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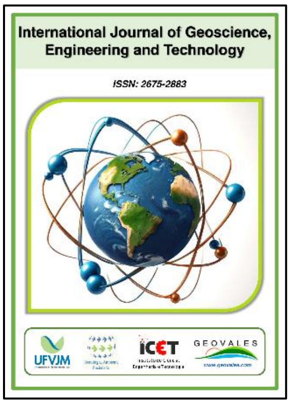

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Comparative Analysis Between the Empirical DNIT Method and the Mechanistic-Empirical MeDiNa in Flexible Pavement Design: A Case Study on BR-135 (Itacarambi–Manga Section)

Cinthia Emanuelle Alves de Souza[1], Alana Ellen Valeriano Rocha[1], Paulo Cesar Mendes Junior [1], Breno Alcantara Silva[2]

[1] Federal Institute of Northern Minas Gerais, Januária, Brazil.
[2] Federal Institute of Northern Minas Gerais, Pirapora, Brazil.

Email address
ceads@aluno.ifnmg.edu.br (Cínthia E.A. Souza)
aevr@aluno.ifnmg.edu.br (Alana E.V. Rocha)
pcdsmj@aluno.ifnmg.edu.br (Paulo C. Mendes Junior)
breno.silva@ifnmg.edu.br (Breno A. Silva) – Corresponding author.

Abstract

This study presents a comparative analysis between the empirical DNIT method and the mechanistic-empirical MeDiNa method for flexible pavement design. The research aimed to identify the conceptual and practical differences between the methodologies, highlighting calculation criteria, structural parameters, and long-term performance. Case studies and technical references were used to demonstrate the advantages of MeDiNa, such as greater accuracy in handling traffic, climate, and material variables, as well as the ability to estimate pavement behavior over time. On the other hand, the empirical DNIT method, although well-established, shows limitations under current conditions. The results indicate that MeDiNa represents a significant advancement, allowing for more efficient and durable designs, and is considered a superior alternative for modern pavement design in Brazil.

Keywords: Pavement design, DNIT, MeDiNa, Structural performance, Flexible pavements.

1. Introduction

Brazil's highway network plays a strategic role in the country's socioeconomic development, as road transport accounts for more than 60% of freight movement in Brazil (CNT, 2016).

In this context, flexible pavements represent most of the road infrastructure. They are composed of multiple superimposed layers in which the asphalt surfacing resists traffic loads and provides comfort and safety to users (Costa, 2021).

The proper dimensioning of these structures is important to ensure their designed service life, avoiding pathologies such as fatigue cracking and permanent deformations, such as wheel track sinking (Franco, 2007).

In Brazil, the traditionally adopted method is that of the National Department of Transport Infrastructure (DNIT), an empirical approach adapted from tests carried out in the United States and formalized in the 1960s (Biedacha, 2020; DNIT, 2006). Its main objective is to protect the subgrade from excessive plastic deformations over the pavement's service life.

To that end, it relies on two fundamental parameters: the California Bearing Ratio (CBR), which represents the bearing capacity of the subgrade soil, and the Number N, corresponding to the total repetitions of a standard 8.2-ton axle during the design period.

Total pavement thickness is obtained from abaci or the DNIT empirical equation and then distributed among the asphalt layer, base, subbase, and subgrade improvement.

Traditionally, pavement design methods in Brazil are based on empirical approaches developed from limited datasets and calibrated for specific climate and traffic conditions (DNIT, 2006). However, recent studies point to the need to adopt mechanistic–empirical methods that more realistically account for stresses and strains within the pavement (El-Ashwah et al., 2021).

The DNIT method also adopts structural equivalency coefficients that express the relative ability of materials to distribute stresses, as well as climatic factors that adjust soil strength according to moisture variation.

Although widespread and simple to apply, it remains essentially empirical. It does not explicitly consider important phenomena such as asphalt fatigue, permanent deformation of unbound layers, traffic growth, and Brazil's climatic particularities, which can compromise design reliability (CNT, 2017; Franco et al., 2007).

