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Research Article

A Model for the Evaluation of Brazilian Road Transport: A Sustainable Perspective

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Freight transportation in Brazil is heavily based on the road mode bringing heavy dependence of this mode to the country and some consequences such as high operating costs and high air emissions. For these reasons, it was considered the necessity of evaluating new investments made in this mode from a sustainable perspective, taking into account not only economic but also social and environmental concepts. Towards this purpose, the study develops an evaluation model of road transport infrastructure, the TIM, which will help decision making in situations of choice between different alternatives of road projects. The model includes ten variables that count from the initial investment in the road to air emissions of carbon dioxide. All are monetarized individually and then consolidated into a single equation. The result of applying the model is innovative when considering the three spheres of sustainability to evaluate future road transport projects and rank them.

1. Introduction

The transport infrastructure of a country boosts its socioeconomic development by enabling a better flow of production in terms of volume and time. Depending on the volume, the origin, and destination of the commodity and the type of consumer, the choice must occur regarding a specific mode of transport. The Brazilian transportation network for freight is based on road (61.1%), followed by railroad (20.7%), waterway (13.6%), pipeline (4.2%), and air (4%) [1]. The consequences of this imbalance are negative for the country in several aspects, such as the higher cost of road transport over railroad. The higher atmospheric emissions of carbon dioxide (CO_2) of those type (highways) compared with others, and so on, will be deepened in the present study.

Regarding Brazilian states the analysis shows the great influence of some types of products in the transport mode choice. In the state of Minas Gerais, for example, there is an option for railroad transportation oriented to iron ore, since there is such availability of the commodity in the region and the cargo has low added value and can be transported in large volumes. Meanwhile, the state of São Paulo strongly uses the waterway mode in the transportation of bulk products, automobiles, and others, through the strong participation of the Port of Santos. However, not all states are benefited from a more diversified matrix relying heavily on road transport alone.

The five modes of cargo transport are differentiated based on the characteristics: possible volume of transport; initial cost of installing a new route; cost of operating an existing transport infrastructure; security that the environment provides to the workers involved and users; the possibility of having a door-to-door service; availability of transportation of any type of cargo; and finally, the social impact generated to the population with the use of this mode of transportation.

The road transport mode, for example, is advisable for door-to-door transportation, especially in the case of fragmented products deliveries to the final customer. Railways are mainly used towards large volumes of low value-added products. Ships are also used for large volumes, which can carry products in container or in bulk. In this case the range is a little more limited, having the product to be in some port or near waterways within the country. In some situations these two modes are combined, resulting in multimodal transportation. The cargo is transported by rail to the port, where it will continue by ship to the next destination, whether in the country or not.

More specifically there is transportation via pipelines, which allows a continuous flow of fluids and gases for some commodities that have these characteristics. It allows a large volume shift and that is from point to point, previously determined. Finally, air transport, with high cost, less time, and greater security, is appropriate for commodities that have high added value. This also requires a complementary mode for delivery and withdrawal of the product at airports.

In contrast to our explanation above, the circulation of goods in practice does not exactly follow the priorities presented because it depends on the existing infrastructure in each region. As we have already seen, in Brazil, road transport is predominant and it is by this means that most of the country's cargo flows. For this reason this mode of transport will be the focus of this study.

The simplest way to analyze the impacts of an infrastructure project is from models that consider direct impacts, mainly represented by the reduction in total travel time, number of accidents, and transportation costs [2–7]. More complex models that take into account indirect impacts, such as the generation of indirect jobs and the increase of municipal GDP, are few and very directed to a specific project [8].

Another issue is the environmental impact, still weakly considered in this type of analysis. According to [9], sustainability in transportation is a recent concept derived from sustainable development and it is based on measurements through various transport indicators and also in proposals to change old habits, such as encouragement to mass transportation.

For the already explained reasons, this article provides an evaluation of the transport infrastructure projects in the road mode in Brazil, allowing comparisons between different alternatives and justifying the choice of one of them through technical arguments. The model seeks flexibility and can be adapted according to the local reality, since the regional conditions influence and show ramifications in various social, economic, and environmental aspects. The model calculates a monetary value for the analyzed alternatives in any time frame.

The article is composed of six sections, including the introduction. They are divided as follows: Section 2 presents the theoretical foundations, surveying international references for the structuring; in Section 3 the methodology used for the construction of the model is described; Section 4 shows the development of the Transport Infrastructure Model (TIM) and the equation that defines it; Section 5 brings the results obtained, and finally, the sixth section concludes this article and suggests future studies that can enrich it.

2. Literature Review

According to [10], economic development, in addition to growth, measured by the increase in Gross Domestic Product (GDP) in the long term, reduces poverty rates and improves health, education, housing, and transportation conditions. One of the indicators used to assess impacts on the population is the Human Development Index (HDI), which calculates the relationship between quality of life and economic development.

