

Rutting Models for the Use in Pavement Maintenance Management

J. Veiga & R. Micaelo

Department of Civil Engineering, Universidade Nova de Lisboa, Caparica, Portugal

A. Ferreira

Department of Civil Engineering, University of Coimbra, Coimbra, Portugal

ABSTRACT: With the recent approval of the Portuguese Law No. 110/2009 of 18 May, within the scope of road concession contracts, the concessionaires need to submit to the Portuguese Road Infrastructures Institute (InIR) a Quality Control Plan (QCP) and a Maintenance and Operation Manual (MOM). Therefore a Pavement Management Systems (PMS) must consider one pavement performance prediction model for each pavement state parameter so that it permits the definition of maintenance and rehabilitation (M&R) interventions in order that the concessionaire fulfils the values defined in the QCP in each year of the concession period. The QCP presents the admissible values for each pavement state parameters (cracking, rutting, roughness, etc.) that a concessionaire of highways needs to verify. Contractual infractions are penalized with fines, in which the global sum varies, according to its gravity, between €5000 and €100000.

This paper describes briefly the state-of-the-art in terms of rutting models. Some of the models are analysed by comparing rutting evolution prediction for a set of representative Portuguese pavements structures and traffic conditions. HDM-4 deterioration model was considered to be the most promising to implement in a new Portuguese Maintenance Optimisation System (MOS).

KEY WORDS: Maintenance & rehabilitation; pavement management systems; performance models; rutting.

1 INTRODUCTION

A Pavement Management System (PMS) can be defined as a set of tools which helps a road network administration optimize maintenance and rehabilitation (M&R) actions for keeping pavements in good service condition. One of the modules of a PMS is the Pavement Performance Model (PPM), which is a mathematical representation that can be used to predict the future state of pavements, based on current state, deterioration factors and effects resulting from M&R actions (Ferreira *et al.* 1999).

Currently the PMS of Estradas de Portugal S.A., the Portuguese Road Administration, uses for PPM the AASHTO pavement performance model that computes a global pavement condition index, the present serviceability index (PSI), based on several factors like the traffic, the material properties and the drainage and environmental conditions (Ferreira *et al.* 2011). The extent and severity of distresses at the time that the pavement condition index reaches the warning level restricts the implementation of more cost-effective techniques (Lou *et al.* 2003).

In 2007 and 2009 the Portuguese Government (MOPTC 2007, 2009) published legislation establishing EP – Estradas de Portugal, S.A., as the global road network concessionaire and the basis of the concession contract. Within this contract it was established that concessionaires have to submit to the Portuguese Road Infrastructures Institute (InIR), the supervisor institution, on a regular basis, a Quality Control Plan (QCP) and a Maintenance and operation Manual (MOM). The QCP defines the limits of pavement condition parameters (rutting, cracking, roughness, etc.) than can be found at any time of the concession period. For the preparation of both documents, specially the first one, it is required to know the pavement condition ahead, not only the general pavement service condition, but quantifying the extent and the magnitude of pavement distresses and the actions to be implemented in every situation. When a concessionaire does not fulfil the QCP, InIR can apply a contractual infraction, in which the global sum varies, according to its gravity, between €5,000 and €100,000, or daily values that can vary between €500 and €5,000 (MOPTC 2009).

A concessionaire, beyond the annual pavement inspections to demonstrate to the InIR and the conessor (the Portuguese State or represented by the EP - Estradas de Portugal, S.A.) the fulfilment of the QCP, wants to predict the year when their pavements do not fulfil the admissible values for some state parameter. A concessionaire knowing this information can apply M&R preventive interventions at a minimum cost in order to effectively fulfil the QCP in all the remaining years of the concession period.

This paper describes the state-of-the-art in terms of permanent deformation (rutting) models, and evaluates the performance of the selected models considering the rut depth evolution for a set of representative Portuguese pavements structures and traffic conditions.

