Optimization of soybean outflow routes from Mato Grosso, Brazil

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Abstract

The purpose of this work is to apply a transshipment model, based on the theory of linear programming in a problem of optimization of the flow cost of soybeans from the State of Mato Grosso. The model consisted of analyzing the cost of transportation through the current transportation infrastructure, proposing two new options, being waterway and railway, as well as maintaining the port capacity of Arco Norte. 2018 production and projections for 2025 and 2030 were also considered. The results showed that the greatest reductions in transportation costs in 2018 occurred in the flow of production through Arco Norte. In addition, the new intermodal routes have significantly changed the transportation matrix, contributing to Brazilian competitiveness in the foreign market and assisting in the development of the North and Northeast regions.

Keywords: Linear Programming; Transshipment problem; Logistics.

1. Introduction

Brazilian agribusiness corresponds to 21.1% of the country's Gross Domestic Product (GDP) [3]. Exports in 2019 reached 82 million tons, with the Midwest region responsible for 45% of the total [19]. Brazil, then, is the second largest producer of soy in the world, and the state of Mato Grosso is configured as the largest producer state. However, inconsistent with the positive impact of agribusiness on the Brazilian economy, the country has an ineffective logistics infrastructure, which increases transport costs and contributes to greater environmental impacts.

Logistic service providers respond to the tension between transport demand and transport supply by dynamically adapting their services and strategies, ensuring that producer, product, and client are met. They make strategic decisions about the selection of the right modes of transport, the location of distribution centers, and the connections between distribution center locations and modes of transport, in an effort to continuously reduce generalized logistics cost [12]. In terms of cost, transportation represents around 60% of logistics costs, which makes it a strategic activity for any production chain [6].

For producing regions more distant from exporting ports, such as Mato Grosso, the transportation cost represents up to 27.5% of the soybean price that arrives at the final importing port, with internal transport responsible for up to 23% of these costs [24]. In 2018, Brazil's logistical costs were estimated at 12% of the Gross Domestic Product (GDP), the amount invested by the federal government in infrastructure was only 0.16% of GDP, and the cost to solve deficiencies in the infrastructure of transportation and logistics

was estimated at US$ 3.3 billion, in all modes [4].
Brazilian soy is transported to the foreign market mainly through the ports of the South and Southeast regions, with Santos, in the State of São Paulo, Paranaguá, in the State of Paraná, and Rio Grande, in the State of Rio Grande do Sul being the main exporting ports of the Brasil [19]. These ports, despite having better port infrastructure in terms of productivity, will soon be unable to keep up with the increased demand [18]. With the growing expansion of production in the Midwest, Northeast and North, the lack of port infrastructure in these regions drives exports through ports in the South and Southeast [26].

Within this aspect, the state of Mato Grosso stands out because it is the only one that exports cargo to all the main ports, and many counties have more than one destination port. In Brazil, 27 cities export more than 500 thousand tons of soy and corn and have more than one port as destination. Of these, 15 are in Mato Grosso, which makes it beyond the largest producing state, also the state with more options for transshipment terminals. However, most of the soy from mato grosso is transported by roads, totalizing 3042 km, of which 1647 km are unpaved and 1395 km are paved and the investment to adapt the infrastructure to agribusiness exports is at least US$ 67.50 million, of which US$ 10.36 million in conservation and US$ 57.14 million in [8, 14].

In this paper we set the soybean transportation cost as the research object, based on linear programming model, we optimize the soy logistics distribution for the ports. We adopt the transshipment problem (TP) to model the cost of the routes, considering the current routes and proposing two new routes, the Ferrogrão Railway and the Araguaia-Tocantins Waterway. Calculations of the models are implemented on General Algebraic Modelling System (GAMS) [2] and it will be made an analysis on cost reduction and change in the transportation matrix in the current and proposed scenarios.

2. Agribusiness and cargo transportation infrastructure

Agribusiness continues to emerge as a segment of significant relevance in the Brazilian economy and can be defined according to data from the Center for Advanced Studies in Applied Economics (CEPEA) in a set of four segments: inputs, basic or primary agricultural production, agribusiness and agroservices. Its participation in Brazil's Gross Domestic Product (GDP) in 2017 was 21.6%, with an average of 24.63% when considering the period from 1996 to 2017 [20].

The significant increase in soybean production in the last decades is due to five factors: 1) an important product for human and animal food, as it has a significantly high protein content, around 40% of its composition; 2) potential for the production of oil products by extracting its oil and bran, mainly for food and biodiesel production; 3) the characterization of soy as commodity, that is, it is standardized and uniform, with wide possibility of cultivation; 4) the presence of liquidity and high demand in the global market and 5) increased supply due to productive technological advances [14].

