

# Analysis of the Pavement's Performance in the Crystalline Basement Geological Region at Santa Catarina State

A. de Oliveira, G. Trichês & A. F. Marcon  
*Federal University of Santa Catarina, Florianópolis, Brazil*

**ABSTRACT:** In order to achieve a better understanding of the pavement's performance in the crystalline basement geological region in Santa Catarina - Brazil, this research aims to obtain deflection, cracking and roughness trend lines for the prediction of the pavement's future conditions. For this analysis it was used the data collected in the years of 1990, 1995, 1997 and 2001 by the Maintenance Management System and the Pavement Management System of former Highway Department of Santa Catarina State (DER/SC), currently Infrastructure Department of Santa Catarina State (DEINFRA) in 1995, 1997 e 2001. The analyses were carried out considering the evolution of the mentioned parameters above, before and after pavement rehabilitation works. The trend lines determination was carried out through the process of simple regression considering only one independent variable equivalent 8.2 ton axle load repetitions or age. Additionally, it was performed multiple linear regression analyses, considering parameters as the total equivalent granular thickness of the pavement layers ( $H_{total}$ ), surface layer thickness ( $H_{surface}$ ), overlay thickness ( $H_{overlay}$ ) and average annual daily volume traffic (AADT). It is also shown the determination coefficient ( $R^2$ ), the standard error (SE) and the significance level ( $\alpha$ ) for each trend line equation.

## 1 INTRODUCTION

In Brazil, as a result of the deterioration and scarce usage of railway transportation for cargo and passengers, the highways play a vital role in the distribution of agricultural and industrial products, very often, being the only option for transporting goods between production centers and consumers, as well as ports and airports.

On the other hand, the overloading of the roads sparked the evident need to create maintenance and rehabilitation services for the Brazilian road network, seeing as the means required for these activities is, in almost 100% of cases, greater than that which is available. In this manner, the few means available must be used in the most rational and efficient way.

This situation has led the road authorities and research institutions to study the real behaviour of pavements and their constituent materials and structures. This type of action enables the development of processes which allow the selection of the most efficient methods of planning, design, construction and maintenance of pavements in acceptable conditions of trafficking. However, in order to know the behaviour of pavements both now and in the long-term, and to establish the best measures to take for the conservation of the road network of a determined region, one must, firstly, think about the organization. For this reason, the Pavement Management Systems (PMS) have been the subject of a high number of studies and works carried out in the area of road engineering, especially during the last two decades in Brazil.

The initial milestone of the PMS on DEINFRA (Infrastructure Department of Santa Catarina State, former Highway Department of Santa Catarina State - DER/SC), was characterised by

surveys on the distress, roughness and deflection, executed in 1990. From there, until the start of the present research, other surveys were taken on the conditions of the pavements in 1995, 1997 and 2001.

The objective of the present research is to analyse the data of the mentioned surveys undertaken by the PMS of DEINFRA, searching for a trend line to predict the evolution of the deflection, the all cracking and the roughness of the pavements.

## 2 PAVEMENT MANAGEMENT SYSTEM

### 2.1 *Definition and importance*

In countries which are extremely dependent on road transport, as is the case in Brazil, the condition of the roads has a significant influence on the cost of the life of society as a whole, because roads in poor condition increase the vehicle operational cost, the journey time and the rate of accidents, all of which are directly reflected in the value of the freight and final cost of products transported (CAMPOS, 2004).

Compiling the work of AASHTO (1993), DNER (1993), CHEN et al (1993), QUEIROZ et al (1982), HAAS et al (1994), MARCON (1996); MAJIDZADEH et al (1990) e ULLIDTZ (1987), one observes that there is little difference between the different authors' concepts of PMS. Therefore, PMS is a set of tools or methods that helps decision-makers to rationalise administrative decisions, with efficiency and efficacy, in the search for an excellent strategy for the application of resources in road works. These decisions have to be taken in rational, clearly established proceedings that involve a co-ordinated treatment of all activities, including planning or programming of investments, design, construction, maintenance, periodical evaluations, research and training in pavement engineering, aiming at maintaining the pavement in an adequate condition for use during a determined time period.

### 2.2 *The DEINFRA Pavement Management System*

The DEINFRA Pavement Management System (DER/SC, 1997) was conceived to work based on 4 main subsystems. The 4 subsystems are named: Information Subsystem (data bank); Strategies Evaluation Subsystem; Programming Subsystem; and Monitoring Subsystem. The analysis, the optimum use of available resources and work programming are made on the network level, and the technical solutions are determined on the project level.