To overcome these limitations, the National Pavement Design Method (MeDiNa) was developed, adopting a mechanistic–empirical approach (DNIT, 2020). Unlike DNIT's method, which depends on fixed experimental relations, MeDiNa integrates empirical observations with pavement mechanics, evaluating the structure as a multilayer system simultaneously subjected to traffic and climate. It uses broader parameters obtained through laboratory testing, such as the resilient modulus of soils and granular materials, the asphalt mixture fatigue curve, and materials' permanent deformation. It also considers interlayer bonding, drainage conditions, and local climatic characteristics.

The development of Brazil's mechanistic–empirical method, MeDiNa, represents a significant step forward in pavement design because it integrates traffic, climate, and material properties calibrated to Brazilian conditions (Machado, Marques and Rocha, 2020). This national adaptation is key to improving performance predictions and reducing maintenance costs, aligning with international trends toward more realistic and sustainable pavement design.

Design with the MeDiNa software employs Multilayer Elastic Analysis (AEMC) to compute internal stresses and strains. Performance verification involves criteria such as fatigue resistance, rutting limits, interlayer bonding, and reliability levels adjusted to road hierarchy (Chiarello, 2019; Costa, 2021). Although it requires more input data and laboratory testing, the method offers more realistic simulations of structural behavior and greater reliability, enabling analysis of design alternatives to optimize cost and durability.

The relevance of comparing methods is even greater when applied to regionally important highways. The BR-135 section between the municipalities of Manga and Itacarambi, in Minas Gerais, is currently unpaved, which hinders access, increases travel time, and causes user discomfort. Designing this road segment is therefore fundamental to meet this demand, providing technical support for efficient and durable pavement implementation.

Although a design was previously prepared for this section, construction never took place. Since then, there have been significant changes in traffic conditions and design techniques, making it necessary to update the data and perform new designs using both the DNIT and MeDiNa methods. This update enables direct comparison between approaches and highlights implications for expected performance and service life.

Given this scenario, the objective of this article is to compare the flexible pavement design of BR-135 between Manga and Itacarambi (MG), applying DNIT (2006) and MeDiNa (DNIT,2020). The comparison aims to show conceptual and operational differences between the methodologies and their implications for structural performance and durability.

2. Methodology

Recent studies have contrasted Brazil's legacy empirical approach (DNER, 1996) with the newer mechanistic–empirical procedures, showing consistent differences in required inputs, structural response evaluation, and resulting overlay designs. For example, Machado, Marques, and Rocha (2020) compare empirical practice with the MeDiNa/BackMeDiNa workflow on the UFJF ring road, illustrating how the M–E framework—supported by FWD backcalculation and performance models—can lead to design decisions not captured by purely empirical rules.

The methodology was structured to update BR-135 traffic data and to enable a comparative application of two distinct pavement design methods. A step-by-step sequence was defined to update and consolidate information and, finally, to carry out the designs and comparative analyses. Figure (1) presents the methodological flowchart for the research.

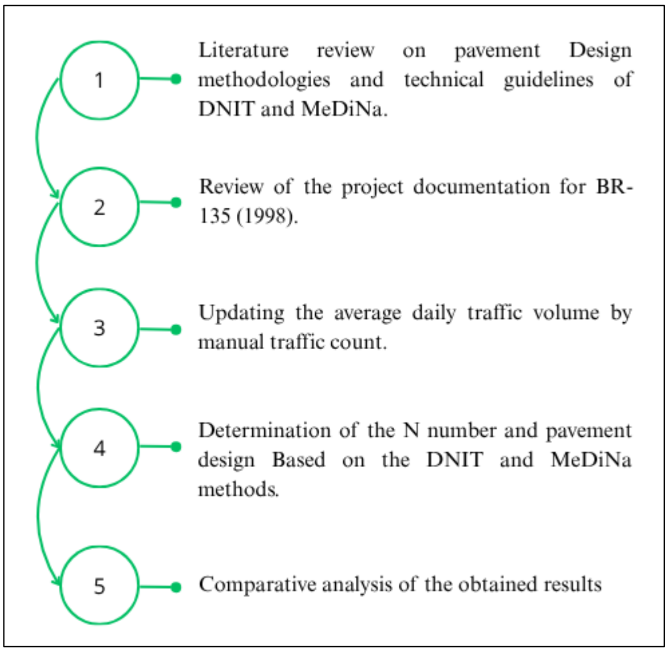

Figure 1 – Methodological flowchart of the research.

