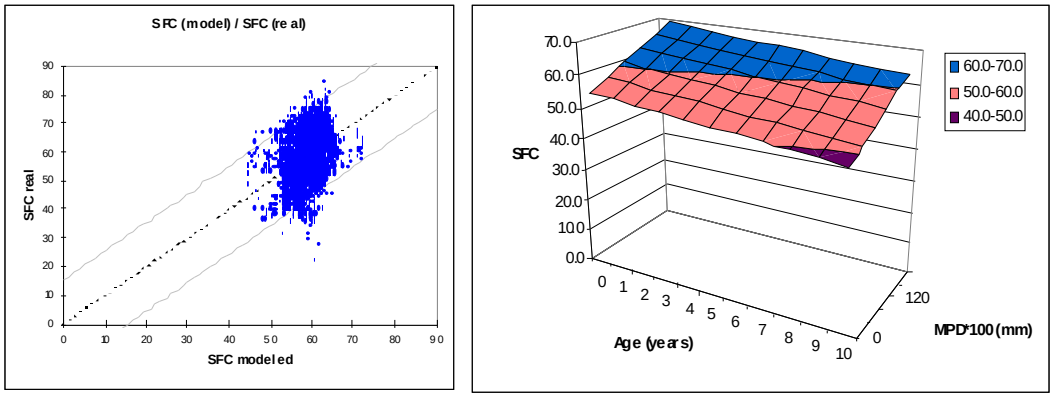
a) 
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Figure 7 - Linear regression with two variables (age and MPD) for very thin asphalt concrete: (a) comparison between prediction and actual values; (b) theoretical variation of SFC with age and MPD.

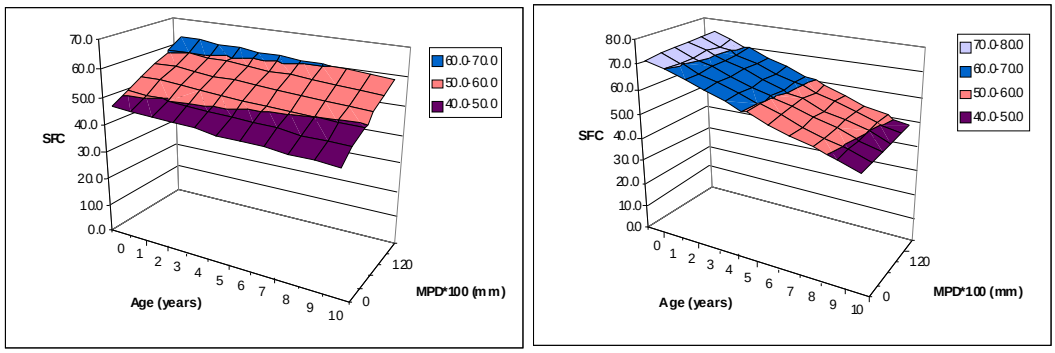
a) 
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Figure 8 - Theoretical variation of SFC with age and MPD for: a) semi-coarse asphalt concrete; b) porous asphalt concrete.

Observations of actual roads show that the skid resistance loss, in terms of SFC, is between 10 and 30 units (meaning that the friction loss is between 0.1 and 0.3) 10 years after the road construction, the order of magnitude depends on the type of road surface. Figures 7b and 8 show that the statistical models reproduce fairly well these observations. Nevertheless, the SFC values considered at early age seem to be over-estimated regarding real-site measurements. The statistical model is not able either to simulate the scouring of the bituminous film wrapping the aggregates and the increase of friction values during the first months.

3 PHENOMENOLOGICAL MODEL

Development of the phenomenological model is based on laboratory tests performed by the Wehner/Schulze polishing machine (Do et al. 2007). Details related to the formulae presented in the following sections can be found in (Do et al. 2009).

The friction coefficient measured on an asphalt surface can be written as:

$$\mu = (1-d)\cdot\mu_B + d\cdot\mu_G \qquad (2)$$

where μ = friction coefficient; μ_B = friction coefficient measured on the binder-covered part; μ_G = friction coefficient measured on the binder-removed part; and d = factor varying between 0 and 1.

Physically, the weight factor (d) represents the binder-removed surface fraction. The μ_B component is time dependent due to the time dependency of bitumen properties. Since the binder removal is traffic and climate dependent, the weight factor (d) varies with the number of vehicles and time. Actually, aggregates also evolve over time but, compared with the pavement lifetime (between ten and twenty years), their characteristics can be assumed to remain constant. Therefore, μ_G should depend only on the number of vehicles.

With these considerations, equation (1) can be completed as:

$$\mu(t,N) = [1 - d(t,N)] \cdot \mu_B(t) + d(t,N) \cdot \mu_G(N) \tag{3}$$

where t = time; and N = number of vehicles.