## 3 PAVEMENT PERFORMANCE MODELS

### 3.1 *Basic Types of Performance Models*

One basic classification for performance models was suggested by MAHONEY (1990) based on the preliminary work of LYTTON (1987) *apud* HAAS et al (1994). This classification takes into consideration the network and project levels of a PMS, and also two types of performance models: deterministic and probabilistic.

A convenient way is to aggregate prediction models within 4 basic types for operational aims that would be: purely mechanistic; mechanistic-empirical; regression; and subjective.

### 3.2 *Division of Pavements in Families in Order to Obtain the Performance Models*

This methodology consists in grouping together network road sections and organising them in families. Each pavement family is defined as a group of roads sections with similar characteristics, in relation to the type, use, functional classification and deterioration level.

The parameters used to classify a pavement family depend on system user and on the available information. After the families are defined, an information archive is created, containing all the

relevant characteristics of each section. This methodology is based on the hypothesis that road sections with similar structures, but with different ages, traffic and condition indexes, represent the long term condition change of each section of a determined family (SHAHIN *et al*, 1987; BOLIVAR e ACHÚTEGUI, 1998). In this way, it is possible to have an idea of the general performance or long term tendency that can be hoped for each section of a family (SHAHIN, 1994).

## 4 RESEARCH METHODOLOGY

### 4.1 Geological Characteristics of Santa Catarina State

The DNPM (National Department of Mineral Production)/CRM (1987) and TEIXEIRA (1993) establish that Santa Catarina state can be divided into three large categories from a geological point of view:

- Geological Region 1 – Rocks of crystalline basement – this category is mainly formed of granite and gneisses;
- Geological Region 2 – Gondwanic rocks - this category is formed by sedimentary rocks, such as sandstone, siltstone and claystone.
- Geological Region 3 – Volcanic Rocks: region formed by volcanic rocks such as basalt with some small and localized occurrences of acid rocks.

### 4.2 Localization of Selected Road Sections

The road network of Santa Catarina State is the most important way for travel and goods transportation, being made up of 8,843 km of roads managed by federal, state and municipal organizations. The road network system is spread out with regular homogeneity across the whole State area.

For this research only the state roads localized in the Geological Region 1 and paved until 2001 were analysed, totaling an extension of 867 km. Figure 1 highlights the studied region.

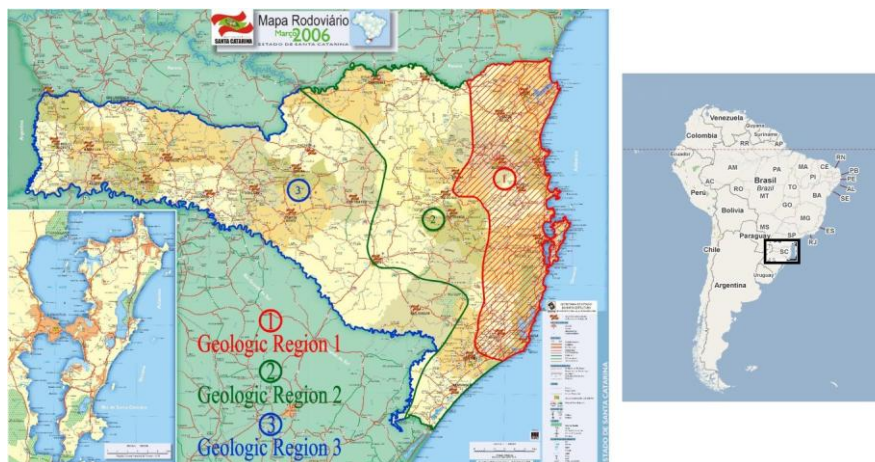


Figure 1. Localization map of the Region 1

### 4.3 Types of Materials and Structure of the Pavements

In the studied region, the composition of pavement structures is quite homogenous and the few variations that occur are a result of local peculiarities. The types of materials used in pavement surface construction are:

- Asphalt Concrete – AC;
- Asphalt Concrete + Binder (Open Graded Asphalt Concrete) – AC+Binder;
- Binder (Open-graded asphalt concrete) + Slurry seal – B + SS

- Cold Asphalt Mixture + Slurry seal – ACM + SS;
- Types of materials used for construction of Base and Sub-Base layers:
- Graded Crushed Stone – GCS
  - Macadam – M;
  - Gravel – G;
  - Pebble – P

#### 4.4 Data Used in the Research

The evaluation on pavements in Santa Catarina were initiated in 1990 by the organisation then called DER/SC, currently DEINFRA. The sections were divided into homogenous sections through subjective evaluations. In sequence, objective evaluations of surface distresses, roughness and deflection (Benkelman Beam) were done on the homogenous sections.

