Rolling Surface Evaluation Model Considering Topographic, Geotechnical, and Climatic Aspects in Low-Volume Roads

Case Study in Aquiraz, Ceará, Brazil

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This paper presents an innovative model for assessing surface conditions in low-volume roads. The proposed approach focuses on intemperate weather influences (e.g., rain, wind), traffic, soil type, and relief in the reduction of the level of service of the unpaved road. It is concerned with the evolution of distress present in unpaved roads. The intention is to improve the performance evaluation method for surface conditions proposed by Correia et al., the ALYNO method. A case study is presented for the municipality of Aquiraz, Ceará, Brazil. A mathematical model is developed to forecast a performance evaluation model by using a topographical survey of unpaved roads; the result is the modified method called ALYNOMO. The main performance evaluation methods of surface conditions for unpaved roads are also studied. Several considerations about the geometric evolution of distress according to the usefulness of the studied branch are drawn from the case study. This research contributes toward improving the unpaved performance evaluation process and the ALYNO method, proposing a model to forecast the performance for regular and appropriate unpaved roads. The need for rational maintenance of this type of road is emphasized.

The authors call attention to the fact that transportation systems do not last forever (*1*). The lack of attention paid to roads, paved or not, in developing countries leads to the precariousness and inefficiency of their transport systems, representing a major obstacle to their development. Ultimately, without a transportation system that fits local and regional characteristics, there will be an increase in the cost of transport, consequently, agricultural and industrial products will become more expensive, making them less attractive to consumer markets.

In Ceará, 90% of the road network is unpaved, and most of it is under the jurisdiction of the 184 counties that lack a pavement management system. This situation creates great difficulties for the flow of inputs and the products of rural areas, a circumstance that reinforces and justifies the need for studies in this field of knowledge.

Although the budgetary reality of many municipalities is insecure, the abandonment of unpaved roads inevitably leads to higher costs when the necessary rehabilitation is carried out to improve their functionality. This is so mainly because the degradation process of a road grows exponentially with time, and consequently, given the necessary resources for rehabilitation of the road, the logistics costs in Brazil also increase.

The ALYNO method developed by Correia et al. was used in this research (*2*), but improvements were made and a model of performance prediction as to the usefulness of unpaved roads was proposed; that method is called the ALYNOMO method.

Several approaches to develop efficient methods to classify surface conditions in low-volume roads have been reported in the literature. These methods can be grouped into objective and subjective approaches. The latter have gained a greater reception from planners and decision makers because the subjective methods consider the calculation of condition indexes as a way to measure the overall quality of a rolling surface.

Among the subjective methods, one can highlight the proposed approach developed by Riverson et al. (*3*). Among the objective methods developed for pavement management systems for low-volume roads, one can highlight the method proposed by Eaton et al. (*4*), which was adopted as a technical manual by the U.S. Army Corps of Engineers (USACE) (*5, 6*), as well as the Gravel-PASER system developed by the University of Wisconsin (*7*).

A comparison between the method used by USACE and the ALYNOMO method is presented by Almeida et al. (*8*). This method is applied in three stretches in the city of Aquiraz, Ceará, Brazil. Despite the high level of complexity of the ALYNOMO method for surveying running surface conditions, the method proved to be closer to reality.

This paper aims to present an innovative method for evaluating surface conditions of unpaved roads. The above-mentioned method includes a georeferenced database that deals with the history of the surface degradation of the studied segment considering hydrology, traffic, geotechnics, and topography.

The rest of this paper is structured as follows. The proposed approach is presented next. Then the new method is applied, and the results are presented, analyzed, and discussed. Finally, some conclusions and suggestions for future research are presented.

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PROPOSED APPROACH

There is no standard method for assessing and classifying unpaved roads. So, in the case study presented in this research, the method proposed by Correia et al., the ALYNO method, was adopted (*2*). The method, based on high-precision topographic surveys, proved to be easy to use and understand. This method involved the rating of the pavement surface conditions, which showed it would be easily done in the region of Aquiraz. However, some modifications were necessary, without the loss of precision. Thus, the ALYNOMO method was created.

These adaptations occurred mainly in the isolation of variables of geometric conditions and the occurrence of geotechnical materials, leading to the inclusion of surveys of geotechnical data and the definition of topographic sections in the study area. When the density and severity of the registered distresses were calculated, the procedures of the ALYNOMO and the ALYNO methods were the same. The defects considered in this study and observed in the monitored sections were those used in Correia (*2*).