2 RUTTING PREDICTION MODELS

Rutting is one of the most important pavement distresses. It results from the accumulation overtime of permanent traffic-induced deformations in the wheel path. There is a change in cross profile that affects driving safety (water accumulation, lower skid resistance, etc.) and accelerates pavement deterioration (dynamic loading, narrow wheel loading distribution).

The width and depth of rut differ with the mechanisms of deformation, which depend on the pavement structure, the traffic and the environmental conditions. Kannemeyer (NLDI, 1995) distinguishes three phases in the rutting process, (1) initial consolidation; (2) constant rate of deformation; (3) accelerating deformation. The first is related with after construction compaction, which depends mainly on compaction attained during construction. The rate of deformation is fast after traffic opening and decreases rapidly with time. The second phase is recognized by a stabilization of the rate of deformation, with the plastic flow and shear deformation of all (or some) layers being mainly the origin of it. In the last phase there is a fast increase of rutting deformation, which it is mainly influenced by the materials and traffic characteristics. Infiltration of water in subgrade and high air temperature seasons (asphalt mixtures temperature sensibility) are the factors most contributing to the acceleration of deformation.

Regarding pavement condition assessment, procedures and used equipment have evolved significantly. Before, rutting characterization was man made with eye inspection and ruler measurements, based on procedure manuals. Nowadays, laser and high definition cameras on board of vehicles measure and record all data.

The decision for intervention with M&R in a specific road section due to a warning rut level may vary greatly based on agency available budget and country practice. INIR requires for each road section the representation of a rutting distribution histogram with the following classes (< 10 mm; 10-15 mm; 15-20 mm; 20-30 mm; > 30 mm), INIR, 2011. Ferreira *et al.*

(2002) consider 20 mm as a warning level for rutting in their pavement maintenance system while Cardoso and Marcon (1998) use 5 mm and Fwa *et al.* (1996) choose 15 mm.

In this study, the methodology used was to analyse several pavement rutting deterioration models available in the literature with the objective of its integration in the Portuguese Pavement Management Systems. The following models are described: the Brazilian model; the PAVENET-R; the HDM-4; the AASHTO MEPDG; the RILEM model; the PARIS model and the Austroads model.

Brazilian model (1987)

This model was developed by Paterson based on a long-term pavement monitoring program carried out in Brazil between 1975 and 1985 and it is considered the first empirical model with considerations of densification and plastic flow mechanisms (Cardoso and Marcon 1998, NLDI 1995). The monitored road sections were unbound granular base flexible pavements, with surface treatment or asphalt concrete (20-100 mm), in areas with tropical to subtropical climate with an average annual precipitation between 1200 and 1700 mm/year.

Rut depth is predicted with equations (1) and (2), based on a continuous non-linear model. This model is interesting for PMS's with in-service (for some time) road networks while for concessionaries with recently constructed roads a two-phase prediction model seems more suitable. This model considers the Benkelman beam to measure pavement deflections, but this equipment is not used in Europe any more. However, some regressions relating the modified structural number with the Benkelman beam maximum deflection have been proposed by several authors such as Eq. (3) by Paterson (NLDI 1995, Bennett 1994). The modified structural number is the evolution of the AASHTO structural number by considering the subgrade contribution (detailed information at the HDM-4 model description).

This model has poor prediction for high rut depths situations due to 95% of pavement sections monitored had rut depth values less than 8 mm (NLDI 1995).

$$R_t = Y_t^{0.166} \times SNC^{-0.502} \times COMP^{-2.3} \times N80c_t^{ERM} \quad (1)$$

$$ERM = 0.09 + 0.0384 \times B - 0.0009 \times RH + 0.00158 \times MMP \times C_t \quad (2)$$

$$SNC = 3.2 \times B^{-0.63} \quad (3)$$

Where R_t is the rut depth in year t (mm); Y_t is the age of pavement since original construction or since subsequent AC overlay (years); SNC is the modified structural number for the pavement; $COMP$ is the compaction index (%); $N80c_t$ is the cumulative 80 kN equivalent single axle load (ESAL) at age t (million ESAL/lane); C_t is the pavement cracked area factor (0 if $Y_t < 6$ or 21.6 otherwise); B is the Benkelman beam maximum deflection for the existing pavement (0.01 mm); RH is the rehabilitation factor (0 if pavement without overlay or 1 otherwise); MMP is the mean monthly precipitation (mm).