The evaluations carried out in 1995, 1997 and 2001 were made as an activity of the Pavement Management System. The test localizations were identified using a kilometric reference so that it was always possible to correctly identify the position of the distresses of each evaluation. The evaluations consisted of the determination of surface pavement distress, using the Desyroute equipment, measuring roughness using response type equipment (Bump Integrator) and deflection measurements in 1995 and 2001 by FWD (Falling Weight Deflectometer) equipment.

#### 4.5 Traffic Evaluation

The evaluation of average daily traffic volume and respective growth rates were carried out from the following data sources:

- historical series of traffic volume from periodic evaluations made by DER-SC;
- vehicle classification evaluations conducted by consultant companies;
- special studies executed for planning of the Santa Catarina Transportation System;
- Information from MARCON (1996) thesis; and
- data obtained from the DER-SC (1991) report.

The available information on equivalent vehicle load factors were obtained from (MARCON, 1996), (DNER, 1988), (QUEIROZ (1982); and (MENEZES *et al* (1988).

The equivalent vehicle load factors adopted for this study are shown in Table 1.

Tabela 1. Equivalent Vehicle Load Factors

Grupo de Veículos	Equivalent Vehicle Load Factors	
	AASHTO	USACE
Buses	0,67	0,79
Medium Trucks	0,68	1,23
Heavy Trucks	1,07	5,62
Articulated Trucks	3,34	11,53

## 5 ANALYSIS OF PAVEMENT PERFORMANCE

The procedures adopted for this research are based on studies made for the development of PAV-ER program (O'BRIEN III *et al*, 1983; NUNEZ E SHAHIN, 1986). These studies show that any road department that conducts at least one evaluation of each section of its road network can objectively use the technique described by SHAHIN *et al* (1987).

In the attempt to overcome the problems of the lack of periodic evaluation of a pavement network (O'BRIEN III *et al*, 1983; NUNEZ e SHAHIN, 1986) developed a methodology for pavement performance modelling based on *families* approach for sections of a road network. Road sections that possess the same type of surface, structure, use and classification form a group. In this approach, road sections of a family having different ages and/or different functional and structural conditions represent the deterioration degree of each section of this same family as it deteriorates in the long-term.

For this research, the *families* concept was used for modelling of tendencies of pavement performances. The variable dependents considered were:

- Maximum Average Deflection – MAD ( $\times 10^{-2}$ mm);
- International Roughness Index – IRI (m/km); and
- All cracking - ACR (%).

It can still be highlighted, in relation to Maximum Average Deflection, that the deflection data carried out with FWD (Falling Weight Deflectometer) were converted to Benkelman Beam using equations from BORGES (2001).

### 5.1 Pavement families and subfamilies

Based on the constituent materials of the pavements belonging to Geological Region 1, the 83 sections or 867,2km of roads studied can be divided into two large families:

- Family 1: sections constructed with sub-base in macadam or pebble; and
- Family 2: sections constructed with sub-base in gravel.

These two large Families were further subdivided into two other subfamilies according to the constituent materials of base and covering, as shown in Figure 2.