The concentration of soy production is mainly in the Brazil's Midwest region (see Figure 1), being responsible for 45% of production in the 2018/19 and 2019/20 harvest, with 52.6 and 54.5 million tons respectively and the main producing state is Mato Grosso, with 33 million tons, about 27.5% of all national production. The southern region is the second most productive, concentrating about 32% of soy production, corresponding to 40.0 million tons. The Northeast has the third largest production in the country, with 10.5 million. Finally, the Southeast and North regions, with respectively 8.8 and 6.2 million tons [5].

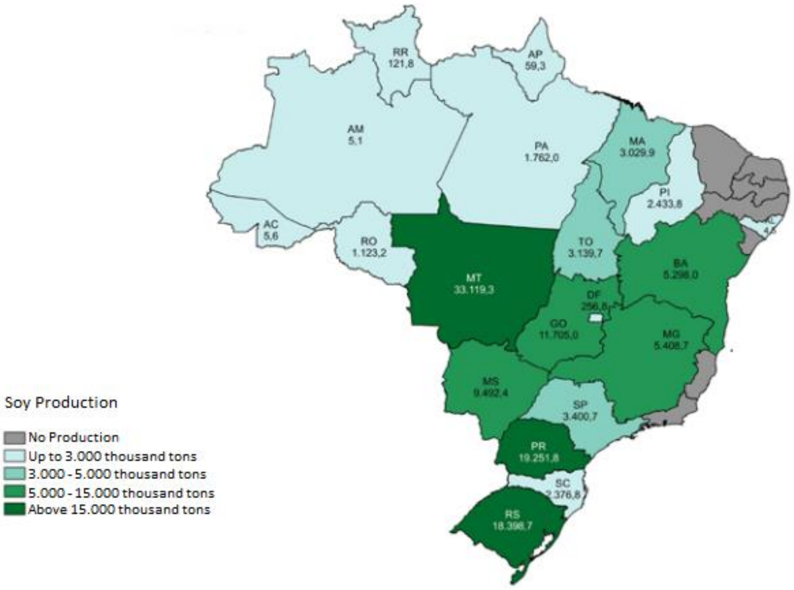

Figure 1: Agricultural production - Soybeans (2018/2019 harvest)

2.1 Soy transportation logistics

The flow of agricultural production occurs in different stages. One is sent directly from crops to public warehouses, rural properties, cooperatives or tradings characterized by fragmented road transport and high costs. The other is for transporting products from crops to processing industries or directly to export ports [4]. Figure 2 illustrates the process of transporting from origins to destinations.

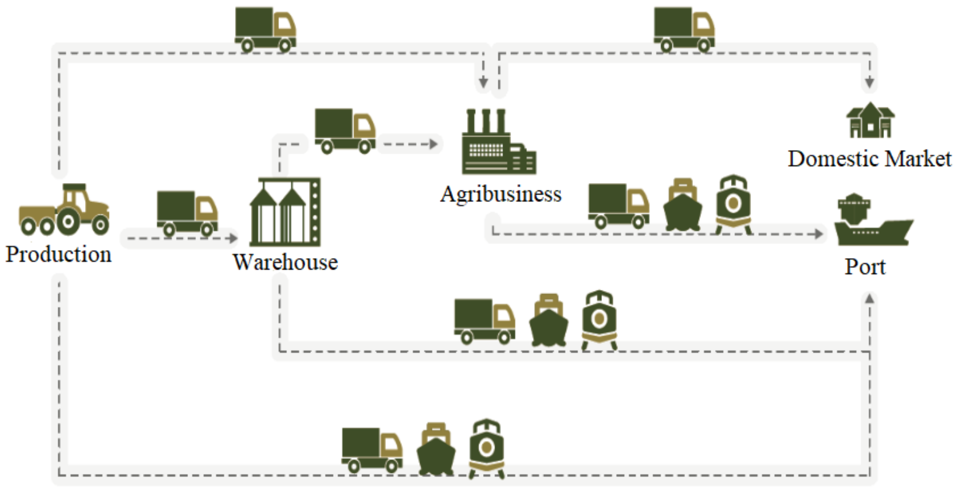

Figure 2: Logistics of the distribution of grains and derivatives in Brazil

The outflow of soy production is carried out mainly by road, and according [11] the problem with the road transport of most of the soy is the load capacity, which is extremely reduced in relation to the rail and waterway modes. The distribution of production destined to the processing industries and later the domestic consumer market is carried out by road. The cargo destined for export ports is transported by highways, railways and waterways, and in some cases by the combination of modes [4].

In addition to implications for fuel consumption and emission of polluting gases, soy transportation takes place over long distances on poorly maintained roads [15]. The infrastructure for the flow must consider not only the modes of transport, but also the existence of warehouses for the maintenance of harvests and port infrastructure for cargo transshipment or export on long-haul vessels. Currently, the growth estimate for grain production exceeds the capacity to expand national infrastructure with direct consequences on transportation, breaches of contract, delays in delivery and loss of significant portions of international markets [4].

