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Geographical modeling for the simulation of soybean transport costs in logistic basins

Modelagem geográfica para a simulação de custos de transporte de soja em bacias logísticas

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Submitted:
30 September, 2021
Accepted for publication:
23 January, 2023
Published:
3 May, 2023

Editor in charge:
Marcio de Almeida D'Agosto

Keywords:
Transportation.
Soybean.
Geotechnologies.
Simulation.

Palavras-chave:
Transporte.
Soja.
Geotecnologias.
Simulação.

DOI: 10.58922/transportes.v31i1.2700

ABSTRACT
Soybean freight, a commodity whose exportation accounts for 14% of national volume, corresponds to 80% of the total transportation cost. The attenuation of transportation costs is foreseen in the Brazilian National Logistics Plan 2025 through investments in critical transportation infrastructures. Notwithstanding, the methods used to support and justify the assets are unclear. This work addresses an investigation focusing on soybean routes between producer municipalities and the main exportation ports using geotechnologies and geospatial simulation for predictive scenarios. The research relied on official public data considering the infrastructure of 2020 and 2025 to create a multi-modal, multi-origin, and multi-destination model developed on an open-source platform and covered the entire conterminous national territory. The results qualify and quantify the reduction in the cost of transporting soybeans. Findings show a 10% average cost reduction between the two simulated scenarios. Furthermore, along with 79 producing municipalities analyzed, we found a 19% chance of considering re-routing destinations to different ports for the 2020 and 2025 scenarios. Of this total change, 73% are from municipalities that now have the port of Santarém-PA, indicating not only the importance of the projects but also the changes in the regions of influence of the ports with the inclusion of new transport routes. The study benefits society not only for the transparency of the data but also for anticipating scenarios that can support public policies.

RESUMO
O custo de frete da soja, commodity que responde por 14% da exportação nacional, corresponde a 80% do custo total de seu transporte. Redução dos custos logísticos são previstas no Plano Nacional de Logística 2025 através de investimentos nas infraestruturas de transporte, cdo, os métodos utilizados para dar suporte e justificar os investimentos não são claros. Este trabalho investiga as rotas de exportação de soja entre os municípios produtores e os principais portos de destino utilizando geotecnologias e simulação para cenários preditivos. A pesquisa abrangeu todo o território nacional e foi alimentada por dados públicos oficiais considera a infraestrutura de 2020 e 2025 na criação de um modelo multimodal, multiorigem e multidestino desesultados qualificam e quantificam a redução do custo do transporte da soja. A média de redução no custo foi de 10% entre os 2 cenários simulados. Nos 79 municípios produtores analisados, houve uma alteração em 19% deles considerando os portos de destino para os cenários de 2020 e 2025. Dessa alteração total, 73% são de municípios que passaram a ter como rota de destino o porto de Santarém-PA, indicando não somente a

importância dos projetos como também as alterações das regiões de influência dos portos com a inclusão de novas rotas de transporte. O estudo beneficia a sociedade, não apenas pela transparência dos dados, mas também por antecipar cenários que podem subsidiar políticas públicas.

1. INTRODUCTION

Other than Brazil, the leading countries in the world's soy production are the United States and Argentina. China is the main driver for the increase in exports. As highlighted in the report Oilseeds: “World Markets and Trade released by the United States Department of Agriculture (USDA) for the 2020/2021 soybean crop”, the global production of oilseeds is estimated at approximately 610 million tons. In a publication released in 2018, specialists from the Brazilian Agricultural Research Corporation (Embrapa) indicated that the world's demand for soybeans in 2050 will be twice as high as it is today (Embrapa, 2018a). Brazil can benefit from a booming trade through investments in research and infrastructure improvement, therefore preparing to face the main challenges in producing this important crop. Along with these production challenges, there is also the increasing concentration of soybean and corn production in the North, Midwest, and Northeast regions, which has created store and transport difficulties by increasing freight costs and, consequently, decreasing competitiveness with grains originating in other countries (Lemos et al., 2017). As an example of the challenge, most soy-producing municipalities, including those with the highest production, are also the farthest locations from large consumer centers and ports (Figure 1).

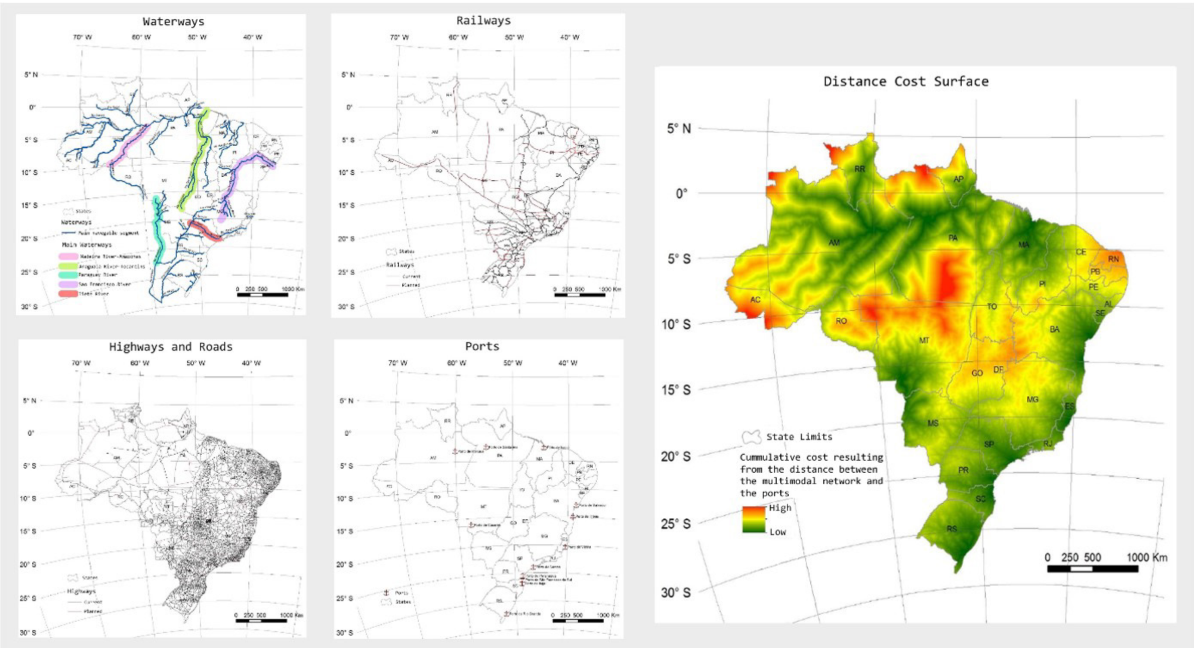

Figure 1. Factors contributing to low competitiveness and the rise in Brazil's transportation cost (Costa, 2013)

Transport systems, including those involving intermodal flows, have been increasingly studied. However, transportation planning lacks more critical studies and diagnoses involving the geographic context in macro-logistics analyses and simulations. Thus, it is essential to understand the space from two different perspectives: the producing and consuming regions, where specific loads can characterize the logistic basins (geographical delimitation of the regions of origin and destination of the loads, considering the ports of influence). For example, the geographic analyzes of agricultural macro-logistics basins in Brazil indicate a strong dependence on ports in the southeast and southern regions, which are located far from large production centers, increasing the cost of logistics and, consequently, the Brazilian agricultural product (Castro et al., 2019; Costa, 2013). In addition, the authors reported difficulty in accessing the riverport terminals in Brazilian Amazon North Arc, where there is potential for expanding export capacity.