For this reason the tripod of sustainability has become the subject of great questions in several countries and different areas, including the transportation of cargo and passengers. The social and environmental criteria are gaining relevance in this scenario, as well as the economic ones. The economic benefits obtained from transportation are usually observed in long-term periods. In this way the quantification of these is made from the knowledge of costs to direct users and their externalities, taking into account the socioeconomic and environmental context [11].

2.1. Relationship between the Influence of Infrastructure and Regional Sustainable Development. Studies indicate the relationship between transport infrastructures and the regional development that accompanies it under social, economic, and environmental aspects. The better the design of a route and the more interconnections it has, the better the consequences for that region. In Brazil some researchers show this relationship and seek to prove it through significant variables [10, 12–15].

The railroads present their role in the economic development of Brazil. Reference [10] evaluates the behavior of the state GDP and the operating income of the company during the year, being the last one obtained through the amount of cargo transported in the period. On the other hand [15], trying to understand the influence of the North-South Railroad analyzes the impacts on the variables: product, income, employment, and tax collection in the municipalities involved. The projections are calculated from the variables of GDP per capita, service tax of any kind (ISSQN), formal employment, and average wage of the worker. The deflation index used is the General Price Index.

Identifying the parts involved in an infrastructure project is a differential in the [14] study on the subway deployment process. The actors are divided between private and public, the first of them being focused on their survival. In addition, the study identifies the economic development and real estate valuation for the region that receives subway stations as benefits to the population, as well as the reduction of traffic in the adjacent road system and urban development centered on public transport.

The proposition of evaluation of transportation projects in Brazil [13] uses a more qualitative multicriteria method to relate the increase of infrastructure efficiency in the country aligned with sustainable development. Thirty stakeholders evaluated under the criteria: intermodal connection, job creation, social welfare, environmental impact, recovery of environmental liabilities, costs and benefits, and project execution period. On the other hand, [12] adopts a more qualitative and economic methodology that uses VPL, TIR, and B/C indicators (benefits and costs). That study proposes that only financial profit is enough to make a project viable.

Based on the American reality, the variables considered valid for the case study are the number of transportation modals in the region; quality of transport (average speed, safety, traffic jam, and physical conditions); sound, air, and water pollution; impacts on the community life and surroundings; access to education and job creation; impacts on economic activities and in the estate of the region; and income distribution [16]. Some US states have developed their own models to set priority on investments in infrastructure and, according to [17], consider direct and indirect benefits under the three pillars of sustainability. The direct ones are the economic ones and the indirect ones are time of the trip, creation of jobs, and security.

Another study that considers cost-benefit analysis (CBA) was conducted by Barfod and Leleur [6] at the Danish Ministry of Transportation. The VPL calculation is given by the difference between the benefits and costs of the project. The primary variables are construction cost, disturbance in the construction period, maintenance costs, work completion costs, travel time reduction, driver costs, and taxes (road toll). The secondary ones are noise pollution, number of accidents, local pollution, and global pollution.

Analyzing the potential impact that each project can generate in the population [18] consolidates the study through sixteen criteria. Traffic, travel time, distance, average speed, local inhabitants, age group, births and deaths, migrations and marriages, family income, GDP, CO_2 emissions and land occupation rate, distance between housing and work, and number of vehicles in the region.

However, according to [19] the analysis is more focused on highway safety. Thus, its main concerns are divided into three groups: security, economy, and social importance. The criteria used are reduction of accidents, reduction of fatal accidents, investment, project continuity period, daily traffic average, and percentage of growth.

2.2. Models for Evaluating Transport Infrastructure Projects. Infrastructure project evaluation models are mostly acknowledged through quantitative methods in order to compare two or more alternatives, or even to justify investments from long-term viability. However, a model may also have references in qualitative methods when it is not possible to give it real values, or if it is to consider the opinion of those involved.

For qualitative variables [20] use the Likert scale to analyze the energetic efficiency of 29 provinces in China through Data Envelopment Analysis (DEA) model. The inputs of the model are capital invested in assets, employment, and energy consumption; the outputs are GDP, CO_2 emissions, and air quality level.

The use of ACB is widely used for engineering, health, and public policy applications, among others. These analyze range from natural hazard mitigation strategies to the development of electric vehicles [21, 22]. For transport infrastructure this analysis is also used since it considers the trade-off between the costs and benefits of the highways, helping in the decision making to invest in an alternative.

Reference [23] developed the Eco-Mobility (EM) that considers, besides the ACB, the risk analysis (Monte Carlo simulation) and the multicriteria complementary analysis of decision. The first two work as inputs for the third. Eco-Mobility evaluates alternatives from the point of view of sustainability. The criteria adopted are socioeconomic strength, improved mobility for drivers and users of public transport, visual impact on cities, economic impact on the region, impact on logistics flexibility, and contribution to the European green corridor. Another similar model is [24] that considers travel time, traffic volume, construction time, and traffic demand variation in the work.