Seasonal changes should be included as the fourth influent phenomenon, in addition to the aggregate polishing, the binder removal and the climate effect. Seasonal variations are complex and their causes are not well known. Even if periodic functions are frequently used to approximate these changes (Henry & Meyer 1984), it was found (unpublished results) that the magnitude and the frequency depend on climatic conditions. Due to the complexity of the phenomenon and a lack of data, it was decided not to include seasonal variations in the model.

Regarding the polishing process, μ_G depends mostly on aggregate microtexture, which is usually rough before subjected to traffics. It is then expected that μ_G starts from a maximum then decreases with the number of vehicles. The following model is used:

$$\mu_G = a \cdot (N + b)^c \tag{4}$$

where a, b, c = parameters to be determined by data fitting.

Three experimental sites had been followed up since their construction. Cores were taken every six months and friction measurements performed. Details can be found in (Do et al. 2007). Figure 3 shows the evolution of friction coefficient measured on roadside cores (not subjected to traffic). It can be seen that the friction coefficient can evolve significantly without any action from the traffic. Zhao et al. (2010) showed that climate actions (sunlight, rains, etc.) explain part of this evolution.

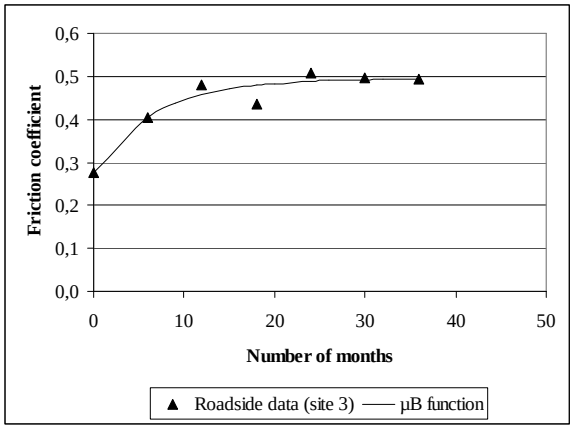

Figure 3 - Plot of friction coefficient versus elapsed time.

From Figure 3, the following model is used to represent μ_B:

$$\mu_B = \mu_0 + \mu_v(t) = \mu_0 + \mu_1 \cdot \left[1 - e^{\left(-\frac{t}{t_0}\right)} \right] \tag{5}$$

where μ_0 = friction coefficient of new asphalt road; μ_v = friction gain in the absence of traffic due to climate effect; and μ_1, t_0 = parameters to be determined by data fitting.

Values of μ_0 are obtained from friction measurements performed on cores of newly constructed roads. The parameter μ_1 represents the asymptotic value of μ_v, in other words, the maximum friction gain due to climate effect.

The weight factor (d) can be deducted from the formula (1) as:

$$d = \frac{\mu - \mu_B}{\mu_G - \mu_B} \tag{6}$$

As indicated in the formula (2), (d) should be time and traffic dependent. The time dependency is linked to climate effect. Generally changes of binder properties are visible after 7-8 year life. Since available data are not “old” enough to assess correctly the time-dependency part of (d), the weight factor is supposed to depend only on the number of vehicles. The plot of (d) versus (N) (Figure 4) can be modeled by the following formula:

$$d = 1 - e^{\left(-\frac{N}{N_0}\right)} \tag{7}$$

where N_0 = parameter to be determined by data fitting.

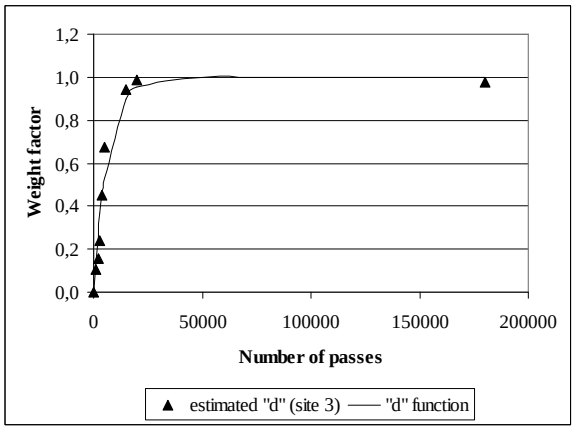

Figure 4 - Plot of weight factor (d) versus number of vehicles (N) and adjustment of formula (7).