The 2025 National Logistics Plan's executive report, released in 2018, foresees investments in highways, railways, sabotage, and waterways for further reducing the cargo transporting cost in the country. Shorter and more timely routes can trigger economic benefits to the profitability of Brazilian agricultural production. However, to find the optimal solutions, it is necessary to analyze the reality of the Brazilian logistics infrastructure. Determining the operating capacity of the modes of transport and their interconnections is fundamental to guaranteeing production flow within the defined period. Note that this is a highly complex operation due to the prerogative of being unable to negatively impact the turnaround management of the agricultural logistics system and increase final costs.

Some researchers have resorted to applying and using the Geographic Information System to assess the logistical and infrastructure problems. This system is beneficial for analysis and decision-making in Public Policies for the Transport Sector to improve the infrastructure of transport modes and the flow of products in the search for more efficient solutions and the interconnection of modes to a multi-modal structure (Borba and Silva, 2010).

The primary objective of this investigation is to identify, quantify and simulate the soybean export routes to the largest soybean producer municipalities and the main ports of destination in Brazil using geospatial analysis. The investigation considered the current logistic infrastructure (the reference year 2020) and the infrastructure proposed in the National Logistics Plan (the reference year 2025). The proposed analysis method comprises the use of GIS (Geographic Information System) technology in conjunction with simulation and modeling tools to calculate and illustrate the cost of transportation in predictive scenarios.

Two key questions motivated the investigation: (i) will the implementation of the PNL 2025 reduce the cost of soybeans transportation originating in the top municipalities' producer in Brazil? (ii) In comparison to the current transportation scenario, how will the infrastructure of the PNL 2025 modify the macro-logistic basins for the soybean outflow routes?

The study provides greater visibility in the strategic planning of future investments related to logistics infrastructure in Brazil, contributing to economic growth in a sustainable manner and allowing better distribution and supply of products with more competitive prices given current policies, reducing uncertainties about possible impacts of new projects.

2. BACKGROUND

For the last 25 years, soy is the reference commodity in Brazilian agricultural production. The state of Mato Grosso in the central-west region is the largest grain producer (35.9 million tons), followed by the southern states of Paraná and Rio Grande do Sul, respectively (Comex Stat, 2021). The 2021 Bulletin for Monitoring the Brazilian Grain Harvest, released by the National Supply Company (Conab, 2021), estimates 135.54 million tons of soybean production for 2020/21, an increase of 8.6% compared to the previous harvest, which was 124.85 million tons.

Soy also significantly represents the Brazilian most exported agricultural product. In 2020 it was the leading national export cargo, with China as the main destination (Comex Stat, 2021). More than one mode of transport is generally used to transport soybeans and corn from the origin (farms) to the final destination in Brazil (ports). As expected, intermodal transport occurs when cargo is moved using two or more transport modes. The better application and use of network infrastructure, the reduction of the total cost, and lower energy and traffic consumption are among the main advantages of intermodality (Silva and Marujo, 2012). However, according to Embrapa (2020), when considering the arrival at ports exclusively, the distribution of the transport matrix shows different behavior. Embrapa (2020) indicated that around 47% of grains (corn and soy) arrive at ports by rail, 42% via highways, and 11% using waterways.

The states of São Paulo, Bahia, Paraná, and Rio Grande do Sul have well-defined routes for the export of soy, a factor that can be explained due to the port infrastructure, as the south and southeast regions concentrate most of the Brazilian grain exporters' ports. However, in the center-west states such as Goiás, Mato Grosso do Sul, and in special Mato Grosso, identifying feasible alternatives to the flow of products through different routes seeking competitiveness in the scenarios of internal and external logistics is still an open game (Dassan et al., 2016). The federal government made investments in the search for conditioning transport through ports in the northern Brazil region, such as the Port of Itaqui and the Grain Terminal -Tegram.

The diagnosis of the Ministry of Transport, Ports and Civil Aviation released (MTPA, 2017) found that logistical costs significantly impact grain commodities' competitiveness since agricultural products have low added value and are transported primarily on large volumes. Thus, the rational use of transport modes, such as transferring road transport to other modes, would reduce logistical costs and increase the competitiveness of products against international competitors. The transport cost for a route is linked to several reasons, among them the type of transport equipment. This structure pays for transport inputs separated into the fixed cost (the cost that does not depend on the use of the asset), variable cost (the cost that depends on the use of the active), and the operational productivity of the route. According to Kussano and Batalha (2012), in the composition of transport costs, the freight cost is the most representative and corresponds to approximately 80% of the total transport cost.

The National Logistics Plan (PNL) points out the mandatory undertakings and investments for the optimization of the infrastructure until the year 2025. The PNL aims to develop a methodology capable of providing actions involving all modes of transport, generating improvements in the efficiency of the transport matrix, and reducing logistical costs and pollutant emissions.

According to the 2018 Executive Report of the Planning and Logistics Company (EPL, 2018), it is expected to have 3.200 kilometers of new infrastructure foreseen "PNL 2025 Scenario" from the program Avançar Parcerias Program. The EF-151 Railway North-South (FNS), EF- 170vFerrogrão Railway, and EF-334 West-East Integration Railway (FIOL) are among the railroads. The FNS was planned to be the backbone, strategically interconnecting the Brazilian territory and contributing to reducing the logistical cost of cargo transportation. The business model was orchestrated by the Investment Partnerships Program (PPI) of the Ministry of Economy and involved the concession of the stretch with a length of 1,537 km, connecting Estrela d'Oeste in the stare os Sao Paulo up north to Porto Nacional in the state of Tocantins (MAPA, 2020).

Moreover, the Ministry of Transport, Ports and Civil Aviation highlights that with the completion of all railroad sections, the connection of the FNS to the Carajás Railroad in Açailândia in the state of Maranhão will enable access to the Atlantic Ocean via Port of Itaqui in the same state. The connection will also allow connection to the Port of Barcarena in the state of Pará (MTPA, 2017). In the southern region, the FNS will connect to the Malha Paulista Railway in Estrela d'Oeste, the state of São Paulo, allowing access to the Port of Santos in the same state. Consideration was also given to expanding the capacities of the railroads and networks of the Estrada de Ferro Vitória a Minas, MRS Logística, Ferrovia Centro-Atlântica, Rumo Malha Paulista and Estrada de Ferro Carajás.