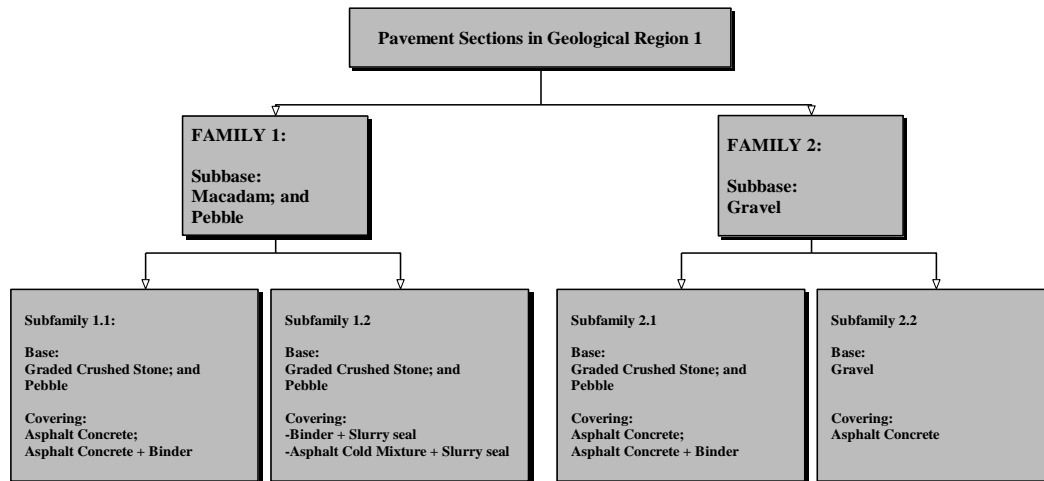


Figure 2. Pavements families and subfamilies

### 5.2 Determination of preliminary trend lines

SHAHIN *et al* (1987) affirm that in order to obtain the most appropriate model for the data, it is necessary to do a preliminary analysis, choosing one type of the mathematical function that means the evolutionary tendency of pavement distress within each family or subfamily.

To have a preliminary idea of the evolutionary tendency of the parameters studied in this research, a more simple analysis was proposed, in accordance with the available tools, but which might be able to provide sufficiently consistent data. For this, the preliminary view of the performance tendencies of each subfamily of pavements was decided, considering each proposed parameter, through the analysis of simple linear regression, logarithmic, exponential or potential.

Alongside the analysis, it was noted that the statistical models provided un-expected performances tendency lines in so far as tendency lines with decreasing evolution in the long-term. Besides this, the statistical models did not present significant differences among determination coefficients ( $R^2$ ). Based in the exposed, the model used for the definition of preliminary trend lines was based in the simple linear statistical model.

### 5.3 “Knots” Analysis

Based on the experience of SHAHIN *et al* (1987), and observing the decreasing form of some preliminary trend lines, the objective of the process adopted was precisely to localize groups of points or intervals of frequency (Knots) that contribute to the decreasing tendency or to the low-

est co-efficient of the correlation ( $R^2$ ), removing them from the analysis. This analysis was carried out for the parameters Maximum Average Deflection, IRI and all cracking within each sub-family analysed. The definition of “Knots”, that is the frequency intervals of the independent variables “Age (Years)” and “ $N_{8,2t}$  AASHTO”, was made and adapted using the following statistical empiric equation (NETO, 2000) :

$$K = 1 + 3 \log n \quad (1)$$

Where  $K$  = number of classes or intervals of frequency;  $n$  = number of observations.

#### 5.4 Determination of the final trend lines

The final trend lines were defined after the “Knots” analysis had been completed. Four types of statistical models were tested: linear; logarithmic; exponential and potential. For each pair of variables the model which presented the best determination coefficient ( $R^2$ ) was indicated. The analyses were conducted with each variable selected as much in the form of simple regressions as in analyses of multiple linear regression (ANOVA Tables) involving parameters such as:

- $N_{8,2}$  AASHTO: equivalent number of operations of the accumulated 8.2 tons standard axle load since the year the road was opened to traffic or after rehabilitation activities;
- AGE: age since the year the road was opened to traffic or after rehabilitation activities.
- VMD: Average volume of daily traffic calculated since the road was opened to traffic.
- $H_{total}$  (cm): Total pavement thickness equivalent to granular material (DNER, 1979);
- $H_{surface}$  (cm): Surface layer thickness equivalent to Asphalt Concrete (DNER, 1979) considering existent pavement before the rehabilitation; and
- $H_{overlay}$  (cm): Overlay thickness equivalent to asphalt concrete (DNER, 1979).

From the proposed analyses resulted auxiliary graphs that show tendency lines obtained and can be used in an indirect form to decrease the estimation error of pavement performance of each section through the use of its relative position to the tendency line of the family (SHAHIN *et al*, 1987). It's assumed that the deterioration of all the pavements in a family is similar and is a function of its present condition.

Figure 3 shows the evolutionary tendency of IRI with the traffic ( $N_{8,2}$  AASHTO) for Subfamily 1.1 before the rehabilitation services. The models of other subfamilies can be accessed in [www.pos.ufsc.br/engcivil/teses](http://www.pos.ufsc.br/engcivil/teses).

