Optimization method applied to decision-making on intermodal alternative for soybean outflow in the State of Pará-Brazil

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Abstract

In Brazil, the sector of agribusiness suffers with the lack of infrastructure for the production outflow and as transportation costs increase, they affect its competitiveness in the world scenario. In this work, an optimization model was developed to support decision-making to soybeans transport for export, in regions in the state of Para (Brazil) near to Tocantins-Araguaia waterway. The study applied a Linear Programming model, adopting the transport problem, in search of minimizing the costs of alternative routes, restricted to the respective supply and demand limitations. The model aimed to minimize the transport costs from the production centers to the exporting port, through the current infrastructure and suggesting the road and waterway intermodal alternative by means of the interior navigation, considering diverse points for transshipment. The results showed a cost reduction for production outflow in the base year of the study when the intermodal transport was used. Furthermore, the new routes only by waterway created a new transport network configuration, decreasing the road distances for the municipalities production outflow, supporting the increasing of competitiveness of the state, as well as providing wealth generation in the region.

Keywords: Intermodal transport; Linear programming; Waterway route, Optimization.

1. Introduction

The agribusiness plays an important role in the Brazilian economy, as demonstrated by the Confederation of Agriculture and Livestock of Brazil (*CNA*), according to information from the National Household Sample Survey (*PNAD*) (IBGE, 2015), with the estimative of 32.3% of Brazilian workers being in the agribusiness (CNA, 2020). The total harvest production of 2019/2020 reached the record of 257,8 million tons of grains, among these, the historical record of 124,8 million tons of soybean (CONAB, 2020). Therewith, the Brazil soybean harvest in 2019/2020 surpassed the USA, which evolved to 96.68 million tons, an estimative of the United States Department of Agriculture (USDA, 2020), this result makes Brazil the largest producer and exporter of soybean in the world.

Among the soybean producing Brazilian states, the State of Para has a growing on a fast rate production. Between the years of 2010 and 2017, there was an expansion in the soybean planted area from 85.4 to 500.4 thousand hectares in Para state. That soy planted area corresponds to 30% of the total area of crops, a greater representativeness among the cultivated cultures in the state (FAEPA, 2019). Figure 1 shows the expanded area of planted soybean in Brazil.

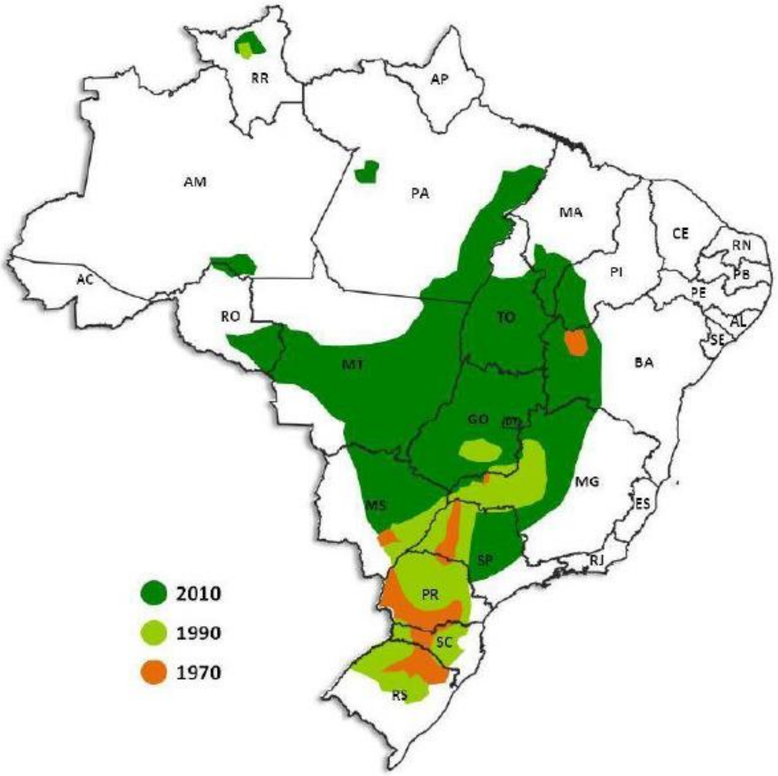

Figure 1: Expansion area of planted soybean in Brazil

Source: CONAB (2016)

Regarding the encouraging data of production growth of agribusiness in Brazil, the sector still suffers with the lack of infrastructure for the production outflow; as transportation costs increase, reaches its competitiveness in the world scenario. The missing conditions of good transportation structure and storage are the biggest problems in the agribusiness (KUSSANO and BATALHA, 2012). Additionally, according to Fioroni *et al.* (2015), the soybean plantations are located in the Brazilian countryside region, away from the cost, which, then, it results in large problems for production outflow.

The transportation costs on the countryside, on average, compose of 80% of the total transport cost of international remittances; however, the transport in that region only corresponds to 10% from the total distance (RODRIGUES and NOTTEBOOM, 2012). Henceforth, the improvements on the countryside-port distribution systems could positively affect the competitiveness, moreover having an important role on the choice of the sender's port and, consequently, on the routing and volume of freight transport (HALIM *et al.*, 2015). It is worth noting that inadequate choices of type of transport result in high operational cost, which narrows the regional development (SOLLIANI, 2015).