As for road projects, approximately 7,800 kilometers of road works in the Avançar Program were evaluated, involving duplication, construction, and rehabilitation. Concerning infrastructure in the supply of maritime cabotage, investments aim to provide and enhance rail and road access to ports and terminals along the entire Brazilian coast. Also, in the assumptions inserted for the "2025 PNL Scenario," the possibility was foreseen for all Brazilian ports to be used for maritime cabotage navigation, including those that currently do not carry out this operation.

Investigations such as Lopes, Lima and Ferreira (2016) and Silva and Marujo (2012) present and analyze the optimization of intermodal models for the flow of soybean production. Investigations such as Silva and D'Agosto (2013) modeling estimations of the origin-destination matrix of the production-export chain of this commodity in Brazil. However, although they are inserted in the geographic context, these investigations are based on the scope of the logistic optimization of the process.

Regarding the geographic information system (GIS) applied to transport planning in Brazil, particularly for agricultural products, several studies were prepared by Embrapa, among which the determination of the macro logistics basins stands out. The logistic basin is the grouping of municipalities in which production flows preferentially through the same routes, modes of transport, and destinations (Embrapa, 2018b). Using georeferencing tools to assess the origin/destination flow of soy and corn production, classifications and mappings were established for the determined logistic basins. The delimitation of logistic basins is influenced by conditions such as freight costs, making it flexible (Costa, 2013). Other elements, such as changes related to production variation, road improvement works, or new modes of transport, also modify the basins.

GIS tools have developed capabilities to geoprocessing data and produce information. Geoprocessing, in the explanation of Câmara and Davis (2001), refers to the use of mathematical and computational techniques for the processing of geographic information, being increasingly used in the areas of Defense, Transport, Communications, Energy, and Planning, among others. It allows complex evaluations, integrating information from various sources and building georeferenced databases. It also makes it possible to automate the preparation of cartographic documents.

A GIS model can offer great potential for supporting decision-making processes in large territories such as Brazil, especially when evaluating low-cost technologies. The application of the GIS is strategic in transport planning and management, mainly when it covers large territorial extensions due to the various opportunities to explore geographic relationships and the use of the information system within the scope of activities in the logistics chain (Borba and Silva, 2010). Also, studies of geographic intelligence applied to the technical, economic, and environmental feasibility of rail and road corridors used geographic modeling to develop scenarios and alternatives to support decision-making such as Nobrega et al. (2016) and Araujo et al. (2015). Location optimization studies such as Souza et al. (2020) and Souza (2019) integrate classic spatial decision-making techniques in matrix architecture, such as the Hierarchical Analytical Process (AHP) with location-allocation methods based on topological network analysis of vector architecture, demonstrating the versatility of geoprocessing to meet to demands, many of them still latent, of transport planning and management.

3. MATERIALS AND METHODS

This research integrates GIS technology coupled with simulation and modeling tools. The GIS method was used in the first phase to select and prepare the infrastructure maps and those referring to the main agricultural production areas and ports. These maps then served as premises for modeling and simulation in the Dinamica EGO tool, together with the input variables of freight costs by mode of transport. Then, simulations of the scenarios of transport routes and logistics basins were done, one considering the current transport infrastructure (2020) and the other with the PNL database (2025).

3.1. Presentation and data preparation

The georeferenced maps of the Brazilian logistics infrastructure (waterways, cabotage, highways, railways, ports, and cargo transshipment terminals) were gathered from the EPL database and the Brazilian Ministry of Infrastructure. We selected data referring to the infrastructure scenario for the years 2020 and 2025., with already includes the new infrastructure foreseen in the PNL 2025. First, the selection of soy-producing municipalities in 2020 was carried out using the database extracted from the Comex Stat platform of the Brazilian foreign trade data system. Then, we classified the data using Pareto analysis or ABC curve to prioritize the leading producers. Of the total of 342 municipalities, 79 were included in the study, representing 90.09% of the total number of municipalities producing soy extracted from the Comex Stat base.

For geoprocessing, the base of these municipalities was correlated with the geographical codes (geocodes) of the municipal seats provided by the IBGE (Brazilian Institute of Geography and Statistics). The information was extracted from the 2020 soy export database of the Comex Stat platform for the ports. The ports were ranked by the volume of agricultural grain received in tons from all the Brazilian municipalities. Thus, those ports that received a total annual cargo above 1 million tons were selected, resulting in 10 ports.

As support for calculating logistical costs for the predetermined routes and for each mode of transport, the Transport Cost Simulator developed by EPL was used, obtaining the average cost per kilometer in reais/ton for the soybean load and for each mode carriage. The EPL simulator is an official basis used by the Brazilian government for the calculation of agricultural transport projects, considering in the calculation methodology the coefficients of the minimum floors for the cargo transport service under the publication of the regulated freight table by National Land Transport Agency (ANTT, 2022). This tool is available for public access at https://ontl.epl.gov.br/aplicacoes/simulador-de-custo-de-transporte/. Table 1 shows the summary of data selection in terms of format and source.

Table 1: Model's input data, data format, and source. Source: Authers, 2021

Model Input VariableModel Input Variabless	ForFormatmat	SourSourcece
Freight Cost	Table	EPL
Railway, roadway, and waterway transport modes	Vector	EPL and the Ministry of Infrastructure
Transshipment terminals	Vector	EPL
Soy Exporting Ports	Table and vector	Comex Stat
Soybean Producing Municipalities	Table and vector	Comex Stat

Once the data were selected, they were loaded into the free QGIS platform for pre-processing and standardization. The Albers equal-area conic cartographic projection was used as a spatial reference, as it provides a representation that minimizes the deformation of areas and maintains parity in proportion to the accurate area. All data that integrated the geographic layers of the model were projected for the pattern mentioned above.

The selected vector maps were converted to a raster format, which is represented by rows (horizontal) and columns (vertical) of cells (pixels) in a matrix structure. The pixel represents a geographic region, and the value assigned to it establishes an attribute of that region. A spatial resolution of 1,000 meters per pixel was used. The choice of this spatial resolution meets the representations of the modes of transport used (railway, highway, and waterway), considering the geographic amplitude of the study area that covers the entire country.

The choice for raster format files was due to the better representation of the phenomena that vary continuously in space and also because of the compatibility with the matrix-based architecture of the modeling platform used. The calculations performed during the spatial analysis stage that precedes modeling can only be performed with matrix files (map algebra). The geographic data processing used the free platform Dinamica EGO (Environment for Geoprocessing Objects). Dinamica EGO is based on landscape modeling and is based on input geospatial data, including time series, resulting in landscape maps and tables, for each time step, including maps of transition probabilities and dynamic variables (Soares-Filho, 1998). It has a graphical and modular modeling interface that provides benefits for its flexibility, simplicity, and speed in programming.