In the ALYNO method, the final results were calculated from the resulting function, that is, from the influence of the combined action on all factors that led to the degradation of the road's usefulness, while the final result of the ALYNOMO method was calculated according to the types of materials found and the relief of the study area, as shown in the following items:

1. The definition of the sections is based on the geotechnical classification of the different soil types found according to their characteristics and the subsequent creation of geotechnical zones (GZs), as shown in Figure 1. With the creation of GZs, the variable of the geotechnical characteristics becomes constant throughout the length of each GZ.
2. There is also a subdivision of GZs. This subdivision is based on the sharp variation of the longitudinal ramps of the road axis, thus creating the topographical zones (TZs). Each TZ features a unique longitudinal ramp value, accepting little variation, for more or for less. So each TZ is studied as a separate section, with the straight length depending on the length of the longitudinal ramp considered; in other words, there is great variability in length between the TZs. With the creation of TZs, the topographical variable (longitudinal ramp of the road axis) also becomes constant throughout the length of each TZ.
3. The cadastral topographic surveying with millimeter precision is accomplished through the operation of topographic high-precision electronic equipment (total station). The topographic survey is performed in the analyzed area and in places in which the distresses were found.
4. Distresses found are classified according to type and georeferenced location within each TZ.
5. A vector representation of all section TZs with their respective distresses for subsequent generation of the digital terrain model (DTM) and the digital model of distresses (DMD) is accomplished.
6. The areas of distresses found are measured by means of a topographic app, through the area calculation for georeferenced coordinates (Gauss method). Calculation of the depth of such distresses is done by simply counting the contour lines inserted into the distress area. These contour lines are all spaced 1 cm apart, which facilitates the assignment of values to the level of individual severity (LIS). This value is found on the basis of the type of distress adopted. The attributes of severity—low, medium, and high—correspond to Values 1, 2, and 3, respectively.
7. Once the LIS of each type of distress in the topographic zone is found, it is time to calculate the average for the type of distress. This average is the average severity in a topographical zone (AS). The value varies from 0 to 3.
8. Next, it is time to calculate the relative surface density of each distress in a topographical zone (RS), which is the result of the sum of the areas or the length of each type of distress divided by the total area or total length of the topographical zone where the distresses are inserted. The RS is calculated for each type of defect.
9. Once the values for AS and RS for each type of defect are found, they are multiplied to provide an indicative value of the relative severity of distresses in a topographical area. This value is expressed in values to three decimal places, ranging from 0 to 3, and is called the index of relative usefulness by topographical zone (ISR).
10. Each distress in a section has its own ISR. If a particular section in the study has two or more types of distresses, the section has two or more ISRs. According to Correia, the index that measures the severity condition that the section under study is subjected to is the largest ISR found (*2*). This higher value of ISR is called the index of the condition of the topographical zone (IC), whose classification attributes are presented in Table 1.
11. In accordance with the technical literature, the index of usefulness in a section measures how this section is functional and comfortable for traffic. Thus, it is possible to conclude that the usefulness is inversely proportional to the severity. In this work the value of usefulness, ranging from 0 to 3, is expressed to three decimal places. This value is called the index of the usefulness of the topographical zone (IS), whose classification attributes are listed in Table 2.

For the phase of analysis and measurement of distresses using the data obtained from the topographic survey, a computer-assisted drafting platform capable of receiving these data and treating them topographically in vector form is necessary. From the periodic monitoring of the studied area, the data obtained can be worked in geographical information systems.

Knowing the seasonal changes of the sections, this tool can be very useful in providing priority sections, which are usually more damaged during rainy periods. This whole process is fundamental to decision makers, who can manage the unpaved road network and make decisions that meet their needs. The parameters used in this research satisfy the local conditions and require adaptation studies to be applied in other regions.

CASE STUDY: THE MUNICIPALITY OF AQUIRAZ

Initial Considerations

The municipality of Aquiraz has an area of 482.8 km^2 and is located 32.30 km from the city of Fortaleza, the capital of Ceará.

The study area is approximately 2 km long, which allows one to consider the rainfall and the traffic constant. The rainfall for the study period was 946.20 mm. During the topographic survey a traffic count was also taken, with a total of 47 vehicles per day, which included passenger cars, vans, small and medium trucks, and dump trucks.

For better execution and detailing, the area was divided into three polygonals—AQZ 01, AQZ 02, and AQZ 03—whose demarcation