The MicroBenCost model, according to [2], developed in the 1990s by the Texas Transportation Institute and widely used to this day, is one of the ways to evaluate highway improvement projects from the ACB, following the increased transport capacity and improved track safety. The following factors are analyzed as benefits: travel time, vehicle operating cost, and number of accidents.

Developed and used by the World Bank, the HDM-4 is a model that proposes an evaluation of the performance with regard to the following aspects: traffic volume, type of pavement, maintenance standards, and regional characteristics. In addition, the benefits identified for the consumer are reductions in operating costs, travel time, and number of accidents; traffic jam; social benefits and environmental impacts (air pollution and energy efficiency) [3].

From the HDM-4 [7] they also constructed a multicriteria analysis model to optimize investments in highways. The criteria are the economic, social, and environmental impacts that present different weights. The quantified cost-benefits for each of the global impacts are measured from these weights. The following are evaluated: atmospheric emissions, energy efficiency, number of accidents, comfort to users, traffic jam, accessibility to schools, hospitals, and commerce. Another model is *Computational General Equilibrium* (CGE), which contributes to estimating the economic impacts from the travel time inputs and truck operating costs [17].

The study developed by Cascetta et al. [25] is based on three processes for decision making in transport projects: a rational cognitive approach, a 5-step model to identify stakeholders engagement, and a quantitative analysis. The process begins in the analysis of the scenario and formulation of the alternatives until the choice for a region to implement it.

In the European Union, the choice of transport projects is also based on the ACB and considers as influence factors investments in the road, operation and maintenance costs, road toll revenue, travel time, vehicle operating cost, accidents, noise, air pollution, and climate change. The data are monetarized [5]. To support the European model, a manual on external transport costs has been developed [26]. This presents the state of the art in terms of categories: traffic jam, accidents, noise and atmospheric pollution, climate change, other environmental impacts, and the deterioration of railway and road infrastructure. The study shows that there are two approaches to data collection: top-down or bottom-up, where the former is more generic and has lower costs and the second is based on actual data.

Reference [11] uses the AHP (Analytic Hierarchy Process) method to choose criteria that focus on infrastructure projects in Brazil. The model is based on the opinion of thirty-three professionals and evaluated transport costs, financial feasibility of the project, intermodality, transport supply in the region, HDI, environmental impacts, and atmospheric emissions.

Table 1 summarizes the main variables considered by each author in their models. Travel time, for example, is the main one, present in 61% of the models. Environmental impacts are in second place, addressing issues such as air pollution, atmospheric emissions, air quality, and climate change. Economic impacts are shown in fifth position.

3. Research Methodology

Based on the same proposal made by Zheng et al. [27] for the development of an index that evaluates sustainability in transportation, this study follows four of the five proposed steps to evaluate transport infrastructures: (A) identify the positive and negative impacts of a highway; (B) select appropriate variables; (C) monetarize the data to make them comparable; (D) aggregate the considered components.

From the adjustment, the steps that compose the methodology of this study are described. Initially the literature survey is composed by the study of the main models of transport infrastructure evaluation and analysis of the variables used. The second part is the selection of the variables that will compose the TIM model, monetarization, and development.

4. Transport Infrastructure Model

The proposal of the developed model is an evaluation of projects that, according to [28], aims to present a positive relationship between the costs involved in an infrastructure and the benefits generated, comparing road transport projects. Not only technical aspects of the projects, but also social ones will be considered, achieving an efficient model with reduced chances of error and a transparent process. The analysis will be based on the sustainability tripod considering social, environmental, and economic issues.

The scenarios evaluated are dynamic and the result obtained today can be different from the results during the construction of the project and at the end of it, making the analysis a little more complex, as evidenced by Bagloee and Asadi [24]. For this reason the projects are comparable in the base scenario. A highway may be preferable to the other in the initial conditions adopted but not at the end of its operation.

The great advantage of the model is the transferability to other cities or regions in Brazil. It happens because variables consider both national and local data, such as GDP and the number of formal jobs.

4.1. Quantitative Method. The model of this study proposes an evaluation of the road infrastructures of cargo transportation in Brazil that uses as base only quantitative variables. Some of these are presented in monetary terms and others are not, requiring an additional process of transformation. This measure is intended to consolidate the data and make it comparable.

According to [5] investments in new infrastructures can be of eight types, since the increasing demand of the route until the complete improvement of the inoperability of the transport networks. In a simplified procedure, the model considered only three types: (a) improvement, when the initial mileage of the highway is maintained; (b) expansion, when there is increase of the initial mileage and, (c) creation, when there is no initial highway infrastructure in place. Positive and negative impacts are generated for the involved parties, presented in vehicle per kilometer, for example, [16].

4.2. Stakeholders of the Model. It is critical to check who the stakeholders are in this process and what their particular interests are, as done by the National Cooperative Highway Research Program (NCHRP) [29]. Stakeholders are all those who, directly or indirectly, are affected by the development of a project or can contribute positively or negatively in it. Some interests are common to all and others are group-specific, such as the increase in municipal tax collection.

