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Proposal for classification and prioritization for environmental road liabilities management

Proposta de classificação e priorização para gestão de passivos ambientais rodoviários

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ABSTRACT
It is possible to find environmental nonconformities that are characterized as debts to society and the environment along federal highways. These are called environmental liabilities. When these liabilities are physical and/or material, engineering works are needed for mitigation. Since many environmental nonconformities pose installed or imminent danger, especially to road users, the surrounding population and, the environment in which they operate, together with the massive amount of liabilities present in Brazilian federal highways, justify a management plan. In this context this work proposes a road environmental liabilities management model through a classification and prioritization methodology. The proposed methodology is applied and consolidated in a database consisting of 187 liabilities collected in non-concessioned stretches of the BR 116 highway. Additionally, the management model is implemented in case study. This study's product stands out for addressing all the factors determined as relevant in the prioritization of road environmental liabilities in a unified manner, as well as conducting a critical analysis of the results. Therefore, it is possible to establish a concise model to manage the existing non-conformities in the national highway network, reducing the risk of accidents and assisting in the public resources' administration.

RESUMO
É possível encontrar ao longo das rodovias federais não conformidades ambientais que se caracterizam como débitos para com a sociedade e ambiente, podendo esses ser chamados de passivos ambientais. Tais passivos, quando de natureza física e/ou material, necessitam de obras da engenharia para mitigação. Devido ao fato desses proporcionarem um perigo instalado ou eminente, principalmente aos usuários da rodovia, à população lindeira e ao meio ambiente, e devido à quantidade de passivos existentes nas rodovias, justifica-se realizar um plano de gestão. Assim, o presente trabalho propõe um modelo de gestão de passivos ambientais rodoviários, através de um método de classificação e um método de priorização. Os métodos são consolidados em um banco de dados de 187 passivos coletados em trechos não concessionados da BR 116, bem como é realizada aplicação detalhada em um estudo de caso. O estudo se destaca por abordar de forma unificada todos os fatores que se julgaram pertinentes em uma priorização de passivos ambientais rodoviários, bem como por realizar uma análise crítica dos resultados. Desse modo, é possível estabelecer um modelo conciso de gestão das não conformidades existentes na malha rodoviária nacional, e, assim, diminuir o risco de acidentes e auxiliar na administração de recursos públicos.

1. INTRODUCTION

Since the creation of the WCED (World Commission on Environment and Development) in 1987, the theme “environmental sustainability” has been given its rightfully worldwide importance. The control of environmental impacts, intrinsic to the WCED agenda, was included by the committee to generate awareness through Corporate Social Responsibility (CSR) and Corporate Environmental Responsibility (CER) in relation to the environmental aspects of their activities.

Therefore, considerable importance is given in relation to environmental liabilities (“Passivos Ambientais” in Portuguese) triggered by product-making or service-provisioning by a productive nucleus. However, the term “environmental liability” is too complex to conceptualize singlehandedly since its definition is related to the context in which the term is inserted into.

The term “environmental liabilities” is used to refer to the occurrence of failures within the domain range, due to the design, maintenance, or improvements in a highway (Ibama, 2008) in the road-wise Brazilian context. However, the term “Passivos Ambientais” stems from the English term “environmental liabilities” linked to its legal context. According to the United States Environmental Protection Agency (1996), the term is used to refer to the potential for fines and penalties due to violations of environmental laws. Thus, when companies make commitments of "environmental responsibility", they want to know the exposure possibilities to environmental debts, even when they are in complete compliance with regulatory standards.

Several manuals made available by international management bodies utilize a similar approach to the Brazilian one, which considers the occurrences along the domain range of the highway to be recovered as environmental liabilities. Some examples are the Maintenance Manual Washington State Department of Transportation (WSDOT, 2019), Botswana Roads Maintenance Manual (Botswana Government, 2010), and the Indian Affairs Manual - Transportation Facilities Maintenance Handbook (Bia Road Maintenance Program, 2020). Such approach is also found in manuals created by road management agencies in Africa and Canada (Piagentini; Favareto, 2014). In such documents, the activities for recovery of environmental non-conformities are addressed in two aspects: deteriorated landscape restoration and road maintenance activities.

Thus, due to the disparities in the definition of "environmental liability" as a concept, there is a gap to be filled in the Brazilian reality regarding its recovery. In addition, there are many environmental events to be mitigated/recovered along the Brazilian federal highways (Silva *et al.*, 2018), and these represent a risk to road users, to the degradation of highways which are public assets, and an environmental risk.

According to the Brazilian approach, environmental liabilities can be divided into two categories: "physical and/or material liabilities" and "social, moral, or legal liabilities" (Pimentel *et al.*, 2014). Physical and/or material liabilities are amenable to remediation through engineering works, and often involve problems in the geotechnical aspect, such as erosive processes, mass movements and processes involving vertical displacements, whereas social liabilities involve problems at the administrative level, such as littering in the domain range and irregular occupations.

Given the diverse demands for public investment in the road sector, such as the considerable management plan.

number of unpaved roads, unkempt roads, and roads in need of lane duplication, as noted in annual reports by the National Transport Confederation - CNT (CNT, 2020), the development of a method for prioritizing environmental liabilities is justified, in order to determine a recovery

This work aims to present a model for the management of physical and/or material environmental liabilities, based on tools that assist the process of solving the problems stated above using a classification method and a prioritization method as a premise.