2.2 The Arco Norte

With the presence of the largest producers in the northern region of Mato Grosso, an option would be the flow of production through ports in the North and Northeast. Thus, the search for new alternatives became a priority due to the geographical expansion of the agribusiness frontier [4]. From this analysis, flow via Arco Norte emerged as a possible alternative. The same was defined as the export zone by the Porto Velho (state of Rondônia) and Miritituba (state of Pará) terminals destined for the ports in the North and Northeast of the country, bringing together the ports of Itacoatiara (state of Amazonas), Santarém (state of Pará), Vila do Conde (state of Pará), Itaqui (state of Maranhão) and Santana (state of Amapá) [9, 26].

Within the infrastructure investment aspect, especially in Arco Norte, a project stands out for the possibility of increasing Brazil's competitiveness in the face of international trade and establishing it as the world's largest soy exporter in the coming years, the Ferrogrão railway. The project, has an extension of 933 km, connecting the grain-producing region of the Midwest to the State of Pará, ending at the Port of Miritituba, later reaching the port of Santarém. The projected demand for the year 2020 is 25 million Useful Tonnes (TU) and 42 million TU in 2050, with a concession term of 65 to the private sector. The project is currently under public consultation [21].

Another opportune enterprise for the logistics of Arco Norte is the Araguaia-Tocantins Waterway. The project defines the capacity of transport in trains in 108 meters in length, 16 meters in breadth and draft of 1.5 meters. The 43 km stretch of Pedral do Lourenço, which lies between Ilha da Bogéa and Santa Terezinha do Tauri, includes trains 150 meters long and 32 meters wide, with a minimum draft of 2.1 meters [7] Currently, there is a project to demolish the Pedral do Lourenço, which seeks to facilitate commercial navigation on the waterway throughout the year. According to [22] this initiative is in the environmental licensing phase and the completion of the work is scheduled for October 2022.

The use of waterways in the Amazon basin, as well as railroads, combined with the shortest distances between producing regions and ports, drive the reduction of logistics costs and increase competitiveness. However, there are still major obstacles, such as the lack of investments in port facilities and road access, in addition to the expansion and integration of the rail network with other modes. Figure 3 illustrates the Arco Norte, with the projects of Ferrogrão Railway and Araguaia-Tocantins Waterway.

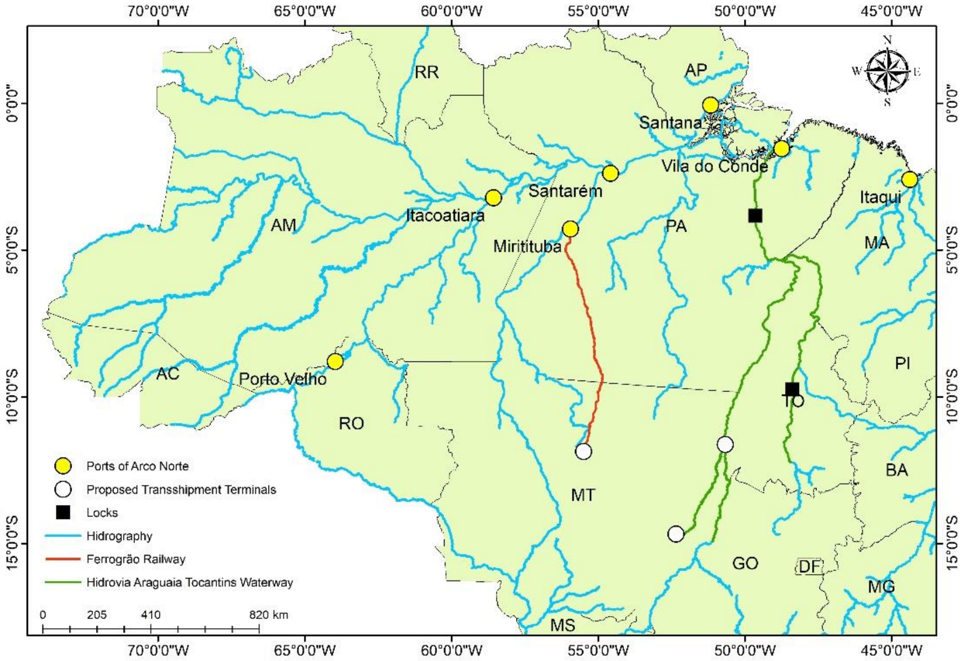

Figure 3: The Arco Norte

3. Case study

For the collection of data related to road taxes, intermodal freight and port taxes, the values were taken from [25], where secondary sources are also used to survey other data, namely the Brazilian Institute of Geography and Statistics (IBGE) and National Supply Company (CONAB) for production and Ministry of Agriculture, Livestock and Supply (MAPA) for production projections; System of Freight Information (SIFRECA), for rail freight and waterways; and the Ministry of Industry, Development and Foreign Trade (MDIC), for export. Inflation projections were taken from the Fiscal Monitoring Report, carried out by the Brazil's Federal Senate.