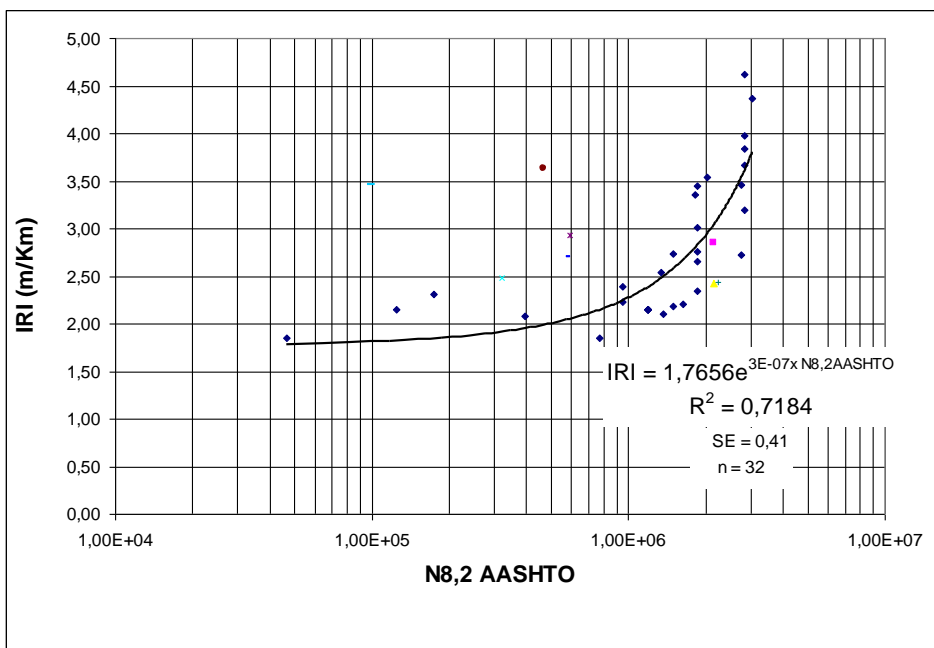


Figure 3. Subfamily 1.1. – Trend line obtained before the rehabilitation

## 6 COMPARISONS OF PERFORMANCE MODELS

It was judged important to have an idea of the differences among the performance predictions for the IRI through the use of models existing in literature and those obtained by the present work. It is necessary to highlight that the justification for the choice of IRI as parameter of comparison with the literature models was its consistency, presented alongside the whole analytical process of the PMS data DEINFRA.

### 6.1 Literature Models Selected

#### 6.1.1 QUEIROZ (1981)

$$QI - 12,63 - 5,16RH + 3,31ST + 0,393IDADE + 8,66\left(\frac{\log NA}{SNC}\right) + 7,17 \times 10^{-5} (D_{VB} \times \log NA)^2 \quad (2)$$

Where:  $RH$  = variable indicator of the rehabilitation state ( $RH = 0$  – as constructed,  $RH = 1$  – overlaid);  $IDADE$  = age of the pavement since construction or rehabilitation, in years;  $NA$  = equivalent 8,2 ton axle load, calculated by the AASHTO method;  $SNC$  = modified structural number;  $QI$  = roughness coefficient (count/Km);  $ST$  = variable indicator of the type of pavement surface ( $ST = 0$  – asphaltic concrete,  $ST = 1$  – double surface treatment;  $D_{VB}$  = maximum average deflection with Benkelman Beam, in 0,01mm.

In order to evaluate the magnitude of the SNC, the statistic equation obtained by PATTERSON (1987) was used, which correlates with the Maximum Deflection of the pavement measured using Benkelman Beam, as shown by the following equation:

$$SNC = 3,2 \times DVB^{-0,63} \quad (3)$$

Where  $SNC$  = modified structural number;  $DVB$  = average maximum deflection using the Benkelman Beam, in 0,01 mm.

#### 6.1.2 PATERSON (1987)

$$RI = \left[ RI_0 + 725(1 + SNC)^{-4,99} \times YE_4 \right] e^{-0,0153 \times IDADE} \quad (4)$$

Where  $RI$  = pavement roughness for a determined age (m/km);  $RI_0$  = roughness at the start of the analysis in m/km (IRI);  $YE_4$  = equivalent 8,2 ton axle load calculated using the AASHTO method, in millions per lane;  $IDADE$  = age of the pavement since construction or rehabilitation, in years; and  $SNC$  = modified structural number.

#### 6.1.3 MARCON (1996)

$$QI = 21,891 \times e^{0,0339 \times IDADE} \quad (5)$$

$$QI = 25,798 + 6 \times 10^{-6} NA - 3 \times 10^{-13} NA \quad (6)$$

Where:  $IDADE$  = age of the pavement since construction or rehabilitation, in years;  $NA$  = equivalent 8,2ton axle load, calculated using the AASHTO method.