The 5 stages of the tool proposed by Bjugn and Casati [30] for stakeholders analysis are identification, assignment of values, prioritization, engagement plan of the participants, and monitoring. The developed model presents an adaptation, preserving the same logic. Initially, those involved are identified and then the main interests of each group are listed. The third step is to verify the influence exercised by the parts in the infrastructure project and finally to classify according to the degree of this influence. The classification is qualitative, based on the concepts of high, medium, and low. The last step is monitoring, which occurs through constant reevaluation in the course of the project.

The monitoring routine should occur at each critical phase of the project. Six milestones were identified for this routine: initial evaluation to execute the project, beginning of the project implementation, construction, project completion, and beginning of operation and periodically at each predefined period. Review periods should be between 2 and 5 years, at which time those involved may exhibit changes of interest or change the power of influence they perform, depending on the size of the project and the time frame of the project. For monitoring, all stakeholders should be reviewed in its entirety, by surveying the compliance and demand of the interests of the parts and field research with those directly involved.

Mapping all the stakeholders allows an analysis of the economy of the municipalities involved and the transformations that occurred during the period of construction of the road and after its completion. From this information it is possible to understand what the positive and negative impacts are, perceived in short and long terms, and how they modify the lives of those involved.

For [15] the impacted municipalities were divided into three groups: municipalities where goods embark/disembark, transit municipalities, and municipalities located in the area of influence. In the present model only two types are considered: those directly involved and those indirectly as well, since, in this way, it is possible to analyze all that receive some type of impact and to quantify them. This division is important because each one will have interests and will exercise distinct charges on the infrastructure.

The main gains of a model that considers the stakeholders in the process are the concern with all involved and the search

Table 1: Overview of the models (variables × authors).

Variables	Barfod and Salling 2015 [23]	Bagloee and Asadi 2015 [24]	Odoki et al. 2015 [7]	Rabello Quadros and Nassi 2015 [11]	Barfod and Leleur 2015 [6]	Campos 2015 [15]	Sartori et al. 2014 [5]	Nogués and González-González 2014 [18]	Sage et al. 2013 [4]	Kansas & North Carolina DOT 2013	Michigan DOT 2013	Indiana DOT 2013	Montana DOT 2013	MPPP tool 2013	Wang et al. 2013 [17]	Dewan et al. 2013	Yu and Liu 2012 [19]	Da Silva and Netto 2010 [13]	Guenther & Farkav-cová 2010	Sehn 2009 [12]	Litman 2002 [16]	Kerali 2000 [3]	McFarland et al. 1993 [2]	*Total*
Travel time	×	×	×		×		×	×	×				×	×	×	×					×	×	×	*14*
Environmental impact (air pollution)			×	×	×		×	×	×						×	×		×	×		×	×	×	*13*
Security			×		×		×		×					×			×				×	×	×	*9*
Operational costs			×		×		×		×					×	×							×	×	*8*
Economic impacts	×		×						×	×	×				×					×	×			*8*
Employment						×				×	×	×						×			×			*6*
Transportation cost				×									×			×					×	×		*5*
Household income						×		×		×	×										×			*5*
Construction and maintenance cost					×		×										×	×					×	*5*
Social impacts			×		×																×	×		*4*
Traffic volume		×					×	×									×							*4*
Quality																×					×	×		*3*
Energy efficiency			×																×			×		*3*
Noise pollution					×		×														×			*3*

Source. Author.

for the balance between them; that is to say, neither part can be harmed compared with another. In addition, equality between the three pillars of sustainability is still foreseen, ensuring that both economic, social, and environmental aspects must all be considered with the same degree of importance.

4.3. Variables. A solid study must consider as many variables as possible which adopt the three spheres intended. On the other hand, one must evaluate which are really relevant in order to avoid many variables, making it impossible to consolidate the equation. The division of variables follows the concept of sustainability for projects developments. The first deals with the economic impact that can be caused to stakeholders. The social variable refers to the way in which the population is directly affected and, finally, the environmental variable is related to the environment in which the projects are being developed.

The variables will have all the same relevance in the final equation, thus showing the importance given to each of the three groups through a horizontal model. The methods for estimating the variables are presented based on best market practices. The top-down approach uses the average of the national data, in a generic way.

4.3.1. Traffic Volume. The prediction of the demand is the variable of greater impact of the model and according to [4] it will mean the main direction of the project, since all the others will be influenced by it. For this reason the prediction must be made from a drive record, considering the matrices of origin-destination (OD matrices). This data will be generated for the first year of track operation and the following years will be projected from the accumulation of the annual growth rate.

The matrix is a quantitative technique widely used in transport engineering and also has application in diverse studies [31–33]. The tool allows knowing in depth the prediction of a route utilisation, facilitating both its dimensioning and diagnosis of the impacts as to highway deterioration and traffic jams, among others. The original matrix tool will not be drawn because it requires a lot of development time.

