Available online at http://www.journalijdr.com

ISSN: 2230-9926

IJDR

International Journal of Development Research
Vol. 11, Issue, 11, pp. 51912-51918, November, 2021
https://doi.org/10.37118/ijdr.23318.11.2021

RESEARCH ARTICLE

OPEN ACCESS

OPTIMIZATION METHOD FOR THE ANALYSIS OF INTERMODAL ALTERNATIVES TO TRANSPORT SOYBEAN PRODUCTION IN THE STATES OF PARÁ AND TOCANTINS, BRAZIL

Vitor Hugo Pereira de Oliveira[1]*, Maisa Sales Gama Tobias[1], Marcus Pinto da Costa da Rocha[2], Valcir João da Cunha Farias[2] and Matheus Melo de Souza[1]

[1]Institute of Technology, Federal University of Pará;
[2]Institute of Exact and Natural Sciences, Federal University of Pará

ARTICLE INFO

Article History:
Received 15th August, 2021
Received in revised form
16th September, 2021
Accepted 10th October, 2021
Published online 28th November, 2021

Key Words:
Intermodality; Linear Programming;
Soybean production;
Transport routes; Optimization.

***Corresponding author:**
Vitor Hugo Pereira de Oliveira

ABSTRACT

In Brazil, in particular, the states of the North Region themselves as new agricultural frontiers for soybeans. However, they need to be competitive in transporting production. In this context, this research performed an analysis of intermodal alternative routes using an optimization model based on linear programming, to analyze the transport network, plan the infrastructure and identify the best solution to flow production, in supporting of decision-making in the transport of soybeans for export. The case study was in the region located between states of Pará and Tocantins, close to the Araguaia-Tocantins waterway. Within the categories of linear programming models, the transport and transshipment problem cases were used. The model aimed to minimize transport costs from the production centers to the exporting ports, through the current infrastructure and, under scenarios of intermodal alternatives formed by the projects of Paraense Railway and Araguaia-Tocantins Waterway. The results showed that the scenarios with waterway transport bring greater benefit, achieving savings up to 23%, furthermore, the Vila do Conde port complex expands its zone of influence; thus, obtain an increase in the exported quantity in up to 1059.7%. Beyond that, the new routes reduce the flow in the main highways. The conclusion is that the intermodal alternatives favor the development of the states.

Citation: ***Vitor Hugo Pereira de Oliveira, Maisa Sales Gama Tobias, Marcus Pinto da Costa da Rocha, Valcir João da Cunha Farias and Matheus Melo de Souza.*** "Optimization method for the analysis of intermodal alternatives to transport soybean production in the States of Pará and Tocantins, Brazil", *International Journal of Development Research*, 11, (11), 51912-51918.

INTRODUCTION

The production of soy is growing in the states of the North Region of Brazil, leading to the need to have transport for export in a competitive way for this product. Among the soy-producing states is Pará, whose production is growing at a fast pace. In the period from 2010 to 2017, the planted area increased from 85.4 thousand to 500.4 thousand hectares, which is equivalent to 30% of the total tillage area in the state in 2017, making it the largest crop cultivated (FAEPA, 2020). The increase of production raised up from 243,616.00 tons in 2010 to 1,781,672.00 in 2019 (IBGE, 2021). Another state in the northern region that is on the way to expanding soy production is the state of Tocantins. According to IBGE data, the region increased its harvested area from 352.9 thousand hectares to 905.4 thousand hectares; in addition, there was an increase in its production, going from 875,428.00 tons in 2009 to 2,615,178.00 tons in 2019.

In Brazil, however, the sector still suffers from the lack of logistical infrastructure for the flow of production, which increases its transport costs, reaching then, the competitiveness in the international scenario. The lack of good structural conditions for transport and storage represents the main problems of agribusiness (KUSSANO and BATALHA, 2012). According to Fioroni *et al.* (2015), soy plantations are located in regions in the interior of Brazil, far from the coast, which results in great difficulties to transport production. Moreover, Rodrigue and Notteboom (2012) describe the transport costs within inland of the continent, on average; compose 80% of the total cost of international transport shipments, while transport within the country covers only 10% of the total distance. Soliani (2015) exemplifies those Inappropriate modes of transport produce high operational costs, limiting the regional development. Furthermore, Halim *et al.* (2016) indicate that improvements in the port-inland distribution systems can positively affect competitiveness, beyond performing an important role in the choice of the sender's port and, therefore, in the routing and volume of transported goods.

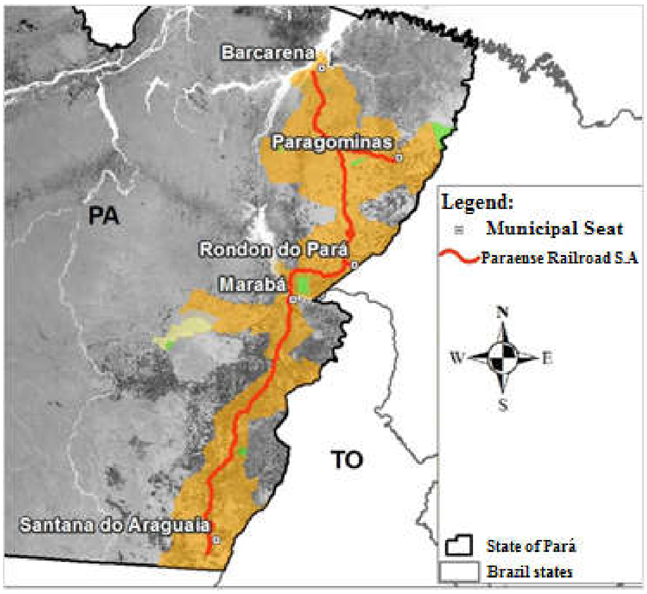
The transport, from the south of the state of Pará, is done by bulk trucks with a net cargo capacity of 50 tons, until reaching the port area in Vila do Conde, in the municipality of Barcarena in the state of Pará. Meanwhile, in the state of Tocantins, soy production is distributed throughout its regions, with the main corridors to transport the production formed by the Belém-Brasília and BR-226 highways, as well as the intermodal option by the North-South railroad, using transport points in locations in the municipalities of Porto Nacional - TO, Palmeirante -TO and Porto Franco - MA. However, as a possibility of a modal alternative for the state of Pará and Tocantins, two new possibilities of intermodal transport are presented: railway modal and waterway modal. The Araguaia-Tocantins waterway is identified by The National Department of Transport Infrastructure – DNIT, as having the capacity to be one of the main transport routes in the Center-North brazilian corridor, with the potential to become one of the main navigable waterways of the country (DNIT, 2021). Another alternative is the Paraense railroad SA project, which, according to the State Secretariat for Economic Development, Mining and Energy – SEDEME (2017), could have an extension of 1319 km, connecting the south of Pará to the Vila do Conde port complex. One way to analyze the modal options to transport soybean production in Brazil is by optimizing the cost of transport for export. Thus, Souza *et al*. (2020), optimized current routes and proposals to transport soybean production from the brazilian state of Mato Grosso. As well as Oliveira, V. *et al*. (2021), uses linear programming to analyze a new intermodal option to transport soybean production in the state of Pará – Brazil. Thus, the transport problem and the transshipment problem were adopted as a basis for the elaboration of the linear programming model. Furthermore, to assess the green corridors for brazilian soybean exports to China, the research by Péra *et al*. (2019), elaborates a linear programming problem model.