The study presented here is the product of a masters' thesis (Silva, 2019), carried out based on data obtained from the Environmental Regularization Project of non-concessioned stretches of the BR 116 highway in the Ceará, Paraíba, Pernambuco, Bahia, Minas Gerais and Rio Grande do Sul states, a result of an agreement between the Federal University of Paraná (UFPR), represented by the Technological Institute of Transport and Infrastructure (UFPR / ITTI) and the National Department of Transport Infrastructure (DNIT). In total, 332 environmental liabilities were registered in January 2018, of which 187 were related to geotechnical problems. The other occurrences were characterized by being of moral or legal nature.

2. METHODOLOGY

This work development process was divided into two main parts: Firstly, displaying the management model and secondly, its validation. The validation of the environmental liabilities management model was conducted through the presentation of the results applied in a database and through a detailed case study application. The management model consists of substantial assisting tools in the decision-making process. The assisting tools usage is conditioned to the liability's classification and its Priority Index (PI) calculation.

2.1. Liability Classification

The environmental liabilities classification proposal is aimed at non-conformities found in highway infrastructure and is intended to assist in recovery management processes. Classifications of geotechnical environmental liabilities present in the literature were used for its definition, such as the ones present in federal and state manuals: from the National Department of Transport Infrastructures (DNIT), from the National Department of Highways of Santa Catarina and São Paulo (DNIT, 2006; Santa Catarina, 2006 and São Paulo, 2007), as well as classifications proposed by authors such as Carvalho *et al*. (1991), Malafaia (2004) and Blasi (2014).

In addition, definitions and concepts of geotechnical instabilities present in the literature were used, divided into three themes: (i) erosive processes (Kronen, 1990; Fendrich, 1997; Lima, 2001 and Bigarella, 2013), (ii) mass movements (Varnes, 1978; Nieble, Guidicini, 1984; Terzaghi, 1996; Augusto Filho, 1998 and Bigarella, 2013), (iii) vertical displacements (Nieble; Guidicini, 1984; Carvalho *et al*., 1991; Lambe; Whitman, 1969 and Bigarella, 2013).

Based on the three divisions, subdivisions were used to classify liabilities from a geotechnical standpoint according to the classifications proposed in the aforementioned literature, and to the analysis of which would be the most appropriate to adopt in the context of the recovery of environmental liabilities in roads. Thus:

1) **Erosive processes:** this classification was subdivided into 1.1 *uniform erosion* and 1.2 *concentrated erosion*, being that its evolution was considered in the scope of ridges, ravines, gullies, and landslides.
2) **Gravitational mass movements**: this classification was subdivided into 2.1 *rotational slip*,

2.2 *landslides*, 2.3 *rockfall*, 2.4 *slump* and 2.5 *creep*.

3) **Vertical displacements**: they can be fast and abrupt or gradual over time, therefore, the classification was given based on the subdivision into 3.1 *compaction*, 3.2 *densification* and 3.3 colapse.

2.2. Priority Index (PI)

The Priority Index (PI) was defined to characterize the prioritization method and was obtained through the prioritization equation, based on the Multicriteria Decision-Aid (MCDA) tool known as the Analytic Hierarchy Process (AHP) method, presented by Millet and Saaty (2000). The matrix of paired importance was established by weighting each pre-established criterion using the relative paired importance.

In this context and based on other prioritization methods in the literature, four main factors that influence the priority of intervention of a liability in relation to the others were defined: Risk (R), Highway Importance (HI), Magnitude (M), and Traffic Interference and Temporality (TI).

2.2.1. Risk

The concept of risk was defined as "The combination of an event probability and its consequences" according to the manual Risk Management-Vocabulary-Guidelines for Use in Standards (ISO / IEC Guide 73: 2002). Risk prioritization was already used by some authors in the literature, such as the Risk Degree proposed by DNER (2007) and the Severity of Occurrence presented by Blasi (2014). However, in the proposal for this work, Risk was considered by the occurrence probability and the liability's possible consequences.

The three possible types of damage considered were: to the user, to the property and to the environment. The probability was established as "whether the liability would provide danger to the to the user, to the property and to the environment", and can be classified as (i) safe (0.0), (ii) potential danger (0.5), (iii) imminent danger (1.0) – if it is almost occurring or (iv) installed danger (1.5) - if it is already causing damage to one or more of the subjects mentioned before.

Each environmental liability can have more than one probable consequence, which were parameterized and described as (i) landscape degradation (0.0), (ii) sediment accumulation on the roadway (0.2), (iii) silting of drainage systems (0.2), (iv) user discomfort and insecurity (0.2), (v) silting of water courses (0.3), (vi) pavement structure impairment (0.3) , (vii) drainage system impairment (0.5), (viii) damage to surrounding areas (0.5), (ix) interference in engineering structures (Obras de Artes Especiais – OAEs in Portuguese) (0.5), (x) induction to geotechnical problems in general (0.7), (xi) obstruction of the main and/or hard shoulder lanes (0.7) and (xii) accidents (1.2). Therefore, the consequence partial is given by the sum of all the possible consequences indicated in the risk analysis stage.