To quantify the supply of soybeans in Mato Grosso, data from Municipal Agricultural Production from the Brazilian Institute of Geography and Statistics was used. To quantify the production projections for 2025 and 2030, data from Ministry of Agriculture, Livestock and Supply (MAPA) was used [19]. Eight centroides were considered responsible for concentrating all state production and considering all four micro-regions. To standardize the analysis, some regions had more than one producer centroid, such as the North region, while other regions concentrated production in only one region, such as Northeast and Southwest-Center-South, as shown in Table 1.

Table 1: Projection of Municipal Agricultural Production 2018/2030 - IBGE / MAPA

Mesoregion	**Centroid**	**Production (t)**		
		2018	2025	**2030**
North	Brasnorte	1,441,854	1,872,808	**2,097,785**
	Campo Novo dos Parecis	6,736,102	8,8749,446	**9,800,505**
	Sorriso	7,810,388	10,144,824	**11,362,507**
	Sinop	4,053,449	5,264,979	**5,897,453**
Northeast	Querência	5,961,411	7,743,248	**8,673,433**
Southwest-Center-South	Tangará da Serra	1,149,866	1,493,548	**1,672,966**
Southeast	Primavera do Leste	2,382,233	3,094,250	**3,465,958**
	Itiquira	2,073,233	2,692,899	**3,016,393**
TOTAL		**31,608,562**	**41,056,000**	**45,988,000**

In the quantification of demand, we considered the volume of exports from the State of Mato Grosso through the main ports, which concentrate more than 90% of exports, namely: Santos, State of São Paulo; Paranaguá, State of Paraná; Rio Grande, State of Rio Grande do Sul; São Francisco do Sul, State of Santa Catarina; Santarém, State of Pará; Vila do Conde, State of Pará; Vitória, State of Espírito Santo; Itaqui, State of Maranhão and Itacoatiara, State of Amazonas.

In this work, three years were considered in the analysis, 2018, 2025 and 2030, taking into account the respective production (2018) and projections (2025, 2030) in the cities and demand in the Brazilian ports. In the scenarios 2018.1, 2018.2, 2018.3 and 2018.4 the values of road freight, intermodal freight and port tariffs remained the same with respect to the of the modeling. In the scenarios 2025.1, 2025.2, 2025.3, 2025.4, 2030.1, 2030.2, 2030.3 and 2030.4, the production and demand values were corrected taking into account the projections according. Table 2 illustrates the analyzed scenarios.

Table 2: Scenario analysis proposed

Scenarios	**Routes**	**Port Capacity**
2018.1	Current	**Current**
2018.2	Current	**+50% Arco Norte**
2018.3	Current + Railway + Waterway	**+50% Arco Norte**
2018.4	Current + Railway + Waterway	**+100% Arco Norte**
2025.1	Current	**Projected**
2025.2	Current	**+50% Arco Norte**
2025.3	Current + Railway + Waterway	**+50% Arco Norte**
2025.4	Current + Railway + Waterway	**+100% Arco Norte**
2030.1	Current	**Projected**
2030.2	Current	**+50% Arco Norte**
2030.3	Current + Railway + Waterway	**+50% Arco Norte**
2030.4	Current + Railway + Waterway	**+100% Arco Norte**

For modeling, the scenarios 2018.1, 2025.1 and 2030.1 represent the base scenarios and the scenarios 2018.4, 2025.4 and 2030.4 are considered the optimal scenarios. The scenarios 2018.3, 2018.4, 2025.3, 2025.4, 2030.3 and 2030.4 include Ferrogrão Railway and Araguaia Tocantins Waterway. Figure 5 shows the current soybean logistics and the proposed routes.