2.1. Documentary analysis

The documentary analysis was based on the BR-135 project documents for the Itacarambi–Manga section, dated 1998 and provided by DNIT upon formal request. This set included design reports, traffic studies, technical specifications, and geotechnical data, including CBR values and subgrade characteristics.

Although the highway has not been paved, the existing project contains relevant information on traffic and local conditions, which have not changed significantly over time.

Thus, for the new design, the subgrade geotechnical parameters—especially CBR values—were retained as representative of the region. By contrast, traffic volumes were updated to reflect current conditions, while other parameters were kept from the original project.

2.2. Traffic volume count

The traffic volume count was carried out on the BR-135 section between Itacarambi and Manga (study area shown in Figure 2).

Measurements were conducted over four consecutive days, from Thursday to Sunday, during a week without holidays or regional events that could affect normal flow. On each day, observations were made continuously for 16 hours, except on Saturday, when monitoring lasted 10 hours.

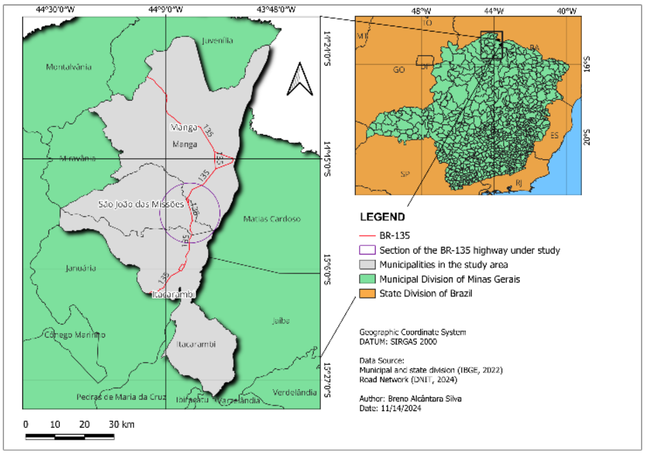

Figure 2 – Study area.

Data collection followed the DNIT Traffic Study Manual (2006), with two operators positioned in opposite directions. Although the National Traffic Count Plan (PNCT) recommends continuous seven-day (24 h) campaigns, the survey was limited to four days due to safety and staffing constraints. To mitigate sampling distortions, counts were conducted on days considered representative of typical road conditions.

The collected data enabled vehicle classification and calculation of Average Daily Volume (VMD). An annual growth rate of 10% was adopted, consistent with the DNIT Pavement Manual (2006), to represent future increases in traffic. These inputs formed the basis for calculating the Equivalent Axle Load Repetitions (N), an essential parameter for structural design.

2.3. Calculation of Average Daily Volume (VMD)

Based on the traffic counts, the VMD was calculated in accordance with the DNIT Traffic Study Manual (2006). VMD estimates the total demand that the pavement structure must withstand over its service life, representing the daily average of commercial vehicles traveling the section. It is used to compute the accumulated Equivalent Axle Load Repetitions (N). The VMD calculation is given by Equation (1).

$$VMD = \frac{365}{30} MMD \tag{1}$$

After computing VMD, the two designs were performed. In the DNIT methodology, this value was used to determine N, which guided the thicknesses of structural layers via empirical equations. In MeDiNa, VMD (DNIT, 2020; Medina and Motta, 2015) was entered along with material and climatic data, enabling mechanistic–empirical analysis. The resulting designs were then compared.

2.4. Design using the DNIT method

The DNIT (2006) method adopts an empirical approach based on two main parameters: the subgrade CBR and the Number N, which represents the total repetitions of a standard 8.2-ton axle over the design life. The calculation of N was carried out using Equation (2).

$$N = 365.P.VMD.FV.Fr \quad (2)$$

Where:
VMD = Average Daily Volume;
P = design period (10–20 years for highways);
Fr = Climate Factor;
FV = Vehicle Factor, determined by Equation (3).

$$Fv = Fe \cdot Fc \quad (3)$$

Where:
Fe = Axle Factor, the product of the number of vehicles and an assigned value yielding corresponding axle counts, calculated by Equation (4);
Fc - Load Factor, indicating the damage potential of vehicles in operation, calculated by Equation (5).

$$F_{e=\frac{n}{v_t}} \quad (4)$$

Where:
n = total number of axles;
v_t = total number of vehicles.

$$F_c = \frac{\sum(P_j - F_{cj})}{100} \quad (5)$$

Where:

P_j= Incidence of a given vehicle as a percentage obtained by traffic counting, as recommended by the Paving Manual (DNIT, 2006)
F_{cj} = Operational equivalency factor for each vehicle class.