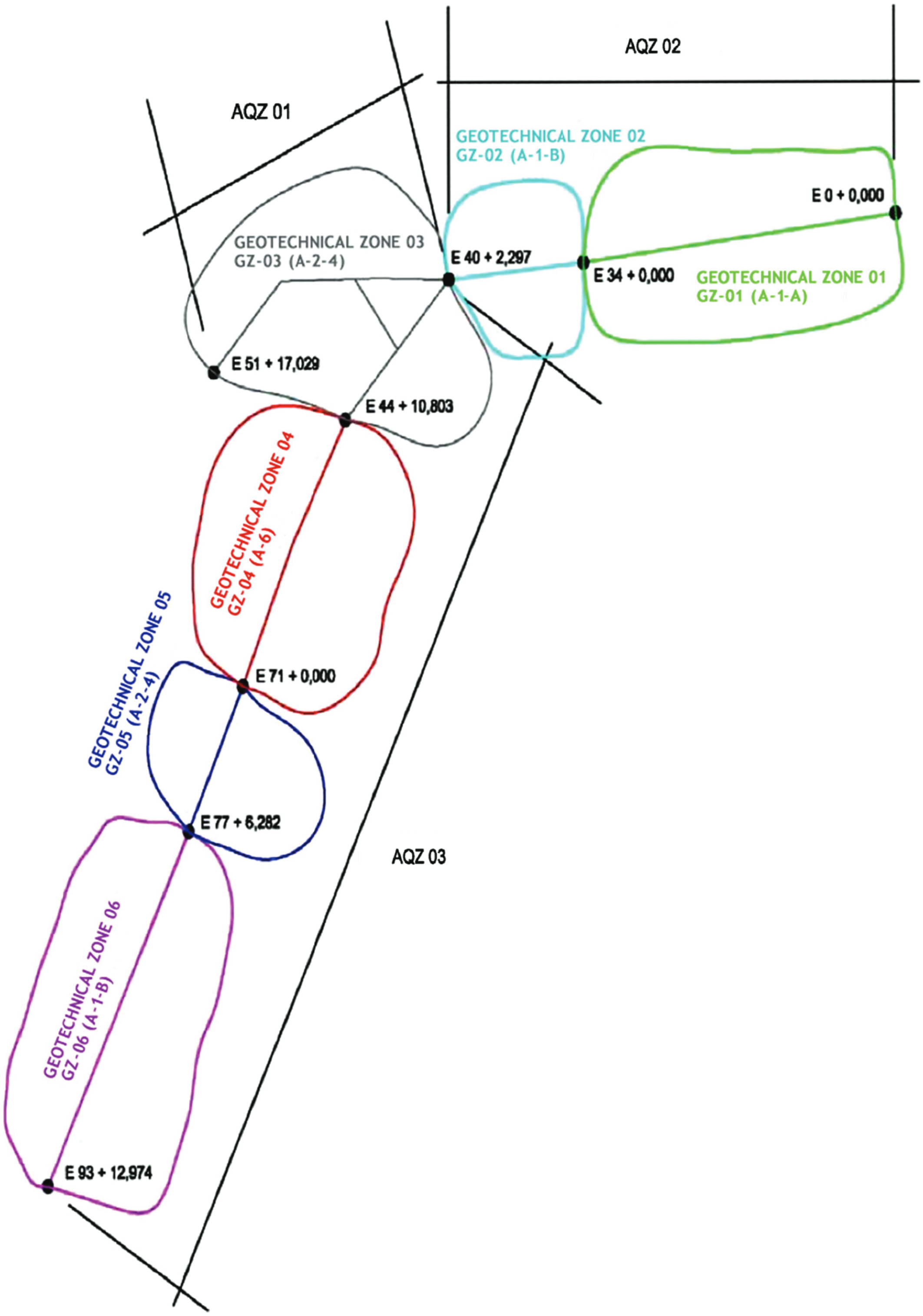


FIGURE 1 Diagram of location of polygonal and geotechnical zones and Highway Research Board classification of geotechnical areas (not to scale).

TABLE 1 Classification for Index of Condition of Topographical Zone

IC	Classification	IC	Classification
0.000–0.199	Excellent	1.100–1.599	Bad
0.200–0.649	Good	1.600–2.199	Very bad
0.650–1.099	Regular	2.200–3.000	Poor

was performed with the aid of a differential GPS with submeter accuracy (see Figure 1). In the periodic topographic surveys in polygonals, 2,500 points were collected, on average. A total of approximately 10,000 points were collected; they were subsequently georeferenced and checked against the model proposed by Correia et al. (*2*).

After the data collection was completed, the data were downloaded to the computer directly into the topographic data analysis software, the Topograph System 98 SE. This app was used to download, process, and generate the DTM and the DMD, analyze and deliver relevant reports of the results, and generate full reports of the topographic surveys.

With the full reports downloaded, the polygonal generated by the surveys was calculated. The average relative error that was found in the polygonal was 1:3.053827, which means an average error of 1 mm for every 3.054 km of survey obtained, which is approximately 30 times lower than that accepted by Brazilian legislation. After the polygonal was closed, the coordinates of the irradiated points were calculated.

With the coordinates of the points of the polygonal station and the irradiated points, the DTM and DMD were generated in triangular mesh for later obtaining the contour lines of the terrain, equidistant from 1 cm.

With a visual inspection, it was possible to see the various types of soils in the study area. On the basis of this variety, a tactile–visual survey of these materials was made, resulting in a primary qualification and location of the start and end for each soil type found. Also, a geotechnical survey of the study area was done, and for that, enough geotechnical material to run each borehole (approximately 50 kg) was collected to do the characterization tests and then the geotechnical classification.