2.2.2. Highway Importance

The highway importance (HI) factor was based on the traffic parameter (T) addressed by Blasi (2014). However, based on the collected data from counting stations present on national highways (Plano Nacional de Contagem de Tráfego - PNCT), an update of the Average Daily Volume Ranges (VMDa) parameter defined in the traffic parameter (T) is needed. Also, the logistic routes for cargo transportation should be considered.

Therefore, the Highway Importance (HI) parameter was defined based on the federal arterial highways' importance map (Figure 1), elaborated using the Average Daily Average Volume

(VMDa) data and classificatory counting from the 2017 PNCT as proposed in the study by Silva (2019). The adopted classification for Highway Importance (HI) was: (i) low (1.0), (ii) marginal (2.0), (iii) remote (3.0), (iv) considerable (4.0) and (v) high (5.0). So, it is possible to correlate

the Highway Importance (HI) and the crossed attribute on the map (Figure 1), using the liability's geographical location.

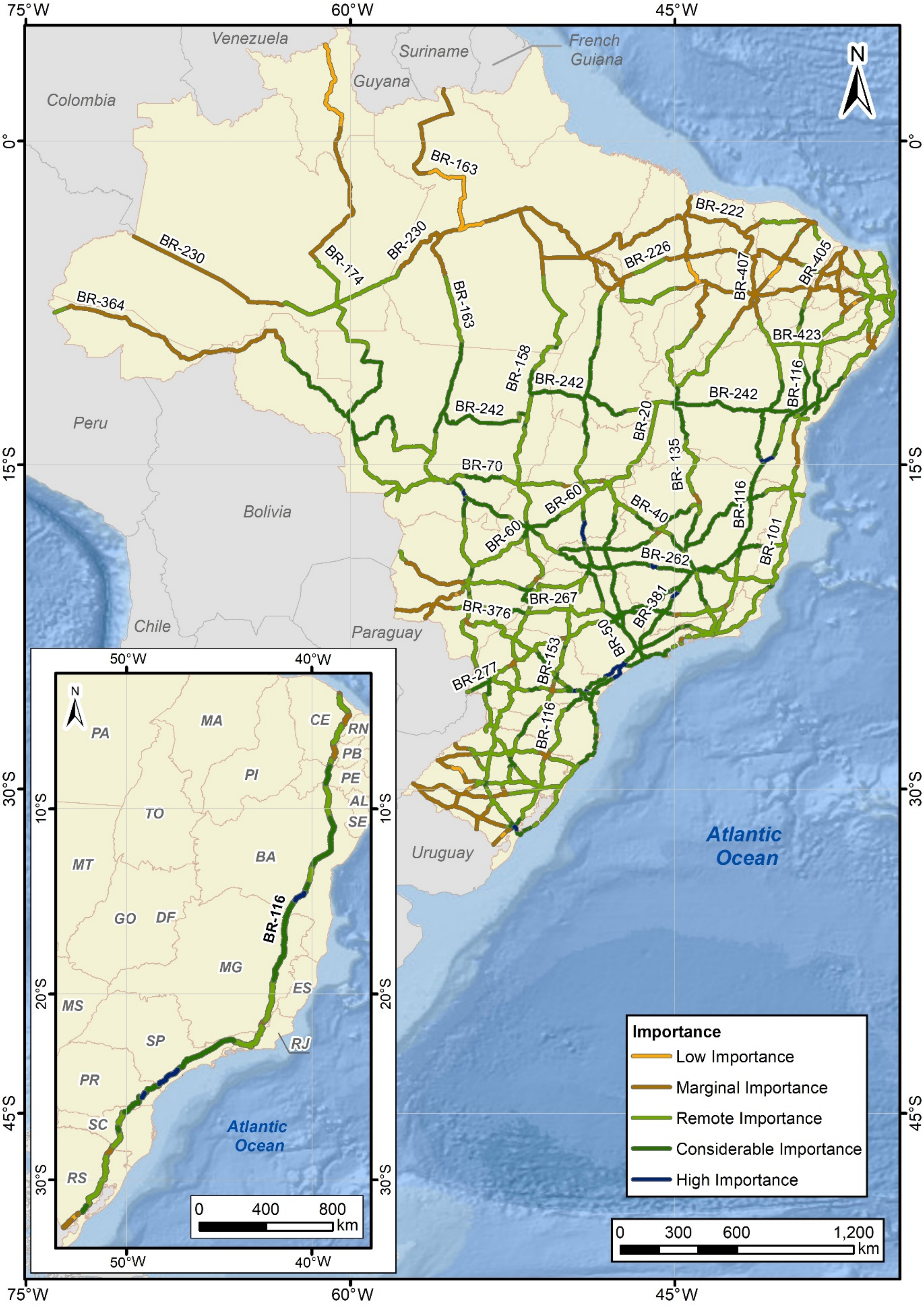

Figure 1. Highway Importance Map

The BR 116 highway is highlighted on the presented map above because it includes the records that were used in this article’s study. It is possible to find sections that were classified from low to high importance along it. The Highway Importance Map is conditioned to and must be updated with the realization of new PNCT research campaigns and with the introduction of new automatic counting stations, as proposed by Silva (2019).

