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Statistical Analysis of Climatic Seasonality on the Paving Conditions of a Brazilian Highway

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Abstract

Road transport in Brazil is the main mean of people and cargo transportation and it becomes increasingly intense. Traffic loads and environmental factors are the primary causes of failures in asphalt paving, once the asphalt overlay is completely exposed to environmental hazards. The aims of the present work were to monitor and record occurrences involving paving failures in the highway granted to the Brazilian Public Private Partnership (PPP) that has the MG-050 Highway as the main link connection between the midwest of Minas Gerais and São Paulo state, with 402 km long, serving as an integration axis of the economy developed in these regions. Data involving general events of paving failures and, more specifically, pits and potholes parameters were collected during the years 2010 and 2011. A statistical analysis was performed using non-parametric tests, evaluating seasonal climate differences - dry and rainy seasons - in the quantitative data of such events. With 95% confidence, it was possible to verify that the number of occurrences of pits and potholes parameter is significantly different to the investigated seasons, more intense on rainy periods, when the paving becomes more susceptible to the occurrence of this event. This work evaluates, statistically, the action of the environment in the paving structure as a function of recorded failures, a preliminary analysis that deserves further studies.

Keywords: Climatic seasonality; Statistical analysis; Asphalt paving; Brazilian highways; MG 050

Introduction

Second Bernucci et al. [1], the main objective of paving is to ensure the trafficability at any time of year and weather conditions, and provide for users comfort and safety. Once the natural soil is not resistant enough to withstand the repetition of wheel loads without suffer significant deformations, it becomes necessary to construct a structure called paving. It is built on the sub grade to withstand the vehicles loads and to distribute the requests to its several layers, limiting the stresses and strains in order to ensure a proper performance of the paving for a long time.

Traffic loads and environmental factors are the primary causes of asphalt paving deformation and damage, the asphalt overlay is completely exposed to environmental hazards.

The effect of climate changes, such as solar radiation and wind speed, on the paving material is inevitable. In particular, when the temperature of the asphalt overlay reaches 50°C, the deformation resistance of the paving structure considerably weakens [2].

In other hand, with water penetrating into the interface of the asphalt and aggregate, excess pore water pressure will be produced under overloading, leading to the separation of asphalt membrane from the aggregate surface. This occurrence leaves the pavement with pits and grooves, which could form loose structures or cracks and rapidly decrease the resistance against shearing or sliding failure because the bonding force between the aggregates has been greatly weakened [3].

Analysis on the design of asphalt paving have shown that, for this special engineering structure, the consideration of environmental influence is not specific and appropriate and the corresponding countermeasures often cannot reach people's anticipation. Yang and Ning [4] verified that high temperature leads rutting disease in asphalt paving and low temperature leads paving cracking; water penetrated into the interface of asphalt and aggregate, and the asphalt membrane began to peel from aggregates, then aggregates loose and turn into pits.

For most road applications, conventional asphalts shown good behavior, satisfying fully the necessary requirements for the proper performance of asphalt mixtures under traffic loading and weather conditions. However, conditions for volume of commercial vehicle and axle weight increasing, year over year, on designated roads or airports, in heavy traffic corridors and to adverse weather conditions, with large temperature differences between winter and summer, these are situations that has been increasingly necessary the use of modified asphalts [1].

Second Botaro et al. [5] the use of polymer-modified asphalts to improve the performance paving has been observed. When there is a match between the polymer and the asphalt matrix, the properties of the formed blends can contribute effectively to the reduction of the coating breakdown, thermal cracking and formation of wheel tracks. The use of polymer-modified asphalt matrix also increases the fatigue life of the paving.

The present work aims to analyze statistically the quantitative data of occurrences on paving failures and evaluate significant differences due to climatic seasonality. It is a result of a monitoring occurred in the years 2010 and 2011 on the highway road that was ceded a Public-Private Partnership (PPP) involving the MG-050 Highway, located in Minas Gerais-Brazil, and smaller stretches of BR-491 and BR-265 Highways.

Materials and Methods

This work was performed, in a first step, through a description and characterization stage of the main study object, the MG-050 Highway.

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This corridor was chosen because it is an important route of inter-regional integration, serving as an axis of the economic development. In a second step, analytical, a statistical analysis was performed focusing on quantitative data of general events of paving failures and pits and potholes recorded to the years 2010 and 2011, in order to identify significant differences related to the climatic seasonality, in a proper results interpretation.