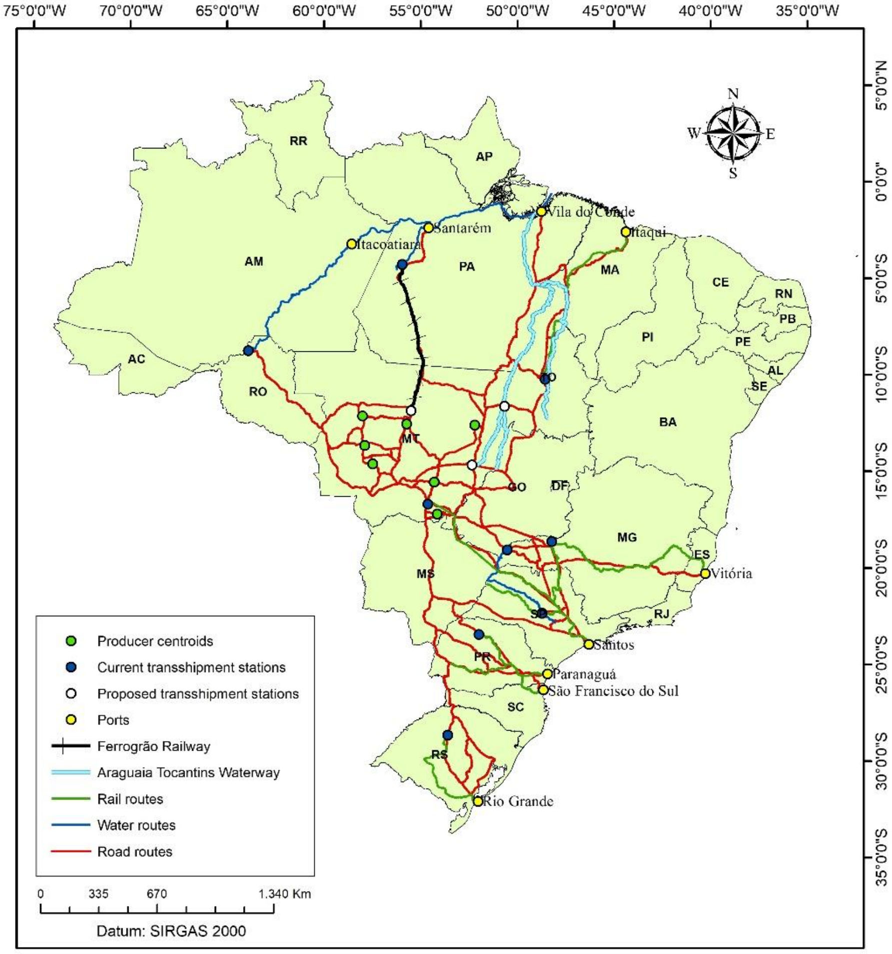

Figure 4:The flow of soy from Mato Grosso, Brazil

The basis for calculating values such as port taxes and road and intermodal freight was based on the Fiscal Monitoring Report (RAF) which details the projections of the macro-fiscal variables in the months of May and November. Table 3 shows the values in three scenarios: base, optimistic and pessimistic and was published in November 2019.

Table 3: Macroeconomic projections - Federal Senate of Brazil

RAF	**Base scenario**			**Optimistic scenario**			**Pessimistic scenario**		
	2018	2020	2023-2030	2018	2020	2023-2030	2018	2020	**2023-2030**
IPCA (%)	3.7	3.5	3.5	3.1	3.4	3.3	3.3	4.4	**5.0**

Regarding road freight, the values were based on [25], which estimated the freight curves by logistic corridors. The query database was the Freight Information System (SIFRECA). Table 4 shows the freight per corridor.

The data for transshipment, rail freight and water freight rates used in this work come from [25], as shown in Table 5, obtained through the collection of information from the agents involved in the respective operations. The capacity was considered sufficient for the flow of production in all terminals, in all scenarios.

Table 4: Freight by corridor type

Corridor type	Destination	Angular coefficient	Intercept	Estimated freight (US$/t)		
				200 km	1000 km	2000 km
Railway	Rondonópolis (SP)	0.0214	7.1561	11.43	28.53	49.91
Railway	Maringá (PR)	0.0224	3.2674	7.74	25.64	48.01
Railway	Araguari (MG)	0.0231	5.8835	10.50	28.95	52.02
Railway	Cruz Alta (RS)	0.0241	2.0565	6.88	26.17	50.29
Railway	Porto Nacional (TO)	0.0302	1.9883	8.03	32.18	62.38
Railway/Waterway	Sinop (MT)	0.0211	5.4912	9.70	26.56	47.63
Waterway	São Simão (GO)	0.0273	4.5676	10.03	31.89	59.21
Waterway	Miritituba (PA)	0.0237	25.7223	30.46	49.43	73.14
Waterway	Porto Velho (RO)	0.0136	16.2660	18.99	29.90	43.53
Waterway	Nova Xavantina (MT)	0.0211	5.4912	9.70	26.56	47.63
Waterway	S. Félix Araguaia (MT)	0.0211	5.4912	9.70	26.56	47.63
Port	Santos (SP)	0.0216	10.4616	14.78	32.03	53.61
Port	Paranaguá (PR)	0.0205	8.7569	12.85	29.22	49.69
Port	Vila do Conde (PA)	0.0172	16.3612	19.81	33.60	50.85
Port	Santarém (PA)	0.0172	16.3612	19.81	33.60	50.85
Port	Rio Grande (RS)	0.0196	5.0052	8.92	24.60	44.19
Port	São F. do Sul (SC)	0.0201	7.7836	11.81	27.92	48.06
Port	Itaqui (MA)	0.0164	10.8295	14.10	27.20	43.57
Port	Vitória (ES)	0.0188	11.1003	14.86	29.88	48.65

The ports chosen in this research correspond to more than 90% of the soy flow through Brazilian ports and the data regarding export capacity refer to the largest annual flow per port between the years 2014 and 2018, which were obtained from the Ministry of Industry (Table 6), Development and Foreign Trade [19].