Thus, this work analyzes the effects of infrastructure investments in reducing the cost and CO2 emissions that involve transport to brazilian soy produced flow in the midwest. Another research is that of Oliveira, A. *et al*. (2021), in which the transport routes for soybeans in the region called MATOPIBA are optimized, so that the model allows examining the configuration of the logistical chain of exports through ports in the northeast and southeast of Brazil. Also, to analyze the impact of investments in brazilian port infrastructure on the flows of the fertilizer transport network, the study by Simões *et al.* (2018) uses a linear programming model based on the transport problem. Another study is that by Lin *et al*. (2019), which uses linear programming to assess the flow of the food supply chain between US counties. This article intent to analyze and identify the intermodal alternatives for transporting soybeans of municipalities in the states of Pará and Tocantins, based on the minimization of operating costs, to support planning in transport investments. In this way, contribute with information to serve as guidelines for decision-making related to soybean transport for export in the region, then analyzing the intermodal alternatives by Paraense railroad and Araguaia-Tocantins waterway to transport soybean production in the states of Pará and Tocantins. From regions that are close to the Araguaia and Tocantins rivers, to the export ports, proposing different scenarios and using the Linear Programming technique. Adopting, then, the linear programming problem classes, the transport problem and the transshipment problem, both are encompassed in network problems. In order to mold the costs, considering the current routes and proposing the new modes as an alternative, being then, the new routes through the Araguaia-Tocantins waterway and the Paraense railroad (FPA). The change in the transport network between the rated scenarios will be analyzed, for the model calculations the General Algebraic Modeling System - GAMS (2021) software will be used as a computational tool.

Description: The propensity is for a significant increase of soybean production in Brazil to continue, as indicated by agribusiness projections until the 2029/2030 harvest, acquired by studies performed by the Agricultural Policy Secretariat - SPA, of the Ministry of Agriculture, Livestock and Supply (MAPA, 2020). The 2029/2030 harvest is projected at 156.5 million tons, but it could reach 185.9 million tons. These numbers represent additions that vary from 30.1% to 54.5%. The infrastructure for the transport of soy is composed by ports, warehouses and specialized terminals, the reduced infrastructure to support the transport of soy is considered a bottleneck in the sector (DUBKE and PIZZOLATO, 2011). Made explicit by CONAB (2017), the road modal, is still heavily used to transport grains, contributing to an increase in the transportation costs. Thereby, also, as reminds, the northern system alternative requires urgent investments in infrastructure, since the biggest attraction of national agricultural commodities will depend on new and efficient transport corridors, as well as provide cost reductions.

Area Description: The region of the state of Pará, for this study, had a total of 181.7 thousand hectares of planted area in 2019, which corresponds to 31.5% of the total planted area of the state of Pará (IBGE, 2021), and that the amount of soy produced in the municipalities was 563,442.00 tons. The region of the state of Tocantins had in 2019 a total of 833.1 thousand hectares of gathered area, which is equivalent to 92% of the total gathered area of soybean in the state, according to IBGE, the amount of soybean produced in the municipalities was of 2,388,032.00 tons. According to the DNIT (2018), the road connection between the municipalities in the south of the state of Pará and the Barcarena - PA ports can reach an extension of over 1000 km by federal and state highways. Furthermore, according to the road network in the state of Tocantins presented by AGETO (2020), the Br-153 and the Br-223 total more than 800 km in the state. The state of Tocantins also counts with the intermodal option for the North-South Railroad, currently controlled by VLI Logística – VLI (2021), with a total extension of 720 km of railway between Açailândia - MA and Porto Nacional - TO. From Açailândia, the railroad connects with the Carajás railway, allowing access to the Itaqui complex port.

Intermodal Routes Suggested: The Paraense railroad S.A is a project that proposes the implementation of a railway in the state of Pará. As described by SEDEME (2017), consequently, as transshipment points for agricultural bulk proposed for the first eight years of operation, there will be transshipment stations in the municipalities of Marabá and Santana do Araguaia. In this way, it will cover a total railway distance of 596 km from Barcarena to Marabá, in sequence, foreseen to the second stage, in the fifth year of implementation, the connection of 560 km from Marabá to Santana do Araguaia.



Source: Extract from SEDEME, 2017.