A table identifies the volumes transported and details the origin and destination of each cargo, that is, where they come from and where they are going to and at what time they cross the highway in question. Finally, the volume and the percentage of each OD absorbed by the highway are dimensioned. The expected result is the sum of the volume expected to travel in the alternative, that is to say, the multiplication of the percentage of each of these loads by the volumes which will be absorbed by this option. The volume is measured in trucks per year because the other variables are calculated in this unit. The measurement of a medium truck with three axles and 40 tons of capacity is used as reference.

4.3.2. Traffic Volume Growth Rate. To plan the behavior of the coming years, as done by Yu and Liu [19], the growth rate is used. For the authors, this criterion has social and environmental importance in the validation of an infrastructure improvement. Its growth is linked to the average GDP growth expected for the country, industrial and agricultural production, and population size [34]. The authors make a demand prediction from the traffic record in the region. The relation between tax rate and these factors is used because there is a direct proportion between the increase in GDP and the traffic on the highways.

In addition to the indicator used above, because it is a new highway, there is also a heating factor in which drivers usually give preference to the highway gradually. Three behavior scenarios are described: (1) highway emerges as a much better alternative than existing ones, either in road toll exemption or in better pavement conditions or with less traffic jam; (2) highway is a good alternative for transportation in the region and has good traffic and safety conditions; (3) highway has some more favorable conditions than other alternatives (good paving, signaling, and less traffic jam) and some less favorable conditions (road toll taxes or poor security). The scenarios will follow the additional growth rate [35] of 3.5%; 2.5%; and 1.5%, respectively. Thus, the final rate will correspond to the annual forecast of GDP added, in the first three years of operation, to the percentage referring to the highway scenario.

Another point which should be observed is that the tax rate will not grow infinitely because there is a saturation point, determined by the track capacity. This measure can vary according to several factors: number and width of the traffic lane, percentage of heavy vehicles, existence of roadside, bus stops, and number of entrances and exits, among others [36]. A visual indicator for saturation is traffic congestion on the highway, showing that its capacity has already been reached, especially at peak times.

4.3.3. Reduction in Travel Time. The reduction in the travel time of each vehicle is presented in minutes from the comparison with the available alternatives. When choosing the infrastructure under analysis it is intended to gain time in the course, since in some cases the goal is to improve the traffic flow and possible reductions in travel. The calculation is based on the congestion band, average speed, and distance traveled in the alternative in question against the average of the others, as shown in Table 2.

In order to assist in measuring the impact of traffic jams, the comparison between the highways is based on the classification of each one in the congestion bands, varying between 1 and 5 [26]. One lane in band 5 operates above its average vehicular traffic capacity, resulting in frequent traffic jams and a percentage reduction of the actual average speed. Alternative lanes with this feature are likely to transfer a significant portion of this volume, as drivers will give preference to avoid traffic jam and drive on less busy highways.

Index 4, when applicable, may also show a decrease in speed, since at peak times the perceived flux is greater than that supported. With the index being between 1 and 3, there is no impact on speed. Classification 5 represents a relationship between volume and capacity greater than 1, and index 4 occurs when this ratio is between 0.75 and 1.

Table 2: Alternatives comparative (travel time).

Alternatives	Congestion band	Average speed	Average distance	Reduction in time

Source. Authors.

Table 3: Alternatives comparative (operating costs).

Alternatives	Traffic flow	Pavement	Signaling

Source. Authors.

4.3.4. Reduction of Vehicle Operating Costs. The reduction in vehicle operating costs is one of the consequences of a more fluid traffic, since the new route will have less traffic jam, better quality of asphalt, and others. Costs are just variables because we want to understand the difference between alternatives, and fixed costs are inherent to the choice of route. According to the WSDOT model they include fuel and lubricant consumption, tyre consumption, and vehicle maintenance, totaling one value per kilometer [17]. Each vehicle has a manual with specifications for the optimal scenario.

The characteristics of the highway can maintain these values or make them worse. In traffic jams the consumption of fuel is greater and in a route poorly conserved there is greater tyre wear and more demanding of maintenance of the vehicle, for example. For [37] there are two classifications that differentiate the conditions of a highway: better and worse.

Reference [38] considers, in relation to urban transport, twenty-one quantitative and qualitative indicators to characterize urban road transport; among them are connectivity with the transportation network, traffic jam, average speed, track monitoring, pavement, and accident rate. Reference [39] uses as influence in the system traffic flow, pavement conditions, and signaling.

The qualitative method used in this study deals with the evaluation of subjective characteristics with complexity and high cost. The low credibility of this method occurs due to the judgment made by the evaluators, which may tend towards their objectives. On the other hand, by selecting the sample correctly, the opinion of the judges can bring a more up-to-date assessment to the problem in question. For this reason the qualitative method, when combined with the quantitative one, becomes more solid [40].