3.2. Characterization of the evaluated scenarios

The scenarios defined in this study comprise the entire Brazilian national territory, considering soy export routes. The approach is divided into two main simulations, presented below and illustrated in Figure 2:

1) Current infrastructure scenario: this is the “2020 Basic Network Scenario” composed of the georeferenced network present in the year 2020 (Figure 2a). The network contains road, waterway (river and maritime), and rail infrastructure elements from the EPL database;
2) Planned infrastructure scenario: the “PNL 2025 Scenario” considers the current infrastructure and the infrastructure projects estimated to be completed and in operation by the year 2025 according to PNL 2025 database (Figure 2b).

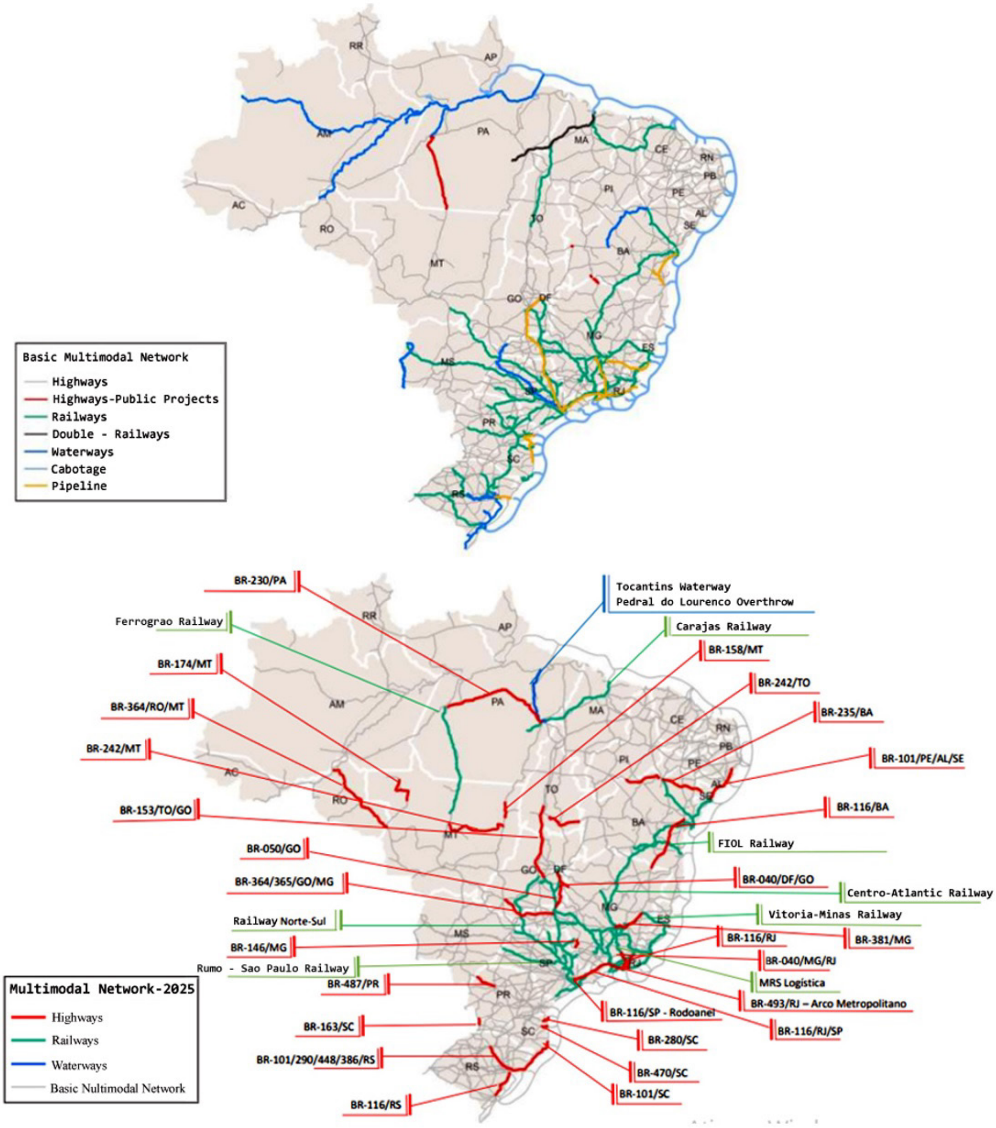

Figure 2. Operational multi-modal network in 2020 (a) and multi-modal network with interventions proposed in the National Logistics Plan for operation for 2025 (b) that were used in the model. Source: EPL (2021)

3.3. Description of the model

The model is composed of three processes: the first refers to data input and the preparation of model variables, the second refers to the calculation of the cost surface between the points of origin and destination on the multi-modal mesh, and the third refers to the determination of lower cost transportation alternatives and consecutive mapping of routes. Figure 3 illustrates the commented flowchart of the processes.