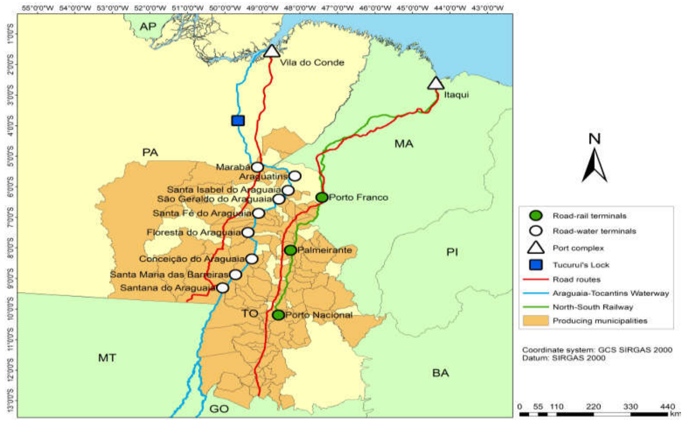
Figure 1. Paraense Railroad

Figure 1 shows the railway layout formed. According to the DNIT (2021), the waterway Araguaia-Tocantins has a navigable potential of approximately 3,000 km. Hence, there are government planning and projects for the Araguaia-Tocantins waterway that aim to define the works and services to be executed on the waterway in order to guarantee commercial, safe and continuous navigation, among them is the National Waterway Integration Plan prepared by ANTAQ (2013). Additionally, there is the Pedral do Lourenço destruction project, which are demolition and dredging works between Marabá – PA e Baião – PA, that aims to make navigation possible throughout the year on the stretch, and according to the Investment Partnerships Program (BRASIL, 2020) the project is in the environmental licensing stage and the work completion is scheduled for 2022. Given the possibility of making the waterway viable, a modal alternative that may present itself as alternative for the flow of soy production in the state of Pará and Tocantins is envisaged.

MATERIALS AND METHODS

Production centers: In 2019, the exported soy, having Pará as the origin of the product, was of 1,508,827.76 tons, which is equivalent to 85% of the 2019 production in the state of Pará. In 2020, 2,226,511.63 tons were exported, which is equivalent to 25% above the production in 2019, which was 1,781,672.00. Exports, having Tocantins as their origin, were of 2,213,290.72 tons in 2019 and 2,553,876.22 tons in 2020, which is equivalent to 85% and 98% of the 2019 production, respectively.[1] The region, in this study, had about 1,014,800 hectares of soy harvested area in 2019, which corresponded to the sum of 31.5% and 92% of the total area cultivated with soy in the state of Pará and Tocantins (IBGE, 2021), with the amount of soy produced in the municipalities of 2,951,474.00 tons. The most updated production data released by the IBGE refer to the year 2019. However, it is likely that in 2021 the exports of soy production in the states of Pará and Tocantins will exceed the amount produced in 2019. Ergo, based on projections for growth in production and exports of soy, it was considered in this work that the entire annual production of 2019 of the municipalities will be destined for export, with the production data for each municipality taken from the survey performed by the IBGE (2021). The area of the municipal headquarters was considered as the point of origin of transport. Figure 2 shows the producing municipalities that will be considered in this research.

Economic values: The data on transshipment values from the road modal to the waterway modal (Road-Waterway) used in this work were obtained from two references. The work by Cruz (2019), who obtained the value experienced by the market in 2018, which was US\$[2] 5.00 per ton, the tariff of the company Hidrovias do Brasil. The second reference is the standard average transshipment tariff provided and experienced by the company Unitapajós (2021), at its Miritituba Cargo Transshipment Station in the municipality of Itaituba – PA, with the same value being US\$ 5.00 per ton. Thus, the value considered for the road-waterway intermodal transshipment will be US\$ 5.00 per ton. For the railway mode, the values considered will be those charged by the Norte Sul railroad concessionaire. Which is the company VLI (2021a), as disclosed by the company, the values charged on the railroad were 0.0152 US\$/ton.km plus a fixed installment of US\$ 4.83 per ton in the year of 2018, already including the transshipment of the soybean cargo, this value will also be considered for the Paraense railroad. The transport costs of the waterway modal were obtained through the Transport Cost Simulator tool, developed and made available by the Planning and Logistics Company S.A. – EPL. The tool was designed to give support to the elaboration of the National Logistics Plan (EPL, 2021). The available values refer to the average cost for waterway transport of agricultural solid bulk in the year 2018. The EPL (2021a) considers three types of waterway costs, the values are divided for navigation on roads with low, medium and high restriction. The parameters for choosing the type of road consider the limitations of the waterway. For road freight, the values were calculated based on the mathematical formulation of the table of minimum prices for road freight transport, stipulated by the National Land Transport Agency (ANTT, 2018). Freights were calculated for nine-axle trucks, having a total weight of seventy-four tons and a net load of fifty tons. Besides, as the economic values for rail and waterway transport refer to those practiced in 2018, in order to maintain all economic values obtained for the same year, the freight table used is the one formulated and practiced in 2018.



Source: Authors, 2021.

Figure 2. Main ways to transport production from the municipalities

For the flow of soy production from the municipalities, several alternative locations for the transshipment of cargo along the waterway were stipulated. The purpose of this distribution of waterway terminal options along the way is to provide several possible transshipment points to compose the production flow routes. The proposed intermodal terminal points (see Figure 2) were established in accordance with their existing logistical infrastructure and the quality of accesses, then, are in spaces available in proximities of crossings already established between the two states, bridges and municipalities and districts. In addition, as a criterion to maintain the transshipment terminal, motion values were sought in the published statistical yearbook of ANTAQ (2021), with the smallest movement of soybean shipped for inland navigation in 2020, considering the movement of cargo in the terminal exclusively for inland navigation. Thus, it was observed that, for example, the ETC - Porto Murtinho waterway terminal handled 52,932.00 tons of soy in 2020. Based on this value, it was considered to adopt the terminal with a minimum movement of 52,932.00 tons for the model. Some scenarios were considered for the analysis of this work, these scenarios were based on the production data for the year 2019. As well as the current infrastructure, which is composed by road corridors that go to the ports, as well as the option for the North South railroad, with three transshipment stations. Subsequently, the proposed routes formed by Paraense railroad and the Araguaia-Tocantins waterway were added as alternatives for intermodal transport. In consequence, fifteen scenarios were elaborated. In the base 2019.1scenario, only the routes used by the road modal and the rail modal by the North South railroad were considered. In the 2019.2 scenario, in addition to the existing routes, the Paraense Railroad SA project was included as a proposed intermodal alternative, with the locations planned for transshipment located in the municipalities of Marabá – PA and Santana do Araguaia – PA. According to the details of inland navigation route described by ANTAQ (2013) and according to the examples cited by EPL (2021b), this work considered the hypothesis that the waterway has medium or high restriction. For 2019.3 scenario, the waterway to Araguaia-Tocantins a with medium restriction is included, as a proposed intermodal alternative merely in the path that will be possible only with the destruction of Pedral do Lourenço (as quoted in the Description). In other words, until the district of Santa Isabel - PA from this point the upstream only will be possible to maintain commercial navigation if a hydroelectric dam with a lock is installed, as commented by ANTAQ (2013).