#### 6.1.4 GULEN et al (2001)

Flexible pavements with overlay in INDOT road network

$$IRI = 65 + 8,1AGE + 0,0009AADT \quad (7)$$

As constructed flexible pavements in INDOT road network

$$IRI = 64 + 4,0AGE + 0,0008AADT \quad (8)$$

Where: *IRI* = International Roughness Index (inch/mile); *AGE* = Age of the pavement (years); *AADT* = average annual daily volume traffic

## 6.2 Comparisons of Models

The analysis proposed for this item obeys the considerations made previously and uses graphs in order to show the prediction differences among the models and obtained trend lines. Figure 4 shows the comparisons in reference to Subfamily 1.1 for the situation previous to the first rehabilitation, i.e., as constructed.

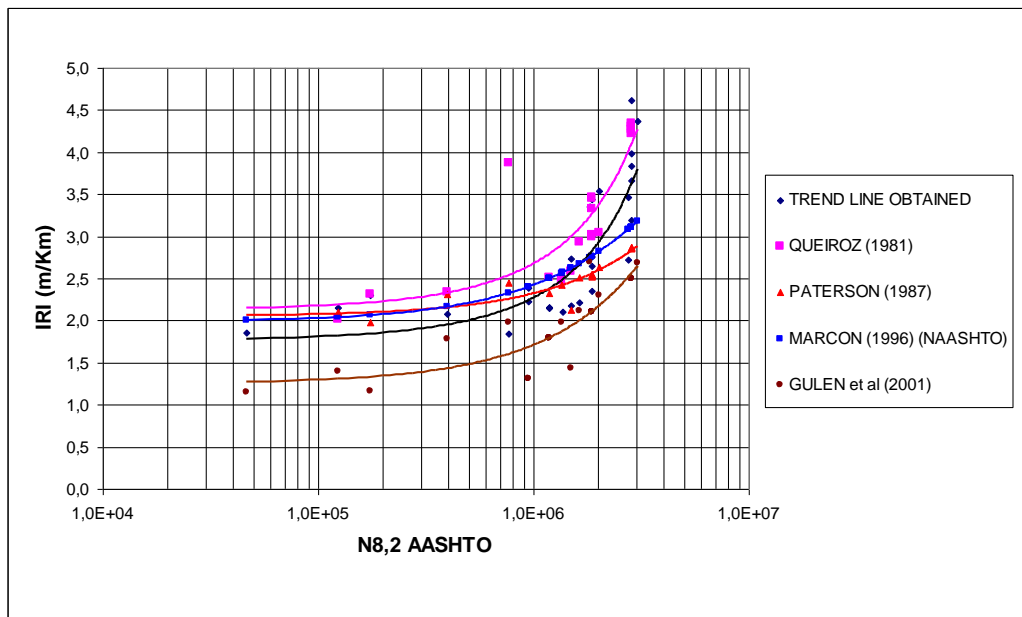


Figure 4. Comparison of predictions for Subfamily 1.1

It can be noted that the MARCON (1996) and PATTERSON (1987) existent equations are those that most closely approximate to the obtained tendency line, with a slight accelerative tendency of the IRI growth for  $N_{8,2}$  values higher than  $10^6$ . For higher values they tend to provide less conservative IRI values.

The QUEIROZ (1981) model presents a parallel curve in relation to the obtained trend equation, with a tendency to calculate higher IRI values, approximately 0.5 m/km for equivalent  $10^6$  standard axle repetitions. From that point, the two curves tend to have values increasingly closer. Equation obtained from INDOT road network (GULEN *et al*, 2001) show parallel curve to that from obtained equation, but the results are lower.

## 7 CONCLUSIONS

In the regression analysis of the preliminary trend lines, the deflection variable offered the lowest determination coefficient, also presenting curves with negative inclinations in all the subfamilies. The negative inclinations also occurred for the IRI in two subfamilies (Subfamilies 1.2 and 2.2 – before the rehabilitation) and in only one for All cracking (ACR) (Subfamily 2.2 before rehabilitation);

For the final trend lines obtained, the roughness (IRI) and the All cracking (ACR) were the parameters that presented the highest determination coefficients ( $R^2$ ).