The AASHTO structural number (SN), calculated using Eq. (7), does not include the subgrade contribution as it is considered in the pavement design procedure through the resilient modulus. In opposition, the modified structural number (SNC), calculated using Eq. (4), takes into account the subgrade strength that is calculated using Eq. (5), (NLDI 1995).

$$SNC = 0.0396 \sum_{n=1}^N (H_n / 25.4) \times C_n^e \times C_n^d + SNSG \quad (4)$$

$$SNSG = 3.51 \times \log(CBR) - 0.85 \times [\log(CBR)]^2 - 1.43 \quad \text{if } CBR \geq 3 \quad (5)$$

Where SNC is the modified structural number; C_n^e is the structural coefficient of layer n ; C_n^d is the drainage coefficient of layer n ; and H_n is the thickness of layer n (mm).

PAVENET-R (1996)

The rutting prediction model defined by Eq. (6) is used in the computer model PAVENET-R (Fwa *et al.* 1996) aiming at the optimization of the maintenance-rehabilitation problem at the network level. The rut depth over time is predicted based on traffic and the pavement bearing capacity (the AASHTO structural number is calculated using Eq. (7)). As for the previous model it is a continuous phase model.

$$R_t = 4.98 \times Y_t^{0.166} \times N80c_t^{0.13} \times SN^{-0.5} \quad (6)$$

$$SN = \sum_{n=1}^N H_n \times C_n^e \times C_n^d \quad (7)$$

Where R_t is the rut depth in year t (mm); Y_t is the age of pavement since original construction or since subsequent AC overlay (years); $N80c_t$ is the cumulative equivalent standard axle load (ESAL) at age t (million ESAL/lane); SN is a structural number; C_n^e is the structural coefficient of layer n ; C_n^d is the drainage coefficient of layer n ; and H_n is the thickness of layer n (mm).

PARIS (1999)

The European PARIS (Performance Analysis of Road Infrastructure) project was carried out during the 90's, aiming the development of robust pavement deterioration models for the use in pavement management systems. The complete set of data used for the analysis came from 700 monitorized road sections and past studies with accelerated loading testing. The final rutting model estimates the rut depth progression with the rut value at the last inspection and the number of ESALs carried out or the age of the pavement surface.

$$RD_{slope} = 10^{0.05 + 0.93 \times \log_{10} \left(\frac{RD}{N80} \right)} \quad (8)$$

$$RD_{slope} = -0.02 + 1.05 \times \frac{RD}{age} \quad (9)$$

Where RD_{slope} is the rut depth increase with time (mm/year); RD is the rut depth at the last inspection (mm); $N80$ is the equivalent standard axle load (million ESAL/lane); age is time since last inspection or intervention (years).

This model may be adequate for distress evolution estimation of an in-service road network while for the prediction at project level or on road sections without historic data is less interesting.

HDM-4 (2000)

The most recent version of the Highway Development and Management system (HDM-4) determines the pavement rut depth (R_i) from the sum of four components (NLDI 1995, Theyse 2008): initial densification – Eq. (10); structural deformation – Eq. (11); plastic deformation – Eq. (12); wear from studded tyres. The last component equation is not presented as studded tyres are not used in Portugal. Structural deformation accounts for the densification and shear deformation of granular and cemented layers, with split in 2 sequential phases. In the first phase there is rutting increase at constant rate, which is interrupted with cracking initiation. From that point forward due expected water infiltration the rate of rutting deformation increases with the cracking area. This formulation is valid for flexible pavements with asphalt or surface treatment as surface course and granular (unbound or stabilised) or asphalt base course.