---

[1]The data were released by COMEX STAT (2021), a government system that publishes data on brazilian foreign trade statement-based byexporters.

[2]All monetary values in this work were obtained initially in Brazilian Real currency, later converted to the year 2021, released by the Institute of Applied Economic Research (IPEA, 2021). Exchange rate - R\$/US\$: 5.0016.

Table 1. Proposed scenario analysis

Scenarios	Corridors	Production (t)
2019.1	Highway + railway (North-South)	2019
2019.2	Include Paraense railroad	2019
2019.3	Include waterway (until Sta. Isabel)	2019
2019.4	Include waterway (total extension)	2019
2019.5	Consider high restriction partially in the waterway	2019
2029.1 a 2029.5	Same modal options from 2019.1 to 2019.5	2029
2029s.1 a 2029s.5	Same modal options from 2019.1 to 2019.5	2029 – Upper limit

Table 2. Soy shipment (in tons) to transshipment stations

Type	Intermodal Terminal	2019.1	2019.2	2019.3	2019.4	2019.5
Waterway	Marabá			429,705.00	123,280.00	165,240.00
Waterway	Santa Isabel			756,421.00	317,849.00	60,948.00
Waterway	Santa Fé do Araguaia				63,135.00	
Waterway	Floresta do Araguaia					76,267.00
Waterway	Conceição do Araguaia				440,441.00	316,638.00
Waterway	Santa Maria das Barreiras				325,868.00	308,815.00
Waterway	Santana do Araguaia				1,680,901.00	1,037,228.00
Railway (FPA)	Marabá - PA		96,923.00			
Railway (FPA)	Santana do Araguaia – PA		598,881.00	379,281.00		
Railway (FNS)	Porto Franco – MA	388,254.00	388,254.00	377,955.00		262,140.00
Railway (FNS)	Palmeirante – TO	679,163.50	356,249.00			56,958.00
Railway (FNS)	Porto Nacional – TO	1,490,797.58	1,406,167.00	1,386,067.00		667,240.00

Table 3. Soy export by complex port

	Vila do Conde		Itaqui	
Scenario	Tons	%	Tons	%
2019.1	393,260.00	13.3	2,558,214.00	86.7
2019.2	800,804.00	27.1	2,150,670.00	72.9
2019.3	1,565,407.00	53.0	1,386,067.00	47.0
2019.4	2,951,474.00	100.0		0.0
2019.5	1,965,136.00	66.6	986,338.00	33.4

Table 4. Determined waterway terminals: 2029 – 2029s

Terminals	2029.3	2029S.3	2029.4	2029s.4	2029.5	2029s.5
Marabá	X		X	X	X	X
Araguatins		X		X		
Santa Isabel	X		X	X	X	X
São Geraldo do Araguaia						X
Santa fé do Araguaia			X	X		
Floresta do Araguaia				X	X	X
Conceição do Araguaia			X	X	X	X
Santa Maria das Barreiras			X	X	X	X
Santana do Araguaia			X	X	X	X

Table 5. Determined waterway terminals: 2029 – 2029s

	Vila do Conde		Itaqui	
Scenario	Production (t)	%	Production (t)	%
2029.1	511,473.96	13.3	3,327,213.13	86.7
2029.2	1,041,525.68	27.1	2,797,161.40	72.9
2029.3	2,035,598.34	53.0	1,802,718.74	47.0
2029.4	3,838,687.08	100.0	-	0.0
2029.5	2,555,855.88	66.6	1,282,831.20	33.4
2029s.1	607,665.35	13.3	3,952,952.27	86.7
2029s.2	1,237,402.34	27.1	3,323,215.28	72.9
2029s.3	2,418,866.90	53.0	2,141,750.73	47.0
2029s.4	4,560,617.63	100.0	-	0.0
2029s.5	3,057,623.22	67.0	1,502,994.41	33.0

Figure 2, shows the main road corridors used to transport production in the region, as well as the main rivers that compose the discussed waterway, in addition to the route and stations of the North-South railroad. In 2019.4 scenario, in addition to the options that create the other scenarios, the alternative for inland navigation was added, considering the waterway with medium restriction implemented and fully viable up to the border between Pará and Mato Grosso. In addition to these alternatives, based on the EPL waterway restriction criteria and the ANTAQ (2013) report, which characterizes the work necessary to minimize the restriction on the road, for the preparation of the 2019.5 scenario, the hypothesis was accepted that upstream of Marabá the waterway will be highly restricted. In resume, in addition to the intermodal transport options to the port, for all scenarios, you have the option of transporting to the port only by road mode. Furthermore, based on export growth projections, scenarios with an increase of about 30.1% for the year 2029 and 54.5% as the upper limit for 2029s scenarios were considered, Table 1 presents the analyzed scenarios.

