Analysis model of the corridor of the Arco Norte of the Amazon for the soybean of Mato Grosso

Russo, Tatiana O.[a] – telephone: (91) 98484-9827 and e-mail address: eng.tatiana18@gmail.com
Rocha, Marcus P. C.[b] – telephone: (91) 99211-1178 and e-mail address: marcus.rocha60@gmail.com
Tobias, Maisa S. G.[a] – telephone: (91) 98129-2029 and e-mail address: isatobias1@gmail.com
Souza, Matheus M.[c] – telephone: (19) 99200-0248 and e-mail address: matheuusmelodesouza@gmail.com
Silva, Neydson M. S [d] – telephone: (91) 98249-9668 and e-mail address: nmaccarty@gmail.com
[a]Institute of Technology of the Federal University of Pará.
[b]Institute of Exact and Natural Sciences of the Federal University of Pará
[c]Agricultural Engineering Faculty of Campinas State University
[d]Bachelor of Environmental Sciences of the University Center of Pará

Abstract

Nowadays, Brazil consolidated itself as the biggest exporter of soybean beans in the world, and the Brazilian state that has most contributed to this rate is the state of Mato Grosso, and for your geographic location, Mato Grosso also its products to the ports of Arco Norte. This study proposes to develop a model for optimization of the logistic corridors of transport, for the soybean from the mato-grossense destined for the ports of Arco Norte, trying to obtain a more effective logistic in the face of quantitative indicators such: transport price, municipal production, and dock capacity, the corridors that are being studied are BR-163 (MT-PA), Ferrogrão (EF-170) and the Araguaia-Tocantins waterway. The analysis about corridors it will be through a linear programming, which is a method capable of enabling hierarchization processes, which contributes to the analysis of the proposed problem. In this sense, the results show that the intermodal transport, using the Ferrogrão and the waterway Araguaia-Tocantins, were the least costly routes transporting mato-grossense soybean to the Arco Norte Amazonian ports.

Keywords: Soybean; Arco Norte; Logistic; Linear Programming.

1. Introduction

Agribusiness has been known as a crucial vector for Brazilian economic growth. In 2019 a sum of goods and services generated in agribusiness reached R$ 1,55 trillion or 21,4% of the Brazilian brute domestic product. In the agriculture business, soybean is mainly responsible for the gross value in production of 2019 and 2020, with respective values of R$ 155,36 billion and R$ 175,63 billion [7]. Such results emphasize the importance of agribusiness in the growth and economic development of the country.

Soybean is considered one of the main agricultural products of Brazil and has been winning more and more notoriety over the years with the technological advances of production [23]. In the harvest of july 2021, Brazil reached it soybean production record estimated at 135,9 million tons, 11 million tons more than years of 2019/2020, positioning Brazil as the biggest soybean exporter of the world [9]. Therefore, we know that Brazil has a great potential in the production of soybean, and there is a soybean output possibility from the middle east through the ports of Arco Norte and the absence of an effective logistic alternative makes soybean's pricen very high to compete in the consumer's market. In this case, we ask: what would be the best alternative?

In this perspective, there is a possible alternative of the output of grains via Arco Norte. The same is defined as the export zone through the terminals and private use of the ports of Porto Velho (RO), Miritituba (PA), Porto National (TO), and Nova Xavantina (MT) destined for the North and Northeast of the country, joining the ports of Itacoatiara (AM), Santarém (PA), Vila do Conde (PA) and Itaqui (MA) [31], being such delimited to development of this research, with the objective of studying the logistic best viable in relation to the three routes involving BR-163 (Cuiabá-Santarém), the Ferrogrão (EF-170) and the Araguaia-Tocantins waterway.

In a study carried out by [31], the cost of soybean transport was defined as research's objective, based on the Linear Programming model, optimizing the soybean logistic distribution to main brazilian ports, adopting the problem of flooding to model cost of routes, considering the actual routes and proposing two new routes. The Ferrogrão railroad and the Araguaia-Tocantins waterway. In the development of this study, including the studied routes by [31], an investigation about the soybean transport of the state of Mato Grosso was proposed, also, by route BR-163, which connects the state of Mato Grosso, to the state of Pará, which was totally floored and ceded.

Therefore, it becomes imperative to investigate the possible routes that will constitute these investments and define which route is more viable for the soybean's flow of Mato Grosso destined for Northern ports. Furthermore, a relevant point to evaluate is the possible arrangements of these infrastructures of logistic corridors, there's always the possibility of facing many uncertainties variations involved and , to follow, logistic efficiencies. This depends by the model and process selected for transport type based on the minimization of cost, having as a methodological instrument of analysis, Linear Programming [2].

In this research, the analysis proposed for corridors, will be by the implant of Linear Programming , which is a method capable of enabling hierarchy processes that involve technical and economic aspects, present the benefits of variation treatment, quantitative and linear, which contributes to the analysis of the efficiency of the proposed problem [2].

2. Soybean, a golden commodity of Brazil

Soybean, actually is the most important oilseed and the most relevant in the international market. It is mainly produced in three countries, Brazil the U.S.A and Argentina, who currently, together, correspond to 81,5% of the world's production [12].

In the harvest of 2020/21, there was a soybean world production of 362,95 million tons in a planted area of 127,8 hectares, being that of this value, Brazil reached a record of production of 135,9 million tons in an area of 38,5 million hectares. Positioning itself as the biggest producer and exporter of soybean in the world [9]. With participation in the exportation of grains of 74,1 million tons, with sums of U$ 28,56 Billion [12].