$$R_i = 51740 \times (N80 \times 10^6)^{0.09 + 0.0384B} \times SNC_i^{-0.502} \times COMP^{-2.30} \quad (10)$$

$$\Delta R_{st} = (0.333 + 0.0494 \times B + 0.0021 \times MMP \times C_t) / Y_t + 0.0285 \times MMP \times (C_t - C_{t-1}) \times \ln(\max(1, Y_t \times N80)) \times R_{t-1} \quad (11)$$

$$\Delta R_{pd} = 2.46 \times V^{-0.78} \times H^{0.71} \times [PT / (SP_{t-1} + 0.017 \times VIM_{t-1} \times PT^{0.076})]^{1.34} \times VIM_t^{-1.20} \quad (12)$$

$$VIM_t = VIM_{t-1} - a1 \times N80 \times V^{a2} \times (PT/SP_t)^{a3} \quad (13)$$

Where R_t is the total rut depth at year t (mm); ΔR_i is the rut depth from initial densification (mm); ΔR_{st} is the incremental rutting in year t due to structural deformation (mm); ΔR_{pd} is the incremental rutting in year t due to plastic deformation within asphalt layers (mm); N80 is the annual equivalent standard axle load (million ESAL/lane); SNC_t is the modified structural number for the pavement in year t ; COMP is the compaction index (%); MMP is the mean monthly precipitation (mm); V is the speed of heavy vehicles (km/h); H is the thickness of asphalt surface layer; C_t is the area of index cracking at the beginning of the analysis year (%); PT is the pavement temperature at 20 mm depth ($^{\circ}C$); SP_t is the softening point of the bitumen in asphalt layers at year t ($^{\circ}C$); VIM_t is the air voids of asphalt layers at year t (%); $a1, a2, a3$ are constant values (different for the first and the following years).

AASHTO MEPDG (2008)

AASHTO presented in 2008 the Mechanistic-Empirical Pavement Design Guide (MEPDG), (NCHRP 2004, AASHTO 2008), which succeeds the 1993 pavement design version and the 1998 update. This version presents substantial differences over the previous version, namely, the performance equations developed using 1950's AASHTO Road Test are abandoned and the design is now based on the mechanistic-empirical procedure and the prediction of distresses evolution. The distress prediction models were calibrated using data from the LTPP database, the Mn/Road experiment and the states/Federal agency research projects.

The approach for the rutting evolution determination considers the contribution of all layers for the permanent deformation in each time period. Each material layer is subdivided in sublayers and one year divided in seasons, and rutting estimated, Eq. (14), for each sub-season at the mid-depth of each sublayer within the pavement structure. For the cumulative deformation calculation is used a "strain hardening" approach, which is based on determining the equivalent number of load cycles for each subseason that results the same rutting at the beginning of that season. For asphalt layers is used Eq. (15) and for unbound layers and subgrade is used Eq. (16). The model excludes the contribution of hydraulic binders stabilized layers. The calculus is carried out sequentially for each axle type and load combination.

$$R = \sum_{i=1}^n \varepsilon_p^i \times h^i \quad (14)$$

$$\Delta R_a = \beta_{1r} \times k_z \times \varepsilon_r \times 10^{k_{1r}} \times n^{k_{2r} \times \beta_{2r}} \times T^{k_{3r} \times \beta_{3r}} \times h \quad (15)$$

$$\Delta R_g = \beta_{s1} \times k_{s1} \times \varepsilon_v \times h \times \left(\frac{\varepsilon_0}{\varepsilon_r} \right)^{lab} \times e^{-\left(\frac{p}{n} \right)^{\beta}} \quad (16)$$

Where R is the rut depth at the end of the season (mm); ε_p^i is the plastic strain in sublayer i (m/m); h^i is the thickness of sublayer i (mm); ΔR_a is the accumulated deformation in the asphalt sublayer (mm); ΔR_g is the accumulated deformation in the granular or subgrade sublayer (mm); T is the temperature at mid-depth of the sublayer ($^{\circ}C$); n is the number of axle-load repetitions; ε_r is the vertical resilient strain at mid-depth of the asphalt sublayer (m/m); ε_v is the vertical elastic strain at mid-depth of the granular/soil sublayer (m/m); $(\varepsilon_0 / \varepsilon_r)^{lab}$ is the intercept value to the vertical elastic strain ratio from the laboratory test to obtain material properties; k_z is the depth confinement factor; $k_{1r}, k_{2r}, k_{3r}, k_{s1}$ are the global field calibration parameters; $\beta_{1r}, \beta_{2r}, \beta_{3r}, \beta_{s1}$ are the local calibration factors (default = 1.0).