Proposed transport model: The transport network for the flow of soybean exportation will start at producing municipalities (production centers), transshipment points at the proposed intermodal terminals and the end point at the export port, with modal alternatives to connect the knots of the logistics network. As described by Kazemi and Szmerekovs (2015), the storage at transshipment locations is done in a short period, the operation aims to transfer the cargo to another modal, thus, transshipment locations are defined as zero stock points. The model was elaborated based on the optimization technique using linear programming as a tool, thus, the concepts of the linear programming were applied to transport problems and transshipment problems (ARENALES *et al.*, 2011; FÁVERO and BELFIORE, 2013; HILLER and LIEBERMAN, 2006). The linear optimization model will have the objective of minimizing the overall transport cost, in consequence, it is composed by transport costs in the road modal to the exporting port or to the intermodal terminal, the intermodal transshipment costs and the costs in the waterway modal performed from the terminal to the port. Below (eq. 1) is the objective function Z:

$$Z = \sum_{i=1}^{I}\sum_{j=1}^{J} SMP_{ij} * DMP_{ij} * CR_{ij} + \sum_{i=1}^{I}\sum_{k=1}^{K} SMT_{ik} * DMT_{ik} * CT_{ik} + \sum_{i=1}^{I}\sum_{k=1}^{K} SMT_{ik} * TR_{k} + \sum_{k=1}^{K}\sum_{j=1}^{J} ST_{kj} * DT_{kj} * CI_{kj} \quad (1)$$

Subject to:

$$\sum_{j=1}^{J} SMP_{ij} + \sum_{k=1}^{K} SMT_{ik} = PRO_i, \text{ for all } I \quad (2)$$

$$\sum_{i=1}^{I} SMP_{ij} + \sum_{k=1}^{K} ST_{kj} = EXP_j, \text{ for all } J \quad (3)$$

$$\sum_{k=1}^{K} SMT_{ik} - \sum_{k=1}^{K} ST_{kj} = 0, \text{ for all } K \quad (4)$$

Where:

i : Soybean producing municipalities, $i \in I$.
j : Soybean exporting port $j \in J$.
k : Soybean intermodal transshipment terminals, $k \in K$.
I : Set associated with origins (producing municipalities).
J : Set associated with the export port.
K : Set associated with intermodal transfer terminals.
CR_{ij} : Cost of road transport in US$ per ton from producing municipality i to exporting j port.
CT_{ik} : Cost of road transport in US$ per ton originated in the producing municipality i and destined for the intermodal transshipment k terminal.
CI_{kj} : Cost of intermodal waterway transport in US$ per ton with origin at the intermodal transshipment terminal k and destined for the exporting j port.
DMP_{ij} : Distance in kilometers between producing municipality i and exporting j port.
DMT_{ik} : Distance in kilometers between producer municipality i and intermodal transshipment k terminal.
DT_{kj} : Distance in kilometers between the intermodal transshipment terminal k and exporting j port.
EXP_j : Total grain export from exporting j port in tons per year.
PRO_i : Total production of soybeans for export by producing municipalities i in tons per year.
SMP_{ij} : Grain flow in tons in the road modal, originating in producer municipality i and destined for export j port.
SMT_{ik} : Grain flow in tons in the road modal originated in producer municipality i and destined for the intermodal transshipment k terminal.
ST_{kj} : Grain flow in tons in the road modal, originated in the intermodal transshipment k terminal and destined for the exporting j port.
TR_k : Cost for transshipment operation at the intermodal road-waterway terminal k in US$ per ton.

RESULTS AND DISCUSSION

In this chapter are the results of the developed modeling. It is noteworthy that the monetary data were updated according to the Extended National Consumer Price Index - IPCA (IBGE, 2021a), whose accumulated correction of 13% for the year 2021. In the formation of the transport network, in the scenario which uses the waterway modal, were determined waterway terminals are the best contribute to the flow of agricultural production, considering the criterion of minimum annual movement. In the optimization process, it was admitted that the offer of available waterway terminals is modified until all available road-waterway terminals reach the minimum movement, with the lowest total cost. These waterway terminals are determined as a result of the optimization of the total cost, obtaining the best route configuration for the various municipalities studied. To verify the results obtained after the reduction of the waterway terminals, the model was again optimized, containing as a road-waterway transshipment option only the waterway terminals determined for the configuration of the routes. Once done, the results of the optimal solution were maintained, as it can be deduced as satisfactory the result of the model for choosing the terminals.

The results are presented and discussed by state and then for the transport network, regardless of geographic location, and by the scenario type. In order to transport 563,442.00 tons of soy from the state of Pará, the scenario with waterway transport to Santana do Araguaia with medium restriction, a reduction of 42% was obtained in relation to the costs of the 2019.1 base-scenario. The total savings was of US$ 7,807,548.95 in the total cost of shipping the soybean production of the state. The results for the state of Pará were in 2019.1 scenario the total freight cost of US$ 18,430,459.68 and the total cost related to the movement of soybean, that is, the value for transporting one ton of soybean was 32.71 US$/t. In 2019.2 scenario, US$ 16,562,262.24 and 29.39 US$/t. In 2019.3 scenario, US$ 15,654,423.95 and 27.78 US$/t. In 2019.4 scenario, US$ 10,622,910.73 and 18.85 US$/t. In 2019.5 scenario, it was US$ 12,996,414.95 and 23.07 US$/t. In 2019.1scenario, 30.4% of the production was transported by North South railroad. In 2019.2 scenario, 98.32% of the production of the state of Pará started to be exported by the state port itself and only one municipality sent by road. In the other scenarios, all municipalities use intermodal transport. Furthermore, considering the values of each route, the average freight per ton of municipalities to transport soybeans to the port in 2019.1 scenario was 28.57 US$/t; in 2019.2 scenario was 26.95 US$/t; in 2019,3 scenario resulted in 23.19 US$/t; in 2019.4 scenario of 19.79 US$/t and, in 2019.5 scenario, the average was 21.66 US$/t. The production center that presented the smallest difference in value in the scenario with the best performance, 2019.4scenario, compared to the baseline 2019.1scenario, was in Tucumã with 20.08%. However, Rondon do Pará has the second shortest road distance until the port in 2019.1scenario, with Tucumã and São Felix do Xingu being far from the banks of the waterway. The biggest difference between the freight values for transport in the scenarios occurred in Santana do Araguaia and Santa Maria das Barreiras, with decreases of 49% and 51% in transport costs, respectively. The two municipalities have a predominance of the waterway mode in 2019.4scenario, and are close to the waterway, as well as being the most distant production centers from the port. For the state of Tocantins, 2019.4 scenario presented a reduction of 18.6% in relation to the costs of the 2019.1 scenario. Thus, obtaining a total savings of US$ 15,152,800.32 to transport the state's soy production. The results for the state of Tocantins were US$ 81,314,747.59 and 34.05 US$/t, in 2019.1 scenario; US$ 80,562,262.24 and 33.81 US$/t, in 2019.2scenario; US$ 78,929,079.40 and 33.05 US$/t, in 2019.3