The current picture of the Brazilian agribusiness modal matrix, according to the Brazilian Agriculture Research Corporation (*EMBRAPA*), demonstrates that 42% of grans are transported on highways, 47% on railroads and 11% on waterway routes; the latter being the preferred modal for outflow to the *Arco Norte* ports (ports in Brazil above the 16º Parallel, comprising the terminals in the North and Northeast regions), for its low cost, as a result of more participation on the outflow routes in the last years.

In the State of Para, soybean production comprises of three major hubs: The Northeast, led by the municipality of Paragominas; the South, highlighting Santana do Araguaia as its main producing municipality; and the West, led by Santarem. In particular, the production of the South Pole is transported through the highway corridor composed of the BR-158, BR-155 and PA-150 highways, which the transport is carried out by B-double type trucks, with a 57 tons load capacity, for an extension greater than 1,300 km, to reach the port area in Vila do Conde, in the Municipality of Barcarena, in the State of Para. With the predominance of road transport, at a high operational cost, it is common to notice conflicts that increase travel time, such as passing through urban stretches. However, the possibility of making the Tocantins-Araguaia waterway route feasible, there is a new modal alternative which is better for the outflow of soy production in the region (CRUZ, 2019).

Based on these reasons, this work has the purpose of developing an intermodal model of alternative route analysis, to support the decision-making of soybeans transport for export, from various counties in the State of Para. With the premise that it is a transportation problem of a linear programming model (SOUZA et al, 2020), here was a framing in an optimization process of a logistic network of road and waterway transport, serving as base of cost minimization. As analysis, there is the study of the waterway route through the Araguaia-Tocantins route, with scenario simulations, using the General Algebraic Modeling System (GAMS) software, as a computational tool.

2. Grain production and cargo transport aspects

According to APROSOJA/PA (2017) *apud* Cruz (2019), the State of Para holds 130 grain producing counties, with approximately 527,000 hectares of planted area, divided by poles, which are: South, Paragominas and Santarem. Figure 2 provides data about the soybean production in the State of Para.

2.1 Soybean transport

The infrastructure for the transportation of soy is composed of ports, warehouses and specialized terminals, and noting that the reduced infrastructure to support soy transport as being a problem to the sector (DUBKE and PIZZOLATO, 2011). The National Transport Confederation (CNT, 2020) stated that part of the production is destined for the domestic market, sent firstly by road transport to warehouses or processing industries and, later, to the final consumer. Another part is sent to exported ports by highways, railways and waterways. These routes for the production outflow are shown in Figure 3, highlighting the strategic logistical corridors for the soybean export. The high flow of trucks, along with the low state of conversation of the highways, results in high rates of grain losses during the journey to the final destination for every harvest. Moreover, the railroads and waterway routes networks have serious deficiencies (KUSSANO, 2010).

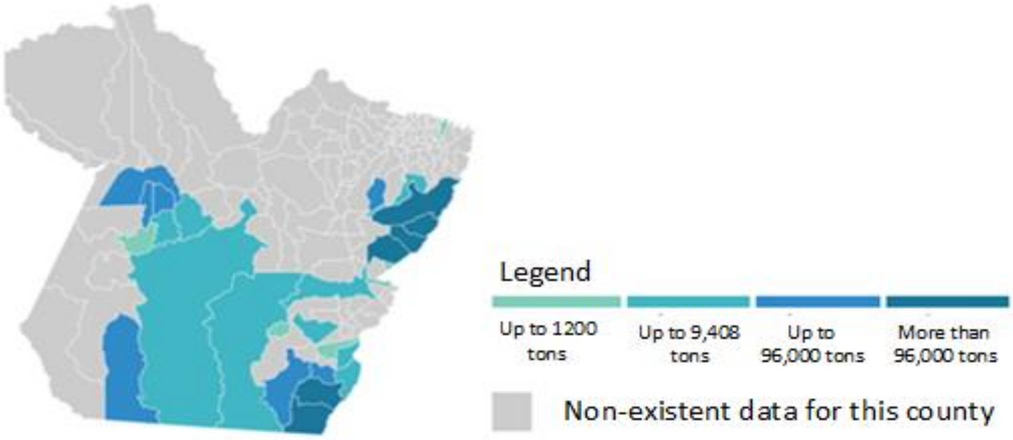

Figure 2: Production of soybean producing counties in the State of Para.