The implementation of this model demands an enormous amount of data (traffic, materials, climate), though it can be considered the most complete, mechanistic-empirical approach.

RILEM (2009)

The RILEM TC 206 ATB obtained Eq. (17) with regression adjustment analysis to 10 years rutting data of a highway test section (100 m) in Austria (Piber *et al.* 2009). The model considers only the number of heavy vehicles as prediction variable. The two constants in the model hide the influence of other factors for the rutting progression. Therefore, the applicability of this model is very limited.

$$R_t = 0.2406 \times HV^{0.2113} \quad (17)$$

Where R_t is the total rut depth at year t (mm); HV is the accumulated number of heavy vehicles per lane in year t .

AUSTROADS model (2010)

Austrroads has recently developed road deterioration models for the roughness, rutting and cracking prediction of sealed granular pavements, which represents 85% of sealed pavements in Australia, with data from the Long Term Pavement Performance and Long Term Performance Maintenance programmes (Austrroads 2010). The total rut depth is predicted using Eq. (18), which depends on traffic, age, climate (using Thornthwaite Moisture Index), rut depth after first year and maintenance expenditure. The initial densification (first year) was considered an important variable for the estimate, which due to the lack of data from sites, can be predicted with Eq. (19) from HDM-4 model.

$$R_t = R_0 + K \times (Y_t - 1)^{0.617} \times \left(0.022 \times \frac{100 - TI_t}{SNC_0} + 0.594 \times N80 - 0.000102 \times me \right) \quad (18)$$

$$R_0 = K_{rid} \times 1.30 \times (N80 \times 10^6)^{(0.09 + 0.2496 \times SNC_0^{-1.6})} \times SNC_0^{-0.502} \quad (19)$$

Where R_t is the rut depth at year t (mm); R_0 is the rut depth at the end of first year (mm); Y_t is the age of pavement since original construction (years); TI_t is the Thornthwaite Moisture Index for climate pavement conditions at year t ; $N80$ is the annual equivalent standard axle load (million ESAL/lane); SNC_0 is the modified structural number for the initial pavement; me is the annualised maintenance expenditure (\$/lane-km); K and K_{rid} are the calibration factors (default = 1.0).

Pavements with granular base and surface treatments are not a common solution in Portugal. It does not include deformation from asphalt mixtures that it is considered to play a very important role in rutting, which makes this model not applicable to the Portuguese PMS.

3 CASE STUDY

In the Portuguese Pavements Design Manual (JAE, 1995), a pavement structure is recommended depending on the traffic class, which varies between T1 and T6, and the pavement foundation class, which varies between F1 and F4. The traffic class is defined by the number of 80 kN ESAL applications during the design life or the design period calculated in relation to the annual average daily heavy traffic (AADTh), the annual average growth rate of heavy traffic (gh) and the average heavy-traffic damage factor or, simply, truck factor (α) (see Table 1). On the other hand, the pavement foundation class is defined by the California bearing ratio (CBR) of sub-grade materials and the design stiffness modulus (E) (see Table 2). The design manual considers 16 different flexible pavement structures for different combinations between traffic and pavement foundation. These pavement structures were defined using the Shell pavement design method (Shell, 1978), with verification by using the University of Nottingham (Brunton *et al.* 1987) and Asphalt Institute (AI, 2001) pavement design methods.