Chart 1- Estimate of world production and exportation of soybean for the harvest of 21/22 – FIESP (2021)

World production (millions of tons)					**World exportation (millions of tons)**				
Countries	**Harvest**		**Variation**		**Countries**	**Harvest**		**Variation**	
	20/21	21/22	Abs	%		20/21	21/22	Abs	%
Brazil	136,0	144,0	8,0	5,9	Brazil	86,0	93,0	7,0	8,1
The U.S.A	112,5	119,9	7,3	6,5	The U.S.A	62,1	56,5	-5,6	-9,0
Argentina	47,0	52,0	5,0	10,6	Argentina	6,6	6,5	-0,1	-1,5
China	19,6	19,0	-0,6	-3,1	China	6,4	6,4	0,0	0,0
Other	47,8	50,6	2,8	5,9	Other	10,4	10,6	0,2	2,1
World	362,9	385,5	22,6	6,2	World	171,4	172,9	1,5	0,9

The good performance of the sector is directly connected to exportations, the following sceneries should be considered: high international prices of commodities, predominance of Brazilian exportation because the increase world's demand for food, and the strong devaluation of the real compared to the dollar. Both factors contribute to increase the production and evaluation of the soybean price [20].

We can say that, the exploration of soybean has been the agricultural activity which most expansion in the world. Brazil has enormous participation in the planting, and selling of grain and maintaining levels of growth, year after year. Brazil have a great potential because the space for cultivating soybean. It's clear that soybean is very important for the Brazilian economy [14].

2.1 Arco Norte

Conceptually, the term Arco Norte is defined as "Estrategic plan that understands ports and stations of transhipment of the states of Rondônia, Amazonas, Pará, Amapá and Maranhão". According to [21], Arco Norte and also be defined as "An imaginary line that crosses the Brazilian territory on the parallel 16º south, passing near the cities of Ilhéus (BA), Brasília (DF) and Cuiabá (MT).

The Arco Norte system is formed by the transhipment ports: Itacoatiara, located in the Amazon state; Santarém, Barcarena and Vila do Conde, in Pará; São Luís and Itaqui, located in Maranhão, and Santana, in Amapá. The port platforms that help, are the Stations of Transhipment of Cargo (SFC), which are operational support for the multimodal corridors like: Porto Velho in Rondônia and Miritituba, located in Pará, among others [8].

Figure 1. Ports and stations of flooding and cargo Arco Norte.

The Itaqui Port – MA is directly connected to the Carajás railroad (EF – 315) operated by the Vale the Rio Doce company until Açailândia – MA, 513 kilometers long, to get near the state of Mato Grosso, one has to connect to the Norte – Sul railroad (EF – 151), operated by Valec – Engineering, constructions and railroads S.A until the National Port – TO and is more than 700 kilometers [4].

The port of Itaqui has a strategic location, it is near international markets, being the first port of entrance and the last of exit to the Asian market whose route is the Panamá canal. Besides, this port shortens by approximately 7 days of shipping, compared to other ports of the regions of the southeast and south of Brazil, these factors favor the competition for Arco Norte [30].

The port of Santarém – PA is located in the city of Santarém, on the right margin of the Tapajós river about 3 kilometers from the confluence of the Amazon River. by the Docas do Pará Company (CDP) since it was inaugurated in 1974. Consists in a strategic port between the modals road and waterway for the cargos through BR – 163 and through the Tapajós and Teles-Pires rivers. The Santarém port covers an area of 500 thousand square meters, has 12 docking installations composed of the pier, docking dolphins, river piers solid bulk terminals, three liquid bulk terminals and a roll-on ramp. There is three leased areas, one of these areas was for the company Cargill Agricolas S.A which occupies 93,6 thousand square meters and operates on moving grains with capacity of 1500 tons. The maritime access is through the Tapajós and the Amazon rivers. Road access is by the highway BR – 163 (Cuiabá-Santarém) by the Cuiabá avenue by the BR – 230 Transamazônica highway [12].

The port of Vila of Conde – PA is connected to the port of Itaituba – PA, which is in the district of Miritituba

– PA, through the Tapajós river, at a distance of 1.107 kilometers [10]. In this context, the port of Barcarena, in the Pará state, is becoming a very attractive route for the draining to the external market of soybean produced in the north and northeast regions, consolidating itself as a new alternative of maritime transport.

The port of Itacoatiara – AM is located in the state of Amazonas, on the left margin of the river Negro distant, 13 kilometers of affluence to the Solimões river, this port is the main port of entrance of the state and has an area of 94,5 thousand square meters, including the floating area of 16,8 thousand square meters, with a profoundness of 11 meters. Access to this port is also through highways AM – 010 and highways BR – 174 and BR – 319, connecting the states of Roraima and Rondônia. The main products exported on this port is soybean through a bulk carrier terminal Hermasa and flour imported by TUP Ocrim [11].

The transshipment terminal of Miritituba – PA began operating in 2016 and was designed, initially for the draining of grains. The transshipment operation consists of the reception of trucks and the loading of barges carried out by a vacuum. Transporting the grains between Miritituba and Vila do Conde for exportation the trucks and vessels that would return empty on the same route would transport fertilizers on the return trip [4].

[16] verified in his research that, approaching the potential and difficulties of the exportation of soybean through the north ports, found current lack of port capacity to attend the regional demand of exportation which is worrying when it is considered the prediction of growth of production and exportation.