Source: IBGE, 2018

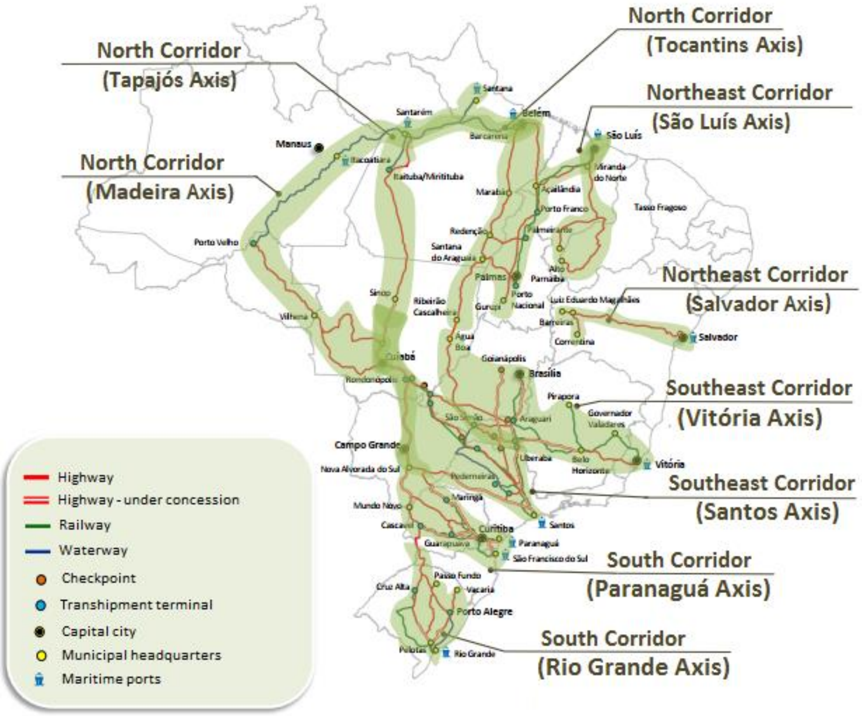

Figure 3: Strategic Logistical Corridors: Exportation

Source: MTPA (2017)

The road modal is also strongly used for logistical outflow in the transport of grains, contributing to the increase of transportation costs. As CONAB explains, the logistical costs of Brazilian agribusiness companies reach 15% of their net revenue in transport, storage and inventory. Thus, the competitiveness of agricultural export commodities is linked to transport costs in multimodal corridors. Therefore, in order to make the decision of the best route, the logistic agent assesses the travel cost and the level of service offered by the transport, and the transport value is relevant to the product competitiveness due to the low added value of the grains (CONAB, 2017).

The expansion of grain production has significant growth in the countryside, in remote locations far away from the export ports, further emphasizing the need for improvements in the Brazilian logistics infrastructure (HIJJAR, 2004). Still, according to CONAB (2017), the North System as an alternative demands crucial investment in infrastructure, given the attractiveness of national agricultural commodities depends on new effective transport corridors, which promote agility for producers and suppliers, good service levels, criteria satisfaction from international customers, as well as provide cost optimization.

2.2 Alternative routes

As the Eastern of Para being one of the new agricultural frontiers, it is expected in the coming years a major increase in production of commodities in that area. In this manner, with the geographical expansion of agribusiness and the increase of agricultural production in the northern regions of the country, a search has been conducted for alternative logistical corridors aiming to soybean and corn outflow (CONAB, 2017). These are the new possibilities presented by *Arco Norte*, considering the ports of main interest in agribusiness that make up this logistical segment (DILOG, 2020): Itacoatiara (State of Amazonas), Santarem and Barcarena (State of Para), Santana (State of Amapa), Sao Luis (State of Maranhao), Salvador and Ilheus (State of Bahia).

Regarding the infrastructure of the *Arco Norte* intermodal corridors, the Araguaia-Tocantins waterway route stands out as an alternative for production outflow of Para. In the case of this waterway route being feasible, it offers an increase of international competitiveness of that region, as well as enlarging the local production. The waterway route has the navigable potential of approximately 3,000 km, noting Araguaia-Tocantins with capacity of 108 m long convoys, 16 m wide and draft of 1,5 m. While the 43 km stretch of Pedral do Lourenco, located between the Ilha da Bogea and Santa Terezinha do Tauri, comprises of 150 m long convoys and 31 m wide, with a minimum draft of 2,1 m (DNIT, 2020).

There is an expectation which the high frequent use of waterway routes in the Amazon hydrographic basin may enhance new intermodal corridors, which will contribute to reducing transport costs from producing regions to export ports. Thus, there are government projects for the Araguaia-Tocantins waterway route, defining the constructions sites and services to be carried out on that route to guarantee continuous, safe and commercial navigation. Among these projects, there is the Araguaia-Tocantins basin executive report of the National Waterway Integration prepared by ANTAQ (2013), which plans improvements of navigation conditions on the waterway route. The report concludes that the infrastructure construction sites to make the marine route as a modal option prove to be viable, as well as there is a significant potential flow of general cargo, solid bulk and solid agricultural bulk to be carried on the waterway route.

Furthermore, there is a project of overthrow in Pedral do Lourenco, to make navigation possible throughout the year on the stretch. The project is on environment license stage and the completion scheduled for October 2022 (PPI, 2020). The waterway route is considered as soon as the construction sites are concluded to allow commercial navigation during all months of the year on the Araguaia-Tocantis waterway route.

3. Case study

The region studied in this work is composed of the municipalities of the State of Para, which are in the area of influence of the Araguaia-Tocantins marine route, considering those areas being part of the Intermediate Geographic Regions Maraba and Redenção, shown in Figure 4. The region of this study has 177,5 thousand hectares of planted area, which corresponds to 32% of the total cultivated area in the State of Para (IBGE, 2018) and the amount of produced soybean in those areas was 498,685.00 tons. For this study, it was considered all annual production dedicated to export, with the production data of each municipality taken from the survey carried out by IBGE (2018), whose values are shown on Table 1.