In this research, the geotechnical classification method chosen was that of the Highway Research Board (HRB). The reason for choosing this method was its simplicity and its diffusion in the technical environment. The grading method has its limitations of applicability in the geotechnical classification of Brazilian soils. The following geotechnical laboratory tests for purposes of HRB classification were performed: (*a*) determination of the consistency limits and (*b*) particle size analysis of the soil. With these data, regions with the same kinds of soil were delimited, thus creating the GZs.

TABLE 2 Classification for Index of Usefulness of Topographical Zone

IS	Classification	IS	Classification
0.000–0.199	Poor	1.100–1.599	Regular
0.200–0.649	Very bad	1.600–2.199	Good
0.650–1.099	Bad	2.200–3.000	Excellent

Modeling of Performance

The proposed performance model is based on the calculation of the following indexes:

1. LIS: This level is determined by calculating the depth of each distress type registered. With the depth of the distress calculated, the severity is obtained by consulting the severity table corresponding to the type of distress.
2. AS: This value is obtained from the simple arithmetic average of the LIS for type of distress and for all distresses.
3. RS: This value is the result of the sum of the areas or lengths of each type of distress divided by the total area or total length of the topographical zone.
4. IS: This index is the result of multiplying AS and RS.
5. IC: This index is the largest of the ISRs calculated in the topographic zone.
6. IS: This index is calculated by subtracting the IC from the maximum usefulness possible (IS = 3 – IC).

The study area is composed of 29 topographical zones. For each topographic area, a spreadsheet with the indexes mentioned above was made for each distress type registered during the topographic surveys in addition to their respective performance modeling.

In this work the following types of performance equations were obtained: 18 straight-line equations and 11 parabolic equations (examples in Figure 2) for a total of 29 equations, which means one equation for each of the 29 topographical zones considered that generate the study area of this work. According to the technical literature, the likely mathematical model of a performance curve is a parabola. The parabolic equations obtained corroborate the above statement. However, the 18 equations of the straight lines obtained are special cases.

The quadratic equation or equation of Degree 2 is an equation of the type

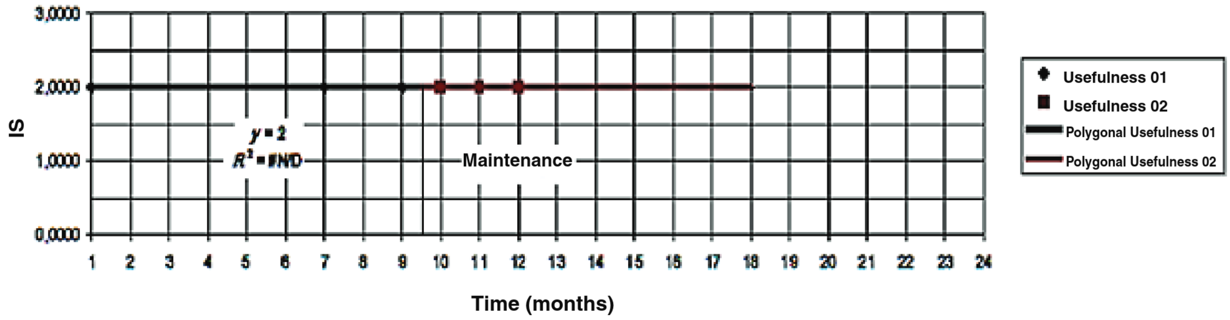
$$y = ax^2 + bx + c \tag{1}$$

where a, b, and c are the coefficients and have distinct geometric properties in the equation. These properties are as follows:

1. Coefficient a is the coefficient of “openness” of the equation, that is, to what degree the parabolic curve is smooth or not. Thus, the closer to zero the value is, the smoother the curve; consequently, the section under study deteriorates more slowly. Likewise it is possible to say that as this coefficient moves away from zero, the curve is less smooth; consequently, the section under study will deteriorate faster. A negative sign with coefficient a means that the concavity of the curve is downward. A positive sign means that the concavity is upward.
2. Coefficient b represents the point of maximum value of the curve displaced relative to the ordinate axis (y-axis), that is, the horizontal distance (x coordinate) of the point of maximum value. When the value of coefficient b is negative, the x coordinate is positive; and when it is positive, the x coordinate will be negative.
3. Coefficient c represents the point at which the parabolic curve intersects the ordinate axis (y-axis). When the value of coefficient c is positive, the y coordinate is positive; when it is negative, the y coordinate will be negative, representing the highest level of usefulness obtained by the executed survey.