Table 3 shows the three criteria that should be evaluated: traffic flow, pavement, and signaling. The classification of each one of them will be compared to the alternative in question and follows a scale of five levels: terrible, poor, medium, good, and excellent: two positive rates, two negative ones, and one neutral [41]. Switching from a higher level to a lower level means an increase of 1.5% in the factor. There may be a recorded worsening of up to 6% in each criterion, since the change from the highest to the lowest level can be translated into four levels.

Considering the three conditions of the route a multiplicative factor is generated and has a maximum increase of 18% in the total operational cost. The percentage defined is based on Inmetro's research methodology for vehicular fuel consumption, which indicates that it is within a range of more or less 20% of that declared [42]. Considering that the behavior of the other criteria is equal, the maximum percentage of 18% acts on the total cost that considers the vehicle consumption. The larger this number is the worse the alternative is, which will increase the operating cost. The minimum factor is one, present in new highways with excellent conditions for the traffic.

The reduction will be calculated by comparing the highway with the average of all existing alternatives. This is why the factor is obtained from the difference between highways. The reduction of operating costs should be presented in *reais* per vehicle, multiplying variable cost, difference in multiplicative factor, and average difference of mileage traveled.

4.3.5. GDP. The Human Development Index (HDI) is not considered in this analysis because it is an interval between 0 and 1, nonmonetary, and its influence factors are income, education, and health. For this reason it is preferable to consider only the income through the GDP variable. The other index factors are not portrayed.

GDP is considered an important economic variable because the transportation of cargo is directly associated with the purchasing power of the region, since the transport of goods is larger in the area. The measurement is made based on the data before the development of the highway with the projection to the average of the municipalities involved. The difference between the years of analysis is then used.

4.3.6. ISSQN. The ISSQN tax also composes the model, clarifying the development of the companies activities in the municipalities involved. It is considered relevant because any contracted service originated in the municipality in question must pay it, being a relevant metric for the growth of economic activities in this locality.

Likewise as the previous criterion, the ISSQN is measured in the base year and in the year of the survey and then its difference is given. The tax is also projected according to GDP growth in the municipalities involved. The warmer the market, the higher the volume of taxes paid.

4.3.7. Fatal Accidents Reduction. Other data of great relevance for all involved in the project is reducing the number of fatal crashes, improving overall safety. This variable deals with the reduction when comparing the project in question with the other alternatives [6]. In order to measure it, safety aspects are raised, such as risks of collision with another vehicle or with road barriers, number of lanes, pavement conditions, landslides, and signaling, among others.

Table 4 consolidates the main factors based on highway improvements (Sinha & Hu 1985) APUD [43]. Assuming that the road analyzed will adopt all these maintenance tasks over time, the reduction factor totals 1.91, which means that practically only 2 accidents can be avoided for every one

Table 4: Accident reduction factors for highways.

Activity	Accident reduction factor or f_{AC}*
Increase in number of lanes (4 to 6)	0,95
Lane and shoulder widening	0,30
Resurfacing	0,33
Pavement maintenance	0,08
Shoulder maintenance	0,25

*Accidents per million vehicles per mile; source [43].

million vehicles per mile, or 1.19 accidents per kilometer. The evaluation of the indices should occur in the comparison between the option analyzed and the average of the other alternatives, being assigned the value of the difference between them. In cases where both highways are new and there is no accident history, the reduction is zero, considering that both will have good traffic conditions.

Thus, the reduction in the number of fatal accidents per year will be multiplied by the projected demand. In (1) the reduction factor (Δf_{AC}) must be multiplied by the difference mileage traveled and divided by 1 million, translated into accidents per vehicle.

$$AC = \frac{\Delta f_{AC} * \Delta \text{km}}{10^6}. \quad (1)$$

4.3.8. Number of Formal Jobs. The number of formal jobs assists in the quantification of social aspects. The inclusion of a new highway or the improvement of an existing one contributes to the installation of new industries and service companies in the region, increasing employability, since there are more opportunities and the dispute for employees tends to increase. For comparison, these data are used before the development of the highway and in the year in question, from the available database. The variable follows the percentage projection of the average GDP growth of the municipalities involved.

4.3.9. Reduction of CO_2 Emissions. The importance of quantifying CO_2 emissions is steadily increasing and takes a lot of space in current literature. Reference [44] analyzes the conflict between the time of travel and the emissions generated in road transport because not always the least travel time corresponds to lower atmospheric emissions.

For the calculation of greenhouse gas emissions, [45] is based on the three main gases (CO_2, N_2O, and CH_4) and compares what was emitted by the main airline companies in relation to the occupation rate of the aircraft. In addition, it considers different emission factors according to the distance traveled because the take-offs and landings have a larger amount of emissions. For road transport there are no great advantages in this segregation because the beginning and end of a travel do not mean a much larger volume.