2.2.3. Magnitude

The Magnitude (Intensity and Span) parameter was adopted in order to consider the evolution of the passive processes more objectively (erosive processes, mass movements and vertical deformations). The evolution trends of environmental liabilities were already addressed by the Risk Index (RI) presented by DNIT (2006) through the analysis of local morpho-climatic conditions, and also by the Evolution Trend (ET) parameter proposed by Blasi (2014).

The Magnitude (M) of the occurrence was defined context-wise as the average of the Span and Intensity. The Span portion was adopted as the affected area proportion in comparison to its potential proportion (Table 1). The Magnitude can also be related to the evolution of the liability. Therefore, as the intensity of the occurrence increases, its relevance does the same consequently, making it more significant (Table 2).

Table 1 – Span Scores within the environmental liability Magnitude analysis

Atribute	Score	Description
Punctual	1.0	Less than 20% of the potential affected area
Medium	2.0	Greater than 20% and less than 50% of the potential affected area
Preponderant	3.0	Greater than que 50% e less than 70% of the potential affected area
Total	4.0	Maior que 70% of the potential affected area, but contained within the domain range
Superior	5.0	Surpasses the domain range

Table 2 – Intensity Scores within the environmental liability Magnitude analysis

Attribute	Score	Erosive Processes	Mass Movements	Vertical Displacements
Small	1.0	Uniform erosion or groove appearance, requires small material fills and surface protection	Small signs of movement (small landslides, small fractures, discontinuities, sloping vegetation, instability checks)	Small displacements, hardly noticed displacements
Medium	3.0	Grooves evolve into ravines, small soil crumbling	Well-fractured massifs, signs of a rupture surface and/or instability	Noticeable displacements which cause discomfort and problems
High	5.0	Gullies caused from the evolution of deep ravines or through piping phenomenon	Beginning of movement or areas with a well-defined rupture surface	Inoperability

2.2.4. Traffic Interference and Temporality

The interference generated by the liability in vehicle flow was already addressed by the Interference (I) criterion, proposed by Blasi (2014), that measures the obstructed roadway proportion in relation to space and time, caused by a liability. Thus, parameterizing how long it would take to recover the liability and what impact it or its recovery works could generate in relation to traffic, the criteria are: (i) no influence on traffic or fast recovery by blocking a roadway (1.0), (ii) slow recovery by interdicting a lane (2.0), (iii) fast recovery by blocking all lanes (3.0) and, (iv) time-consuming recovery by blocking all lanes (5.0).

2.3. Prioritization Equation

The proposed prioritization equation is a function of the four factors mentioned above: Risk

(R), Highway Importance (RI), Magnitude (M), and Traffic Interference and Temporality (TI). Thus, the Risk (R) (probability versus consequences) was considered as the criterion for further investigation because environmental events that represent greater risk to the user or the environment must be recovered, preventing further damage from happening.

The Highway Importance (HI) was considered next, as a result of being the criterion responsible for representing the greatest potential for damage (social, environmental, and economic). The criteria Magnitude (M) and Traffic Interference and Temporality (TI) were considered tied last in relevance, a consequence of these being considered secondary criteria, but important to rank liabilities that reached similar or remarkably similar PI scores, due to the scoring of the two main criteria, Risk (R) and Highway Importance (HI).

Thus, the Risk (R) criterion was considered three times more important than the Highway Importance (HI) criterion, a moderate amount, and was considered five times more important than the Magnitude (M) and the Traffic Interference and Temporality (TI) criteria, a great amount. The Highway Importance (HI) criterion was three times more important than the Magnitude (M) and the Traffic Interference and Temporality (TI) criteria, a moderate amount, and these last two were considered to be equally important. Those amounts were then arranged in the form of a matrix, called the Paired Comparison Matrix, and can be seen in Table 3.

Table 3 – Paired Comparison Matrix of the prioritizing influencing factors of a geotechnical environmental liability

Criteria	Risk (R)	Highway Importance (HI)	Magnitude (M)	Traffic Interference and Temporality (TI)
Risk (R)	1	3	5	5
Highway Importance (Ir)	1/3	1	3	3
Magnitude (G)	1/5	1/3	1	1
Traffic Interference and Temporality (IT)	1/5	1/3	1	1

Therefore, the proposed prioritization equation for obtaining the Priority Index (PI) is a function of these four criteria (equation 1) and was obtained through the Multicriteria Decision Aid tool known as the Analytic Hierarchy Process (AHP) method.

$$PI = 0.55 * R + 0.25 * HI + 0.10 * M + 0.10 * TI \quad (1)$$

2.4. Road Environmental Liabilities Management Model

The proposed management model consists of substantial decision-making aiding tools. The tools are the (i) prioritization order, the (ii) average and standard deviation of the Priority Index (PI) value; (iii) critical Priority Index score; and the (iv) critical regions.

The prioritization order (i) was obtained by calculating the Priority Index (PI) score for each database entry using the prioritization equation. For that, it was necessary to collect some onsite information, such as: Liability Risk, Possible Consequences, Affected Area, Magnitude, Geographical Coordinates and Traffic Interference and Temporality. After calculating the PI score, the results were put into a spreadsheet and hierarchically arranged by descending order. The list of liabilities can be obtained in the study by Silva (2019). The liabilities occupying the initial positions were those that presented the greatest recovery urgency, according to the pre-established criteria.