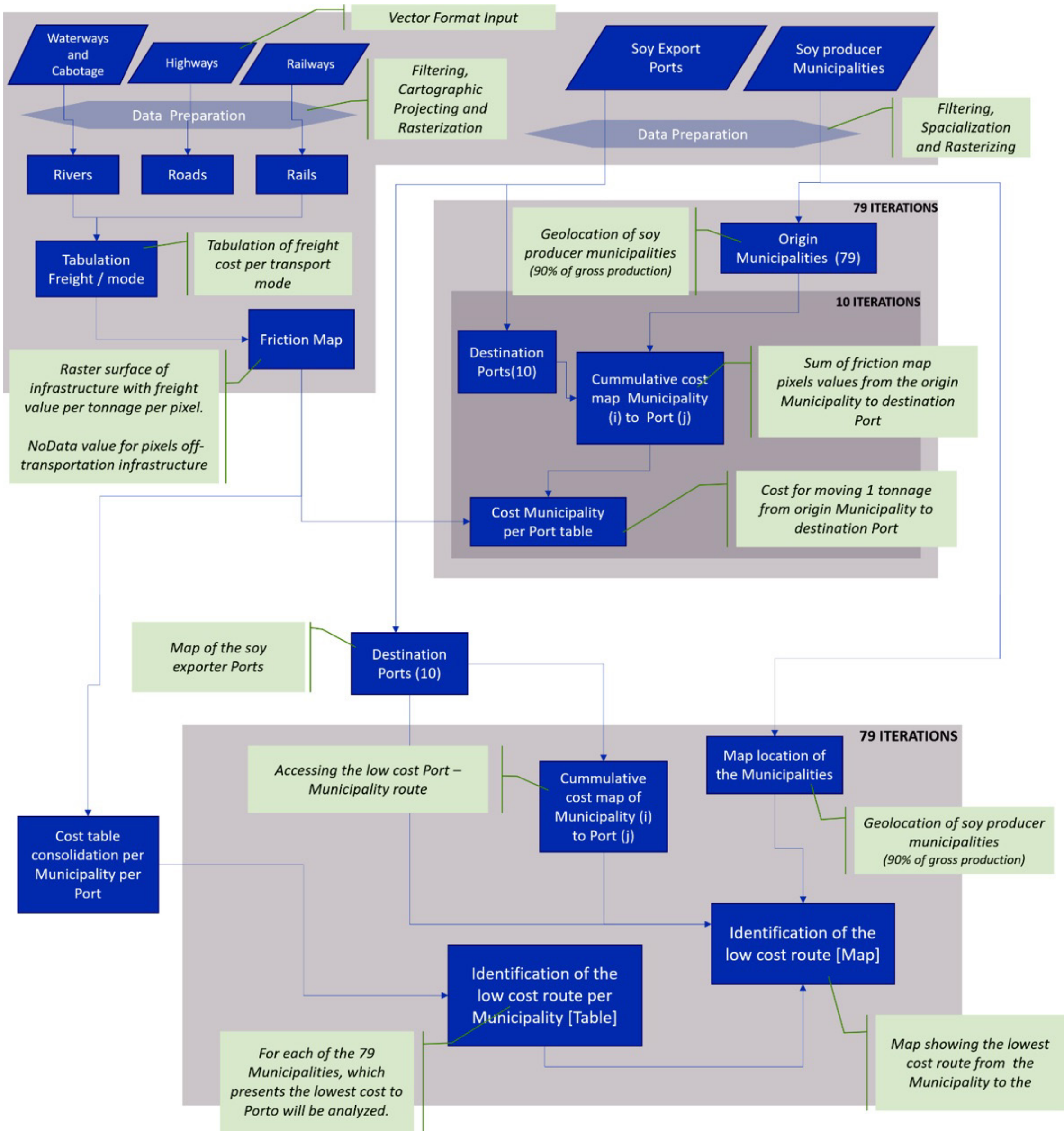

Figure 3. General flowchart of model processes with comments

The solution was developed from vector inputs such as the list of origin (soybean producer municipalities) and destination points (exporting ports), a map of the road, rail, and waterway network, and tabular information on the values of freight. The alternative routes connecting each point of origin to the different destination points were computed, quantifying the corresponding freight values for each alternative and mapping the wheels with the lowest value. The geoprocessing solution operates in matrix architecture and appears as an alternative to methods based on network topology in vector data. However, this article does not delineate comparative analyzes between different methods, but rather the development of a transparent and easy-to-understand method to graphically and metrically explore the future scenarios presented by the federal government and test whether the hypothesis of reducing the cost of transportation can be satisfied.

4. RESULTS

The cumulative cost is computed by considering the logistic infrastructure available for exporting soybeans from the origin to the port. Therefore, it is possible to visualize the regions with the impact of low or high transportation costs to the destination port. For example, Figure 4 illustrates the cumulative freight cost map for the Port of Itaqui, located in the state of Maranhão for both scenarios, the transport infrastructure for 2020 (left side) and the same port with the infrastructure for 2025 (right side).

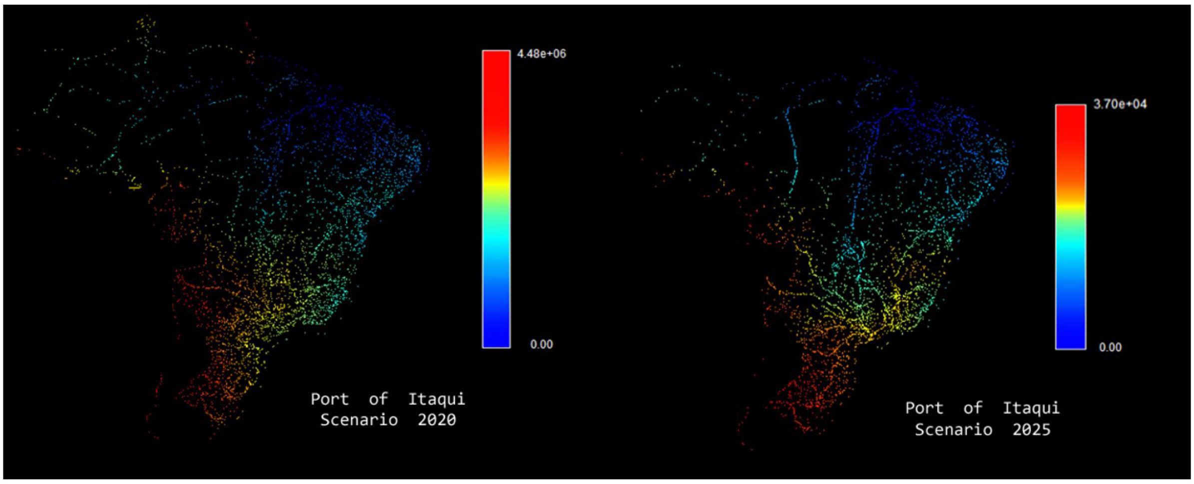

Figure 4. Thematic map of the prioritized transportation network computed for the port of Itaqui-MA

The unit in the map is the transport cost (accumulated cost in tons/km), with red tones corresponding to more expensive stretches and blue tones corresponding to cheaper stretches. The maps illustrate the cumulative cost of transporting a tonnage of soybeans from different sources to the port of Itaqui-MA. Changes are noted with the reduced cost in 2025 compared to 2020 when the regions corresponding to the FNS and Ferrogrão railways are verified.

The friction maps (also known in the literature as cost or effort surfaces) generated by the model indicate the value of freight per kilometer. It should be noted that it is from the friction map that the accumulated cost map is obtained. In the accumulated cost, these values are also added considering all the 10 selected ports, which resulted in different scenarios, justifying the national scope of the study. Figure 5 shows the results for the infrastructure 2020 scenario (on the left) and 2025 scenario (on the right), indicating the points with Brazil's highest cost of transporting soybeans.

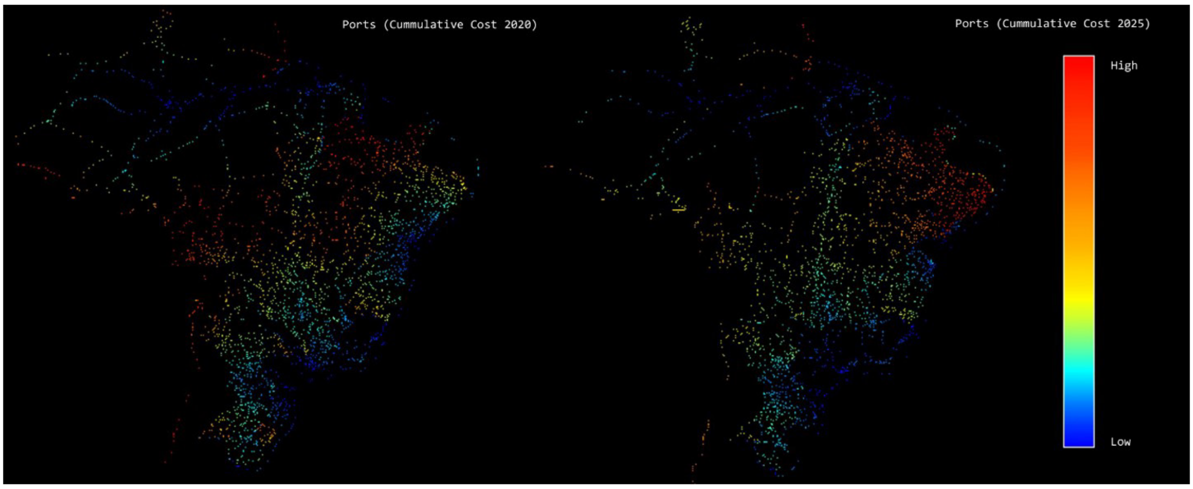

Figure 5. Transportation cumulated cost map used to identify soy logistics macro-basins combining road, rail, and road modes for 2020 and 2025