On the other hand, [26] suggests a cost of air pollution in euros per vehicle-kilometer traveled for several types of vehicles, from cars to heavy trucks. The second division is by region of emission, varying from urban, suburban, countryside, and highway. The more the urbanization, the greater the cost, since the global concentration is higher and the dissipation factor is lower.

In this paper only the reduction of atmospheric emissions of CO_2 is considered. Other gases are also emitted by this mode of transport [46] but are not analyzed because they have an unimpressive percentage. As for the emission of CO_2 the main reason to consider it is because the road transportation mode is a large emitter. Some factors exert an influence: better traffic conditions, less traffic jams, increased collective transport, substitution for less emission modes (rail or waterway), substitution for less polluting fuels, and increase of fuel tariffs, among others [47, 48].

For the purposes of calculation the following are considered: the individual emission index of trucks per kilometer, the average mileage traveled (Δkm relative to the average difference of the alternatives), and the cost of the gas emitted in *reais* per ton. Adopting the premise that loaded trucks have a higher emission rate than the empty ones [49], 50% of the vehicles are given as loaded and 50% are not, since in a complete trip the vehicle leaves the destination full and returns empty.

The index adopted for the emission of the medium-sized diesel trucks loaded (f_C) is 2.75 kg/l, which represents approximately 0.77 kg/km [50]. The study presented by Bartholomeu and Caixeta Filho [37] shows a consumption varying from 2.37 kg/l to 2.07 kg/l, reducing up to 25% of the initial prediction, according to road and truck type conditions. The index of empty vehicles (f_V) is one-third full as the combined total weight of the structure revolves around this percentage. The reduction of these emissions has a direct impact on the air quality of the region and on the health of the population involved.

The importance of the fleet's age to calculate the emissions cannot be denied [46], since the older the vehicle, the higher the CO_2 rates. In this study this characteristic will not be taken into account because it is not possible to predict what fleet will be running. In addition, for the purposes of comparison between highways, the age is the same.

The cost of carbon dioxide (C_{CO2}) emitted is the same for all emission sources, whether it is air transport, industrial activity, or energy sector [51, 52]. Factors that change this cost refer to the country of origin of the emission, the place that receives it, and the situation of the carbon credit market. The value of the ton is dynamic and its variation can be broad depending mainly on political issues and environmental agreements to mitigate them, since they are negotiated between companies. The *cap and trade* variation is large and should be evaluated at the time of the study on BOVESPA. Equation (2) summarizes this cost.

$$\text{CO2} = \left(0{,}5 * f_C + 0{,}5 * f_V\right) * \Delta\text{km} * C_{\text{CO2}}. \quad (2)$$

4.3.10. Variables Consolidation. Of the variables mentioned, three are responsible for the cost of the highway to users: reduction of travel time, vehicle operating costs, and the number of accidents. If there is no regular maintenance on the roads, the tendency is for this number to increase [3].

In the application of the model not always all the variables are available and, therefore, in cases of comparison between projects, they should be considered. All of them present a positive expected signal for the equation, adding up to the evaluation value of an infrastructure project. The positive sign means that the larger the variable, the better for the project. The variables that predict a reduction of value, if this reduction is not effective, their signal must be inverted. The same happens when the variable foresees a growth and in practice there is reduction of its value, as the increase of the number of jobs.

4.4. Monetarization of Variables. The conversion of the variables into a single measure is important to enable a comparison between the routes. Reference [17] transforms all: value of time traveled, operational cost, and the cost of atmospheric emissions. Monetization must occur when the variable is measured in a separate unit. The technique is used for a variety of issues, including environmental issues such as the emission of greenhouse gases in air transport and the impact of forest fires [45, 53]. Travel time, number of fatal accidents, and number of jobs are monetarized.

The calculation of the time value, according to [6], considers some factors such as reason for travel, total distance, mode of transport, urban traffic conditions, trip time, driver's wage, and traffic jam, among others. For the sake of simplicity, this study will consider the trip to work of a driver and a helper of a freight company. The salary of the employees of the region serves as basis for the calculation of the minute worked.

Then the employee's cost is multiplied by the time saved by choosing the infrastructure under analysis. Reduced travel time, in minutes, is based on the average of available options.

In order to transform the reduction in the number of fatal accidents in the route into monetary values, the reduction factor, measured by the comparison between the alternative and the average of the others, is multiplied by the statistical value of life or *value of statistical life* (VSL) [26]. It considers both direct and indirect costs and it is based on the social cost attributed to life in the region analyzed. The value is not constant and varies according to some factors, reflecting risk characteristics and the local population.

Increasing the number of people employed impacts positively on the local economy. To measure it social indicators are designed. Through the difference in the number of employed people, it is multiplied by the current average per capita GDP of the municipalities involved, reaching a monetary increase to the region. GDP is known from the real values for the year of operation. It then multiplies by the growth rate accumulated in the years of analysis.