Month		IC	IS		Prospective	
jan/02	1	1,0000	jan/02	2,0000	jan/03	13
feb/02	2		feb/02		feb/03	14
mar/02	3		mar/02		mar/03	15
apr/02	4		apr/02		apr/03	16
may/02	5		may/02		may/03	17
jun/02	6		jun/02		jun/03	18
jul/02	7	1,0000	jul/02	2,0000	jul/03	19
aug/02	8		aug/02		aug/03	20
sep/02	9	1,0000	sep/02	2,0000	sep/03	21
oct/02	10	1,0000	oct/02	2,0000		
nov/02	11	1,0000	nov/02	2,0000		
jan/03	12	1,0000	jan/03	2,0000		

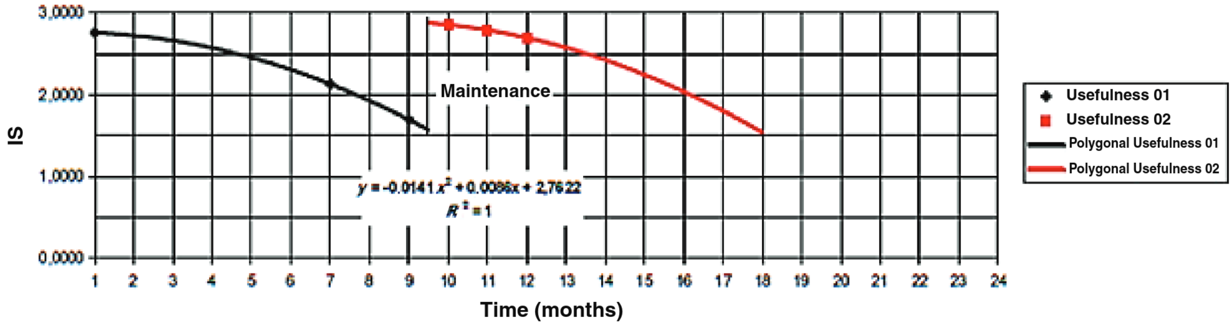
Performance Equations
GZ 01–TZ 09



(a)

Month		IC	IS		Prospective	
jan/02	1	0,2433	jan/02	2,7567	jan/03	13
feb/02	2		feb/02		feb/03	14
mar/02	3		mar/02		mar/03	15
apr/02	4		apr/02		apr/03	16
may/02	5		may/02		may/03	17
jun/02	6		jun/02		jun/03	18
jul/02	7	0,8700	jul/02	2,1300	jul/03	19
aug/02	8		aug/02		aug/03	20
sep/02	9	1,3050	sep/02	1,6950	sep/03	21
oct/02	10	0,1450	oct/02	2,8550		
nov/02	11	0,2104	nov/02	2,7896		
jan/03	12	0,3042	jan/03	2,6958		

Performance Equations
GZ 02–TZ 10



(b)

FIGURE 2 Examples of graphics for predictive modeling of performance (ALYNOMO method) of topographic areas: (*a*) straight-line equation ($y = ax + b$) and (*b*) parabolic equation ($y = ax^2 + bx + c$).

After the HRB classification obtained was associated with the location of points where the occurrences of the same type of soil were initiated and finalized, areas with the same geotechnical behavior were delineated. These areas are simply named the GZs for this study.

Analysis and Discussion of Results

In GZ-01 it was possible to perceive the predominance of one type of distress in all its extension. The defect was an inadequate transversal cross section; therefore, the occurrence of other types of distress does not influence the calculation of the equation, which represents the performance modeling of the section under study. As a result the parabolic equation becomes a straight-line equation, ever constant and equaling the IS value of the section under study; in this case it is equal to 2.

Table 3 shows the coefficients of the parabolic equation as a function of the values of the longitudinal ramp of each topographic zone for GZ-01.

GZ-02 has only one topographical zone as the section presents a nearly constant longitudinal slope. There is not, however, a predominance of one type of defect. Its cross section has camber enough to drain the water from rainfall without difficulty. The type of soil present in the subgrade in this geotechnical zone is classified by HRB as A-1-b. Table 3 shows the coefficients of the parabolic equation based on the values of the ramp of Topographic Zone 10 (TZ-10).

TABLE 3 Longitudinal Ramp Values and Parabola Coefficients (*a*, *b*, *c*) from Each TZ for Each GZ