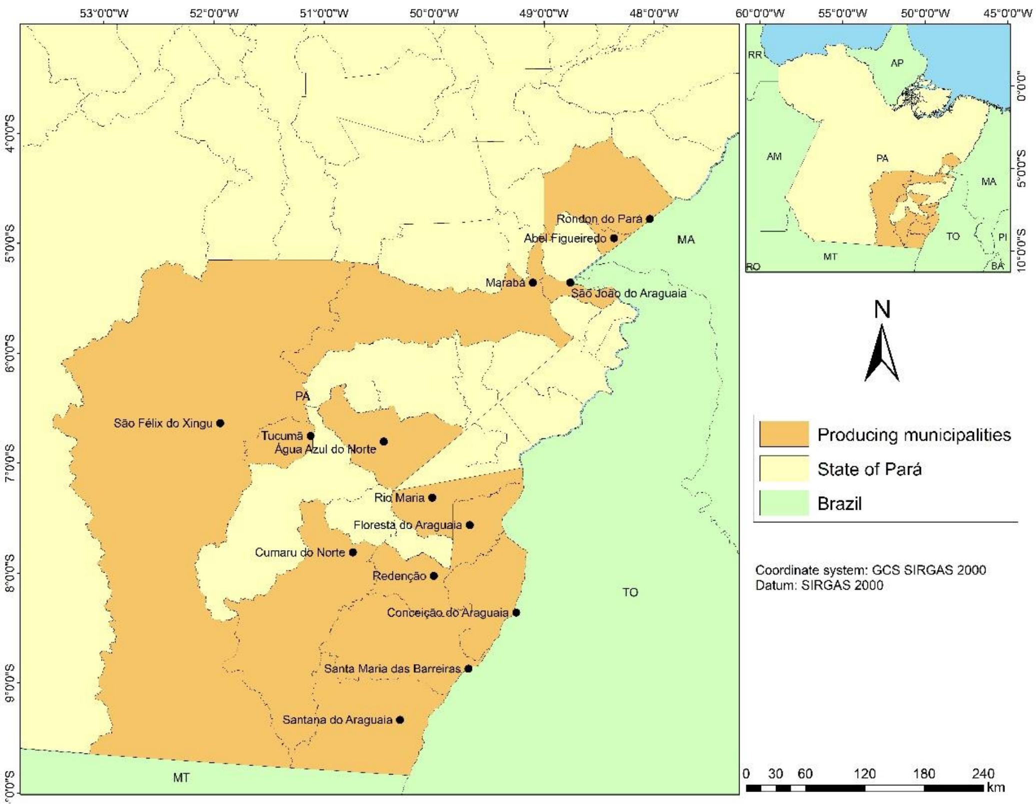

Figure 4: Soybean-producing municipalities chosen for this study.

Source: IBGE (2017)

Table 1: Municipal agricultural production 2018 - IBGE

Municipality	**Anual Production (tons)**
Abel Figueiredo	180.00
Maraba	1,550.00
Rondon do Para	150,000.00
São João do Araguaia	1,120.00
Conceição do Araguaia	4,676.00
Cumaru do Norte	20,504.00
Floresta do Araguaia	8,320.00

Redenção	10,496.00
Santa Maria das Barreiras	96,000.00
Santana do Araguaia	201,600.00
São Félix do Xingu	1,200.00
Tucuma	135.00
Água Azul do Norte	1,800.00
Rio Maria	1,104.00

Source: IBGE (2018)

On the respective analysis carried out in this work, two scenarios were considered, based on the 2018 production data, the current infrastructure and the Araguaia-Tocantins waterway route as a proposed alternative for the intermodal transport. In the 2018-1 scenario, only the routes used by the road modal were considered. On the other hand, the 2018-2 scenario, in addition to the road routes, the Araguaia-Tocantins waterway route was included, with the transport options to the port only by road, as well as intermodal transport (Table 2).

Table 2: Proposed scenario analysis

Scenario	**Routes**	**Production (tons)**
2018-1	Current	Current
2018-2	Road and marine	Current

Source: IBGE (2018)

For the outflow of soybean production from the municipalities studied, several location alternatives were established for cargo transshipment along the waterway route. The purpose of distributed terminal options along the way was to provide several possibilities of points for the optimal choice of the terminal to compose the outflow production routes, in such way the model would have the best locations for the soybean transshipment. The points of the proposed intermodal terminals were established according to existing logistical infrastructure, such as the quality of access, the already established crossings and proximity of municipalities and districts. Figure 5 illustrates the proposed transshipment points on the Araguaia-Tocantins waterway route.

Regarding the road freight, the values were calculated based on the mathematical formulation from the table of minimum prices for road freight transport established by the National Land Transport Agency (ANTT, 2020). The transshipment value data from the road modal to the waterway modal (road and waterway combined) used in this work are based on the work of Cruz (2019), which obtained the value used by the market in 2018. Then, the value considered for the intermodal road and waterway transshipment was R$ 25,00 (Brazilian Real currency) per ton, converting to US dollar currency the value is US$[1] 6.84.

[1] All monetary values of this work were obtained initially in Brazilian Real currency, later converted to the average value of the US dollar in the year 2018, released by the Institute of Applied Economic Research (IPEA). Exchange rate - R$/US$ - commercial - sale - average - 2018: 3.6542 (IPEA, 2021).

Figure 6 has the main road corridors for production outflow of the region, as well as the main rivers, which make up the waterway route under study, the Araguaia-Tocantins.