The transshipment terminal of Porto Velho – RO is a private terminal (TUP) of the Cargill Agricola Company S.A, which is considered a strategic location for the draining grains of Arco Norte. This company has been operating since 2003, in the capital of the state of Rondônia, located on the right margin of the Madeira River, and has the capacity to move two million tons of grains annually. This outlet receives a solid bulk (soybean and corn) produced in the state of Rondônia and in the eastern region of Mato Grosso, from where they are transported by highway until Porto Velho, which receives this product and later carries out the transshipment of the vessels, destined for the Itacoatiara (AM) or directly to the Santarém port (PA) destined for the world markets [5].

The transshipment terminal of Porto National – TO is localized in the state of Tocantins 20 km from Palmas, where there are companies like VLI, which is responsible for carrying out the transshipment of the production of soybean of Mato Grosso through the highway (BR – 158) to the railroad (Ferrovia Norte Sul – EF – 151) destined to the Itaqui port in Maranhão [33].

The biggest demand, related to the increase grains production in the states of Mato Grosso, Tocantins, Góias, Bahia and Piauí, demand the amplification of operational capacity of the Itaqui port (MA) which has location advantages for the exportation in relation to the ports of Santos (SP) and Vitória (ES) because they are further away from the Asian and European markets [6].

The transshipment terminal of Nova Xavantina – MT is localized in the state of Mato Grosso, where is mode possible the options of multimodal routes, the first by railroad mode until Nova Xavantina to the port of Santos (SP) and the second option that involves the multimodal corridors of Arco Norte, using the waterway mode between the municipalities of Nova Xavantina until Xambioá (TO), from there continues by highway mode for 130 km until the Norte – Sul railroad (EF – 151), destined for the Itaqui port in Maranhão [28].

2.2 The logistic of grains in Brazil

In Brazil, the soybean transport is carried out by the unimodal mode (using the only type of transport generally by road). As much by the intermodal mode (using more than one way of transport, being by road, railroad or waterway).

According to data from the Brazilian Agricultural Research Corporation [13] the mode of transport most used for the soybean logistic is by road (67%), which going long distances becomes the mode more expensive than railroad and more than by waterway, which respond to only (28%) and (5%) respectively, of the total of soybean transported in the country.

As a form of making the flow of soybean more economic, there emerged the alternative to transport the product by ways of, however, it is worth highlighting that other than getting an efficiency in the intermodal transport it is necessary the presence of some support as, some storage and intermodal terminals of support [32].

Therefore, according to chart 5 below it's possible to identify in the flowchart the logistic of soybean production, since the origin in rural properties to the final destiny, in the internal market, processing industries and exportation ports.

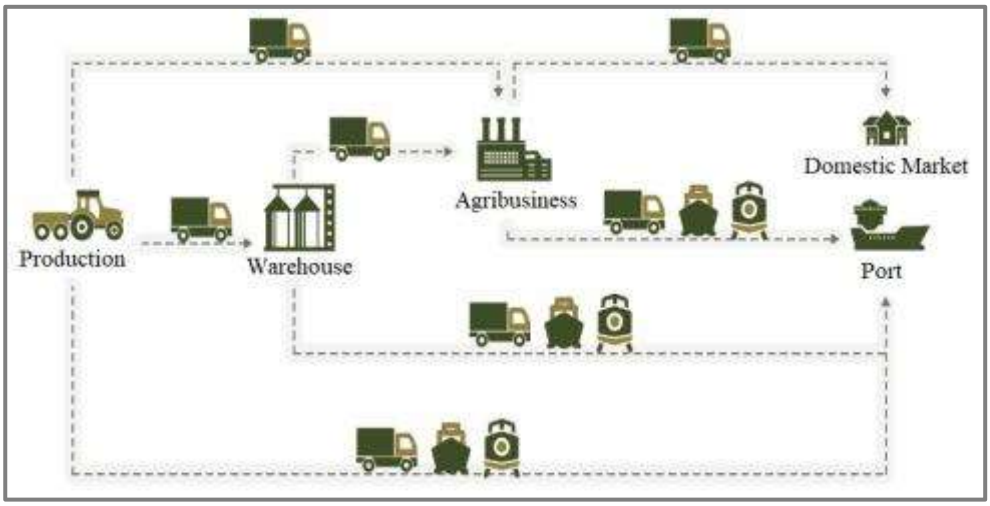

Figure 2. Grain distribution logistics in Brazil.

According to [25] the flow of agricultural production happens in two distinct phases. One destined directly from the harvest to public storage of rural properties, of cooperatives or of trading characterized by the fragmented road transport and high costs. The other is by the transport of products from the harvest to the processing industries or directly to the exportation ports.

2.3 Logistic corridors of Arco Norte

There are many multimodal corridors used in the Arco Norte system, between them can be defined as the road modal, waterway and railroad. Basically, the origin is localized in the agricultural production zone of the country and follows an axel of transport destined to an exportation platform. The availability of the amazon river system, the main flow of transport used is the waterway, and the road mode serves as support, shifting the production from production centers to units of transshipment between trucks and barges or between trucks and the railway mode [8]. Figure 3 presents the main logistic multimedia corridors of soybean of the middle east to the north of the country.