The accumulated transport cost map of the main soybean-producing municipalities was calculated up to the ports, obtaining the route with the lowest cost. Then, in evaluating the infrastructure scenarios for 2020 and 2025, Table 2 presented the values specified for each origin (municipality) to destination (port), using as a reference the average cost per km in R$/ton indicated by EPL. In some cases, the origin and destination can belong to the same region, leading to lower cumulative freight costs than other results.

Table 2: Cumulative transportation cost from the municipalities with the highest soybean production (90% of national production) to the 10 top ports listed by the EPL as calculated by the model based on the least cost routes. Source: The authors

MunMunicipalityi	State	Geodoce	Least Cost 2020	Destination Port 2020	Least Cost 2025	Destination Port 2025	Variation
Sinop	MT	5107909	R$ 16,686.33	Santarém	R$ 8,709.31	Santarém	-47.8%
Matupá	MT	5105606	R$ 13,399.49	Santarém	R$ 7,034.63	Santarém	-47.5%
Santa Carmem	MT	5107248	R$ 17,246.01	Santarém	R$ 9,268.98	Santarém	-46.3%
Sorriso	MT	5107925	R$ 18,038.43	Santarém	R$ 10,054.40	Santarém	-44.3%
Ipiranga do Norte	MT	5104526	R$ 18,947.76	Santarém	R$ 10,970.74	Santarém	-42.1%
Lucas do Rio Verde	MT	5105259	R$ 19,050.82	Santarém	R$ 11,073.80	Santarém	-41.9%
Nova Ubiratã	MT	5106240	R$ 19,287.90	Santarém	R$ 11,388.50	Santarém	-41.0%
Santa Rita do Trivelato	MT	5107768	R$ 18,687.47	Santos	R$ 12,889.50	Santarém	-31.0%
Bom Jesus	PI	2201903	R$ 13,702.06	Salvador	R$ 9,529.87	Salvador	-30.4%
Nova Mutum	MT	5106224	R$ 17,571.28	Santos	R$ 12,591.69	Santarém	-28.3%
Rio Verde	GO	5218805	R$ 10,747.70	Santos	R$ 7,762.42	Santos	-27.8%
Correntina	BA	2909307	R$ 11,897.52	Salvador	R$ 9,221.82	Salvador	-22.5%
Barreiras	BA	2903201	R$ 12,300.76	Salvador	R$ 9,952.01	Salvador	-19.1%
Jataí	GO	5211909	R$ 11,060.07	Santos	R$ 8,949.76	Santos	-19.1%
Luís Eduardo Magalhães	BA	2919553	R$ 13,707.61	Itaqui	R$ 11,326.77	Salvador	-17.4%
Confresa	MT	5103353	R$ 17,327.92	Itaqui	R$ 14,321.61	Santarém	-17.3%
Itiquira	MT	5104609	R$ 12,739.15	Santos	R$ 10,648.19	Santos	-16.4%
Campo Novo do Parecis	MT	5102637	R$ 19,815.50	Santos	R$ 16,697.93	Santarém	-15.7%
Santana do Araguaia	PA	1506708	R$ 13,472.94	Itaqui	R$ 11,359.94	Belém/Barcarena	-15.7%
Formosa do Rio Preto	BA	2911105	R$ 14,485.76	Salvador	R$ 12,249.80	Salvador	-15.4%
Cristalina	GO	5206206	R$ 9,329.24	Santos	R$ 7,966.52	Santos	-14.6%
Catalão	GO	5205109	R$ 7,218.67	Santos	R$ 6,176.75	Santos	-14.4%
Uruçuí	PI	2211209	R$ 9,658.01	Itaqui	R$ 8,314.16	Itaqui	-13.9%
Diamantino	MT	5103502	R$ 16,600.81	Santos	R$ 14,365.35	Santarém	-13.5%
São Paulo	SP	3550308	R$ 637.12	Santos	R$ 556.92	Santos	-12.6%
Querência	MT	5107065	R$ 18,716.69	Itaqui	R$ 16,463.05	Santarém	-12.0%
Campo Mourão	PR	4104303	R$ 5,723.03	Paranaguá	R$ 5,048.08	Paranaguá	-11.8%
Sapezal	MT	5107875	R$ 21,153.08	Santos	R$ 19,182.56	Santarém	-9.3%
Unaí	MG	3170404	R$ 11,282.94	Vitória	R$ 10,306.44	Santos	-8.7%
Gurupi	TO	1709500	R$ 11,264.39	Itaqui	R$ 10,352.08	Itaqui	-8.1%