Layer thicknesses follow the principle of the structural equivalency coefficient (k), which reflects materials' relative ability to distribute stresses. The higher a material's elastic modulus, the lower the pressure transmitted to the subgrade, ensuring satisfactory performance over the pavement's service life (Bernucci et al., 2010; Franco, 2007).

This concept indicates that the higher the elasticity modulus of the material, the lower the pressure transmitted to the subgrade. Thus, the structural k serves as a starting point for determining the minimum thicknesses of these layers, ensuring that the pavement operates efficiently throughout its design life.

Finally, DNIT's empirical Equations (6), (7), and (8) are applied as exemplified below:

$$Rk_r + BK_B \geq H_{20} \quad (6)$$

$$RK_R + BK + h_{20}\, k_s \geq H_n \quad (7)$$

$$RK_R + BK + h_{20}\, k_s + h_n\, k_{ref} \geq H_m \quad (8)$$

Where:
R = asphalt layer thickness;
K_R= asphalt structural coefficient;
B = base layer thickness;
K_B = base structural coefficient;
H_{20} = required thickness to protect the subbase;
k_s = subbase structural coefficient;
h_{20} = subbase thickness;
H_n = required thickness to protect the subgrade improvement;
h_n= subgrade improvement thickness;
H_m = total thickness required to protect a material with CBR = m%.

The total thickness is then distributed among asphalt, base, subbase, and subgrade improvement, observing normative limits and material performance coefficients.

2.5. Design using the MeDiNa method

The MeDiNa method (DNIT, 2020) is a Brazilian advance inspired by international mechanistic–empirical models such as the Mechanistic–Empirical Pavement Design Guide (AASHTO, 1993) and NCHRP 1-37A. Unlike the DNIT method, MeDiNa considers performance over time, simulating stresses and strains as functions of traffic and environmental conditions (El-Ashwah et al., 2021).

Developed by DNIT (2020) based on the model proposed by Medina and Motta (2015), MeDiNa integrates pavement mechanics with empirical observations, enabling a more realistic analysis of structural behavior under traffic and climatic variability.

Design starts from VMD, used to model traffic over the design period. The software converts traffic into equivalent load applications distributed over time and applies Multilayer Elastic Analysis (AEMC) to determine internal stresses and strains (Franco, 2007; DNIT, 2020).

MeDiNa simulates structural performance over time, evaluating asphalt fatigue, permanent deformation in granular layers, and interlayer bonding, while considering reliability levels according to road hierarchy. This procedure defines the most suitable layer thicknesses and materials for actual traffic and soil conditions, delivering greater durability and efficiency.

According to Franco (2007) and Medina & Motta (2015), mechanistic–empirical models allow validation with laboratory tests and field observations, increasing confidence in the resulting thicknesses.

3. Results and Discussion

3.1. Average Daily Volume (VMD) and N

For the comparative analysis, Table (1) summarizes the calculated VMD, design period, and N (traditionally used by DNIT to define layer thicknesses). It also includes complementary outputs from MeDiNa, such as predicted cracked area and rut depth at the end of the design period.

Table 1 – VMD and Number N by the DNIT and MeDiNa methods.

Parameter	DNIT Method	MeDiNa Method
Average Daily Volume (VMD)	11.845,58 vehicles/day	11.845,58 vehicles/day
Design Period	10 years	10 years
Axle Factor (FE)	0,06276	0,06276
Regional Climatic Factor (FR)	1	1
Vehicle Factor (FV)	7,79	7,79
Equivalent load repetitions (N)	$3,62 \times 10^7$	$2,33 \times 10^7$
Cracked area at end of design	–	29,64%
Rut depth	–	0,87 mm

The DNIT method transforms VMD into an accumulated estimate of total load repetitions over the design period, considering current daily volume and growth projections via correction factors such as commercial vehicle share, annual growth, and load equivalency factors. Thus, VMD yields N, used to define layer thicknesses.