4.5. Tim Model. In order to facilitate the analysis of a road transport infrastructure project, the model will have as output the number of vehicles that travel in the route in relation to the other variables. The final value will be in *reais* per vehicle, making the comparison of the initial investment fair, since a more expensive project can carry greater traffic. From this relation an alternative will be preferable when compared to the other. The analysis is done individually with the purpose of identifying the monetary return, being able to generate a ranking from the consolidation of several options.

Some municipalities are directly affected by the transportation infrastructure and others indirectly affected. This identifies the radius of influence of the highway. The analysis takes place for the year of future projection of the impacts and the identification of what was generated by the project. The variables participate in the final equation considering only the municipalities directly affected.

Equation (3) consolidates the Transportation Infrastructure Model (TIM) by assessing the reality of the traffic at the proposed time. The consolidation of sustainable benefits is divided into three blocks, as proposed by Odoki et al. [7]. The first deals with economic aspects, the second deals with social aspects, and the last deals with environmental aspects. The final equation subtracts the initial investments and multiplies the three blocks by demand and accumulated growth rate until the period.

The equation has as reference the time and all the data are predicted for the project at the moment. What is important is that all infrastructures in comparison deal with the same time horizon, seeking to assist in the decision making process when making the choice for an option.

The distance to be traveled on the highway is considered in operating costs and atmospheric emissions, which are values influenced by mileage. Different weights will not be assigned to the variables because all the criteria are in the same degree of importance for the final equation.

$$\text{TIM}_{AT} = \frac{-I + (D * R) * [(T + C + \text{PIB}/(D * R) + \text{ISS}/(D * R)) + (\text{AC} + \text{EMP}/(D * R)) + (\text{CO2})]}{(D * R)}, \quad (3)$$

where

A is project under analysis,

T is project analysis year A,

I is investment in new infrastructure,

D is demand forecast,

R is annual cumulative growth rate of traffic up to the year being evaluated,

T is reduction of travel time cost,

C is reduction of operating costs,

GDP is GDP growth,

ISS is ISSQN growth,

AC is reduction of accidents,

EMP is increase in the number of jobs in the municipalities involved,

CO2 is reduction of carbon dioxide (CO_2) emissions.

The developed model was applied in a study case of Arco Metropolitano do Rio de Janeiro. This road project was developed in 2007 and inaugurated in 2014 in the state of Rio de Janeiro, Brazil. The main objective was to create an alternative route to flow the production to the Itaguaí Port.

The model is innovative from the point of view of evaluation of road transport infrastructure projects because it considers the three spheres of sustainability in a single analysis and allows the ranking of projects that are competing. In this way, it is possible to make decisions regarding the priority investment for the benefit of the country, enabling a broader improvement. The final value found is intended to be comparative and will have significance when compared to other values presented by other judged projects. The preferred alternative will yield better results and the bigger the option the better.

5. Conclusions and Discussion

This paper presents a quantitative model for evaluating road transport infrastructure projects with the objective of being transparent and helping decision making when it comes to the choice between investments. The project under analysis may be new, expanded or improved, depending on the difference between the initial and the final mileage. As already predicted in the study of [37] a trip on a highway with better conditions of maintenance presents greater environmental benefits than the same trip made in precarious conditions.

The model is synthesized by the equation involving ten variables, separating them into the three sustainable spheres: social, economic, and environmental. It is possible to consolidate a comparative table between the alternatives and generate the ranking of benefits in monetary value per truck projected for the future highway, which may be in the thirtieth year of operation and when compared to other projects may mean its feasibility or not. The more positive the final number, the more feasible the alternative.

Regarding the variables raised in the referential framework, no model adopts all the same variables and the four most relevant ones being considered in this study are travel time, atmospheric emissions, number of accidents, and operating costs. Two variables are present in only one reference model: annual traffic growth rate and the municipal tax, ISSQN.

The TIM model contributes to the development of research in this segment because it is innovative in considering the three spheres of sustainability together to evaluate future road transport projects and assist in decision making by the competent administration. The final value obtained allows ranking alternatives, whether they are competing or not, justifying the choice. The higher the value, the more the priority of the highway for all stakeholders.

The data obtained in this model also allow a secondary analysis, referring to the percentage of reduction that can be perceived in the global value of the products freight costs. This calculation is done with reference to the travel time variables and the vehicle operating costs since the freight is calculated as a function of these. In some cases, the influence can also occur due to the safety of the track, for example.

For the development of future work it is recommended to include qualitative variables in the environmental and social area, ensuring a greater participation of these two spheres. Air quality, for example, may be an option to measure the environmental impact of a new transport infrastructure. In addition, the perception and feelings of the local residents regarding the enterprise can be captured through the social impact variable.

In order to improve the tool developed it is suggested to evaluate scenarios for expected demand considering optimistic and pessimistic projections. In this way it is possible to reevaluate whether the project remains advisable throughout the period of operation.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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