Table 2: Continued…

MunMunicipalityi	State	Geodoce	Least Cost 2020	Destination Port 2020	Least Cost 2025	Destination Port 2025	Variation
Antônio João	MS	5000906	R$ 12,569.22	Paranaguá	R$ 11,631.68	Paranaguá	-7.5%
Guaraí	TO	1709302	R$ 8,608.47	Itaqui	R$ 8,062.18	Itaqui	-6.3%
Dourados	MS	5003702	R$ 10,335.72	Paranaguá	R$ 9,774.40	Santos	-5.4%
Uberlândia	MG	3170206	R$ 5,677.86	Santos	R$ 5,378.09	Santos	-5.3%
Tangará da Serra	MT	5107958	R$ 17,421.88	Santos	R$ 16,507.76	Santarém	-5.2%
Araguari	MG	3103504	R$ 5,859.10	Santos	R$ 5,556.48	Santos	-5.2%
Chapadão do Sul	MS	5002951	R$ 7,814.71	Santos	R$ 7,465.95	Santos	-4.5%
Leme	SP	3526704	R$ 2,094.76	Santos	R$ 2,005.50	Santos	-4.3%
Itaituba	PA	1503606	R$ 1,583.34	Santarém	R$ 1,520.35	Santarém	-4.0%
Luziânia	GO	5212501	R$ 8,389.75	Santos	R$ 8,065.12	Santos	-3.9%
Rondonópolis	MT	5107602	R$ 10,673.67	Santos	R$ 10,327.02	Santos	-3.2%
Colina	SP	3512001	R$ 3,924.66	Santos	R$ 3,815.47	Santos	-2.8%
Maringá	PR	4115200	R$ 4,148.76	Paranaguá	R$ 4,033.66	Paranaguá	-2.8%
Primavera do Leste	MT	5107040	R$ 12,619.13	Santos	R$ 12,270.44	Santos	-2.8%
Campo Verde	MT	5102678	R$ 12,776.60	Santos	R$ 12,436.66	Santos	-2.7%
Sertãozinho	SP	3551702	R$ 3,489.97	Santos	R$ 3,397.62	Santos	-2.6%
Sertanópolis	PR	4126504	R$ 4,504.29	Paranaguá	R$ 4,388.38	Paranaguá	-2.6%
Porto Velho	RO	1100205	R$ 6,852.28	Manaus	R$ 6,676.27	Manaus	-2.6%
São Félix do Araguaia	MT	5107859	R$ 17,318.49	Itaqui	R$ 16,919.25	Santarém	-2.3%
Canarana	MT	5102702	R$ 17,317.68	Santos	R$ 16,920.91	Santos	-2.3%
Campos de Júlio	MT	5102686	R$ 20,456.55	Manaus	R$ 20,025.93	Santarém	-2.1%
Santa Maria	RS	4316907	R$ 3,491.75	Rio Grande	R$ 3,425.86	Rio Grande	-1.9%
Água Boa	MT	5100201	R$ 16,437.49	Santos	R$ 16,137.51	Santos	-1.8%
Cruz Alta	RS	4306106	R$ 4,491.61	Rio Grande	R$ 4,425.72	Rio Grande	-1.5%
Passo Fundo	RS	4314100	R$ 3,676.20	Rio Grande	R$ 3,634.40	Rio Grande	-1.1%
Vilhena	RO	1100304	R$ 17,554.27	Manaus	R$ 17,419.48	Manaus	-0.8%
Cerejeiras	RO	1100056	R$ 18,888.31	Manaus	R$ 18,750.03	Manaus	-0.7%
Balsas	MA	2101400	R$ 9,207.77	Itaqui	R$ 9,168.32	Itaqui	-0.4%
Imbituba	SC	4207304	R$ 2,194.14	São Francisco do Sul	R$ 2,185.98	São Francisco do Sul	-0.4%
Ponta Grossa	PR	4119905	R$ 1,552.41	Paranaguá	R$ 1,546.98	Paranaguá	-0.3%
Palmas	TO	1721000	R$ 9,150.42	Itaqui	R$ 9,132.14	Itaqui	-0.2%
Cascavel	PR	4104808	R$ 4,447.63	Paranaguá	R$ 4,442.19	Paranaguá	-0.1%
Porto Nacional	TO	1718204	R$ 9,987.33	Itaqui	R$ 9,986.48	Itaqui	0.0%
Porto Alegre	RS	4314902	R$ 1,618.71	Rio Grande	R$ 1,618.71	Rio Grande	0.0%
Paragominas	PA	1505502	R$ 4,435.28	Belém/Barcarena	R$ 4,435.28	Belém/Barcarena	0.0%
Porto Franco	MA	2109007	R$ 4,986.42	Itaqui	R$ 4,986.42	Itaqui	0.0%
Anapurus	MA	2100808	R$ 3,193.94	Itaqui	R$ 3,193.94	Itaqui	0.0%
Itapoá	SC	4208450	R$ 1,082.57	Paranaguá	R$ 1,082.57	Paranaguá	0.0%
Bela Vista do Paraíso	PR	4102802	R$ 4,448.08	Paranaguá	R$ 4,448.08	Paranaguá	0.0%
Brasnorte	MT	5101902	R$ 19,166.81	Manaus	R$ 19,237.11	Santarém	0.4%

By analyzing the PNL 2025 scenario prepared by EPL in 2018, we noticed the improvement in the efficiency of the new logistics infrastructure generated an estimate of a 16% reduction in the total transportation cost. Considering the evaluated municipalities and destination ports, the average reduction was 10% between the two simulated scenarios. For the 79 municipalities considered, our findings show there 19% chance of these municipalities considering changing the destination ports for 2025 scenarios. Of this total, 73% exported soybean to the port of Santos-SP, Itaqui-MA, and Manaus-AM as ordinary routes in 2020. The simulation of the 2025 scenario reveals that these changes will head mainly to the port of Santarém-PA. Other route changes are for the ports of Belém/Barcarena-PA, Santos-SP, and Salvador-BA, thus modifying the regions of influence of some ports. Table 2 presents the cumulative transportation cost from the municipalities with the highest soybean production to the 10 top ports listed by the EPL as calculated by the model based on the least-cost routes. It also includes cases where the municipality of origin and destination are the same or are geographically very close, consequently with null or negligible freight values, given the national scope of the study, were excluded.

As noted, Figure 6 shows examples of the changes in transport routes for the municipality of Sapezal-MT to the ports of Santos-SP and Santarém-PA. The black line represents the route towards the port of Santos-SP, which corresponds to the route with the lowest accumulated cost considering the 2020 infrastructure, while the line in green represents the route towards the riverport of Santarém-PA derived from the 2025 scenario as the new lowest-cost route.

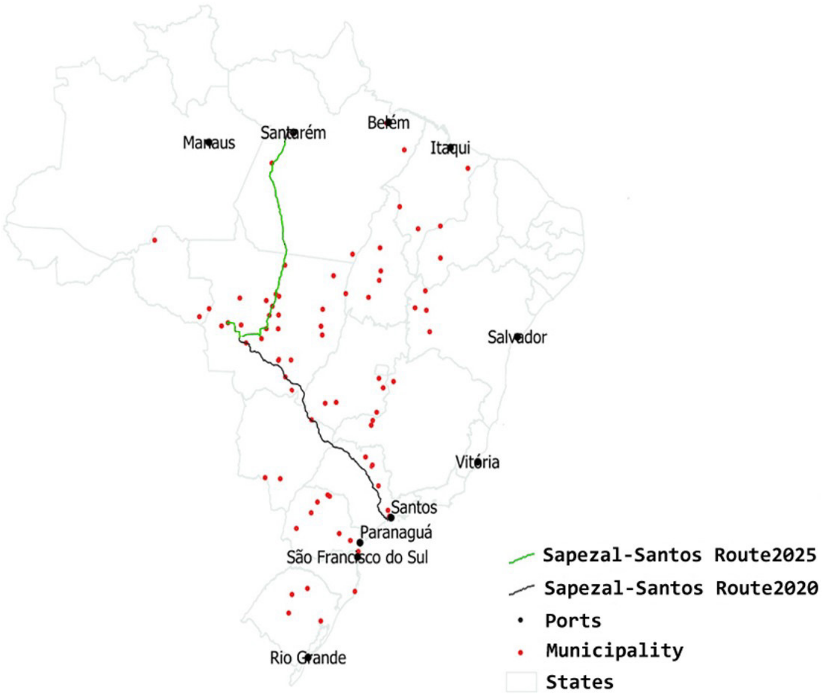

Figure 6. Thematic map of prioritized highways. Example focusing on the municipality of Sapezal-MT, whose lowest cost route is no longer by road to the port of Santos-SP at an accumulated cost of R$ 21,153.08 and becomes by road to the port of Santarém -PA with an estimated cost of BRL 19,182.56. Source: Authors

The combined intermodal road-railway infrastructure was used for both scenarios for the lowest cost for the municipality of Sapezal-MT. It is important to highlight that the Ferrogrão railway drove the changes in the 2025 scenario not only for Sapezal-MT but also for other municipalities in the region.