In MeDiNa, the same VMD is an input, but the software simulates month-by-month loading over 10 years. The calculation of N is distributed over time, allowing the evolution of structural damage to be estimated.

At the end of the design period, the results indicated 29.64% cracked area and 0.87 mm rut depth—both below the software's limits of 30% and 10 mm, respectively. The accumulated N, together with MeDiNa's additional parameters, supports thickness selection and performance prediction.

3.2. Structural results from the DNIT method

With $N = 3.62 \times 10^7$ (within $10^7 < N \leq 5 \times 10^7$), the DNIT design followed Table (2) of the DNIT Manual (2006), which relates N to minimum asphalt thicknesses. Table (2) summarizes the thicknesses for each layer.

Table 2 – Composition of the flexible pavement layers designed by DNIT.

Layer	Material	K	Type	Minimum thickness (cm)
Asphalt	Asphalt Concrete	2	CBUQ surfacing	5
Base	Granular Material	1	Graded Crushed Stone	15
Subbase	Fine silty/clayey soil	1	Yellowish clayey-silty sand	10
Subgrade	Yellowish clayey-silty sand	-	-	-

The design used DNIT (2006) to set minimum asphalt thickness as a function of N. For N between 1×10^7 and 5×10^7, a 10 cm HMA (CBUQ) surface was defined. The base adopted graded crushed stone at 15 cm (the normative minimum and within the 20 cm maximum).

This material shows good structural characteristics and has been used previously in the region (subgrade CBR = 20%).

The subgrade maintained the region's natural soil (yellowish clayey-silty sand), with CBR = 9% per 1998 testing. Despite its relatively low strength, its use is feasible provided upper layers are properly dimensioned or stabilization techniques are employed.

Figure (3) shows the pavement structure designed using the DNIT method, with the thicknesses and materials defined for each layer.

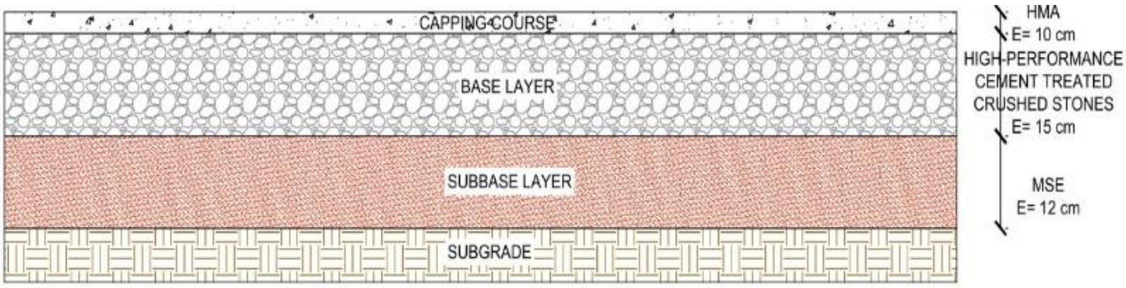

Figure 3 – Pavement structure dimensioned using the DNIT method.

3.3. Structural results from the MeDiNa method

In Brazil, flexible pavement design has largely been based on the CBR method, formalized in 1974. This procedure uses subgrade CBR and N (80 kN standard axle) to define layer thicknesses via charts, usually yielding granular solutions.

Neste estudo, não foram realizados ensaios laboratoriais recentes para a determinação do CBR. Optou-se por empregar os valores já disponíveis no projeto elaborado em 1998 pelo conforme a documentação fornecida pelo DNIT.

In this study, no new laboratory tests were conducted for CBR; values available from the 1998 project (DNIT documentation) were employed. For MeDiNa, the road was classified as Primary Arterial, corresponding to 85% reliability. The design period was 10 years (120 months), during which traffic accumulation was progressively modeled. The performance limits followed the software criteria: ≤ 29.6% cracked area and ≤ 0.87 mm rut depth at the end of life. Table (3) presents key parameters used in MeDiNa.

The asphalt surfacing was designed with Class 4 asphalt concrete (DNIT ES 31), with high fatigue and rut resistance, suitable for heavy traffic. Key parameters include resilient modulus ≈ 10,500 MPa, Poisson's ratio 0.3, specific gravity 2.4 g/cm³, asphalt binder content 5%, air voids ≈ 4.5%, and Los Angeles abrasion 38%. Performance criteria include fatigue class ≥ 4, mineral filler shape factor (FFM) ≥ 1, and minimum Flow Number of 410 cycles (normal traffic) or 1085 cycles (severe).