3.1 The transport model

Optimal selection of transportation-transshipment routes is a challenge faced by many vendors and inability to select the right combination of paths can cause a big dent to profit margins [1]. Transshipment points are defined as points with zero inventory i.e., whatever is transported to such points are not stored for long, rather transferred to next locations [16]. It is important to use warehouses, select acquisition paths, allocate to inventories and target distribution points in an economical way and with a higher response rate, as delivery based on time is appreciated by customers [10].

Table 5: Intermodal freight

Terminal	Port	Intermodal freight (US$/t)
Rondonópolis (SP)	Santos (SP)	28.20
São Simão (GO)	Santos (SP)	19.54
Maringá (PR)	Paranaguá (PR)	15.31
Araguari (MG)	Vitória (ES)	19.14
Miritituba (PA)	Vila do Conde (PA)	12.62
Miritituba (PA)	Santarém (PA)	7.05
Cruz Alta (RS)	Rio Grande (RS)	8.06
Porto Nacional (TO)	Itaqui (MA)	12.09
Porto Velho (RO)	Itacoatiara (AM)	12.09
Sinop (MT)	Santarém (PA)	25.12
Sinop (MT)	Vila do Conde (PA)	31.15
Nova Xavantina (MT)	Vila do Conde (PA)	16.56
S. Félix Araguaia (MT)	Vila do Conde (PA)	16.56

Table 6: Port capacity and taxes

Port	Port capacity (in 1000t)	Port Taxes (US$/t)
Santos (SP)	9,065.656	6,79
Paranaguá (PR)	1,494.180	5.55
Rio Grande (RS)	285.174	5.24
São Francisco do Sul (SC)	758.866	5.49
Vila do Conde (PA)	3,932.242	4.62
Santarém (PA)	1,974.208	4.62
Itaqui (MA)	1,333.275	5.24
Vitória (ES)	1,680.144	5.68
Itacoatiara (AM)	1,747.305	4.87

Based on the theory of Linear Programming [13], in particular the transshipment problem [17], a linear optimization model was developed, with the objective of minimizing the total cost of transport. The data considered in the model, as shown above, were road costs, intermodal and transhipment costs, as well as port taxes.

$$\begin{aligned}\text{Cost } = {} & \sum_{i=1}^{n}\sum_{j=1}^{m} R_{ij} * FR_{ij} + \sum_{i=1}^{n}\sum_{j=1}^{r} P_{ik} * FP_{ik} + \sum_{i=1}^{n}\sum_{j=1}^{r} P_{ik} * CT_k \\ & + \sum_{i=1}^{r}\sum_{j=1}^{m} I_{kj} * FI_{kj} + \sum_{i=1}^{n}\sum_{j=1}^{m}\sum_{k=1}^{r} (R_{ij} + I_{kj}) * \; CE_j \ , \end{aligned} \tag{1}$$

subject to

$$\sum_{j=1}^{m} R_{ij} + \sum_{k=1}^{r} P_{ik} = OFT_i, \qquad \text{for all } I \tag{2}$$

$$\sum_{i=1}^{n} P_{ik} = \sum_{k=1}^{r} I_{kj}\,, \qquad \text{for all } k \tag{3}$$

$$\sum_{k=1}^{r} I_{kj} + \sum_{i=1}^{n} R_{ij} \leq DEM_j, \qquad \text{for all } j. \tag{4}$$

where:

OFT_i : Supply of grains for export to centroide i in tons per year.

DEM$_j$: Demand for shipping from ports j in tonnes per year.

FR_{ij} : Road freight in reais per tonne i originating from the centroid producer i and destined for the exporting port j.

FP_{ik} : Intermodal freight in reais per ton originating from the centroid producer i and destined for the transshipment terminal k .

FI_{kj} : Intermodal freight in reais per ton originating at the k terminal and destined for the j exporting port.

CT_k : Cost to carry out the transfer at the terminal k in reais per ton.

CE_j : Cost of port elevation at the exporting port j per ton.

R_{ij} : Road flow in tons originating from the centroid i and destined for the port j.

P_{ik} : Road flow in tons originating from the centroid i and destined for the transshipment terminal k.

I_{kj} : Intermodal flow in tons originating at the k transhipment terminal and destined for the exporting port j.

i: soybean producing centroid.

j : soybean exporting port.

k : intermodal transhipment terminal for soybeans, with the possibility of being a railroad, waterway or roadway.

n : index referring to the total number of producing centroids.

m : index referring to the total number of ports.

r : index referring to the total number of transshipment terminals.