The studies also indicated that pavements with a sub-base composed of crushed stone materials and asphalt concrete surface have a longer working life in relation to the other subfamilies;

The pavements that belong in Subfamily 2.1 were those that presented the greatest number of elements that could be statistically analysed. Although, they weren't reliable enough to provide good results, except with regards to the All cracking which presented a slightly superior behaviour, as much for the previous situation as for the latter, after rehabilitation. This finding suggests that the analyzed pavements with subbase in gravel show greater heterogeneity in their behavior.

In relation to the comparisons made between the trend lines and the literature models, in general, it can be observed that the PATERSON (1987) and MARCON (1996) curves would be the most reliable to predict the performance of the pavements for the IRI parameter. GULEN *et al* (2001) model presented, in every case, similar evolutionary tendency, but with lower values.

To conclude, this calls on the DEINFRA to make efforts for the continuation of surveys of pavement conditions, in order to obtain models which are increasing more accurate and up-to-dated. Further results of this research can be accessed at the following site: [www.pos.ufsc.br/engcivil/teses](http://www.pos.ufsc.br/engcivil/teses).

## 8 THANKS

The authors thank DEINFRA for the availability and access to the data bank of its Pavement Management System and also CNPq for the financial support provided by the scholarship awarded to the first author.

## 9 REFERENCES

- AASHTO (1993). AASHTO Guide for Design of Pavement Structures. *American Association os State Highway and Transportation Officials*. Washington, DC/USA
- BOLIVAR, O. G., ACHÚTEGUI, F. (1998). Development of Tools for PMS in Spanish State Road Network. *4th International Congress on Managing Pavement*. Africa do Sul, CD-ROM.
- BORGES, C. B. S. (2001). Estudo Comparativo Entre Medidas de Deflexão Com Viga Benkelman e FWD em Pavimentos da Malha Rodoviária Estadual de Santa Catarina. Dissertação de Mestrado. Programa de Pós-Graduação em Engenharia Civil. Universidade Federal de Santa Catarina, Florianópolis/SC.
- CAMPOS, A. C. R. (2004). Metodos De Previsão de Desempenho de Irregularidade Longitudinal Para Pavimentos Asfálticos: Aplicação e Proposição de Critérios de Ajuste. Dissertação de Mestrado. Faculdade de Engenharia Civil, Arquitetura e Urbanismo. Universidade Estadual de Campinas, Campinas/SP
- CHEN, et al (1993). URMS: A Graphical Urban Roadway Management System at Network Level. *Transportation Research Record 1397*, TRB. National Research Council. Washington, D.C., p. 103-111.
- DER-SC (1991). Avaliação Subjetiva e Objetiva com Levantamentos das Condições de Superfícies de Pavimentos, Serviços de Avaliação Estrutural de Pavimentos, Estudos de Alternativas de Proteção ou Restauração de Pavimentos e Estudos de Avaliação Econômica das Alternativas. Departamento de Estradas de Rodagem/SC. Sistema de Administração de Manutenção (SAM). Relatório Final Volumes I e II. DER/SC-APPE, Florianópolis-SC.
- DER-SC (1997). Sistema de Gerência de Pavimentos. Manual de Procedimentos Volumes I, II, III, IV. Departamento de Estradas de Rodagem/SC. Florianópolis/SC
- DER-SC (2001). Anuário Estatístico de Trânsito. Departamento de Estradas de Rodagem/SC.. Florianópolis/SC.
- DNER (1979). Método de Projeto de Pavimentos Flexíveis. Departamento. Departamento Nacional de Estradas de Rodagem (DNER). Instituto de Pesquisas Rodoviárias (IPR). Rio de Janeiro/RJ, 34 p.
- DNER (1988). Tabela de Fatores de Veículos Departamento Nacional de Estradas de Rodagem (DNER). Ministério dos Transportes, Rio de Janeiro-RJ, 194 p.
- DNER (1993). Sistema de Gerência de Pavimentos. Departamento Nacional de Estradas de Rodagem (DNER). Brasília/DF, v. 1 - 202 p.
- DNPM/CRM (1987). Textos Básicos de Geologia e Recursos Minerais de Santa Catarina” - Publicação nº 1 - Departamento Nacional da Produção Mineral (DNPM) do Ministério das Minas e Coordenado-