The evaluated highway was divided into 20 segments with different length, but homogeneous in traffic load, to facilitate the data compilation. A work that was carried out through an engineering firm responsible for the supervision of this highway road, which implemented in 2010 a systematic and automated monitoring system for this purpose. Two groups covered whole stretch of the PPP highway during every week and the new failures occurrences were recorded.

The general events of paving failures were characterized as events related to the operational conditions and paving quality and understand the quantitative data of pits and potholes, depressions, deformations, exudations, cracks, ruts, breakdowns, ripples, upheavals and wheel tracks.

The classification of climatic seasonality adopted in the data analyses was made according to Table 1.

According to Siegel and Castellan [6], a statistical test is used to respond with certain confidence about the hypothesis that arises about particular theory. The data were processed using the statistical package of STATISTICA 6.1 Software, which allowed the application of tests and generation of graphical results.

As a preliminary analysis, time series of general events of paving failures and pits and potholes data, collected monthly from February 2010 to December 2011, are plotted in bar charts in order to evaluate the evolution of them over the monitored period. In addition, in this step of data recognition, an evaluation of descriptive statistics of the related parameters was performed.

Adherence tests to general events of paving failures and pits and potholes data was checked using the Shapiro-Wilk and Chi-Square tests at a significance level (α) equal to 0.05, in order to evaluate the distribution.

According Callegari-Jacques [7], in parametric tests the evaluated data set should fit a normal distribution or normal approximation. In the other hand, non-parametric tests, also called free distribution tests, should be used when there is no requirement as to the knowledge of the distribution of the variable in the population.

One should avoid the use of non parametric tests in situations that a condition of use of parametric tests prevails. The parametric tests are applied under higher stringency conditions, thus they are also more potent than the non parametric [6].

Non parametric statistical test was used to check for significant differences between the medians of general events of paving failures and pits and potholes data sets on dry and rainy seasons, at significance level (α) equal to 0.05. The median represents a better value of central tendency of the evaluated data, a distribution different of normal.

Seasonality	
Dry	**Rainy**
April	October
May	November
June	December
July	January
August	February
September	March

Table 1: Climatic seasonality by month: Dry and Rainy season

The Mann Whitney U test, non parametric, was used to test the following hypotheses:

- H_0: dry season median = rainy season median;
- H_1: dry season median ≠ rainy season median.

Finally, a detailed analysis from the obtained results allowed a conclusion with a significant level of statistical credibility about the tested hypothesis.

Results and Discussion

A Brazilian highway: MG-050

The road system of Minas Gerais is the largest in the country, totaling 273,162 km in extension. However, only 25,981 km correspond to federal and state paved roads. It covers a region with average temperatures ranging from 16 – 18°C in the dry season, and reaches 22-23°C in the rainy season. Moreover, it has a minimum rainfall value about 15 - 50 mm in the dry season, which reaches 240 - 280 mm in the rainy season, approximately [8].

This road network is an important element of integration of this federation unit with other urban centers in Brazil, with MERCOSUL countries and the major ports of the country. Analyzing the survey conducted by the National Department of Transportation-DENATRAN, in June 2012, it is possible to infer that Minas Gerais has a fleet of 7,957,586 vehicles, of which 13.98% are cargo vehicles [9].

The MG-050 highway is an important route of inter-regional integration, which connects Belo Horizonte to the midwest of Minas Gerais and northwest of São Paulo state, with 402 km long, serving as an integration axis of the economy developed in these regions. Its area of influence includes 50 municipalities with a population about 1.5 million inhabitants, which represents approximately 7.6% of the population's state.

By this highway travels much of the agricultural sector production of Minas Gerais, in particular regarding to the poultry industry, swine, dairy and derivatives; moreover, sugar, coffee, fruits and horticulture. It stands out even by industrial activity metallurgy, non-metallic materials, food, mining, textiles, clothing, footwear, rubber, hides and skins. Tourism on the shores of Furnas Lake is another activity much explored in the midwest region of the state, taking this highway as the main access road.

In 1995, Brazil started the Grant Program of Federal Highways to the private initiative, a modality that has been tested and approved. In May 2007, Minas Gerais signed with a private group the concession of the first road PPP in the country, benefiting 344.40 km of MG-050, the main studied highway, 4.65 km of BR 491 and 22.00 km of BR-265 highways [10].