The objective function has five components. The first component represents the road costs directly to the ports. The second component represents the cost of transportation between the producer centroids and the transshipment terminals by road. The third is related to the transshipment cost to the intermodal terminals and the fourth represents the cost of transportation between the intermodal terminals and the ports by roads, waterways or railways. The last component represent the cost of transfer the cargo between the road or intermodal routes and the ports.

Constraint (2) determines that all the cargo produced in the centroids is delivered to the terminals and the ports. Constraint (3) is the balance between the soy produced that enters the terminals and the soy that goes out of these terminals and is shipped to the ports. Lastly, Restriction (4) concerns all cargo that is sent by road directly to the ports and the cargo transported from the intermodal terminals to the ports is less than or equal to the export demand at the ports. The processing of information for the model only was done using the computer program General Algebraic Modelling System (GAMS) [1].

4. Results

Among the 12 scenarios evaluated in this research, the scenario that presents the lowest transport cost (internal transport and port fees), is the 2018.4 scenario. The total savings presented in relation to the base scenario for the year in question (2018.1) is 23.54%, which represents about US$ 234.6 million. It is worth remembering that the scenarios 2018.4, 2025.4 and 2030.4 maintain the capacity of the ports in the South and Southeast and increase the port capacity of Arco Norte, as well as the implementation of the Ferrogrão Railway and Hidrovia Araguaia Tocantins Waterway.

Figure 5 illustrates the transport cost savings proposed by the model applied in the scenarios 2018.2, 2018.3, 2018.4, 2025.2, 2025.3, 2025.4, 2030.2, 2030.3, 2030.4 in relation to the scenarios, 2018.1, 2025.1 and 2030.1, the what are the bases of the study.

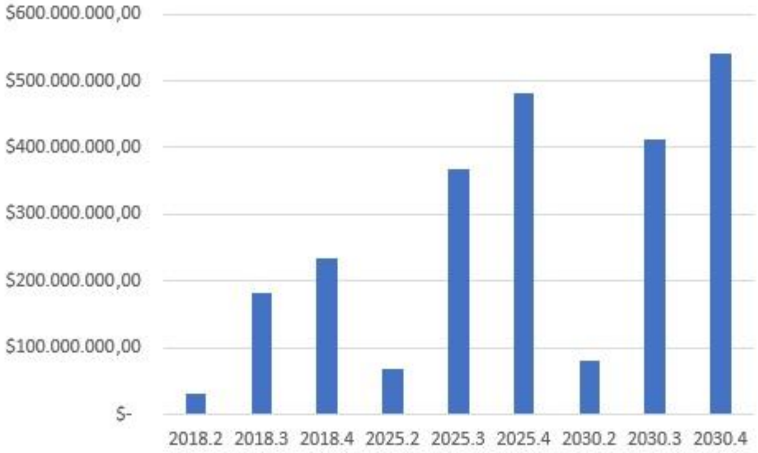

Figure 5: Economy proposed by scenario

Analyzing Figure 5, it is noted that between the scenarios 2018.3, 2025.3 and 2030.4, which promote the expansion of the port capacity of Arco Norte by 50% in addition to the implantation of Ferrogrão and Hidrovia Araguaia Tocantins, the scenario that stands out is 2018.3. Thus, it promotes savings of

US$ 180.97 million or 18.15%. In relation to the scenarios 2018.2, 2025.2 and 2030.2, which only propose the maintenance of the port capacity of Arco Norte, the biggest cost reduction belongs to the scenario 2030.2, the economy reaches 3.36% or US$ 80.19 million.

The analysis of the base years found that the road transport was responsible for 38.7 to 39% of the cargo transport directly to the ports, with Vila do Conde and Santarém being the main destinations. The port of Santos was the most used in all base scenarios, with values between 43 and 45%. The Port of Santarém and Itacoatiara together account for almost 20%, which demonstrates the opportunity to reduce costs through the ports of Arco Norte, even with deficient infrastructure. Table 7 below illustrates the participation of each port in the outflow of soybeans in the base scenarios.

Table 7: Export share of base scenarios – 2018.1, 2025.1 and 2030.1

Ports	**Export Tax (%)**		
	2018.1	2025.1	**2030.1**
Santos	45.8	44.2	**43.4**
Vila do Conde	19.9	19.2	**18.8**
Itacoatiara	8.8	8.5	**8.4**
Santarém	10.0	9.6	**9.4**
Itaqui	6.7	6.5	**6.4**
Paranaguá	5.0	7.3	**7.1**
Vitória	0.0	1.1	**2.9**
São Francisco do Sul	3.8	3.7	**3.6**
Rio Grande	0.0	0.0	**0.0**

In relation to scenarios 2018.2, 2025.2, 2030.2, 2018.3, 2025.3 and 2030.3 (Table 8), only the increase in the port capacity of Arco Norte reduced the participation of the Port of Santos by 15% in the flow of production. In addition, the ports of Paranaguá and São Francisco also stop exporting soybeans. With the insertion of Ferrogrão Railway and Araguaia-Tocantins Waterway together with a same increase in the port capacity of Arco Norte, all cargo transported by road was absorbed by rail and waterway modes, therefore, intermodal transport corresponded to 100% of the transported cargo. In this scenario, the receiving ports remained the same, but the routes showed cost reduction.