Some of the rutting models described in previous section were evaluated by comparing the

evolution of rut depth over time (the design period, taken usually as 20 years) for different combinations of traffic, foundation and pavement structure. The Brazilian, PAVENET-R, HDM-4 and RILEM models were implemented. The PARIS model requires rutting historic data which is not available for a new road section or after complete rehabilitation. The Austroads model was developed with data from pavements with granular bases and surface treatments which differ greatly from Portuguese pavements. The AASHTO model implementation demands accurate climatic, traffic and materials behaviour data, which was not available.

Three traffic classes (T1, T3 and T5) and two foundation classes (F2 and F3) were selected and the corresponding pavement structure defined according to the design manual. Regarding foundation, it was considered the following characteristics: F2 (CBR=10%; E=60 MPa); F3 (CBR=20%; E=100 MPa). Table 3 shows the pavement structures selected for each traffic-foundation combination. All pavement structures have the same granular sub-base layer thickness while the asphalt layer thickness varies between 180 mm and 320 mm.

For the analysis it was considered the central area of Portugal (Coimbra district). The temperature and precipitation values were determined with the weather data collected over the period 1971-2000 by the Portuguese Meteorology Institute (IM, 2011).

Table 1: Traffic data

Traffic class	AADT	AADT _h	g _h (%)	α	ESAL (20 years)
T6	1500	150	3	2	0.29×10^7
T5	3000	300	3	3	0.88×10^7
T4	5000	500	4	4	2.17×10^7
T3	8000	800	4	4.5	3.91×10^7
T2	12,000	1,200	5	5	7.24×10^7
T1	20,000	2,000	5	5.5	13.28×10^7

Table 2: Foundation data

Foundation Class	E (MPa)	Sub-grade CBR (%)
F1	30-50	5-10
F2	50-80	10-20
F3	80-150	≥ 20
F4	≥ 150	≥ 20

Table 3: Characteristics of pavement structures

Traffic class	Foundation class	Pavement structure	Surface layer			Base layer			Sub-base layer		
			Mat.	t _s mm	E MPa	Mat.	t _s mm	E MPa	Mat.	t _s mm	E MPa
T5	F3	P4	AC	40	4000	AC	140	4000	G	200	200
	F2	P7	AC	40	4000	AC	180	4000	G	200	200
T3	F3	P9	AC	50	4000	AC	190	4000	G	200	200
	F2	P13	AC	50	4000	AC	230	4000	G	200	200
T1	F3	P14	AC	60	4000	AC	220	4000	G	200	200
	F2	P16	AC	60	4000	AC	260	4000	G	200	200

4 RESULTS

The results of rutting evolution predicted by the PPM for the selected set of Portuguese representative conditions (traffic, foundation and structure) are summarized in Figures 1-3.