It is considered that the mean and standard deviation (ii) of the Priority Index (PI) score can define a given population, with any given characteristic (Ara, 2003). In this case, the average characterizes the sample, and the standard deviation expresses how representative the average is to the database. The PI score's average was compared to the theoretical average PI score, defined by the mean between minimum and maximum PI scores possible, in order to identify whether the database's average value is above or below the average PI score.

The critical Priority Index (PI) score (iii) was a criterion established to assist in the repair urgency scoring. The criterion was defined based on the concept of the interval ($\mu \pm 2\sigma$) that characterizes the area 95.5% below the normal distribution curve (Bittencourt and Viali, 2006). This interval was considered under the premise that the liabilities that are located outside it differ from the sample's characteristic. In other words, liabilities that scored higher than or equal to the average (μ) plus two standard deviations (σ) present an atypical prioritization, which characterizes an urgent repair.

The critical regions (iv) were defined in order to substantiate recovery plans supported on logistical approaches. The regions were obtained based on their PI score and the environmental occurrences' density, interpolated by the Kernel Density method. The method is used to improve a surface's smoothness by means of the radius of influence, assigned by the program, and calculates an area of magnitude per unit from a feature of points. The Distribution is an input parameter to the geoprocessing software (ArcGIS 10.3), which with a table of attributes (geographic coordinates and PI score), generates a surface.

The surface characterizes the relationship between the PI score and the concentration of liabilities on a color scale and defines the region's criticality. Such criticality was established on a nine-color scale (classes) using the Jenks Natural Breaks Algorithm, which seeks to minimize intra-class variance and maximize inter-class variance. To calculate the values of the Jenks method intervals, a calculation is initially made of the sum of the Classes' Median Absolute Deviation (DAMC). The generated surface was cut into a 250-meter buffer to facilitate visualization and also for aesthetic reasons.

3. RESULTS AND DISCUSSION

To summarize the methods presented in this study, it is emphasized that the proposal to prioritize environmental liabilities as a management tool is valid when there is more than one occurrence to be recovered.

3.1. Road Environmental Liability Management Model

The management model consists of the application the liability classification method and the prioritization method by obtaining its Priority Index (PI) and later to obtain its: (i) prioritization order; (ii) the mean and standard deviation of the Priority Index (PI) score; (iii) the critical Priority Index (PI) score; (iv) the critical regions.

Therefore, the obtained results stemming from the management model application on the BR 116 highway's non-concessioned stretches environmental liabilities database are presented. It is important to note that the survey of environmental liabilities is an action that must occur periodically and that the obtained values may vary according to the database used.

It was observed that of all the geotechnical environmental liabilities (physical and/or material) present, 91% refer to erosive processes, subclassified as: concentrated erosion (73%), followed by uniform erosion (18%). Mass movements accounted for only 9% of registered liabilities, consisting of planar landslides (1%), rotational landslides (2%) and block falls (6%).

After applying the proposed liability classification method, the prioritization method, based on the mathematical equation of the Priority Index (PI) was applied, making it possible to rank all 187 PI scores, where the full results can be observed at Silva (2019).

The PI score can vary between a theoretical minimum of 0.45 and a theoretical maximum of 5.00, with a theoretical average of 2.73. The maximum and minimum scores found for the registered database were 4.47 and 0.95, respectively. The real average score (μ) of all the Priority Index (PI) obtained was 2.09. Therefore, the real average score from the database results is below the theoretical Priority Index average score.

By calculating the Priority Indexes' real average score, the obtained scores are compared to those observed on-site. Since it was noticed that most of the environmental liabilities observed were in an initial or intermediate stage, this justifies the real average score being lower than the theoretical one. These features are often caused by design problems or by a failed/lacking/inefficient drainage system, which are not categorized as high risk, but which could evolve into one over time.

The database could be statistically evaluated using both the prioritization order and the Pareto Principle. Thus, the PI scores were arranged in a normal distribution (Figure 2). The distribution curve shows that environmental liabilities with the highest Priority Index scores have low frequency. This fact corroborates what was observed in the field, since it was possible to measure singular cases in which a structure with recovery priority was diagnosed through visual analysis.