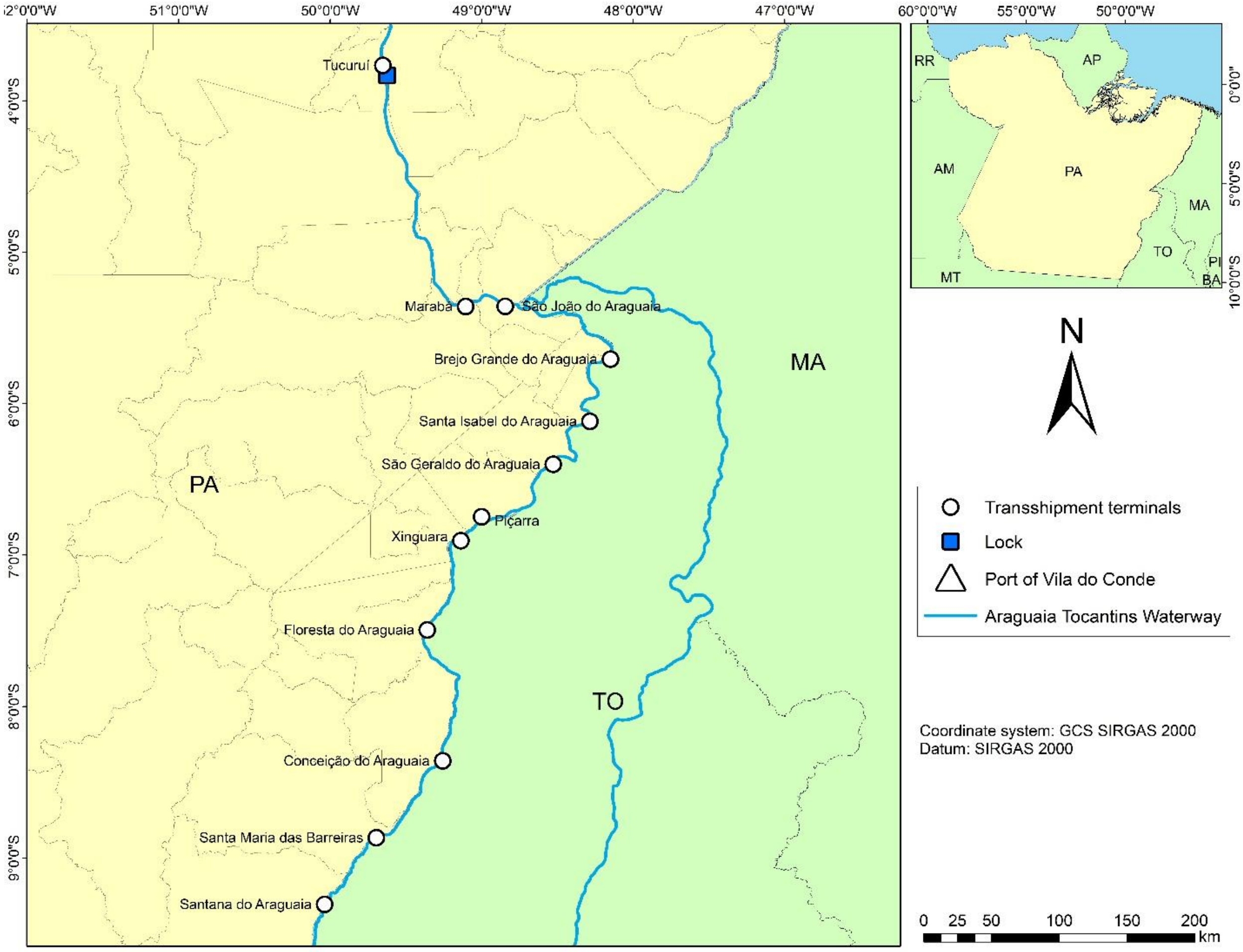

Figure 5: Proposed points for transshipment terminals

Source: IBGE (2017)

The transportation costs of the marine modal were obtained through the Transport Cost Simulator tool (*Simulador de Custo de Transporte*), developed and made available by the Planning and Logistics Company, which is a public initiative aiming to provide services that involve planning of infrastructure, logistic and transport in Brazil (PNL, 2020). Table 3 provides the transport costs on the waterway routes formed from each proposed intermodal transshipment terminal.