5. DISCUSSION

According to the Executive Report of Brazilian Logistics and Planning Company (EPL 2018), the insertion of the Ferrovia de Integração do Centro-Oeste (FICO), the Ferrovia de Integração Oeste Leste (FIOL) and the highways BR-080/GO/ MT and BR-242/TO/MT as foresee in the PNL 2025 scenario, would provide a potential elevated volume of cargo when compared to other projects in the program. However, the model operated by EPL does not make it clear which databases were used at the time, as the databases available to the public are not the same ones used by the company in the modeling.

Thus, our findings enable us to compare them to the evaluations carried out by EPL for the infrastructure scenarios of 2020 and 2025. The results presented for the PNL 2025 scenario compared to the current transport scenario in 2020 allowed for simulating changes in the regions of influence of the ports considering the soy outflow routes. The results show that the most significant impacts occur mainly in the state of Mato Grosso, specifically in municipalities that had the route to the ports of Itaqui-MA and Santos-SP as their destination and that started in 2025 to route the cargo to the port of Santarém-PA through from Ferrogrão. This change could significantly impact the ports' logistic macro-basins, mainly the port of Santos-SP. It should be noted that the delimitation of the logistical macro-basins based on the cost of transport, see Costa (2013), made available in this work, is not disclosed by the EPL. Therefore, it is impossible to make any straight comparison.

Also, considering the FICO deployments., there is also a change to the port of Salvador-BA. Findings from the analysis of all exporting municipalities in Brazi show that these changes in the ports' logistic macro basins for FICO and FIOL may prove to be more evident than expected.

Regarding the cost of logistical transport, the PNL 2025 Executive Report estimates a greater reduction in transport costs than the results found in this study. In fact, there is a possibility that by limiting the number of municipalities defined in the scope of this work based on the Brazilian foreign trade platform, in addition to the restriction on ports with the highest amount of cargo exported in 2020, we may have influenced the final result when compared to the EPL (2018). However, since other municipalities will benefit from the projects defined for 2025, the estimated gain was not incorporated in the final estimate of this research.

Another diagnosis of routing involving multi-modal transport for the transport of agricultural production in Mato Grosso, Waydzik et al. (2020) included the 5 most relevant municipalities in the state and the three main ports of destination, which were included in the origin/destination matrix. It was verified that in some situations, the multi-modal transport of road allied to the rail provided a slight variation of costs about the multi-modal road and waterway and, in some cases, a higher price. This variation was due to the necessary road route to the unloading terminals. The distributions of transshipment terminals are correlated to the final cost result. Thus, some municipalities that, in the simulated scenario for 2025, continue to export to the port of Santos, mainly in the region of the state of Mato Grosso, may be impacted if there is this reduction in distance and the supply of transshipment terminals. However, the choice of the port of destination is more complex. It transcends the object of this study since it also considers the weighting of external factors, such as the viability of the freight compared to the return cargo. In this sense, the customs industry in the Port of Santos-SP holds market hegemony by offering a complete list to leverage return freight.

The result of this study also demonstrates the potential of using multimodality in the flow of soy cargo in comparing infrastructure scenarios, highlighting the importance of strategic planning of the transport system. In a publication by the Ministry of Agriculture, Livestock, and Supply (MAPA) in 2020, the portfolio indicates the need for innovation at Arco Norte to reduce transport routes between producing municipalities, emphasizing the Mato Grosso region and the export ports. In this context, the simulation developed in the present study allowed verifying the improvement regarding the reduction of the accumulated freight cost, with emphasis on the influence of ports in the North region, when demonstrating the migration of the port of destination to Santarém-PA in the scenario with the infrastructure of PNL 2025, relating the municipalities of Mato Grosso to this migration destination. Another point mentioned by MAPA is the possibility of optimizing logistics through intermodal transport (road-water and road-rail), generating increased competitiveness in exports and a reduction in the cost of transport logistics. Including new railroad, highway, and waterway structures resulted in a decrease in logistical costs and a proposal for new service routes for the transportation of soy.

Analyzes of the logistical capacity of modes of transport, storage, or transshipment restrictions, as well as the customs structure of ports, were not considered in the survey. However, the bottlenecks in the soybean transport infrastructure may represent a highly critical issue in the coming years. This problem shows a need for further research and improvements to be implemented in the simulated model considering other variables to identify the possibilities of changing soybean loads to other routes or modes of transport other than those presented.

6. CONCLUSION

The research reached the objective. A geographic model for transport cost prediction was built using official public data on a free platform. The model, assembled in a matrix architecture, was designed to combine multi-modal, multisource and multidestination analyses simultaneously. The study considered the 79 municipalities responsible for 90% of the national soybean production recorded in the Comex Stat, which is distributed in the states of MT, MA, MS, MG, PA, BA, PR, PI, GO, RO, SP, SC, and RS, as well as the 10 main exporting ports (Santos-SP, Paranaguá-PR, Rio Grande-RS, Itaqui-MA, Belém/Barcarena-PA, São Francisco do Sul-SC, Vitória-ES, Santarém-PA, Salvador-BA, and Manaus-AM). Two different scenarios were also considered: the first contemplating the road, rail, and waterway infrastructure operating in 2020 and the second contemplating the changes planned for 2025.

This investigation addressed a comparison of soy export routes and the assessment of the total cost of transporting soy production, showing a reduction in cost between the infrastructure scenarios and the impacts on the regions of influence of each port.

The results found with the model not only confirm the hypothesis that the national road-rail-water network planned for 2025 in the National Logistics Plan will increase the supply of routes for the transportation of soy between the municipalities with the highest production of this commodity to the primary destination export ports, but also quantify the volume and price per segment. The average cost reduction was 10% between the two simulated scenarios. Furthermore, findings show a reduction in transport costs in 19% of the municipalities analyzed considering the destination ports for the 2020 and 2025 scenarios. Of these municipalities, 73% now have the port of Santarém-PA as their destination route with the lowest transport cost, indicating not only the importance of the projects but also changes in the regions of influence of the ports with the inclusion of new transport routes.

The survey contributes to better visibility in allocating infrastructure investments in long-term planning. In addition, the developed model can be replicated as the logistical infrastructure changes, reducing uncertainties about the possible impacts of new projects.

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