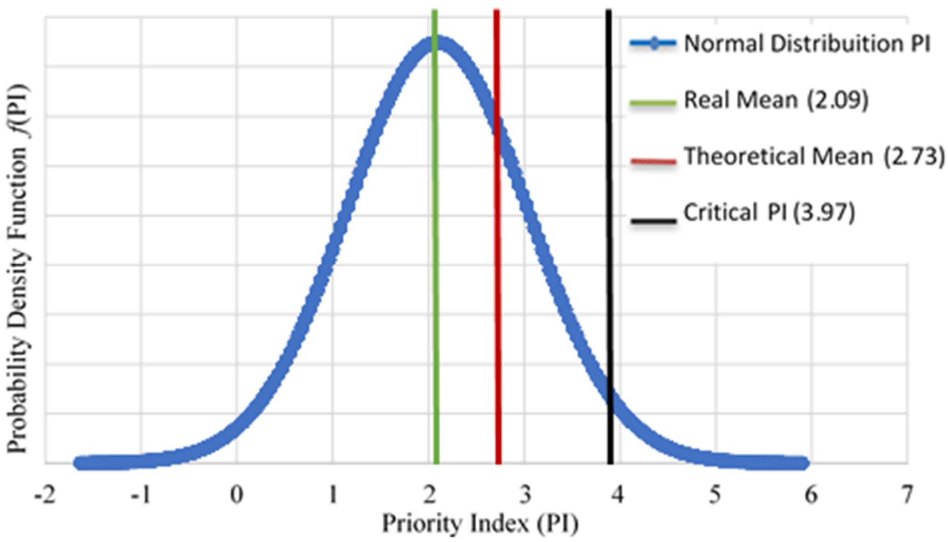

Figure 2. Liability Priority Index (PI) normal distribution graph

Due to the normal distribution properties, the highest point on the curve represents the value with the highest mode of the process (unimodal distribution), which is the most frequent score in the database. Thus, it was found that the results are concentrated around an PI score of 2.09 (green line shown in Figure 2), this being the real mean (μ) observed by the registered liabilities' database.

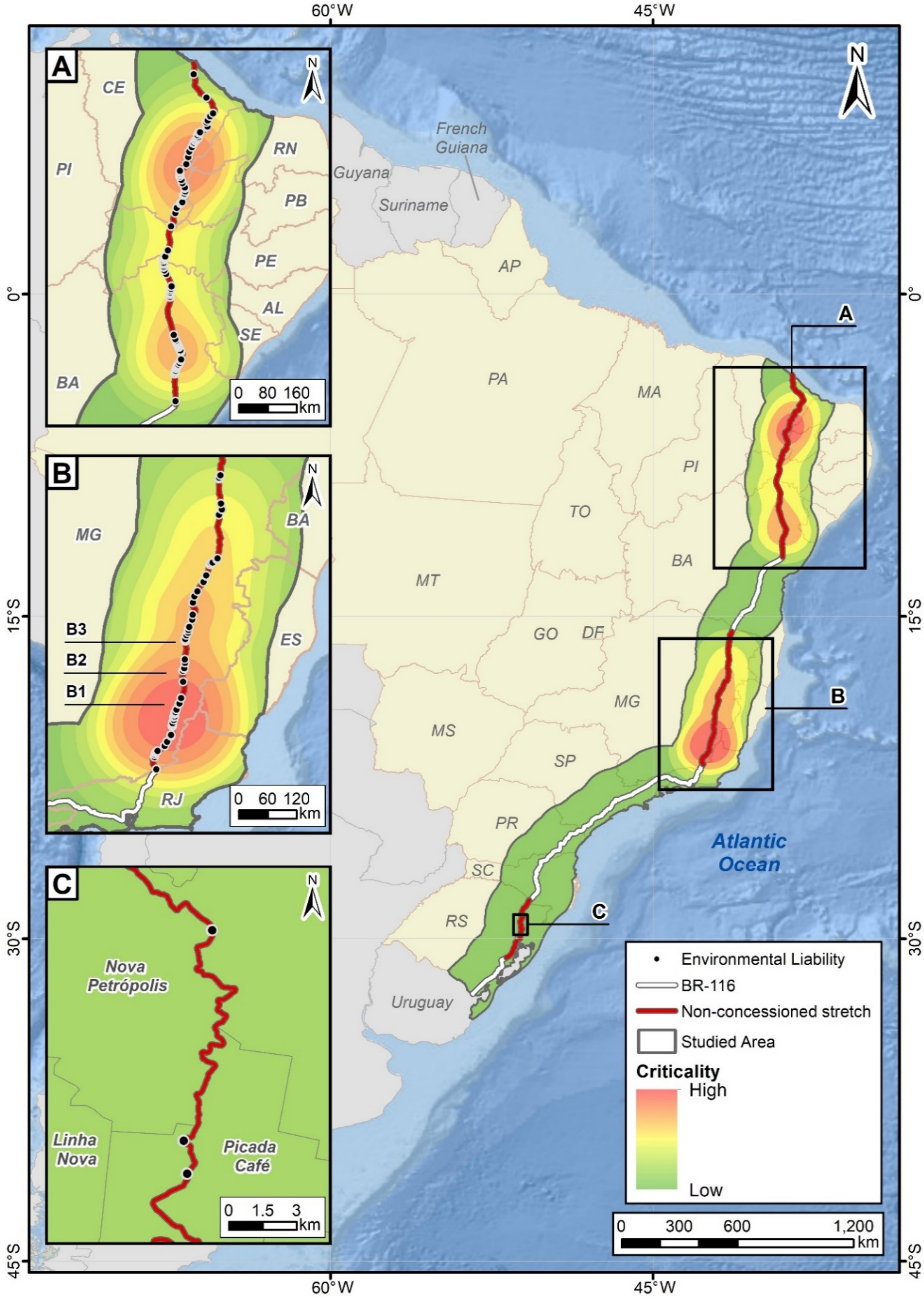

Figure 3. Most critical regions along the BR 116 highway

Since the standard deviation value ($\sigma = 0.94$) is too high for this database and due to the adopted method for composing the normal distribution curve, its results overflow to scores outside the possible PI results realm, meaning the curve includes scores lower than 0.45 and greater than 5.00. Therefore, only the possible PI scores should be considered.