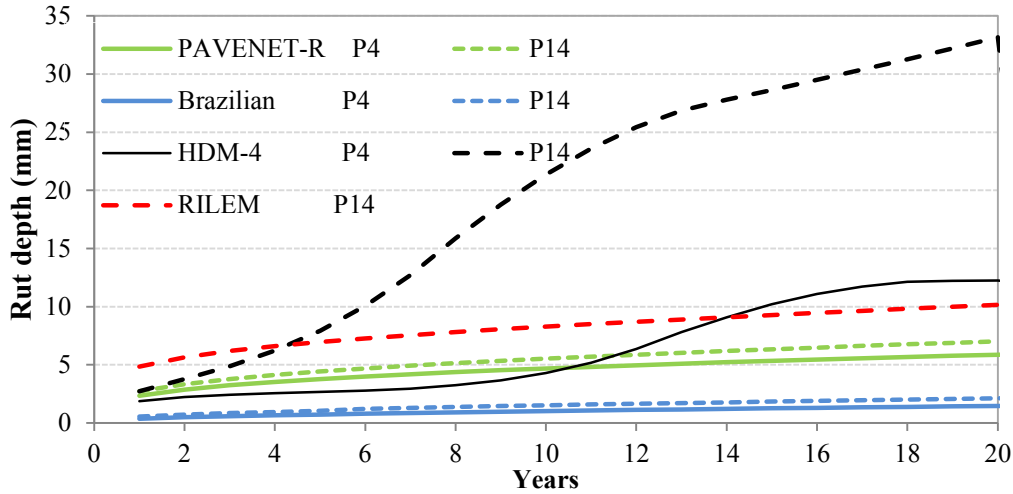


Figure 1: Rut depth evolution: T5 F3 P4 versus T1 F3 P14

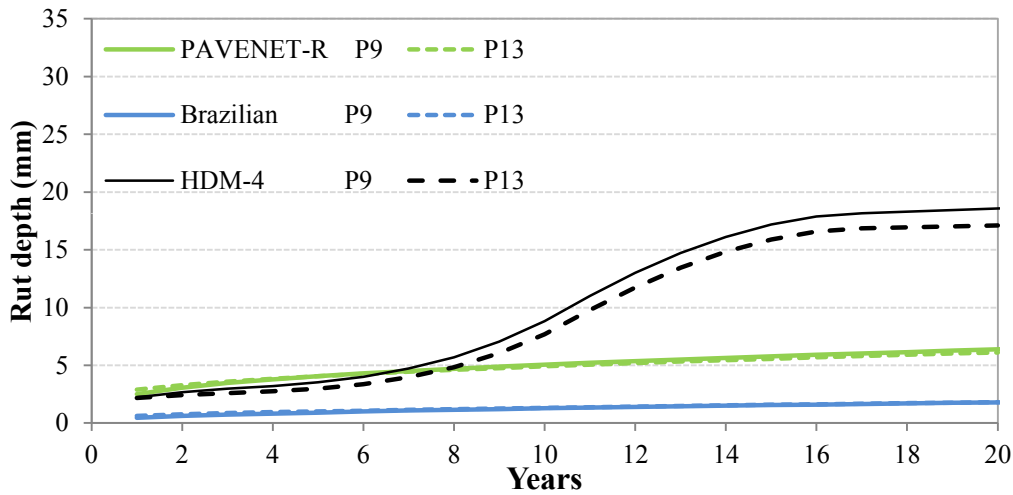


Figure 2: Rut depth evolution: T3 F3 P9 versus T3 F2 P13

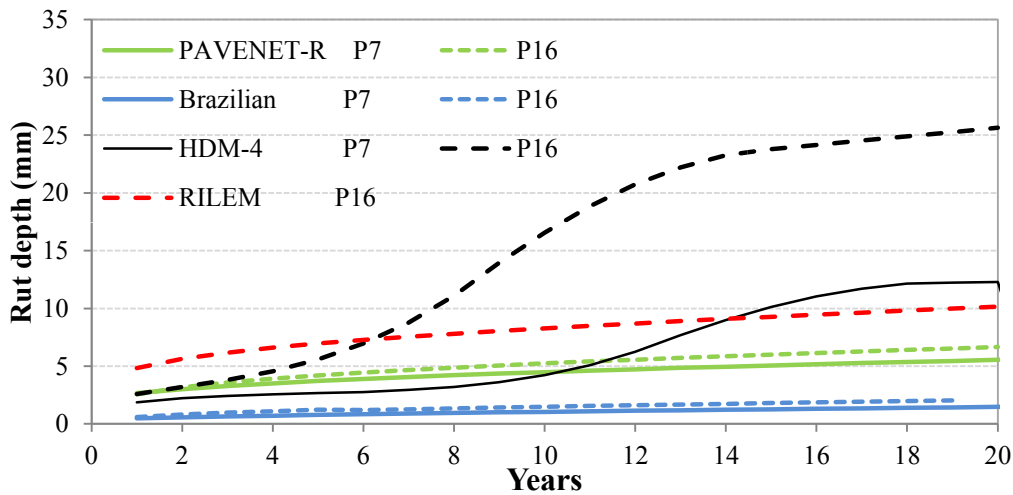


Figure 3: Rut depth evolution: T5 F2 P7 versus T1 F2 P16

It is considered that no M&R actions are implemented during the 20 years. The RILEM model was only implemented to pavement structures P14 and P16 as these are the only studied cases with similar characteristics (traffic and pavement) to the pavement data used for the model development. Figures 1 and 3 compare rutting evolution for 2 pavement structures with the same foundation class and very different traffic classes, while Figure 2 shows the