Therefore, MG-050 highway, linking Minas Gerais to São Paulo state, occupies a preponderant place in the country's road network, leveraging the development and promoting integration through the transport of goods and people.

Statistical analysis

This topic presents the statistical results concerning analyzes realized with the quantitative data of general events of paving failures and, specifically, pits and potholes.

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For general events of paving failures data 456 occurrences were recorded in 2010 and 1391 for the year 2011. In other hand, for the parameter "pits and potholes", 177 events were recorded in 2010 and 794 records for the year 2011. The Figure 1 shows the time series with the evolution of the analyzed data for these parameters.

In general, the quantity of pits and potholes corresponds to 52% of general events of paving failures data. In both cases, the number of recorded data in 2011 is higher than the number of data for the year 2010, a considerable difference which may be due to this last one year be considered a implementation period of the computerized system of monitoring.

The distribution of the data must be checked before performing the statistical analysis, because it will determine the choice of statistical techniques to be used. The parametric analysis should be applied in the case of the normal distribution of data, and the non-parametric analysis when the distribution is asymmetrical, different from the normal distribution. Thus, as a preliminary analysis, a descriptive statistics of the evaluated parameters was performed with the recorded data for segments and its results are presented in Table 2.

The analysis of some parameters shown in Table 2 gives an indication that the data are asymmetric and, thus, do not fit in a normal distribution. The asymmetry coefficient has non-zero values, with a value equal to 2.4 for general events of paving failures and 4.1 for pits and potholes. Other points to consider, the standard deviation parameter, for the two sets, has numerical values higher than the arithmetic mean, moreover, the values for the mean, median and mode parameters are not coincident, a common fact to asymmetrical data.

Normality tests of Shapiro-Wilk and Chi-Square were performed to verify if the data fit significantly to a normal distribution with a significance level equal to 0.05. Results are shown in Figure 2.

Normality tests of Shapiro-Wilk and Chi-Square present p-values less than 0.05 for analysis of general events of paving failures and pits and potholes data, considering the years 2010 and 2011. In both cases it indicates that the data did not fit a normal distribution, which can be justified because there are no homogeneous characteristics with respect to the paving quality along the segments of the granted highway to PPP. Therefore, it is stated with 95% confidence level that the evaluated data, for such years, are asymmetric.

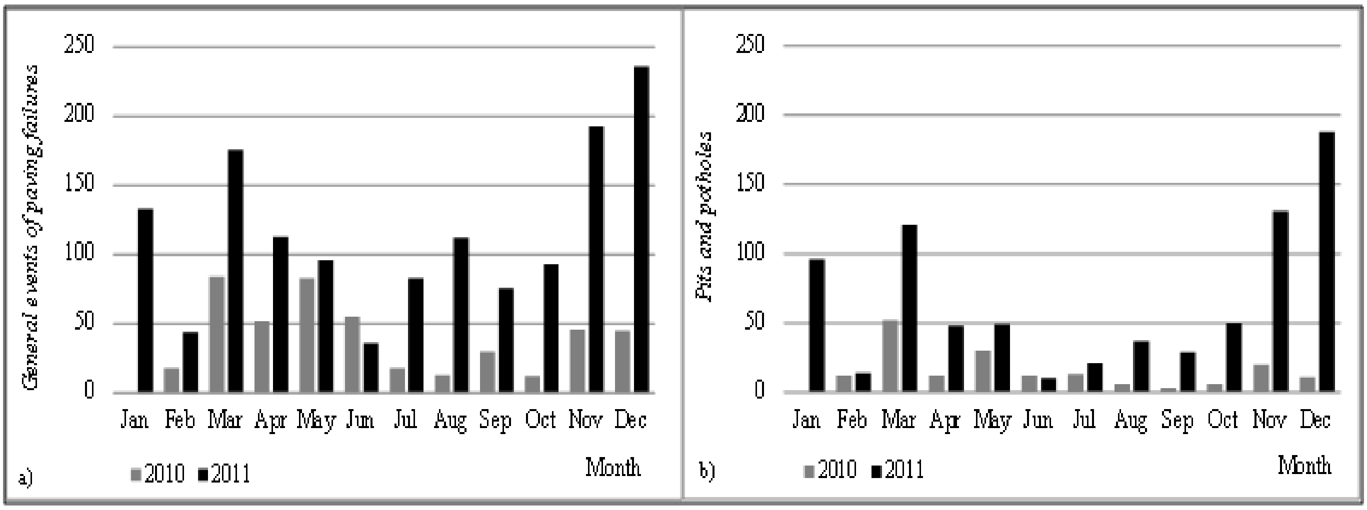

Figure 1: Time Series for analyzed data – years 2010 and 2011: a) General events of paving failures; and b) Pits and potholes.