As recovering a structure demands resources and time, the environmental liability management allows the most critical portion to be acted on right away and, to plan the recovery of the other liabilities afterwards. In order to define a satisfactory critical score for reference in the BR 116 highway environmental liability database, satisfactory results were achieved using the sum of the mode with twice the standard deviation ($\mu \pm 2\sigma$), because around 95.5% of the total area is located between these values in a normal distribution. Thus, a critical Priority Index (PI) score of 3.97 was obtained (black line shown in Figure 2).

It is also justified to conduct a logistical analysis of the environmental liabilities' recovery in addition to defining the presented tools. This analysis was made from the PI data analysis from a spatial perspective. Thus, it was possible to characterize possible critical regions along the BR 116 highway. Such regions were identified through a heat map (Figure 3), created using a geoprocessing software under the premise of considering each liability's PI score and their density along the highway of interest. There was no formation of a heat region due to the low concentration of liabilities in the Rio Grande do Sul state.

Within the most critical regions, it is possible to complement the liabilities' management. Since two sequential liabilities in the prioritization order may be located far from one another, that may not be followed as-is due to the required equipment and labor mobilization. Therefore, it is often it may be more advantageous to focus the work in one region and subsequently in another. The three regions with occurrence clusters were presented with detail on the map to improve visualization. Detail A stands for the northeastern region, detail B for the southeastern region and, detail C for the southern region.

A recovery plan example comes from each DNIT's superintendency. Since each one has its own autonomy, they can perform the recovery plan one region at a time. Thus, for example, when performing a recovery on Minas Gerais state, in the southeastern region, the sub-region B1 would be served first (Figure 3), recovering 26 liabilities in total, with four of these having an above critical PI score (bigger than 3.97). Subsequently, 11 more liabilities would be recovered in the sub-region B2, with two structures having an above critical PI score. Finally, sub-region B3 would be recovered, consisting of 15 environmental liabilities with one having an above critical PI score. The remaining liabilities would be recovered after most critical regions were done.

3.2. Critical analysis of the road environmental liability management model

Using the proposed management model, the recovery plan must act firstly on the most critical liabilities, with an PI score equal or higher than 3.97. However, it is also necessary to perform the recovery of other liabilities, as they may risk evolving over time, or be causing danger to the environment and/or property. Thus, the objective of characterizing the surveyed database in the field in order to manage it through quantitative values was met.

It is important to emphasize the existing dynamics in the survey of environmental liabilities, because even though a representative portion originates from the highway implementation work, the rest is a consequence of road operation and maintenance, meaning the occurrence number in a highway may change over time.

Another management model interpretation is obtained by drawing a parallel between the proposed classification and its prioritization. For this purpose, the liabilities classified as erosive processes were plotted, being subclassified in concentrated erosion (Figure 4a) and uniform erosion (Figure 4b) according to the Priority Index (PI). It was found that among the liabilities classified as uniform erosion, there were no cases that presented above critical PI scores (3.97), but there were a number of occurrences that scored above the theoretical average (2.73). For the liabilities classified as concentrated erosion, it was possible to find a number of occurrences with above critical PI scores (3.97) and an expressive number of occurrences scoring above the theoretical average (2.73).

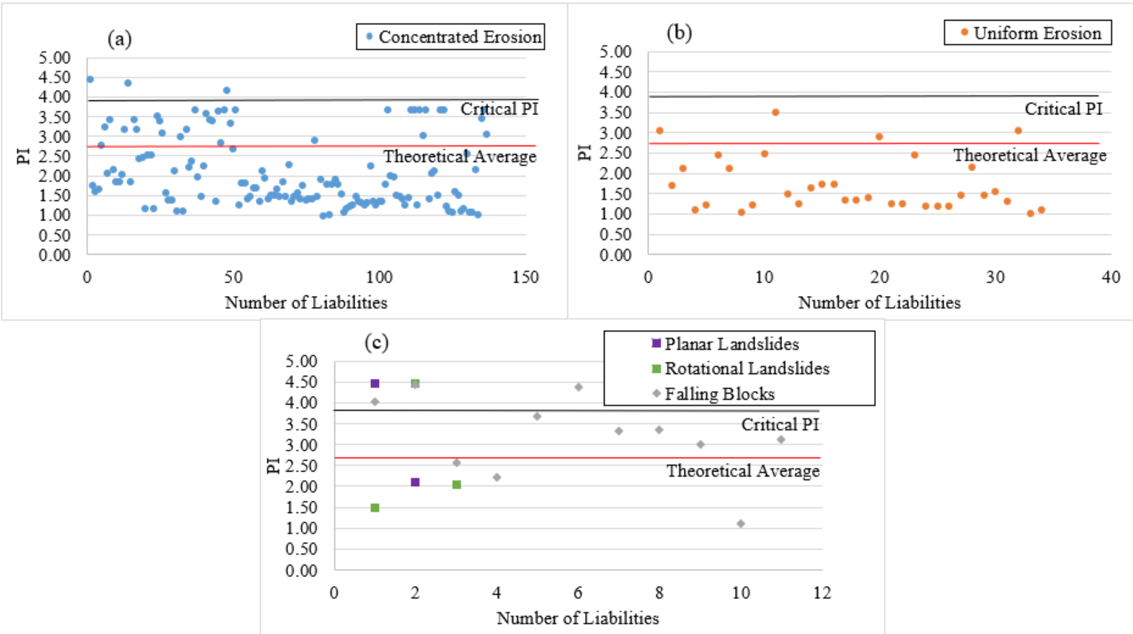

Figure 4. PI scoring distribution for liabilities classified as Uniform Erosion (a), Concentrated Erosion (b) and Mass movements (c)