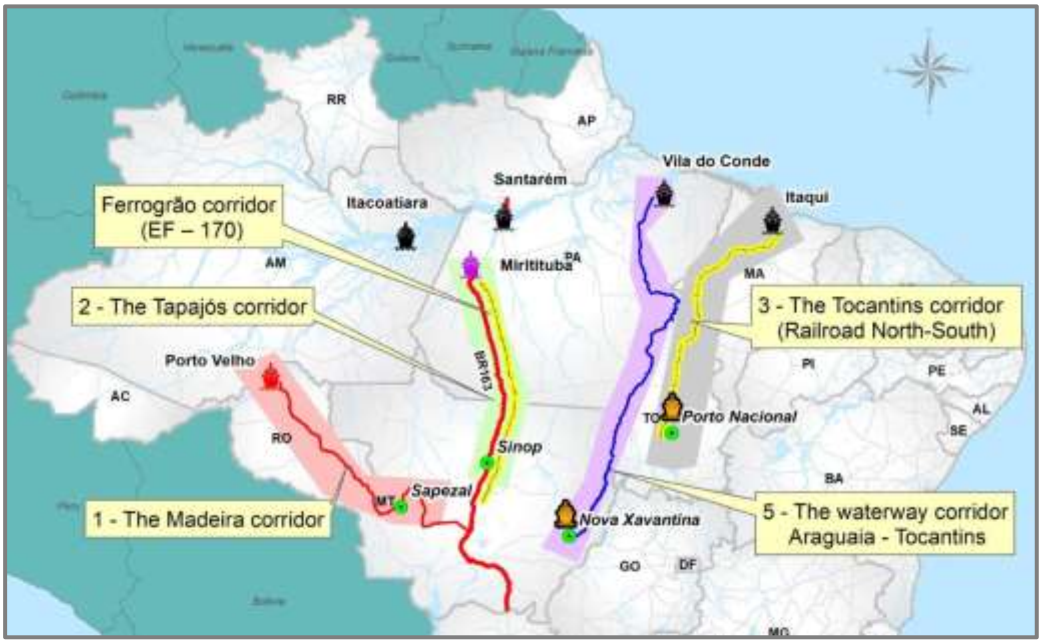

Figure 3. Arco Norte multimodal corridors.

Among these corridors operating corridors can be highlighted as:

1) **The Madeira corridor** – is the corridor that has been using since 1997 by companies such as Amaggi for the flow of harvest of grains from the northwest of the state of Mato Grosso [19]. The products are transported via road mode by BR – 364 (MT-RO), running a distance of 853 km, from Sapezal/MT to the transshipment terminal in the port of the city of Porto Velho/RO. From there the grains are transported by bulk bin barges on the Madeira waterway, then by the Amazonas river to the port of Itacoatiara/AM, being able still to go from Porto Velho to the port of Santarém/PA, where the products are exported to the international markets [8].

2) **The Tapajós corridor** – is formed by the BR – 163 (Cuiabá – Santarém), which uses the road mode to transport the production of grains of the central region of Mato Grosso (Sinop, Sorriso among others) until the transshipment terminal of Miritituba/PA at a distance of about 995 km or directly to the port of Santarém/PA at 1.293 km distant. BR – 163 is a long federal highway, extremely strategic for the logistics of Arco Norte, joining the country's middle west region to the ports of Arco Norte [24]. BR – 163 was completely tarred, recently (1009,5 km) and leased to the company via Brazil BR – 163, which by means of toll, will operate it for a period of 10 years by leasing [26].

3) **The Tocantins corridor** – the support of this corridor is the Tocantins River. However, due to the numerous hydroelectric dams on the waterway and the lack of a transposition lock, the main route became the North-South Railway, which serves Mato Grosso is a Northeast area (Querência, among others), the north of Goiás and the region of MATOPIBA, where the products are transported by road to Porto Nacional is terminals (TO), or in Porto Franco (MA), where they are transferred to the railroad, which then goes on to the ports of São Luís or Itaqui in Maranhão [25].

Projected corridors:

4) **Ferrogrão corridor (EF – 170)** – is a corridor projected to consolidate the new railroad corridor exportation of Brazil through Arco Norte. The railroad depends on an extension of 933 km, connecting the middle-east region that produces grains to the state of Pará, coming out at the port of Miritituba. Being a project that was designed to be implanted parallelly to BR – 163, the railroad could be an important factor to inhibit deforestation, seeing that its construction is parallel to BR – 163 [27].

5) **The waterway corridor Araguaia - Tocantins** – is one of the main means of transport of the middle north corridor of the country, it is localized in the Brazilian cerrado, the largest region of grains of the country. It has a navigational potential of approximately 3.000 km. However, construction improvement is necessary, such as a river lock, dredging, signaling and principally the overthrow of Pedral do Lourenço, so that, its maximal potential of exportation of grains to the ports of Vila do Conde/PA and São Luís/Itaqui/MA can be explored [1].

3. Case study

3.1 The location of the state of Mato Grosso

The state of Mato Grosso is located in the Midwest region of Brazil and borders the states of Rondônia, Amazonas, Pará, Tocantins, Goiás, Mato Grosso do Sul and Bolivia. According to the last [17], the state of Mato Grosso has a territorial area of 903,207.05 km², considered the third largest state in the federation. It has an estimated population of 3,526,220 inhabitants, with 85% of the population residing in urban areas and 15% in rural areas. In figure 18 it is possible to visualize the location of the state of Mato Grosso.

Figure 4. The localization of the state Mato Grosso

Currently, its geographic division comprises 142 municipalities, seven Geographic Macroregions (Northwest, North, Northeast, Middle-North, West, Center-South and Southeast), and twenty-two Geographical Microregions. Given the vast distribution of agribusiness in the territory of Mato Grosso, the IMEA carried out a study to segment the state from an agro-economic point of view, in order to facilitate data collection and dimension its agricultural economy [18].