results for 2 pavement structures with different foundation class and equal traffic class. Results show for most methods a smooth and constant increase of rutting over the pavement age, attaining values from 2 to 33 mm at the end of pavement's life. HDM-4 predicts considerably larger rut depth values in some of the situations tested, with three easily indentified phases along the 20-years period. Initially, low growth rate (4-10 years), then, fast growing, finally, stabilization. The PAVENET-R and RILEM models predict high initial rut depths values, as compared with final values at year 20 for the same models. In a lowest to largest predicted rut depth in year 20, the methods sequence is the following: Brazilian; PAVENET-R; RILEM and HDM-4.

Rutting evolution is very similar for the PAVENET-R and the Brazilian model among the 6 situations, which vary significantly in pavement structure and traffic level. Based on these results, the pavement structures proposed in the design manual for different foundation/traffic conditions are correct. On the other hand, final rut depth values are distant from the warning levels presented previously which may indicate that the pavement structures are oversized for this distress. In opposition, HDM-4 results show large dependence on traffic. P9 and P13 have identical rutting prediction, which are proposed for traffic class T3 and foundation class F2 and F3. Figure 1 and 3 shows an enormous variation between the 2 pavements rutting prediction, which differ on traffic class. The contribution of plastic deformation for HDM-4 rut depth varies from insignificant (0.06 mm/year), for low traffic, to very important (0.93 mm/year), for high traffic. For the calculation it was considered only the contribution of surface layer.

Table 4 shows the number of years to reach two different warning levels, 5 and 20 mm, as predicted by all methods for the different pavement structures. The Brazilian model predicts so low values that not even in 50 years is attained a rut depth of 5 mm. The PAVENET-R model predicts to reach 5 mm in 8 to 15 years depending on pavement structure while 20 mm is not attained in 50 years. HDM-4 predicts to reach 5 mm in 4 to 11 years and 20 mm in 10 to more than 50 years. The RILEM model predicts to reach in 2 years 5 mm but it grows very slowly that it does not reach 20 mm in 50 years.

Table 4: Time to intervention prediction (years) according to rut depth of 5 and 20 mm

	PAVENET-R		HDM-4		RILEM		BRAZILIAN	
	5 mm	20 mm	5 mm	20 mm	5 mm	20 mm	5 mm	20 mm
T5 F3 P4	12	>50	11	>50	—	—	>50	>50
T3 F3 P9	10	>50	8	30	—	—	>50	>50
T1 F3 P14	8	>50	4	10	2	>50	>50	>50
T5 F2 P7	15	>50	11	>50	—	—	>50	>50
T3 F2 P13	12	>50	9	>50	—	—	>50	>50
T1 F2 P16	9	>50	5	12	2	>50	>50	>50

5 CONCLUSIONS

This paper described the state-of-the-art in terms of rutting models which are then analyzed comparing the rut depth evolution prediction for several representative Portuguese road pavements. Four models were tested with very different results, from the Brazilian that predicts a rut depth of 2 mm after 20 years in service to 33 mm with HDM-4. Austroads, PARIS were considered inadequate. PANENET-R and the Brazilian model show little to none variation pavement conditions (structure, foundation, traffic) which is not considered adequate. The RILEM model predicts unreasonable rut depths for the first years and rutting increase seems to optimistic. Rutting prediction evolution with HDM-4 is reasonable despite

high values for some situations. This model includes in the formulation all the mechanisms that contribute to rutting and it has been calibrated with data from different world geographic areas. Although the ASHTO model has solid background on pavement mechanics it has not been implemented due to data requirements.

It is recommended that a full verification and calibration of HDM-4 model should be conducted using Portuguese pavement condition time series data.

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