The physical model developed to describe the skid-resistance evolution is now written as:

$$\mu = e^{\left(-\frac{N}{N_0}\right)} \cdot \left[\mu_0 + \mu_1 \cdot \left(1 - e^{\left(-\frac{t}{t_0}\right)} \right) \right] + \left(1 - e^{\left(-\frac{N}{N_0}\right)} \right) \cdot a(N+b)^c \tag{8}$$

Despite its rather complex form, due to the inclusion of three influential phenomena, the model parameters can be simply identified by means of laboratory polishing tests on asphalt cores; values obtained from data fitting are shown in table 1 (Do et al. 2009). The most innovative point of this model is that it incorporates the binder-removal phase and mainly the climate effect, both responsible for the friction increase at early age. Actually, existing models

(Diringer & Barros 1990) reproduce only the polishing process and published theoretical curves describe only the decreasing part of the friction evolution.

Table 1. Experimental sites and model parameters

Site	Road network	Section length	Traffic (10^5 trucks/year)	Model parameters						
				a	b	c	μ_0	μ_1	t_0	N_0
1	Main road	2700 m	2.89	1.030	0.100	-0.107	0.34	0.18	4.7	3812
2	secondary road	1700 m	1.14	1.041	0.095	-0.103	0.28	0.21	5.0	6413
3	secondary road	800 m	1.10	0.781	0.100	-0.045	0.28	0.22	6.7	6576

4 COMPARISON OF THE TWO MODELS

The comparisons of the models are realized with two types of pavement surfaces: semi-coarse asphalt concrete and very thin asphalt concrete.

The first step of the comparison dealt with the input data, which are somehow different between the two approaches. The statistical model uses mainly the time as input data (age), whereas the phenomenological model uses time and cumulated heavy vehicles traffic (CHVT). The choice was done to change traffic values in time values (years) by considering the relationship between average traffic data and time.

Moreover, experimentations show that a factor k must be used to link N and cumulated heavy vehicle traffic (Do et al. 2008). Thus, we have:

$$N = 0.024 * CHVT \tag{9}$$

Finally, we obtained:

$$N = 0.024 * Average\_Daily\_Traffic\_HV * 365 * time \tag{10}$$

where Average_Daily_Traffic_HV = number of heavy vehicles / day on the section.

In a second step, the type of friction value is considered. Indeed, the statistical model provides a SFC value (Sideway Friction Coefficient), whereas the phenomenological model is calibrated with friction values measured by the Wehner-Schulze machine. Nevertheless, some correlations exist between these two types of friction measurements. These correlations are indicated in (Cerezo & Do, 2012). They are determined on IFSTTAR test tracks.

Friction values calculated with the two approaches are represented on the same graphics (Figs 11 and 12). It can be seen that the statistical model overestimate friction, compared with the phenomenological model, for semi-coarse asphalt concrete and very thin asphalt concrete 0/10; the reverse is true for very thin asphalt concrete 0/6. Adjustments are still necessary to get predictions of the same order of magnitude for both models (points lying on the bisector). Nevertheless, these first results are promising and show that it should be feasible to predict actual road performance, in terms of the skid resistance evolution, by means of laboratory studies taking rigorously into account the involved mechanisms.

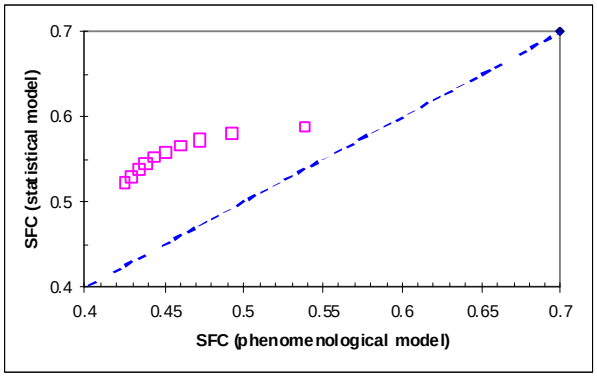

Figure 11 - Comparison between the two models on semi-coarse asphalt concrete.

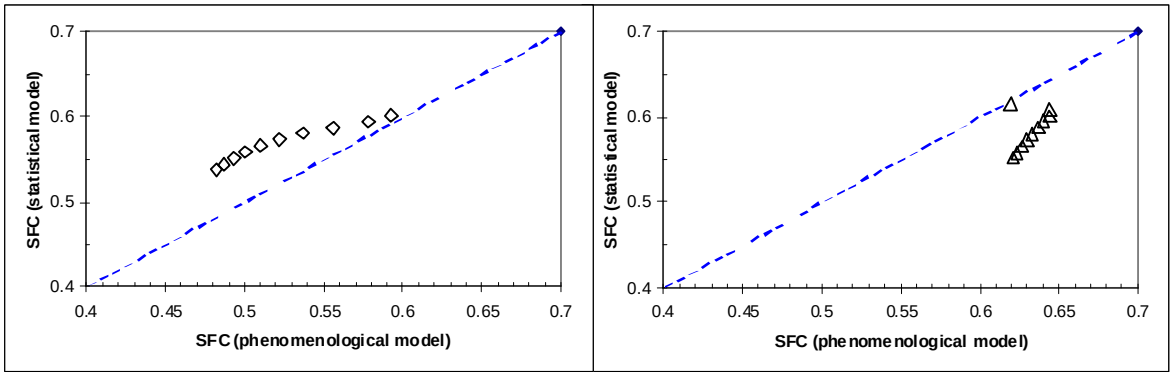

Figure 12 - Comparison between the two models on very thin asphalt concrete: a) 0/10 ; b) 0/6.