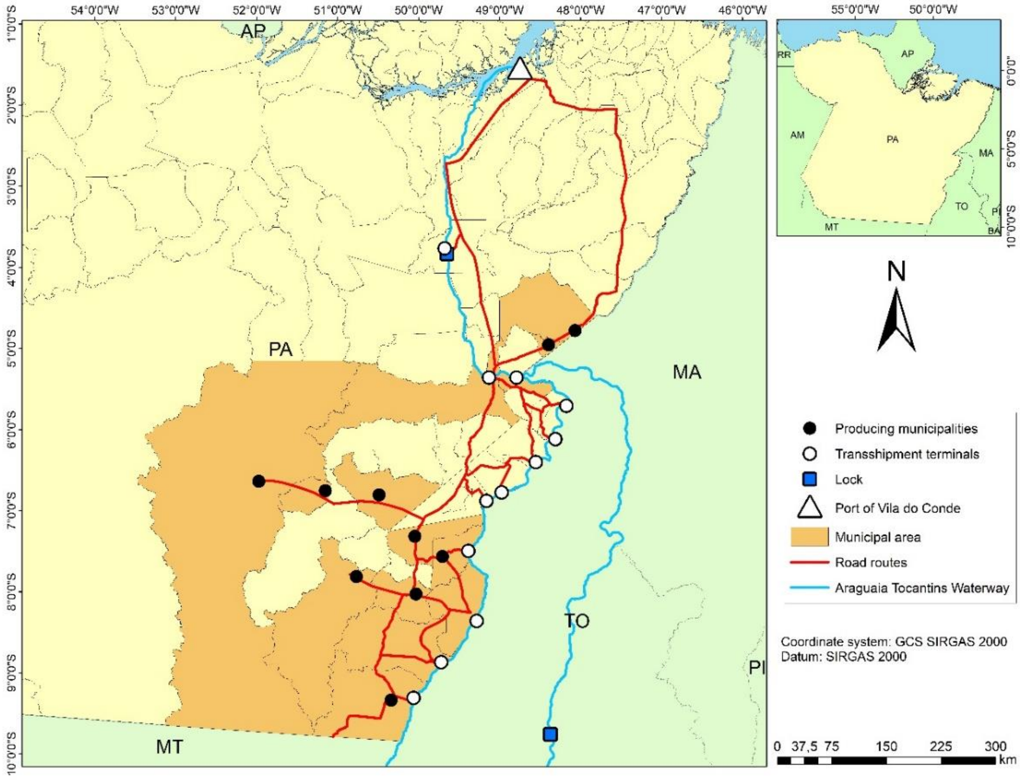

Figure 6: Main routes for municipalities production outflow

Source: IBGE (2017)

Table 3: Freight cost of water transport

Terminal that begins the waterway route	Cost (US$/ton)
Terminal 1 (Tucuruí)	2.84
Terminal 2 (Maraba)	5.89
Terminal 3 (São João do Araguaia)	6.32
Terminal 4 (Brejo Grande do Araguaia)	7.21
Terminal 5 (Santa Isabel do Araguaia, Palestina do Pará)	7.81
Terminal 6 (São Geraldo do Araguaia)	8.36
Terminal 7 (Piçarra)	8.99
Terminal 8 (Xinguara)	9.20
Terminal 9 (Floresta do Araguaia)	9.88
Terminal 10 (Conceição do Araguaia)	10.86
Terminal 11 (Santa Maria das Barreiras)	11.57
Terminal 12 (Santana do Araguaia)	12.14

3.1 Proposed transport model

The transport network for the flow of soybean towards export has the producing municipalities (production centers) as the starting point, transshipment points at the proposed intermodal terminals and end point at the export port, with modal alternatives to connect the nodes from the logistical network. According to Kazemi and Szmerekovs (2015), the storage at the transshipment sites is performed in a short period. The operation aims to transfer the cargo to another modal, in this way, the transshipment sites were defined as zero stock points. Since the model was developed based on the optimization technique, using the linear programming as a tool, the concepts of Networks Models were applied to transport and transshipment problems (ARENALES *et al.*, 2011; FAVERO and BELFIORE, 2013; HILLER and LIEBERMAN, 2006).

The linear optimization model has the objective of minimizing the global transport cost, and, therefore, was composed by the transport costs in road mode to the export port or to the intermodal terminal, intermodal transshipment costs and costs in the waterway mode performed from the terminal to the port. Below (eq. 1), the Z objective function is shown:

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

Subject to:

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

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

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

Where:

i: Producing soybeans municipalities, $i \in I$.

j: Soybean exporter port, $j \in J$.

k: Intermodal transshipment terminals of soybeans, $k \in K$.

I: Set associated with origins (producing municipalities).

J: Set associated with exporter port.

K: Set associated with intermodal transshipment terminals.

CR_{ij}: Road transport cost in Brazilian Real per ton originating at the producing municipality i to the exporting port j.

CT_{ik}: Road transport cost in Brazilian Real per ton originating at producing municipality i to intermodal transshipment terminal k.

CI_{kj}: Intermodal waterway way transport cost in Brazilian Real per ton originating at intermodal transshipment terminal k to the exporting port j.

DMP_{ij}: Distance in kilometers between the producing municipality i and the exporting port j.

DMT_{ik}: Distance in kilometers between the producing municipality i and the intermodal transshipment terminal k.

DT_{kj}: Distance in kilometers between the intermodal transshipment terminal k and the exporting port j.

EXP_j: Total export of grains of the exporting port j, in tons per year.

PRO_i: Total production of grains for export of the producing municipalities i, in tons per year.

SMP_{ij}: Flow of grains in tons in the road modal originating at the production municipality i to the exporting port j.

SMP_{ik}: Flow of grains in tons in the road modal originating at the production municipality i to the intermodal transshipment terminal k.

ST_{kj}: Flow of grains in tons in the road modal originating at the intermodal transshipment terminal k to the exporting port j.

TR_k: Transshipment operation cost at the intermodal terminal k, in Brazilian Real per ton.