The map below classifies the municipalities according to the concentration methodology described in [15], a simple method that was adopted to analyze changes in geographic distribution over time, prioritizing visual representation of temporal variations occurring in space studied geographic areas. These municipalities stand out for their representativeness in the amount of soy produced in tons. In figure 5, it is possible to identify the six origin municipalities, in the regions with the greatest soy production in the state of Mato Grosso:

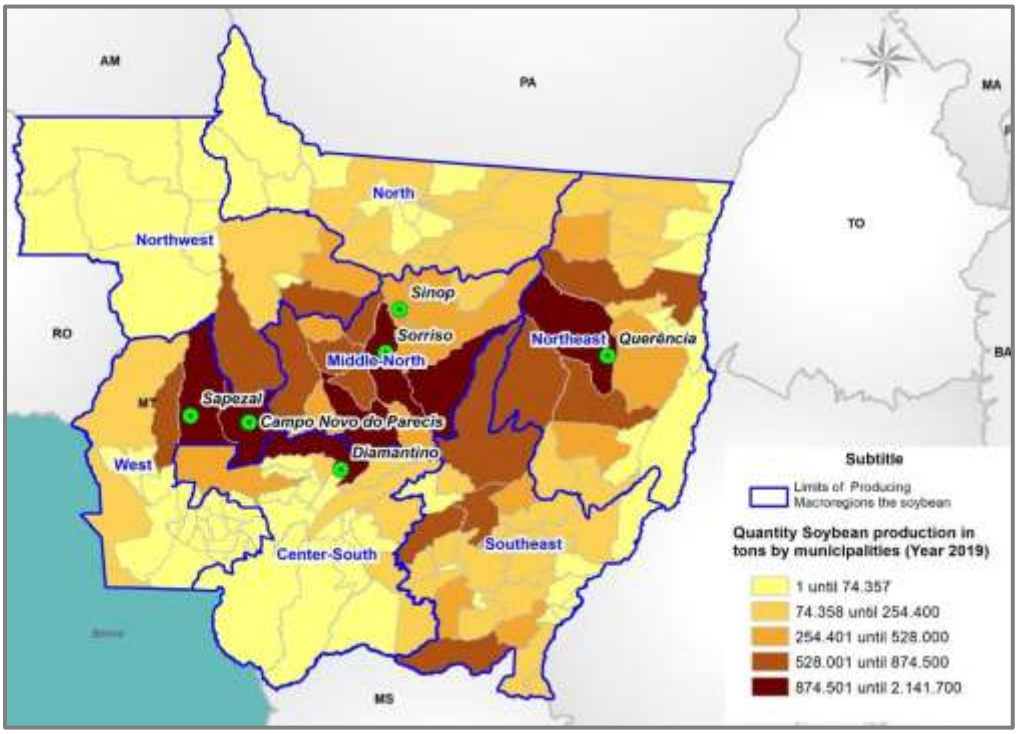

Figure 5. Soybean producing municipalities (origin)

In the development of this study, the Linear Programming method will be initially applied in the optimization in relation to the three studied routes (BR-163, Ferrogrão and Hidrovia Araguaia-Tocantins). Defining itself as the origin, six municipalities in the State of Mato Grosso, such as: Campo Novo do Parecis, Sorriso, Sapezal, Querência, Sinop and Diamantino. The criteria used in the choice of these municipalities were: their large soy production and their geographic location, as they are located in macro-regions (West, Middle North, Northeast and Center South), close to the logistic corridors studied in this research. In table 4, it is possible to observe these data in relation to the six municipalities taken a reference of origin.

Chart 2- Municipalities of origin with their planted and production areas – IBGE (2019)

Macroregions	Origin	Planted Area (km²)	Production in tons
West	Campo Novo do Parecis	3800	1547659,6
Middle - North	Sorriso	6050	2709328,5
West	Sapezal	3550	915921,31
Northeast	Querência	3600	2277048,1
Middle - North	Sinop	1514,22	1652912,8
Center-South	Diamantino	3450	772860,93

3.2 Soybean Flow Routes

Another very important decision variable in the development of the study is the distance traveled, in kilometers (km), from the origin (producing municipalities) to the destinations (ports and transshipment stations). And in relation to the State of Mato Grosso, it is possible to observe in Figure 21 that the highways BR - 364 and BR - 163, are the federal highways most used for the flow of soybeans since they are already established as logistic corridors and they connect the Mato Grosso state with neighboring states.

In road modal, the three main bus stations involved in this logistics are BR - 364 which connects Mato Grosso to Porto Velho (Rondônia) at an average distance of 951 km, BR - 163 which connects Mato Grosso to the transshipment station in Miritituba (Pará) at an average distance of 1,075 km and the BR – 242, which connects the municipality of Querência (Mato Grosso) to the transshipment station in Porto Nacional (Tocantins) at a distance of 657 km. In addition, it is believed that with the concession of the BR - 163 (MT-PA) that connects Sinop (MT) to Miritituba (PA), there will be a continuous improvement in the conditions of the road, resulting in better trafficability as a result of the investments, and consequently, lower transportation cost [31].

The data of the distances covered were obtained through the free application of Google Maps, where, through satellite images, it was possible to obtain these distances, considering the shortest possible distance.