scenario; US$ 66,161,947.28 and 27.71 US$/t, in 2019.4 scenario and, US$ 76,505,679.78 and 32.04 US$/tin 2019.5 scenario. In 2019.1scenario, only one municipality sent only by road. In the other scenarios, all municipalities use intermodal transport. Afterwards, in 2019. 2 scenario, only one municipality sends soybean to Marabá. Furthermore, considering the values of each route, the average freight per ton of municipalities to transport soybeans to the port in 2019.1 scenario was 32.45 US$/t; in 2019.2 scenario was 32.36 US$/t; in 2019,3 scenario resulted in 30.47 US$/t; in 2019.4 scenario, 25.78 US$/t and; finally, in 2019.5scenario, the average was 30.26 US$/t. Regarding the general results of the scenarios, for the entire geographic region of this study. The 2019.4 scenario, presented a reduction of 23% compared to the costs of 2019.1scenario. The proposed intermodal alternatives, Paraense railroad and Araguaia-Tocantins waterway, have a 53% share in 2019.3 scenario until the waterway reaches 100% of the total soy transported in 2019.4 scenario. However, the FNS only does not hold part of the movement in 2019.4 scenario, when considering an average restriction for the waterway cost. Table 2 shows the motion in the terminals.

Table 3 shows the variation of cargo exported by the Vila do Conde - VLC and Itaqui port complexes. It is verified that soy exports were redirected to Vila do Conde. Thereby, due to the inclusion of intermodal alternatives, most of the soy is exported by state of Pará. Consequently, when the infrastructure is modified, the area of influence of Vila do Conde port complex expands, with an increase in the amount of soy exported by up to 650%. In the 2029 scenarios the results were US$ 129,728,616.58 in 2029.1scenario; US$ 126,546,442.99 in 2029.2 scenario; US$ 123,015,304.46 in 2029.3 scenario; US$ 99,866,386.33 in 2029.4 scenario and US$ 116,406,424.40 in 2029.5 scenario. In the 2029s scenarios the results were US$ 154,126,294.28 in 2029s.1scenario; US$ 150,345,658.70 in 2029s.2 scenario; US$ 146,083,234.82 in 2029s.3 scenario; US$ 118,513,138.36 in 2029s.4 scenario and US$ 138,292,676.62 in 2029s.5 scenario. Thus, for the projection at the upper limit, 2029s.4 scenario presented a total savings of US$ 35,613,155.92 and 2029s.5 scenario had savings of US$ 15,833,617.66 in the whole value of total cost to transport the production of soybeans. In this way, the increase in costs is identified as soybean production grows. As well as, if a new infrastructure is built with the new intermodal transport alternatives proposed, over ten years hundreds of millions of dollars can be saved, just to transport this product. Furthermore, analyzing the total cost per ton of soybean transported, changes occurred in the scenarios 2029s.3, 2029s.4 and 2029s.5, which the values for the transport of one ton of soybean were 32.03 US$/t, 25.99 US$/t and 30.323 US$/t, respectively. Therefore, it is observed a reduction in the cost per ton between 2019 and 2029s scenarios, due to the changes in routes. The costs per ton moved are maintained in the other 2029 scenarios, as there is no change in the routes. Table 4 shows the waterway terminals in each scenario and Table 5 shows the variation in exported cargo by the Vila do Conde port complexes - VLC and Itaqui. It appears that as there is a supply of a terminal close to the production center, the cost per ton handled is reduced. It happens that in the projections of 2029s.3, 2029s.4 and 2029s.5 scenarios the municipalities that used to flow through other terminals started to use the routes formed by the waterway terminals of Araguatins, Floresta do Araguaia and São Geraldo do Araguaia. In this way, municipalities close to these terminals reduce the freight price per ton to export production.

CONCLUSION

The suggested model of linear programming, enabled to reach satisfactory results, which allow analyzing the modal alternatives of transport for the flow of soybeans in the region. The state of Pará production, in 2019.1 scenario, shows the lack of influence on Vila do Conde port complex, related to the municipalities studied, even those located in the state port itself. However, in the 2019.1 scenario, with the new intermodal alternative, it increases its exports, besides obtaining a reduction of 10.1% in the cost. It was verified that the great positive impact caused by a new intermodal alternative for the state of Pará. Furthermore, in 2019.3scenario, compared to 2019.2, indicates some competition between waterway transport and Paraense railroad, in terminals of Marabá city, despite the fact that the waterway option proved to be more competitive. In addition, the 2019.4 and 2019.5 scenarios showed greater savings scenarios. Therefore, it is concluded that the waterway will bring greater economic benefits to the state of Pará. The state of Tocantins obtained the best savings in 2019.4 and 2019.5 scenarios. Furthermore, in 2019.3 scenario, Santa Isabel waterway terminal is the one that receives the most soy to transport the state production, so an intermodal alternative starts to be really beneficial from Santa Isabel to the state. In 2019.5 scenario, even though the Santana do Araguaia FPA terminal was competitive, the preference was for Santana do Araguaia waterway terminal to To cantinsmunicipalities. Therefore, the waterway is the most beneficial to the state, both as far as Santa Isabel and as far as Santana do Araguaia, even when there is a high restriction on the waterway. Between North-South railroad, Paraense railroad and the waterway transport, the lowest costs per ton transported occurred in the waterway mode. Another important aspect is that municipalities far from ports and close to the waterway had greater savings, as is the case of Santana do Araguaia – PA and Caseara – TO, reaching a reduction of 49% and 53.9%, respectively. In the 2029 scenarios projections, assuming that transport through the terminals of Araguatins, São Geraldo do Araguaia and Floresta do Araguaia becomes viable, the municipalities that are close may obtain greater savings than 2019 scenarios, and with this distribution of intermodal terminals along the waterway will provide the best route arrangement. Thus, it is concluded that there is a need to seek to implement waterway terminals with less annual movement, in order to increase the supply of terminals on the waterway and obtain greater economy and competitiveness.