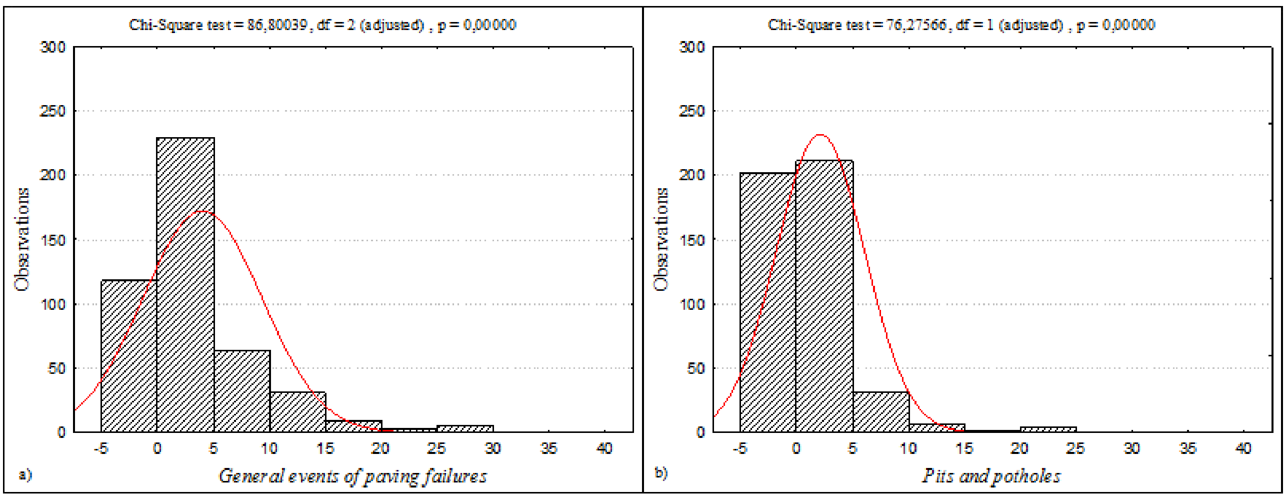

Figure 2: Normal analysis of standardized data distribution: a) General events of paving failures; and b) Pits and potholes.

Parameters	General Events	Pits and potholes
Arithmetic Mean	4.0	2.1
Median	2.0	1.0
Mode	0.0	0.0
Standard Deviation	5.3	4.0
Variance	28.4	15.7
Asymmetry	2.4	4.1
Count	460	460

Table 2: Descriptive statistics of the evaluated parameters: Dry and Rainy seasons