4. Results

Figure 7 shows the results generated by the model, referring to the total cost the transport network, as obtained in each scenario considered in this work, noting the scenario that made use of intermodality presented a result with a lower final value. The scenario with marine route transport showed a reduction of 40.27 % in relation to the costs of the base scenario, with a total reduction cost of US$ 7.280.429,44 for soybean production outflow.

In the 2018-2 scenario, the majority of transport consists of routes in the waterway transport. The results of this scenario demonstrated all municipalities chose intermodal transport to compose a stage of their route to carry out agricultural production. As a result, the major part of costs consisted of the sum of the intermodal transshipment costs and the waterway transport costs. Thus, 82% of the total transport cost in the scenario is related to the waterway mode and 18% to the road mode.

As the best result to form the transport network, in the scenario which makes use of the intermodality, seven terminals were selected which best contributed to the agricultural production outflow. These were the terminals chosen as result of the total cost optimization, obtaining the best route configuration for the various municipalities studied. In order to validate the generated results, the model was remade as transshipment option only the selected terminals in the first optimization (Table 4). In this way, the results of the first optimal solution were maintained, then, it can be concluded the result of the mode for choosing the terminals is satisfactory.

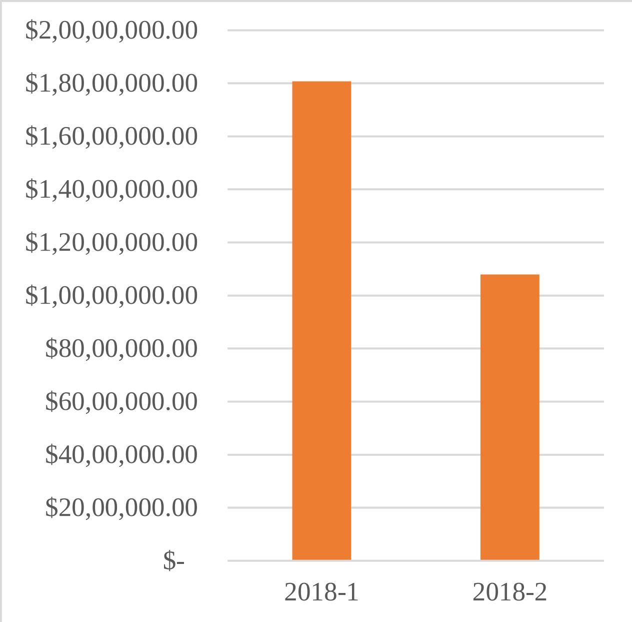

Figure 7: Total cost for each scenario.

Table 4: Selected terminals (2018-2 scenario)

Intermodal terminal	Distance to the port (km)
Terminal 2 (Marabá)	500.00
Terminal 3 (São João do Araguaia)	550.00
Terminal 8 (Xinguara)	880.00
Terminal 9 (Floresta do Araguaia)	958.00
Terminal 10 (Conceição do Araguaia)	1071.00
Terminal 11 (Santa Maria das Barreiras)	1152.00
Terminal 12 (Santana do Araguaia)	1218.00

From the 2018-2 scenario, which all municipalities resulted in the use of intermodal transport to drain their production, with different results between the two scenarios of the routes to transport soybeans, consequently, the total distance traveled, in km, from the production center to the exporting port was different from scenario 2018-1 for all the municipalities, as it is shown in Table 5. Table 5 provides the total distance traveled on the routes from several municipalities in the respective scenarios: Abel Figueiredo, Rondon do Para e Floresta do Araguaia, with a smaller difference and increases of 13%, 30% and 33%, respectively. The major changes among the scenarios occurred in Rio Maria, Cumaru do Norte and Redenção, with differences of 46%, 41% and 45%, respectively. In other words, there is a tendency that the farther away the selected intermodal terminal is from the mouth of Tocantins River, the greater the total distance traveled on the route; this happens because the closer to the mouth it gets, the more linear the waterway route becomes. Table 6 provides the resulting costs, part from the municipalities, in each mode on scenario 2018-2, noting that the waterway route cost includes the transport and transshipment costs.

Table 5: Route's extension

Municipality	Total distance to the port (km)	
	2018-1	2018-2
Abel Figueiredo	553,00	623,30
Rondon do Pará	511,00	666,00
Floresta do Araguaia	756,00	1,004.20
São Felix do Xingu	963,00	1,27900
Tucumã	862,00	1,177.00
Água Azul do Norte	778,00	1,093.00
Rio Maria	738,00	1,078.00
Cumaru do Norte	905,00	1,272.00
Redenção	816,00	1,182.00

Table 6: Cost per modal (2018-2 scenario)

Municipality	Cost (US$/ton)	
	Road	waterway
Abel Figueiredo	US$ 4,93	US$ 13,80
Rondon do Pará	US$ 6,71	US$ 13,80
Floresta do Araguaia	US$ 3,80	US$ 17,51
São Felix do Xingu	US$ 18,48	US$ 16,80
Tucumã	US$ 14,24	US$ 16,80
Água Azul do Norte	US$ 10,74	US$ 16,80
Rio Maria	US$ 6,87	US$ 17,51
Cumaru do Norte	US$ 10.24	US$ 18,54
Redenção	US$ 6,50	US$ 18,54

Figure 8 shows the results of transport cost for soybean outflow for the various municipalities in different admitted scenarios. The production centers with the smallest difference in value between the scenarios were in Tucuma with 7% and 11% in Sao Felix do Xingu and Rondon do Para. Rondon do Para had the second shortest road distance in 2018-1 scenario. Sao Felix do Xingu and Tucuma are the municipalities, which presented the highest percentages of road cost in the total of 2018-2 scenario. Respectively, the first with 52% and the second with 42% of their costs are made up of road transport.