According to the results obtained, if the waterway is implemented, the Vila de Conde complex port may have an increase up to 650% in the amount of exported soy, which may reach an increase up to 1059.7%, in the projections, compared to 2019.1 scenario. Thus, for the state of Pará, modal alternatives, in addition to offer greater savings, also directed exports to the Vila do Conde complex port, which should bring economic advantage to the state, as investments in the complex port. State of Pará, based on the analysis accomplished, it would be the biggest beneficiary with a new intermodal alternative, with the implementation of the waterway being more opportune. The differences between the scenarios, with the proposed modal option and the results obtained in the municipalities that are close to the North-South railroad, indicate that the locations that do not yet have an intermodal alternative are the ones that will obtain the greatest benefit and the greatest increase in competitiveness. Therefore, it can be concluded that upstream of Marabá, the implantation preference should be the Araguaia river, as the river would bring greater competitive gains in its region of influence, related to the Tocantins river, in the municipalities close to it; where the North-South railroad option is already available, in addition to the fact that the Araguaia river has half of the cost per km to be implemented.

Furthermore, evaluating the differences between the results with medium restriction on the waterway and partially high restricted, it is concluded that all the planned works need to be implemented to minimize navigation restrictions on the waterway. Finally, considering the results of the scenarios to transport soybean production in the states of Pará and Tocantins, if nothing is done, if no intermodal alternative is implemented, the trend will be an increase in the cost over the years, only for outflow the soy production. Reinforcing the urgency to implement an intermodal alternative for the states of Pará and Tocantins, in order to not compromise the country's competitiveness on the world stage. In conclusion, the results indicated the waterway as the best option to be implemented, reducing the heavy traffic of trucks on the road corridor, contributing to the sustainable development of the region. Besides the environmental impacts reduction in the cities, that are along the route from the highway to the exporting port; as well as the generation of wealth, regional development and the consolidation of the states as great grain producers and exporters.

REFERENCES

AGETO - Agência Tocantinense de Transportes e Obras. (2020) Mapa Rodoviário 2020. Disponível em: https://www.to.gov.br/seinf/mapas-rodoviarios/28sxwjwwyhse. Acesso em: 07 abr. 2021.

ANTAQ. (2013) Relatório Executivo: bacia do Tocantins-Araguaia. [S. l.]: ANTAQ. Disponível em: http://web.antaq.gov.br/portalv3/PNIH/BaciaTocantinsAraguaia.pdf. Acesso em: 04 mar. 2021.

ANTAQ. Estatísticos Aquaviário. Disponível em: http://web.antaq.gov.br/ANUARIO/. Acesso em: 20 mar. 2021.

ANTT - Agência Nacional de Transporte Terrestres. (2018) Resolução nº 5.835, de 20 de novembro de 2018. Altera o Anexo II da Resolução ANTT nº 5.820, de 30 de maio de 2018, em razão o disposto no §3º do art. 5º da Lei nº 13.703, de 8 de agosto de 2018.

Arenales, M; Armentano, V.; Morabito, R., and Yanasse H. (2011) Pesquisa Operacional: para cursos de engenharia. Rio de Janeiro: Elsevier.

BRASIL. Apoio ao licenciamento ambiental do Pedral do Lourenço: dragagem e derrocamento da via navegável do rio Tocantins. Dragagem e Derrocamento da Via Navegável do Rio Tocantins. Disponível em: https://www.ppi.gov.br/apoio-ao-licenciamento-ambiental-do-pedral-do-lourenco-dragagem-e-derrocamento-da-via-navegavel-do-rio-tocantins. Acesso em: 07 dez. 2020.

COMEX STAT. Exportações e Importações Geral. Disponível em: http://comexstat.mdic.gov.br/pt/geral. Acesso em: 05 maio 2021.

CONAB. (2017) Estimativa do escoamento das exportações do complexo soja e milho pelos portos nacionais: safra 2016/2017. Brasília: Conab, v. 6.

Cruz, R. N. (2019) Utilização do método híbrido AHP-TOPSIS para a escolha modal do escoamento da produção de soja do polo Paragominas/pa. 2019. Dissertação (Mestrado em Transporte Aquaviário) – Faculdade de Engenharia Naval, Universidade Federal do Pará, Belém.

DNIT. (2018) Mapas multimodais - PA. Brasília. Disponível em: https://www.gov.br/dnit/pt-br/assuntos/sistema-nacional-de-viacao/sistema-nacional-de-viacao?b_start:int=20. Acesso em 15 fev. 2021.

DNIT. (2021) Hidrovias – Tocantins/Araguaia. Disponível em: https://www.gov.br/dnit/pt-br/assuntos/aquaviario. Acesso: 03 fev. de 2021.

Dubke, A. F., and Pizzolato, N. D. (2011) Location model of specialized terminals for soybean exports in Brazil. Pesquisa Operacional. Rio de Janeiro, v. 31, n. 1, p. 21–40.

EPL. (2021) Plano Nacional de Logística. Disponível em: https://www.epl.gov.br/plano-nacional-de-logistica-pnl. Acesso em: 16 fev. 2021.

EPL. (2021a) Simulador de Custo de Transporte. Disponível em: https://www.epl.gov.br/ Acesso em: 03 mar. 2021.

EPL. (2021b) Manual: metodologia de custos de transporte. Metodologia de Custos de Transporte. Disponível em: https://www.epl.gov.br/manual-metodologia-de-custos-de-transporte. Acesso em: 07 fev. 2021.

FAEPA - Federação da Agricultura e Pecuária do Pará. Agronegócio Paraense. Disponível em: http://sistemafaepa.com.br/faepa/agronegocio-paraense/. Acesso em: dez. 2020.