The Mato Grosso soy transport route by rail is carried out in an intermodal way, between road and rail, where Mato Grosso soy leaves the municipality of Querência (MT), along BR - 242 to Porto Nacional (TO), transshipping to the North-South railroad (EF-151), following to 700 km to the municipality of Açailândia (MA), where it connects with the Carajás Railroad (EF-315), going directly to the port of Itaqui in Maranhão.

When Ferrogrão was implemented, it will have a second rail transport option for the export of soybeans via the Arco Norte corridor, with a logistics of approximately 933 km and an initial capacity of 42 million tons to the Transshipment Station in Miritituba in Pará.

In relation to waterway transport, the main routes for the flow of soybeans from Mato Grosso, involve the Madeira River extension of approximately 1007.7 km, which is the main route which soybeans flow from Mato Grosso State Midwest's.

Another very important waterway in the flow of soybeans from Mato Grosso is the Tapajós River Waterway with an extension of approximately 469.48 km, it transports soybeans by barges to the port of Santarém or Vila of Conde port in Pará. This route is made in an intermodal way, through the BR - 163 to the Transshipment Stations managed by the company HBSA.

The vast majority of terminals belong to private companies, such as large trading companies such as Bungee, Hidrovias do Brasil (HBSA), Cargill, and they already have in their contracts the transport from the transshipment terminal to the private use terminals, and from there to the final ports in consumer markets. Thus, in practice, the private sector exports most of the Brazilian soy, using the facilities of the port complexes [31]. In Figure 6, it is possible to identify all these routes.

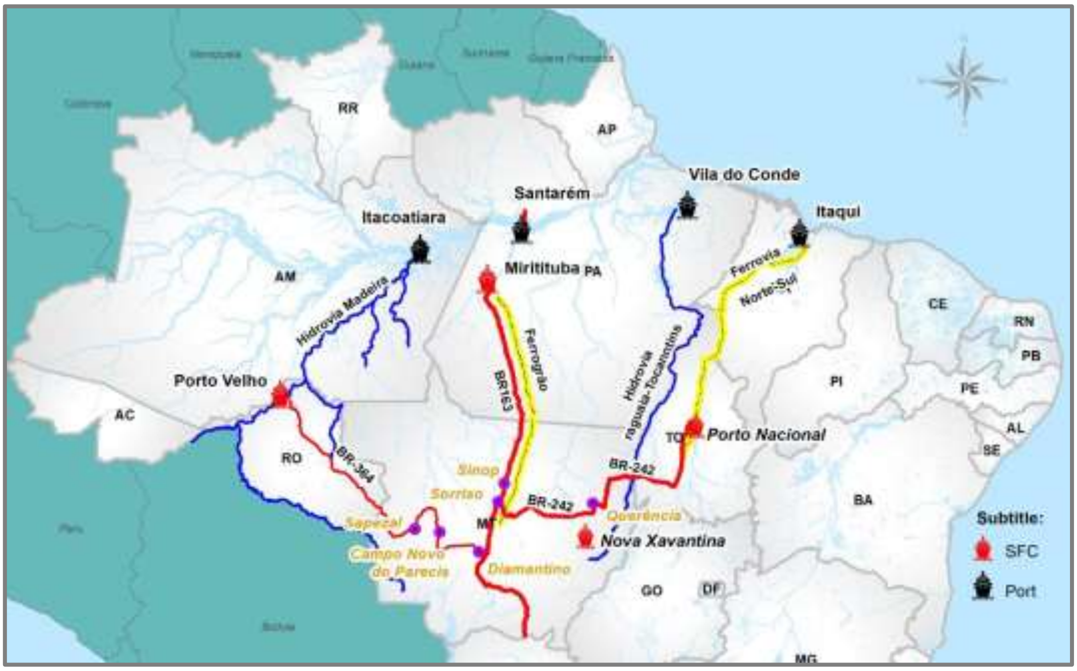

Figure 6. Soybean flow routes

4. The transport model

4.1 Road data

The data referring to demand were divided into road transport and intermodal transport, encompassing freight values, fees and port capacities, since soybeans can be transported by road directly to the ports or using a combination of modals.

Regarding road freight, the values were based on the research by [29], who estimated the freight curves by logistic corridors. Distances between origins and destinations were obtained using the Google Maps software. Chart 3 below shows freights by aisle.

Chart 3- Origins, destinations and variables considered in Linear Programming

Item	Origin	Destination	Maps (Sep, 2021) Distance. (km)	Rocha (2020) Freight R$/ton.km
1	Campo Novo of Parecis	Port of Santarém/PA	1.747	0,1274
2		Port of Vila do Conde/PA	2.372	0,1174
3		Port of Itaqui/MA	2.677	0,1137
4		SFC – Miritituba/PA	1.448	0,1339
5		SFC – Porto Velho/TO	1.053	0,1458
6		SFC – Porto Nacional/RO	1.534	0,1319
7		SFC – Nova Xavantina/MT	1.012	0,1473