Table 3 – MeDiNa design parameters.

Layer	Material	Resilient Modulus (MPa)	Optimum Moisture (%)	Other relevant parameters
Asphalt	Asphalt Concrete C4	10.492	-	Fatigue Class ≥ 4; Flow Number ≥ 410 / 1085 cycles
Base	Graded Crushed Stone	-	-	DNIT ES 141 compliance
Subbase	Fine Lateritic Sandy Soil	494	10,6	Low deformability; ψ_1 = 0.021; ψ_2 = −0.086; ψ_3 = 1.37; ψ_4 = 0.116
Subgrade	Clayey-silty sand (NS – MCT)	189	13	ψ_1=0,244; ψ_2 = 0,419; ψ_3 = 1,309; ψ_4 = 0,069

The base adopted graded crushed stone (DNIT, 2022) due to high bearing capacity and aggregate interlock. The subbase was a fine lateritic sandy soil selected from the software database (Mr = 494 MPa; ν = 0.45; γ = 1.875 g/cm³; wopt = 10.6%; MCT c′ = 1.33; e′ = 1.1; regression coefficients ψ as listed). The subgrade was classified as yellowish clayey-silty sand (NS group), defined by MeDiNa, with γ = 1.8 g/cm³ and wopt = 13% (compaction per DNIT ES 137), and regression coefficients ψ representing the empirical permanent deformation response.

The behavior in relation to permanent deformation is estimated by the coefficients $\psi_1 = 0.244$; $\psi_2 = 0.419$; $\psi_3 = 1.309$; $\psi_4 = 0.069$, which represent the empirical response of the soil under repeated loads.

Table (4) shows the computed layer thicknesses in MeDiNa, considering both traffic and material properties.

Figure (4) illustrates the flexible pavement structure of BR-135, on the section between Itacarambi and Manga, dimensioned using the MeDiNa method.

Table 4 – Composition of flexible pavement layers designed by MeDiNa.

Layer	Material	Type	Thickness (cm)
Asphalt	Asphalt Concrete	Class 4	14,7
Base	Granular Material	Graded Crushed Stone	30
Subbase	Fine silty/clayey soil	Fine Sandy Soil LA’	20
Subgrade	Clayey-silty sand (reddish)	-	-

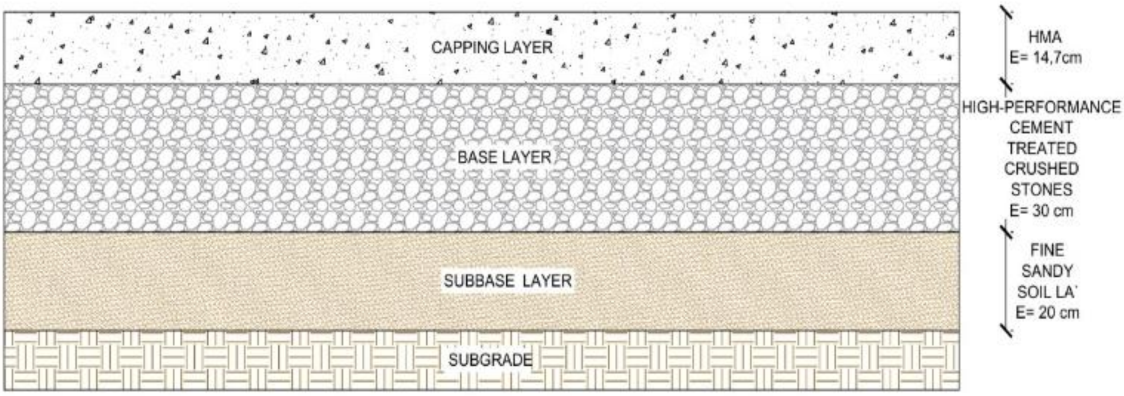

Figure 4 – Flexible pavement structure (MeDiNa design).

3.4. DNIT vs. MeDiNa

Comparing DNIT and MeDiNa for the BR-135 Itacarambi–Manga section is important to identify differences in approaches currently used in Brazil. Such analysis improves pavement projects in terms of durability, safety, and cost-effectiveness.