The scenarios 2018.4, 2025.4 and 2030.4 (Table 9), considered the optimal scenarios by the model, in relation to cargo distribution among ports, the port of Vila do Conde, in Pará, becomes the main exporter of soybeans in the State of Mato Grosso, varying between 30 and 40%, followed by Itacoatiara, in Amazonas, draining from 17 to 21% of the entire load. Santarém, in Pará and Itaqui, in Maranhão, are also established as major exporters of soy from Mato Grosso to the international market, thus consolidating the Arco Norte.

Table 8: Export share – 2018.2, 2025.2, 2030.2, 2018.3, 2025.3 and 2030.3

Ports	**Export Tax (%)**		
	2018.2/3	2025.2/3	**2030.2/3**
Santos	31.9	34.3	**35.5**
Vila do Conde	29.8	28.7	**28.2**
Itacoatiara	13.2	12.8	**12.5**
Santarém	15.0	14.4	**14.2**
Itaqui	10.1	9.7	**9.6**
Paranaguá	0.0	0.0	**0.0**
Vitória	0.0	0.0	**0.0**
São Francisco do Sul	0.0	0.0	**0.0**
Rio Grande	0.0	0.0	**0.0**

Table 9: Export share of optimum scenarios – 2018.4, 2025.4 and 2030.1

Ports	**Export Tax (%)**		
	2018.4	2025.4	**2030.4**
Santos	31.9	34.3	**35.5**
Vila do Conde	29.8	28.7	**28.2**
Itacoatiara	13.2	12.8	**12.5**
Santarém	15.0	14.4	**14.2**
Itaqui	10.1	9.7	**9.6**
Paranaguá	0.0	0.0	**0.0**
Vitória	0.0	0.0	**0.0**
São Francisco do Sul	0.0	0.0	**0.0**
Rio Grande	0.0	0.0	**0.0**

Table 10 presents transport costs in all scenarios in US$/t. In this context, it can be concluded that the average cost to transport a ton of soy from Mato Grosso internally in the base scenarios is US$ 50.35 in 2018, and will be US$ 51.53 in 2025 and US$ 51.97 in 2030. In the optimal scenarios of 2018, 2025 and 2030 the savings will be US$ 11.85, US$ 11.71 and US$ 11.75.

Therefore, it is possible to observe that in all scenarios, with the exception of the base scenarios, the cost of transportation reduces as the port capacities of Arco Norte and the intermodal routes are expanded, decreasing the soybean transportation cost.

5. Conclusion

A measure that increases soy production, leading mainly to spatial redistribution, studies pointed to the need to optimize or use the rational logistic of the structure, in an attempt to reduce costs, providing an increase in the use of soy on the world stage in the coming years. For this, the mathematical model based on linear programming associated with the transport cost components used seems adequate to the objectives.

Table 10: Total cost by scenario

Scenarios	Total Cost (US$/t)
2018.1	**50.35**
2018.2	**48.80**
2018.3	**41.21**
2018.4	**38.50**
2025.1	**51.53**
2025.2	**49.86**
2025.3	**42.57**
2025.4	**39.82**
2030.1	**51.97**
2030.2	**50.23**
2030.3	**43.03**
2030.4	**40.22**

Through the analysis of the scenarios, it was observed that the ideal year for the implementation of the Ferrogrão and Hidrovia Araguaia Tocantins projects would be 2018, considering, mainly, the cost reduction of the transport values and port taxes. In a horizon of 5 to 10 years, proposed by this research, the percentage of cost reduction decreases, but it still proves valid for the implementation of the new routes.

The modeling confirmed the need for investments in transport infrastructure, in addition to encouraging intermodal transport, especially in the Arco Norte region. Only the increase in port capacity of ports in the northern region can represent a reduction of up to US$ 77.6 million in 2030, demonstrating the great opportunity of the region. Therefore, the establishment of states in the North region as major exporters through new routes can bring government and private investments, encourage more sustainable means of transport, as well as the generation of jobs for the population, contributing to the establishment of Brazil as a major producer and soy exporter in the international market.

This present research had as main objective to contribute with the studies that serve as base for investments in transport infrastructure in Brazil. However, in addition to transport cost studies, models are needed that consider the technical-economic-operational feasibility of implementation, as well as the capacity of the transshipment terminals and the quality of the routes. Therefore, it is suggested for future work the considerations of these variables in models of transportation cost of Brazilian soy, as well as, it performs an economic analysis considering an economic optimization using fuzzy logic [23].

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