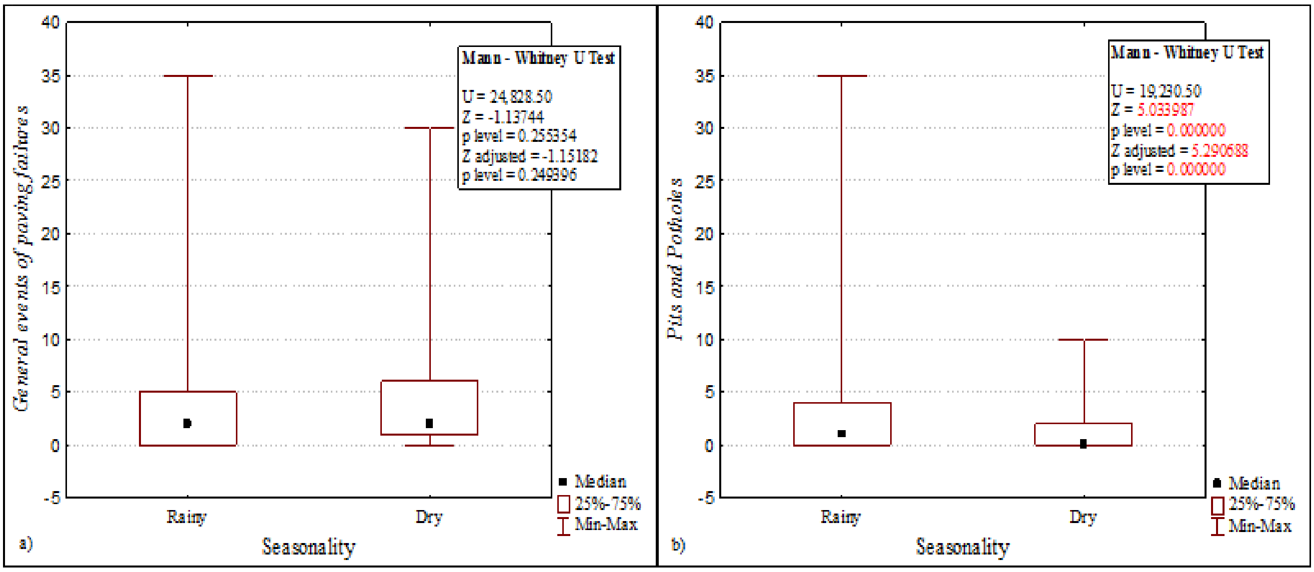

Figure 3: Mann-Whitney U Test – Dry vs. rainy seasons – a) General events of paving failures; and b) Pits and potholes.

Asymmetric data sets are commonly found in monitoring of environmental parameters or under conditions that are difficult to control, as the susceptible data to climate and other natural factors.

This is justified because the highway not shows homogeneous characteristics with respect to the paving quality and traffic load along the section granted to PPP.

As the data sets analyzed showed a distribution different to normal, with a considerable asymmetry observed graphically in Figure 2, the non parametric Mann-Whitney U test was chosen to assess significant differences between the quantitative data obtained in dry and rainy seasons for general events of paving failures and pits and potholes.

The Figure 3 shows the results for the Mann-Whitney U tests, besides the Box-Whisker plots, which allow a visual comparison between the data from dry and rainy seasons of the monitored parameters in 2010 and 2011.

The Mann-Whitney U test was chosen to allow a comparison between the medians of two independent samples, in this case, general events of paving failures and pits and potholes data sets for dry and rainy seasons.

By analyzing this statistical test results, the p-values for the parameter general events of paving failures were higher than 0.05, which indicates that there is no significant difference between the data obtained for the dry and rainy season, i.e., the hypothesis that the tested medians are equal cannot be rejected.

This result can be explained because this parameter includes data of factors that do not relate directly to the tested seasonal difference, for example, problems on paving construction. Another point is that general events data include factors that generate paving failures intensified in the rainy season, or even factors potentiated in the dry season. Thus, in an analysis that considers the median data of general events of paving failures for the two periods, a significant difference is not observed.

In the other hand, a different result was observed for the quantitative data of pits and potholes by comparing the dry and rainy seasons. P-values equal to zero is a result that allows a statistical conclusion that, with 95% confidence, the obtained data show significant differences for the tested periods.

This result is consistent considering the “pits and potholes” parameter, it is susceptible to an increase in rainy seasons and, according Yang and Ning [4], with water penetrating into the interface of the asphalt and aggregate, excess pore water pressure produces an over loading, leading to the separation of asphalt membrane from the aggregate surface.

Beyond the significant statistical difference in the median of the data, it is observed graphically that the upper limit for the rainy season in a random segment reaches 35 cases of occurrences and only 10 cases in the dry season.

In rainy periods related to the months from December to February there is also a possible increase in vehicle traffic load in Brazilian highways, which can be related to the festivities of end of year and holidays. It can explain this result and the quantitative data from this paving failure in rainy seasons.

Conclusion

As a result of the monitoring work on the highway road involving the MG-050 Highway and smaller stretches of BR-491 and BR-265 Highways, it was concluded that, by a statistical analysis of the recorded occurrences in 2010 and 2011, the data distribution to general events of paving failures and pits and potholes parameters is asymmetric, different to a normal distribution. Therefore, non-parametric tests were used in the statistical analysis.

In evaluating the climatic seasonality differences, dry and rainy seasons, of quantitative data for general events of paving failures parameter, it was concluded that, there is no significant difference related to the recorded data during the analyzed period. Now, for pits and potholes parameter, a significant difference was observed between the quantitative data for dry and rainy seasons, in the last one season there is more recorded occurrences. So it is possible to infer in this case study:

- There are paving failures that are more pronounced in dry season and others, characteristic of rainy season;
- There are paving failures that can worsen during the rainy season, with the infiltration of water and traffic load, as pit and potholes, which increase the occurrences and quantitative data in this period.

This is an analysis that involves many factors and deserves further studies.

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