8		SFC - Sinop	457	0,1821
9	Sorriso	Port of Santarém/PA	1.376	0,1358
10		Port of Vila do Conde/PA	2.001	0,1229
11		Port of Itaqui/MA	2.306	0,1183
12		SFC – Miritituba/PA	1.077	0,1449
13		SFC – Porto Velho/TO	1.407	0,1350
14		SFC – Porto Nacional/RO	1.220	0,1402
15		SFC – Nova Xavantina/MT	738	0,1603
16		SFC - Sinop	85	0,2850
17	Sapezal	Port of Santarém/PA	1.855	0,1254
18		Port of Vila do Conde/PA	2.481	0,1160
19		Port of Itaqui/MA	2.786	0,1125
20		SFC – Miritituba/PA	1.557	0,1314
21		SFC – Porto Velho/TO	946	0,1500
22		SFC – Porto Nacional/RO	1.673	0,1289
23		SFC – Nova Xavantina/MT	1.159	0,1421
24		SFC - Sinop	565	0,1721
25	Querência	Port of Santarém/PA	1.675	0,1288
26		Port of Vila do Conde/PA	1.561	0,1313
27		Port of Itaqui/MA	1.923	0,1242
28		SFC – Miritituba/PA	1.376	0,1358
29		SFC – Porto Velho/TO	1.969	0,1234
30		SFC – Porto Nacional/RO	657	0,1653
31		SFC – Nova Xavantina/MT	293	0,2050
32		SFC - Sinop	791	0,1573
33	Sinop	Port of Santarém/PA	1.294	0,1380
34		Port of Vila do Conde/PA	1.862	0,1253
35		Port of Itaqui/MA	2.224	0,1195
36		SFC – Miritituba/PA	995	0,1480
37		SFC – Porto Velho/TO	1.363	0,1361
38		SFC – Porto Nacional/RO	1.138	0,1428
39		SFC – Nova Xavantina/MT	870	0,1534
40		SFC – Sinop	2	0,7735
41	Diamantino	Port of Santarém/PA	3.012	0,1102
42		Port of Vila do Conde/PA	2.528	0,1155
43		Port of Itaqui/MA	2.374	0,1174
44		SFC – Miritituba/PA	1.362	0,1361
45		SFC – Porto Velho/TO	1.284	0,1383
46		SFC – Porto Nacional/RO	1.538	0,1318

47		SFC – Nova Xavantina/MT	830	0,1553
48		SFC - Sinop	371	0,1925

[29] obtained a model of a set of road freight values for Brazilian soybean exporting ports, in 2017, with a coefficient of determination of the linear version equal to 88.47%. Freights were estimated for the same origin-destination (OD) combination between transshipment terminals and ports.

$$Frete = e^{-0{,}072183367} \cdot {d_{od}}^{0{,}733679018} \quad (1)$$

Based on the values found by equation 1, the reference values for waterway and rail freights were obtained through discounts in the value of road freight for the same combination between places of origin and destination. These percentages was obtained by the followed way: Waterway freight corresponds to 40% of the value of road freight F, for the same combination of origin and destination. Rail freight, on the other hand, corresponds to 70% of the value of road freight, also for the same combination of origin and destination.

In relation to the intermodal routes of the Arco Norte corridors, the predominance of the hydrographic potential that the region has is evident, and that perhaps due to lack of interest on the part of decision makers in investing in these corridors, the opportunity to obtain more efficient logistics,cheaper freight, with greater cargo transport capacity and with a reduction in environmental impacts is lost. Chart 4 below illustrates the distances of the routes, as well as their classification by type, stretch, corridor and the value of intermodal freight.

Chart 4 – Intermodal freight

Type	Terminal	Port	Distance (km)	Intermodal freight (R$/t.km)
Road-waterway	SFC Miritituba (PA)	Vila of Conde (PA)	1274,62	70,64
Road-waterway	Porto Velho (RO)	Itacoatiara (AM)	1007,62	59,46
Road-waterway	Sinop (MT)	Santarém (PA)	1293	126,48
Road-waterway	Nova Xavantina (MT)	Vila of Conde (PA)	2656,75	121,08
Road-waterway	SFC Miritituba (PA	Santarém (PA)	363,74	28,15
Road-waterway	SFC Porto Nacional	Itaqui	1249,46	121,83
Road-waterway	SFC Sinop	Miritituba	933	98,33

4.2 Objective function

Based on the theory of Linear Programming (2), in particular the transshipment problem, a linear optimization model was developed, with the objective of minimize the total cost of transport. The data considered in the model, as shown above, were road cost, intermodal and transshipment costs, as well as pot taxes.

$$Custo = \sum_{i=1}^{n} \sum_{j=1}^{m} R_i \cdot FR_{ij} + \sum_{i=1}^{n} \sum_{j=1}^{r} P_{ik} \cdot FP_{ik} + \sum_{i=1}^{n} \sum_{j=1}^{r} P_{ik} \cdot CT_k + \sum_{i=1}^{r} \sum_{j=1}^{m} I_{kj} \cdot FI_{kj} + \sum_{i=1}^{n} \sum_{k=1}^{r} (R_{ij} + I_{kj}) \cdot CE_j \quad (2)$$

- The restriction that guarantees the offer's flow:

$$\sum_{j=1}^{m} R_{ij} + \sum_{j=1}^{m} P_{ik} = OFT_i, \ \ para\ todo\ i \quad (3)$$

- The restriction that guarantees the continuity of the flow that arrives at the transshipment terminal:

$$\sum_{i=1}^{n} P_{ik} + \sum_{k=1}^{r} I_{kj} = 0, \ \ para\ todo\ k \quad (4)$$

- The restriction of demand in exporting ports:

$$\sum_{i=1}^{n} P_{ik} + \sum_{k=1}^{r} I_{kj}, \leq DEMj \ \ para\ todo\ k \quad (5)$$

Where:

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

DEM_j: Demand for shipping from ports j in tons per year.

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

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

FI_{kj}: Intermodal freight in reais per ton originating at the from 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 center i and destined for the port j.