Still, in Figure 8, there are the biggest differences between the transport cost values of the scenarios, occurred in Floresta do Araguaia, Rio Maria and Conceição do Araguaia, with a decrease of 45%, 41% and 53% in transport, respectively. Such municipalities have a predominance of waterway route mode, accounting with 88% of the route by waterway transport in 2018-2 scenario. By analyzing the total cost in relation to the total flow of soybean, in 2018-1 scenario, the value for transporting one ton of soybean was US$ 36,25/ton and, in 2018-2 scenario, was US$ 21,66/ton. Considering the values of each route, the average cost per ton of the municipalities to transport soy to the exporting port, in 2018-1 scenario, was US$ 33,64/ton and, in 2018-2 scenario, was US$ 23,36/ton, with latter scenario presenting the lowest values.

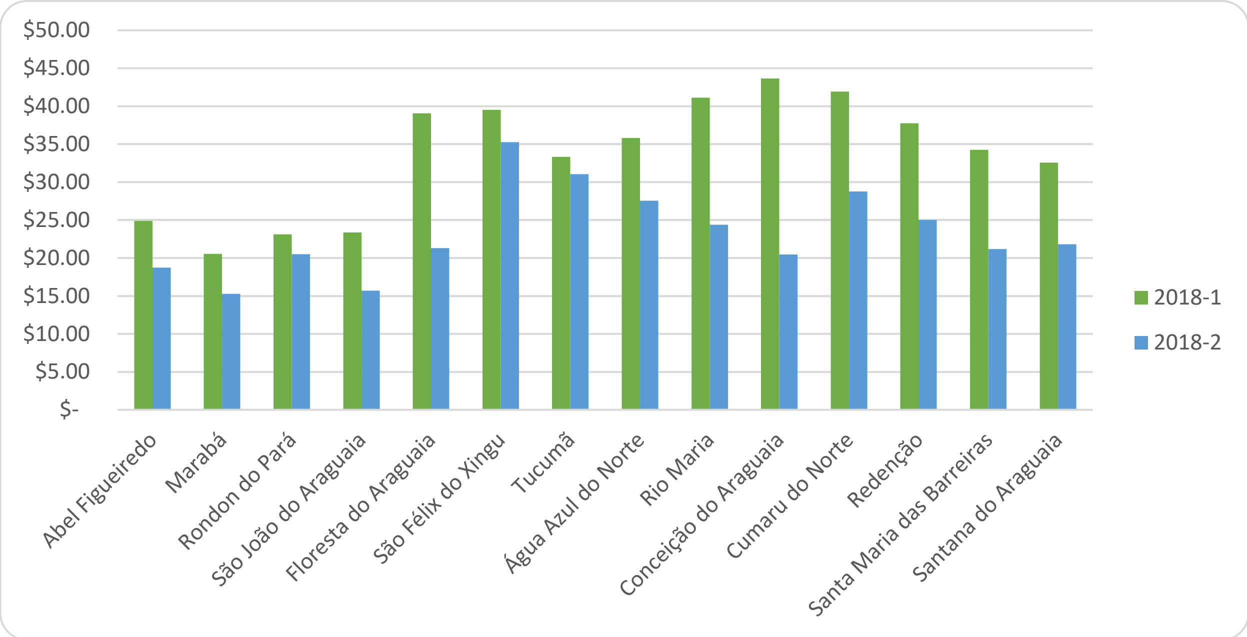

Figure 8: Cost per transported ton of the municipalities in each scenario

5. Conclusion

Considering the production increase of soybean in the State of Para, which requires competitive infrastructure for the agricultural production outflow, the proposed model presented satisfactory results in the analysis of modal transport alternative for the soybean outflow, in the studied region, concluding the waterway transport as logistically feasible, as an alternative to the transport of soybeans and, also, due to the reliability of the model results, there is the hypothesis of application in other scenarios and situations.

In the admitted scenarios for analysis in this work, all production centers achieved reduction cost when using intermodal transport, showing an increase of competitiveness, with inland navigation implemented for municipalities production transport. In this scenario, there is a change in the transport network configuration, with the trend of distribution intermodal terminals along the waterway route, in order to provide the best arrangement of routes. Thus, this work showed the benefits which can be generated through the implementation of the Araguaia-Tocantins waterway route.

Therefore, the modeling presented the need for investments in infrastructure in the region, aiming to make marine transport fully viable, to guarantee reduction costs, since the results obtained pointed to a reduction of R$ 26,604,154.27 in transport costs. On the other hand, there is a great opportunity to increase competitiveness, with a greater participation of a sustainable transport, thus, reducing the heavy truck traffic on the road corridor, reducing environmental impacts in the cities that are along the route to the exporting port, also, provide wealth generation and, moreover, make the State as a large producer and exporter of grains.

Although the objective of this work was to bring information to support decision-making, studies that complement it are necessary, such as the analysis of technical-economic feasibility for the marine route implementation and the transshipment capacity of intermodal terminals.

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