5 CONCLUDING REMARKS

This paper presents the comparison between two models of evolution for friction coefficient. In a first part, the use of statistical approach is proposed. Principal Components Analyses and ANOVA allow determining the most relevant parameters and theirs interactions for modelling friction evolution. These parameters are age, radius of curvature, macrotexture and crossfall. Various evolution laws are tested and the best correlations are obtained with multiple linear regressions.

In a second part, a phenomenological model is developed. This model takes into account polishing effect due to traffic, binder evolution due to weather and time, the seasonal variations. This model is calibrated with laboratory tests and validated on three real sites.

In a third part, the two approaches are used on the same set of data. Some modifications of the model must be applied in view of comparing the friction coefficients values. The results are satisfying for very thin asphalt concrete. For semi-coarse asphalt concrete, the statistical approach tend to over-estimate friction coefficient. These results can be explained by the small set of data used in the determination of the laws of evolution for this type of pavement surface. Complementary analysis are in progress in view of increasing the database for statistical studies.

6 REFERENCES

Bouyer, J. Hémon, D. Cordier, S. Derriennic, F. Stücker, I. Stengel, B. & Clavel, J. 2009. *Epidémiologie: Principes et méthodes quantitatives*, Ed. Tec & Doc, Lavoisier, 498 pages.

Cerezo, V. & Do, M.T. 2012 *Correlation between friction measurements devices – experimentation CetE of Lyon / IFSTTAR*. Research Report (in French), Research Program 11S103, 24 pages.

Cerezo, V. 2009. *Skid Resistance Evolution and Accidents – A Literature Review*. Research Report (in French), Research Program 11K081, 61 pages.

Cerezo, V. and Gothié, M. 2008. Pavement prediction performance models and relation with traffic fatalities and injuries, *Proceedings 6th International Symposium SURF 2008 on pavement surface characteristics*, Portoroz, Slovenia.

Diringer, K.T. & Barros, R.T. 1990. Predicting the skid resistance of bituminous pavements through accelerated laboratory testing of aggregates. *Surface Characteristics of Roadways: International Research and Technologies, ASTM STP* 1031: 61-76. Philadelphia: ASTM.

Do, M.T., Kane, M., Tang, Z. & de Larrard, F. 2009. Physical Model for the Prediction of Pavement Polishing. *Wear* 267: 81-85.

Do, M.T., Tang, Z., Kane, K. & de Larrard, F. 2008. Laboratory Test Method for the Prediction of the Evolution of Road Skid Resistance with Traffic. *Proceedings 6th International Symposium SURF 2008 on pavement surface characteristics*, Portoroz, Slovenia.

Do, M.T., Tang, Z., Kane, K. & de Larrard, F. 2007. Pavement Polishing – Development of a Dedicated Laboratory Test and its Correlation with Road Results. *Wear* 263: 36-42.

Durand, J.F. 2009. *Accident Risk and Road Surface Characteristics of National Road Network*. Research

Report (in French), Research Program 11N066, 120 pages.
Gothié, M. 2002. Skid resistance evolution of different wearing course techniques according to traffic. *Proceedings 9th Int. Conf. of Asphalt Pavements*, Copenhagen, Denmark.
Henry, J.J. & Meyer, W.E. 1984. Prediction of aggregate and pavement polishing. *Bull. Int. Assoc. Eng. Geol.* 29: 365–368.
ISO 13473-1. 2002. *Characterization of pavement texture by use of a surface profile – Part 1: determination of mean profile depth*.
Lorino, T. Lepert, P. & Riouall, A. 2006. Application à la campagne IQRN des méthodes statistiques d'analyse de l'évolution des chaussées. *Bulletin de Liaison des Ponts et Chaussées* 261-262: 25-41.
Lorino, T. Lepert, Ph. Giacobi, C. and Layerle, E. 2008. Pavement surface characteristics evolution. *Proceedings 6th International Symposium SURF 2008 on pavement surface characteristics*, Portoroz, Slovenia.
Zhao, D., Kane, M., Do, M.T. 2010. Effect of Aggregate and Asphalt on Pavement Skid Resistance Evolution. *ASCE Geotechnical Special Publications, n° 203, Proceedings of the GeoShanghai 2010 International Conference*. Shanghai, China.