Fávero, L. P., and Belfiore, P. (2013) Pesquisa Operacional para cursos de Engenharia. Rio de Janeiro: Elsevier.

Fioroni, M. M.; Franzese, L. A. G.; Santana, I. R. de; Lelis, P. E. P.; Silva, C. B. da; Telles, G. D.; Quintáns, J. A. S.; Maeda, F. K., and Varani, R. (2015) From farm to port: simulation of the grain logistics in Brazil. In: Winter Simulation Conference (WSC), 2015, Huntington Beach. Proceedings [...]. Huntington Beach: Winter Simulation Conference (Wsc), p. 1936-1947.

GAMS. GAMS. Disponível em: https://www.gams.com/. Acesso em: fev. 2021.

Halim, R. A.; Kwakkel, J.H., and Tavasszy, L. A. (2016) A strategic model of port-hinterland freight distribution networks. Transportation Research Part e: Logistics and Transportation Review, [s. l.], v. 95, p. 368-384, nov. Elsevier BV. http://dx.doi.org/10.1016/j.tre.2016.05.014.

Hiller, F. S., and Lieberman, G. J. (2006) Introdução à pesquisa operacional. São Paulo: McGraw-Hill.

IBGE. (2021a). Índice Nacional de Preços ao Consumidor Amplo. Disponível em: https://www.ibge.gov.br/estatisticas/economicas/precos-e-custos/9256-indice-nacional-de-precos-ao-consumidor-amplo.html?=&t=o-que-e. Acesso em: jun. 2021.

IBGE. Produção Agrícola Municipal: Produção Agrícola - Lavoura temporária - Soja (em grão). Disponível em: https://cidades.ibge.gov.br/. Acesso em: maio. 2021.

IPEA - Instituto de Pesquisa Econômica Aplicada. (2021) Taxa de câmbio comercial para compra: real (R$) / dólar americano (US$) - média. real (R$) / dólar americano (US$) - média. Disponível em: http://www.ipeadata.gov.br/ExibeSerie.aspx?serid=38590&module=M. Acesso em: 30 jun. 2021.

Kazemi, Y., and Szmerekovsky, J. (2015) Modeling downstream petroleum supply chain: the importance of multi-mode transportation to strategic planning. Transportation Research Part e: Logistics and Transportation Review, [s. l.], v. 83, p. 111-125, nov., Elsevier BV.

Kussano, M. R., and Batalha, M. O. (2012) Custos logísticos agroindustriais: avaliação do escoamento da soja em grão do Mato Grosso para o mercado externo. Revista Gestão & Produção. São Carlos, v. 19, n. 3, p. 619-632.

Lin, X.; Ruess, P. J; Marston, L., and Konar, M. (2019) Food flows between counties in the United States. Environmental Research Letters, [s. l.], v. 14, n. 8, p. 084011, 26 jul. IOP Publishing.

MAPA. (2020) Projeções do Agronegócio: brasil 2019/20 a 2029/30 projeções de longo prazo. Brasil 2019/20 a 2029/30 Projeções de Longo Prazo. 11ª edição. Disponível em: www.agricultura.gov.br. Acesso em: 08 abr. 2021.

Oliveira, A. L. R. de; Filassi, M.; Lopes, B. F. R., and Marsola, K. B. (2021) Logistical transportation routes optimization for Brazilian soybean: an application of the origin-destination matrix. Ciência Rural, [s. l.], v. 51, n. 2. FapUNIFESP (SciELO).

Oliveira, V. H. P. de et al.(2021) Optimization method applied to decision-making on intermodal alternative for soybean outflow in the State of Pará-Brazil. International Journal For Innovation Education And Research, v. 9, n. 7, p. 124-140. http://dx.doi.org/10.31686/ijier.vol9.iss7.3103.

Péra, T. G.; Bartholomeu, D. B.; SU, C. T., and Caixeta Filho, J. V. (2019) Evaluation of green transport corridors of Brazilian soybean exports to China. Brazilian Journal Of Operations & Production Management, [s. l.], v. 16, n. 3, p. 398-412, 28 ago. 2019. Associacao Brasileira de Engenharia de Producao - ABEPRO.

Rodrigue, J., and Notteboom, T. (2012). Dry ports in European and North American intermodal rail systems: two of a kind? Research in Transportation Business & Management. [S. l.], p. 4-15. dez. 2012.

SEDEME - Secretária de Estado de Desenvolvimento Econômico, Mineração e Energia. (2017) Estudo de Impacto Ambiental: Ferrovia Paraense S.A. Belém: Sedeme.1 v.

Simões, D. da C.; Caixeta-Filho, J. V., and Palekar, U. S. (2018) Fertilizer distribution flows and logistic costs in Brazil: changes and benefits arising from investments in port terminals. International Food And Agribusiness Management Review, [s. l.], v. 21, n. 3, p. 407-422, 20 mar. Wageningen Academic Publishers.

Soliani, R. D. (2015) An overview of agribusiness logistics in Brazil. Australian Journal Of Basic And Applied Sciences. [S. l.], p. 410-422. set.

Souza, M. M.; Rocha, M. P. C.; Farias, V. J. C., and Tavares, H. R. (2020) Optimization of soybean outflow routes from Mato Grosso, Brazil. International Journal for Innovation, Education and Research, v. 8, p.176-191.

UNITAPAJÓS. (2021) Nossa Atuação. Valores máximos de referência de tarifa de serviço. Disponível em: https://www.unitapajos.com.br/page/atuacao#atuacao-tres. Acesso em: 03 jun. 2021.

VLI. (2021) Ferrovia Norte Sul - FNS. Disponível em: https://www.vli-logistica.com.br/conheca-a-vli/ferrovias/ferrovia-norte-sul-fns/. Acesso em: 07 jun. 2021.

VLI. (2021a) Tarifa praticada. Disponível em: https://www.vli-logistica.com.br/conheca-a-vli/tarifa-praticada/. Acesso em: 07 jun. 2021.

****