			Parabola Coefficient		
GZ	TZ	LR (%)	*a*	*b*	*c*
GZ-01	TZ-01	−5.4412	0.0000	0.0000	2.0000
	TZ-02	−0.2070	0.0000	0.0000	2.0000
	TZ-03	2.9450	0.0000	0.0000	2.0000
	TZ-04	−0.7400	0.0000	0.0000	2.0000
	TZ-05	−3.1719	0.0000	0.0000	2.0000
	TZ-06	−0.9175	0.0000	0.0000	2.0000
	TZ-07	−3.9714	0.0000	0.0000	2.0000
	TZ-08	−1.4263	0.0000	0.0000	2.0000
	TZ-09	−0.4650	0.0000	0.0000	2.0000
GZ-02	TZ-10	−0.4514	−0.0141	0.0086	2.7622
GZ-03	TZ-11	−0.0850	−0.0226	0.0723	2.6932
	TZ-12	−3.7685	−0.0230	0.0769	2.6982
	TZ-13	−0.0796	−0.0213	0.0600	2.7213
	TZ-14	1.0575	−0.0227	0.0733	2.6794
GZ-04	TZ-15	−1.0900	−0.0327	0.0988	2.4424
	TZ-16	0.7800	−0.0294	0.0650	2.5044
	TZ-17	−1.5117	−0.0323	0.0967	2.4656
	TZ-18	0.3400	−0.0325	0.0950	2.4775
	TZ-19	1.0625	−0.0327	0.0983	2.4544
	TZ-20	6.3200	0.0000	0.0000	1.0000
	TZ-21	−0.3650	0.0000	0.0000	2.0000
	TZ-22	−6.5610	0.0000	0.0000	1.0000
GZ-05	TZ-23	−0.7300	−0.0330	0.1036	2.2250
GZ-06	TZ-24	1.8800	0.0000	0.0000	2.0000
	TZ-25	−0.1850	0.0000	0.0000	2.0000
	TZ-26	−3.7450	0.0000	0.0000	2.0000
	TZ-27	0.2567	0.0000	0.0000	2.0000
	TZ-28	2.4363	0.0000	0.0000	2.0000
	TZ-29	−0.0212	0.0000	0.0000	2.0000

NOTE: LR = longitudinal ramp value.

By analyzing these coefficients, one can check that

1. Coefficient *a* is negative. Therefore, the parabola is concave down. Its value is small, causing the parabolic curve to be smooth and the degradation to be slow in this case: it would take approximately 8.5 months to reach an IS of 1.5.
2. Coefficient *b* is small, but positive, which means that the point of greatest usefulness was before the first surveying.
3. Coefficient *c* is the point at which the curve intersects the *y*-axis, and *b* is very close to the *y*-axis. This value of *c* (2.7622) is positioned between the maximum IS of the curve and the IS obtained (2.7567).

In GZ-03 there were some problems localized in the drainage devices. These problems were caused by neighboring vegetation invading the road. This fact allows the flow of water from rainfall to go in the longitudinal direction; consequently, with this flow the entrainment of fines will occur, slowly eroding the road. The coefficients of the parabolic equation according to the value of the longitudinal ramp for each topographic zone for GZ-03 are also found in Table 3.

Analyzing these coefficients for such topographical zones, it was possible to observe the following:

1. Coefficients *a* are negative, so the concavity of the parabolas face downward. Their values are small, and there is little variation between the topographical zones, making parabolic curves smooth and very close to each other. This feature causes degradation, which is slow in this case; it would take a little more than 8 months to reach an IS of 1.5.
2. Coefficients *b* are small, but positive, which means that the points of greatest usefulness (IS) were before the first surveying.
3. Coefficients *c* are the points at which the curves intersect the *y*-axis, and coefficients *b* are very close to the *y*-axis. These values of *c* are positioned between the maximum ISs of the curves and the ISs.

In GZ-04, the problems located in drainage devices are caused by neighboring vegetation invading the road. The problem is worsening because the vegetation is becoming increasingly dense and the soil type (A-6) hampers infiltration. The type of soil observed in the field contains about 20% of a clay material in its grain size distribution, making drainage more difficult. Table 3 shows the coefficients of the parabolic equation as a function of the values of the longitudinal ramp in GZ-04 in its topographical zones.

By analyzing the coefficients for these topographical zones, it was possible to verify the following:

1. Coefficients *a* are negative, so the concavity of the parabolas face downward. Their values are small, and there is little variation between the topographical zones, making parabolic curves smooth and very close to each other. This feature causes degradation, which is slow in this case: it would take a little more than 6 months to reach an IS of 1.5.
2. Coefficients *b* are small, but positive, which means that the points of greatest usefulness were before the first survey.
3. Coefficients *c* are the points at which the curves intersect the *y*-axis, and coefficients *b* are very close to the *y*-axis. These values of *c* are positioned between the maximum ISs of the curves and the ISs.

In topographical zones TZ-20, TZ-21, and TZ-22, there is a predominance of one type of distress. It is an inadequate transversal cross section in the entire length. In this case, the neighboring vegetation protects the base of the cross section against erosion caused by water flow. Thus, water is forced to flow in the road, causing the entrainment of fine materials and the consequent erosion of the road. In this case the longitudinal ramp acts as a catalyst in the process of erosion.

In cases in which the degree of inadequate transversal cross section is large, the water from rainfall causes erosion and drags the fine materials in the road. It also heavily erodes the road paths originating from the passing traffic and causes the entrainment of fine materials to the base. This erosion occurs only when there is no protection from the neighboring vegetation of the unpaved road.