The comparison makes it possible to evaluate the accuracy of each method, its ability to predict the structural behavior of the pavement over time, and the direct effects on layer thicknesses. Thus, it provides important technical input for more appropriate decisions, considering actual traffic and soil characteristics in the region.

Both methods used the same traffic data and geotechnical parameters from the 1998 project, ensuring a fair comparison between DNIT’s empirical-mechanistic approach and MeDiNa’s mechanistic–empirical approach. The analysis highlights differences in allowable load repetitions, layer thicknesses, and predicted performance over time, clarifying each method’s strengths and limitations.

DNIT—based on Prof. Murilo Lopes de Souza’s proposal—uses standardized parameters (CBR and allowable N). Structural verification occurs only at the end of the 10-year period, without tracking the evolution of stresses and strains over the service life.

MeDiNa, in contrast, evaluates month-by-month behavior over 10 years. Rather than focusing solely on a final N, it continuously tracks the layers’ response to traffic-induced stresses and strains. This enables more precise adjustments to thicknesses and material choices, resulting in a significantly higher number of admissible repetitions and, consequently, greater expected structural capacity.

Although the VMD of 11,845.58 vehicles is the same for both methods, its use differs: DNIT applies it directly and simply to estimate loads, whereas MeDiNa uses it to drive detailed simulations that consider load variations, temporal distribution, and progressive damage.

Table (5) presents the comparative design results for the BR-135 section using both methods.

Table 5 – Comparative design results: DNIT vs. MeDiNa.

	DNIT		MeDiNa	
Layer	**Material**	**Thickness (cm)**	**Material**	**Thickness (cm)**
Asphalt	Asphalt Concrete	10	Asphalt Concrete	14,7
Base	Graded Crushed Stone	15	Graded Crushed Stone	30
Sub-base	Clayey-silty sand	12	Clayey-silty sand	20
Subleito	Solo Natural (Areia Argilo Siltosa de Cor Amarelada)	-	Natural soil (yellowish/reddish clayey-silty sand)	-

MeDiNa produced thicker layers than DNIT: asphalt increased from 10 cm to 14.7 cm, base from 15 cm to 30 cm, and subbase from 12 cm to 20 cm, using similar materials. The increase reflects MeDiNa's effort to limit stresses transmitted to the subgrade below its shear strength. The software applies mechanistic–empirical criteria that consider performance over time, detailed material properties, real traffic, and target reliability.

As detailed in the methodology, no recent laboratory testing was performed; the 1998 project data and literature values were used. This adaptation may introduce small inaccuracies. In this context, CBR—one of the principal parameters for flexible pavement design (Bernucci et al., 2008)—can influence thickness precision when estimated values are used.

The DNIT method uses N, together with CBR, to set minimum layer thicknesses via empirical tables based on existing pavements. Because it does not simulate the evolution of fatigue damage or rutting, its ability to predict performance over time is limited.

By contrast, MeDiNa evaluates fatigue and permanent deformation, allowing more precise performance estimates under real traffic. DNIT's simplicity can lead to overdesign when N is low (thicker-than-necessary layers) and underdesign when N is high, potentially compromising long-term performance.

The DNIT Pavement Manual acknowledges these limitations and recommends complementary criteria or manual adjustments when appropriate.

4. Conclusion

The DNIT method uses simplified parameters—CBR and repetitions of the standard load—based on standardized tables and charts. Its application is practical and economical and may suit projects with technical or financial constraints, but it does not consider the time-dependent evolution of material behavior nor does it fully adjust to local traffic and soil conditions.

MeDiNa, in turn, adopts a more detailed mechanistic–empirical approach that incorporates actual material parameters such as resilient modulus, fatigue resistance, and permanent deformation. This enables a more precise and realistic design that better reflects expected performance over time. The absence of specific laboratory tests in this study required the use of database values, which may slightly influence computed thicknesses.

Choosing between methods depends on project objectives and data availability. DNIT stands out for simplicity and speed, whereas MeDiNa offers greater precision and reliability. Future work should include laboratory testing, apply MeDiNa to different segments, and compare with international methods to ensure more comprehensive assessments and durable, efficient pavement projects.

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