- ria de Recursos Minerais (CRM) da Secretaria da Ciência, Tecnologia, Minas e Energia de Santa Catarina.
- HAAS, R.; HUDSON, W. R.; ZANIEWSKI, J. (1994). *Modern Pavement Management*. Florida, EUA, Krieger Publishing Company. Malabar, Flórida/USA, 583 p.
- GULEN, S., ZHU, K., WEAVER, J., SHAN, J., FLORA, W. F. (2001). *Development of Improved Pavement Performance Prediction Models For The Indiana Pavement Management System*. Indiana Department of Transportation (INDOT). Program Development Division and Research Division. Indiana/USA. 11p.
- MAHONEY, J. (1990). *Introduction to Prediction Models and Performance Curves*. Course Text. FHWA Advance Course on Pavement Management.
- MAJIDZADEH, K., VEDAIE, B., KENNEDY JR, J. R. (1990). *Pavement Management System to Maximize Pavement Investment and Minimize Cost*. Transportation Research Record, 1272, TRB. National Research Council. Washington, D.C., p. 65-73.
- MARCON, A. F; (1996). *Contribuição ao Desenvolvimento de um Sistema de Gerência de Pavimentos para a Malha Rodoviária Estadual de Santa Catarina*. Tese de Doutorado. Instituto Tecnológico da Aeronáutica (ITA). São José dos Campos/SP.
- MENEZES, E. S., SALES, E. P., PESSOA, L. L., COSTA, V. S. (1988). *Comentários e Avaliações sobre as Pesagens de Veículos em Pernambuco*. In *Anais da 23ª Reunião Anual de Pavimentação*. Florianópolis/SC - 3 v. - v. 3 - p. 1363-1382
- NETO, P. L. O. C. (2000). *Estatística*. Editora Edgard Blücher Ltda. - 18ª Reimpressão. São Paulo/SP - 264 p.
- NUÑEZ, M. M., SHAHIN M. Y. (1986). *Pavement Condition Data Analysis and Modeling*. Transportation Research Record (TRR) 1070. Transport Research Board (TRB), p. 125-132.
- O'BRIEN D. E., KOHN S. D., SHAHIN M. Y. (1983). *Prediction of Pavement Performance by Using Nondestructive Test Results*. Transportation Research Record (TRR) 943. Transport Research Board (TRB), p. 13-17.
- OLIVEIRA, A. (2007). *Contribuição à Avaliação do Desempenho dos Pavimentos na Região de Rochas de Embasamento Cristalino em Santa Catarina*. Dissertação de Mestrado. Programa de Pós-Graduação em Engenharia Civil. Universidade Federal de Santa Catarina, Florianópolis/SC.
- PATERSON, W. D. O (1987). *Road Deterioration and Maintenance Effects -Models for Planning and Management"*. World Bank, The Johns Hopkins University Press, Maryland/USA, 454 p..
- QUEIROZ, C. A. V. (1981). *Performance Prediction Models for Pavement Management in Brazil*. Dissertation for the Degree of Doctor of Philosophy. The University of Texas at Austin. Texas/USA, 317 p.
- QUEIROZ, C. A. V. (1982). *Modelos de Desempenho de Pavimentos: Desenvolvimento e Aplicação*. Publicação 692/50. Instituto de Pesquisas Rodoviárias (IPR). Departamento Nacional de Estradas de Rodagem (DNER). Rio de Janeiro/RJ, 66 p.
- SHAHIN, M. Y., NUÑEZ, M. M., BROTON, M. R., CARPENTER, S. H., SAMEH, A. (1987). *New Techniques for Modeling Pavement Deterioration*. Transportation Research Record 1123 - Transportation Research Board, Washington-DC/USA.
- SHAHIN, M. Y.; (1994). *Pavement Management for Airports, Roads and Parking Lots*. New York, USA. Ed. Chapman & Hall, 223 p.
- TEIXEIRA, V. H. (1993). *Considerações Geotécnicas sobre os Solos e Rochas do Estado de Santa Catarina*. Apostila da Disciplina Geologia de Engenharia. Departamento de Engenharia Civil. Universidade Federal de Santa Catarina, Florianópolis/SC.
- ULLIDTZ, P., SIMONSEN. P., LENTZ, G. (1987). *The Analytical-Empirical Method Used in a Pavement Management System*. In *Proceedings of 6th International Conference on the Structural Design on Asphalt Pavements*. Ann Arbor, Michigan/ USA. p. 795-806.

#### Artigo publicado no

6th International Conference on Maintenance and Rehabilitation of Pavements and Technological Control - MAIREPA6. Torino : Ezio Santagata, 2009. v. 2. p. 1047-1055.