Because there is inadequate distress of the transversal cross section in the topographic zones analyzed, the occurrence of other types of distresses does not influence the calculation of the equation that represents the performance modeling of the section under study. For that reason, the parabolic equation becomes a straight-line equation, ever constant and equaling the value of IS in the referred sections.

In GZ-05 the problems located in drainage devices were caused by neighboring vegetation invading the road. The problems worsened because the vegetation was dense, hindering the drainage of water from rainfall, which formed “pools” on the unpaved road during winter that caused vehicle wheels to become stuck in the ground. Table 3 shows the coefficients of the parabolic equation as a function of the values of the longitudinal ramp for the topographic zone in GZ-05.

By analyzing these coefficients, it was possible to verify the following:

1. Coefficient a is negative; therefore the parabola is concave down. Its value is small, causing the parabolic curve to be smooth and the degradation to be slow in this case, taking almost 7 months to reach an IS of 1.5.
2. Coefficient b is small, but positive, which means that the point of greatest usefulness was before the first surveying.
3. Coefficient c is the point at which the curve intersects the y-axis, and coefficient b is very close to the y-axis. The maximum IS of the curve is positioned between the c value (2.2250) and IS (2.2956).

In GZ-06 one type of distress predominates in its entire length. In this case it is the inadequate transversal cross section. As a result the occurrence of other types of distresses does not influence the calculation of the equation, which represents the performance modeling of the section under study. For that reason, the parabolic equation becomes a straight-line equation, ever constant and equaling the IS value of the section under study; in this case it is equal to 2.

The coefficients of the parabolic equation as a function of the values of each longitudinal ramp in each topographical zone for GZ-06 are shown in Table 3.

In this work coefficient c, obtained from the equations' performance, represents a point of usefulness that is less than the maximum obtained from the equation. This finding is natural because the first topographical survey was conducted in January 2002, with the route already having deteriorated as a result of the abrasive action of traffic. Coefficient b depicts that the peak of usefulness was before the first topographical survey. It is still possible to conclude that even if the absolute value of this coefficient is small, it cannot be neglected, the reason being that this value represents 1 or 2 months in advance.

Coefficient a of the performance equations determines the speed with which a given section deteriorates with time. The higher the coefficient, the greater the deterioration speed and vice versa. The variables that most influence the deterioration process obtained in this study were the values of the longitudinal ramp and the presence or absence of drainage equipment.

It has been found that the presence of effective drainage devices in a road slows its deterioration. It was also possible to see that, in instances in which the efficiency of drainage devices decreases, the respective speed of deterioration of the sections increases proportionally. The absence of these devices causes the section to deteriorate very quickly.

The geotechnical type of material also has a great influence on the drainage; the greater the amount of clay or silt materials in the surface layers of the road, the more difficult it is for water from rainfall to infiltrate the soil.

The value of the longitudinal ramp acts as a catalyst in the deterioration process. The higher the value of the ramp, the faster the section will deteriorate; with a high value, the entrainment of fine materials and the consequent soil degradation will occur. For small longitudinal ramp values, water finds it difficult to superficially drain; consequently, water infiltrates in greater quantity, increasing the soil humidity. If the humidity reaches a high value, there will be a proportional loss of the soil's mechanical resistance. In other words, the soil will lose its supporter capacity and become less resistant; consequently, it will deteriorate more rapidly.

The behavior of the geotechnical soil found in areas GZ-02 (A-1-B), GZ-03 (A-2-4), and GZ-04 (A-6) was as expected for these types of materials; that is, they exhibited a decreasing behavior, respectively. GZ-03 (A-2-4) and GZ-05 (A-2-4) should, in principle, exhibit similar behavior, because they contain the same material, but that was not the case.

The behaviors were presented as decreasing, respectively, because in GZ-03, surface drainage devices were present; however, they were absent in GZ-05. It is then concluded that the simple lack of drainage causes the section to degrade more quickly, also considering similar changes in the value of the longitudinal ramp in those zones cited above.

Because the geotechnical zones GZ-01 (A-1-A) and GZ-06 (A-1-B) present an inadequate transversal cross section in all their longitudinal extent, it was not possible to calculate the correct performance equation for the two zones. Consequently, the comparative analysis of the behavior between the referred geotechnical zones was not possible. Thus, a similar behavior between the two was admitted.

As a result of rainfall the vegetation (grass, leaves, twigs, etc.) naturally increases and tends to invade the road. Consequently, in some cases the already disabled or nonexistent drainage devices are damaged. This situation forces the longitudinal flow in the road and, consequently, the entrainment of fine, disaggregating materials and, finally, the deterioration process is accelerated.