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

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

i: Soybean producing center.
j: Soybean exporting port.
k: Intermodal transshipment terminal for soybeans, with the possibility of being a railroad, waterway or roadway.
n: Index referring to the total number of producing center.
m: Index referring to the total number of ports.
r: Index referring to the total number of transshipment terminals.

The model was developed in the General Algebraic Modeling System – GAMS software. GAMS is used to solve complex problems involving linear, non-linear and integer programming. The software uses a high-level language in order to provide a compact representation of large and complex models, so the construction as well as the resolution become more direct for programmers, and more intelligible for users of other disciplines [3].

5. Results

Over the development of this research, four analyzed scenarios were considered, taking into account the offers of the producing municipalities, the demands of the ports and Stations Transshipment of Cargo (SFC) and the freight values.

In (Scenario 1), only the BR – 163 route (MT-PA) was considered, where the optimization model provided a minimum freight cost of R$ 1.934.734.310,78, to carry out the transport of the production offer of the municipalities studied over a period of one year. In the case of transshipment, 5.135.102,23 tons were transported from Miritituba to the port of Santarém from Porto Velho to the port of Itacoatiara there were 2.463.580,91 tons.

In (Scenario 2), only the BR – 163 (MT-PA) and Ferrogrão routes were considered, where the optimization model provided a minimum freight cost of R$ 1.748.431.033,33, transport the municipalities to offer production in one year. Regarding transshipment, 915.921,31 tons were transported from Porto Velho to the port of Itacoatiara, that is, the entire production of Sapezal. And the 6.682.761,83 tons coming from the municipalities of Campo Novo of Parecis, Sorriso, Sinop and Diamantino transported all their production through Ferrogrão to the port of Santarém.

In (Scenario 3), only the routes of the BR – 163 (MT-PA) and the Araguaia – Tocantins waterway were considered, where the optimization model provided a minimum freight cost of R$ 1.504.898.290,43, to carry out the transportation of the production supply of the studied municipalities in one year. In this scenario, the most interesting thing is that the optimization model provided the Nova Xavantina Stations of Transshipment of Cargo as the best and most viable logistic route, which would transport the entire municipality's production through the Araguaia – Tocantins waterway to the port of Vila of Conde in Pará. Further evidence that cargo transport through waterway modal is more economical due to the low-cost of freight and its greater transport capacity. However, one of its biggest obstacles would be its high-cost revitalization, remembering that the corridor is designed because it needs infrastructure works for its full operation.

In (Scenario 4), the three logistic corridors were considered: BR – 163 (MT-PA), Ferrogrão and Araguaia – Tocantins waterway, where the optimization model provided a minimum freight cost of R$ 1.440.937.616,41, to carry out the transport of the production supply of the municipalities in a period of one year. In relation to scenario 4, the optimization of routes was only through the two projected lanes, Ferrogrão and the Nova Xavantina Stations of Transshipment of Cargo. By Ferrogrão, the production of 4.362.241,30 tons were transported directly to the port of Santarém from Nova Xavantina 5.513.489,94 were transported via Araguaia – Tocantins waterway to Vila of Conde is port.

Chart 5 – Regarding the ports and freight cost

Scenario	Origin	SFC	Port	Quantity Exported (tonnes)	Total Cost of Freight (R$)
Scenario 1	Sorriso, Sinop e Diamantino	Miritituba	Santarém	5.135102,23	1.934.734.310,78
	Sapezal e Campo Novo do Parecis	Porto Velho	Itacoatiara	2.463580,91	
	Querência	-	Vila of Conde	277048,10	
Scenario 2	Sapezal	Porto Velho	Itacoatiara	915921,31	1.748.431.033,33
	Querência	-	Vila of Conde	2.277048,10	
	Campo Novo do Parecis, Sorriso, Sinop e Diamantino	Ferrogrão	Santarém	6.682761,83	
Scenario 3	Todos os municípios	Nova Xavantina	Vila of Conde	9.875731,24	1.504.898.290,43
Scenario 4	Sorriso e Sinop	Ferrogrão	Santarém	4.362241,3	1.440.937.616,41
	Querência, Sapezal, Campo Novo do Parecis e Diamantino	Nova Xavantina	Vila of Conde	5.513489,94	

By analyzing the transport model's preliminary results, it was possible to obtain the following results:
The optimized model of soybeans transport is only for the ports of Itacoatiara, Santarém and Vila of Conde, the port of Itaqui was not considered an "optimal" corridor, by the transport model, it is believed that it's due to the cost of intermodal freight (R$ 121,83/ton) considered one of the most expensive, compared to other intermodal freights and also due to the distance traveled of 1.249,46 km, from the transshipment

station in Porto Nacional (TO) to Itaqui is port (MA).

In all scenarios of the transport model, it was possible to observe intermodal transport, which confirms the research by [22], in which intermodality reduces the cost of transport and makes it possible to identify more efficient routes.

Through this, it can be concluded that the best-optimized model was for scenario 4, which includes the three logistic corridors (BR – 163, Ferrogrão and Araguaia – Tocantins Waterway). However, the routes considered "optimal" were the projected corridors (Ferrogrão and Araguaia – Tocantins Waterway), which, compared to all scenarios, presented the lowest transport cost of R$ 1.440.937.616,41, for the six municipalities under study.

As a suggestion for future work, it is suggested that Fuzzy Programming be applied, in order to assess the degree of cost and port capacity uncertainties, and compare the two models.

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