Therefore, it is possible to verify that the proposed environmental liabilities classification has an indirect relationship with the prioritization method, since the liabilities that were classified with features related to the stability problems (Mass Movements), presented an PI score closer to 5.0, thus being prioritized in the recovery plans. This indirect relationship results from considering possible consequences in the Risk part of the analysis, as these are correlated with the classification. Therefore, the other weighted parameters in the priority index calculation, helped to rank liabilities registered within the same classification feature.

3.3. Classification and prioritization proposal application example

The liability named MG147 (Figure 5), classified as concentrated erosion, is analyzed to exemplify a Priority Index (PI) scoring application. The Highway Importance (HI) factor was determined as *remote importance* (3.0) according to their position on the highway using the arterial federal highways importance map (Figure 1). This liability has a Risk occurrence probability linked as *installed hazard* (1.5).

The probable consequences related to the selected liability's risk were degradation of the landscape (0.0), sediment accumulation on the roadway (0.2); drainage system silting up (0.2); pavement structure impairment (0.3); geotechnical problems induction (0.7); the lane and/or shoulder obstruction (0.7); and accidents (1.2), adding up to the score of 3.3. Thus, the Risk (R) score could be calculated as the product between the probability of an event occurring and its consequences, obtaining as a result a score of 4.95.

Figure 5. Environmental Liability MG 147, Concentrated Erosion.

Its occurrence (UTM (23K): 776224.70 m E; 7681904.25 m S) was recorded with medium span (2.0) and high intensity (5.0). Therefore, the Magnitude (M) score of this liability could be calculated as the mean between the intensity and span factors, resulting in a score of 3.50.

The Traffic Interference and Temporality (TI) factor was defined as *time-consuming recovery by blocking all lanes* (5.0). Thus, an PI score of 4.32 is obtained for the MG147 liability, using the proposed prioritization equation, which is a function of the four factors described above. The resultant score surpasses the critical PI threshold of 3.97 for this database, being very close to the theoretical maximum of 5.00, which characterizes a liability with atypical prioritization.

It is noteworthy that it is possible to identify the repair urgency of the occurrence registered as MG 147 (Figure 6) through visual analysis. The perceived urgency is due to the fact that the liability involves a large land massif, which is very close to the highway's traffic lane. There are erosive processes that present an evolution tendency, which can lead to the massif's instability, resulting accidents, highway environmental damage. Through the proposed prioritization method of Priority Index scoring, it is possible to assign numerical values to urgent repairs observed on-site.

4. CONCLUSION

Environmental liabilities are a frequent reality on federal highways as a result of continuous years without inspections regarding their maintenance and conservation state. Recovering those structures is paramount, due to the fact that they may present risk to the user, assets, and/or to the environment. Thus, the development of a liability management model to be used as a basis for recovery plans and to adapt the national road network to current environmental standards is justified.

The proposed model assists conceptualizing the "environmental liability" term, as well as proposing a recovery-aimed classification method. The proposal consisted of three main classifications and their respective subclassifications: 1. Erosive processes (1.1 uniform erosion and 1.2 concentrated erosion); 2. Gravitational mass movements (2.1 rotational slide, 2.2 translational slide, 2.3 falling/tipping blocks, 2.4 running and 2.5 crawling) and 3. Vertical displacements (3.1 compacting, 3.2 thickening and 3.3 landslides). Thus, corroborating with the problem identification and definition of solution and management guidelines.

Applying the proposed management model in the collected database in the non-concessioned stretches of BR 116 highway on January 2018, it was possible to obtain a sensitivity and response analysis and verify the correspondence of the prioritization equation in relation to what was observed in on-site. Context-wise, through the management model, it was possible to calculate the liabilities' Priority Index (PI) score and verify the records that scored above the theoretical average and the defined critical PI. Thus, this sample presented environmental liabilities with non-critical recovery as its main characteristic, since the database average was 2.09, less than the theoretical average PI score which is 2.73. Therefore, according to the defined criteria, the largest portion demands simpler recovery procedures with small portion demanding more complex geotechnical engineering works.

Based on the obtained results, it was possible to exemplify how the developed tools could be used to design recovery plans, a fundamental to logistical and resource management. An analysis of the most critical regions that is also relevant context-wise because it can end up in a more efficient recovery of liabilities, mobilizing people and equipment to recover more liabilities located in the same region, even if they do not have similar PI scores.

The results can be used as a good initial guideline for discussing management problems related to environmental road liabilities within the scope of geotechnical engineering and aim to assist the mitigation of environmental non-conformities present in the national road network.

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