The sections of the study area without drainage equipment showed compromised efficiency. One of several factors (poor geometric conformation of the track in some places) can be pointed out (in the rainy season it impedes any drainage) as catalysts for the deterioration process. And in some situations the bad conformation causes the stoppage of traffic.

The rain, in one way or another, causes the road to deteriorate more rapidly, but if the road's stormwater drainage is efficient, the process is slower. The geometric conformation of the road, both transverse and longitudinal, associated with a network of efficient drainage allows, at any time of year, wet or dry, the trafficability of vehicles to be uninterrupted.

Currently, the model of maintenance performed on unpaved roads by responsible agencies—in the case of the municipalities in Ceará, their own governments—is based on the simple scraping of the top layer of unpaved roads with motor graders and without replacing the scraped material. The continued use of this model will cause a bad conformation of the cross section, which in itself is already a serious defect, causing the appearance of other defects, corrugations, and potholes.

The costly model management (maintenance of unpaved roads) discussed above is fed mainly by the lack of personnel skilled in the subject, in addition to the scarce financial resources. The combined action of these factors causes an unnecessary increase in costs related to the maintenance of transport vehicles, the increase in travel time, and the consequent increase in fuel consumption.

CONCLUSION

The procedure for performance modeling for unpaved roads proposed and tested in this research is easy to understand and simple to apply from the technical point of view, but it is made up of major steps contained in any other method for performance modeling. According to the technical literature, performance modeling is at the center of a management system that is well suited to local conditions and supports the decision making in a maintenance management system.

Evidence shows that the system currently in force in the municipalities of Ceará and especially in the city of Aquiraz is unable to change the current trend. Recognizing its shortcomings in the area of road maintenance, many agencies responsible for this maintenance began to search for answers to the many problems of management, conservation, and maintenance of roads.

Although implementing a pavement management system (PMS) for unpaved roads is not an easy task, it is urgently needed for the vast majority of municipalities of Ceará because their unpaved road networks are not being dealt with properly. The result is their increasing deterioration and, consequently, more-expensive services arising from their use.

The model was applied in Aquiraz, where there is an occurrence of red–yellow podzolic soils, whose occurrence in the municipality is 19% and in the state 29%. To apply the proposed method in places with different types of soil, it is necessary to calibrate the equation for forecasting the rolling surface performance. The reason is related to the nature of the ALYNOMO method, which considers exogenous variables (rainfall, topography, topology and density of defects, and type of performed maintenance) and the type of soil that has a direct impact on the loss of the quality of the road.

For this purpose, it is recommended that the performance curve be fitted for other localities by observing the types of materials and their geotechnical features. Simplified procedures for data surveying (topography, geotechnics, and hydrology) should also be developed.

Future studies could develop mathematical correlations between data (topographic, geotechnical, and rainfall) and the coefficients of the performance curve obtained or could accomplish the formatting and inclusion of a PMS for unpaved roads in a GIS environment, creating a more powerful tool for decision makers to use when utilizing public funds to maintain and rehabilitate unpaved roads.

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REFERENCES

1. Haas, R., W.R. Hudson, and W. Uddin. *Infrastructure Management.* McGraw-Hill, New York, 1997.
2. Correia, J.A.B., E.F. Nobre, Jr., and A.P.H. Cavalcante. Evaluation of Unpaved Roads with Aid of Relative Usefulness Index by Road Branch. Presented at 83rd Annual Meeting of the Transportation Research Board, Washington, D.C., 2004.
3. Riverson, J.D.N., K.C. Sinha, C.F. Scholer, and V.L. Anderson. Evaluation of Subject Rating of Unpaved County Roads in Indiana. In *Transportation Research Record 1128,* TRB, National Research Council, Washington, D.C., 1987, pp. 53–61.
4. Eaton, R.A., S. Gerard, and R.S. Datillo. A Method for Rating Unsurfaced Roads. In *Transportation Research Record 1106,* Vol. 2, TRB, National Research Council, Washington, D.C., 1987, pp. 34–43.
5. Eaton, R.A., and R.E. Beaucham. *Unsurfaced Road Maintenance Management.* Special Report 92-26. Cold Regions Research and Engineering Laboratory, U.S. Army Corps of Engineers, 1992.
6. *Unsurfaced Road Maintenance Management.* TM 5-626. Technical Manual. U.S. Army Corps of Engineers, Headquarters, Department of the Army, Washington, D.C., 1995.
7. *Gravel PASER Manual–Pavement Surface Evaluation and Rating.* Transportation Information Center, University of Wisconsin–Madison, 1989.
8. Almeida, R.V.O., E.F. Nobre, Jr., and J.L.C. Silva. Evaluation Methodologies for Unpaved Road Surface Condition in Municipal District of Aquiraz, Ceara, Brazil. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1989,* Vol. 2, Transportation Research Board of the National Academies, Washington, D.C., 2007, pp. 203–210.

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