11th International Seminar on Inland Waterways and Waterborne Transportation

Brasília/DF, 22th to 24th October 2019

Transportation of Iron Ore – A Case Study of the Northern Brazilian Region

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Abstract

In Brazil, the transportation of iron ore corresponds to 74% of the products handled in the Brazilian railways. One of the important centers of the production of this material is the North Brazilian region, namely the Serra dos Carajás. Iron ore is currently drained by rail, but the northern and north-eastern Brazilian zone has large waterways that could be a modal alternative. Water transport routes as a logistical alternative of rail and road modalities for the disposal of soybeans in other areas of Brazil have already been studied, but modal alternatives have not been evaluated for the transport of iron ore. The objective of this work is to develop a prototype system to evaluate the feasibility of transportation of modal alternatives of iron ore from the North region by a mathematical origin-destination model (export point), considering ore production costs, distance, and quantity demanded at the point of destination implementing Geographic Information System (GIS). The GIS provides functionalities to increase efficiency and reliability in the data analysis process. Among these functionalities the representations of real objects, support for spatial analysis, storage and reliability of information through database concepts can be distinguished. Scenarios will be evaluated to have a cost-benefit comparison of modal alternatives. The case study has as its origin the Carajás complex and as destination two export locations of the product, which are Ponta de Madeira and Belém. Actual data on the current iron ore flow in Brazil were considered. The results are providing a technical tool for decision makers comparing the efficiency of the transport alternatives.

1. Introduction

Brazil has the third-largest iron ore reserve in the world, behind only by Australia and Russia. The iron ore is the second most important product in Brazilian bulk exports and a role of worldwide importance. Currently, China is the largest buyer of Brazilian iron ore, see Figure 1, (Montilha & Botter, 2015).

Iron ore in Brazil is mainly mined in three areas: Quadrilatero Central (1), Maciço do Urucum (2) and Serra dos Carajás (3), see Figure 7. Quadrilatero Central is located at the Center-South region of the State of Minas Gerais. It is responsible for the extraction and large production of iron ore and manganese. The region is also responsible for producing bauxite and cassiterite in smaller quantities.

Maciço do Urucum (Urucum Massif) in the State of Mato Grosso do Sul is located on the margins of the Paraguay River in the Pantanal. This mineral province produces iron ore and manganese.

The third area is Serra dos Carajás, in the State of Pará, The third area is the Serra dos Carajás, in the state of Pará, which in the 1960s was discovered as the largest mineral territory on the planet, with extreme abundance of iron ore and other minerals such as nickel, copper, tin and gold.

The largest Brazilian iron ore operator is Vale and its main competitors are Australian, namely BHP and Rio Tinto.

Cargo transport corridors are subject of continuous logistic study in search of optimized logistic alternatives. Currently, railroads are the major means of transport due to their cargo volume capacity. The waterway system via the Paraná-Paraguay river is the only operating route currently being used in the operations in Mato Grosso do Sul (by Vale).

This study will list the most relevant modes for transportation and the most significant Brazilian ports in the segment.

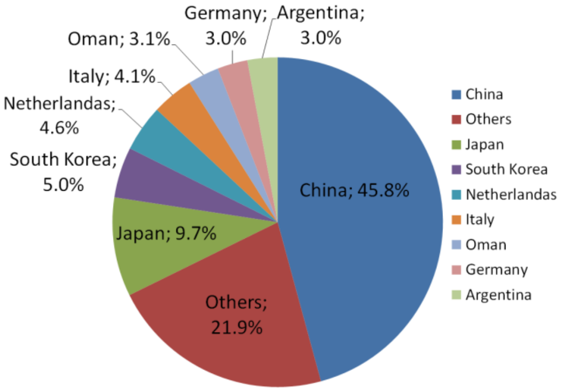

Figure 1 – Brazilian iron ore buying countries, year 2012, (Montilha & Botter, 2015)

The study evaluates the logistic corridor from the iron ore exploration in the Serra dos Carajás in the northern region of Brazil. Carajás ore is considered to have the best quality in the world because the rocks found in Carajás are formed on average by 67% of iron ore content - this is the highest content found on the planet to date. It is Vale's largest operation.

The main objective of this study is to compare the change of modes of transport and the possible use of waterways to transport iron ore from Serra de Carajás to Ponta da Madeira Terminal, located near the port of Itaqui in Maranhão and to the Port of Belem in the State of Pará.

2. State of the Art

In Brazil the logistics involved in the flow of iron ore production from the point of origin (mine) to the destination port (exporting port) is a major challenge.

The worldwide preference for transporting large volumes of iron ore is the rail modal, but the viability condition of this type of transport is that a railway should be built to connect both ends (either owned by the mining company or by third parties), as well as loading and unloading capacity, locomotives and wagons.

The modes of transport rail of iron ore available in Brazil are still of concern and dependent on investments, this is due to the large volume to be exported.

Road transport is not efficient (in the case of exports) and existing infrastructure is often in poor condition. In terms of rail mode, currently the most appropriate when it comes to iron ore transportation, it still needs expansion, maintenance, and investment on its network.

Waterway mode can be slow as it is subject to navigable conditions and has little route flexibility. On the other hand, the pipeline mode, which offers several advantages in iron ore transportation, still depends on the private initiative for its implementation.

There are other studies of alternative transportation for agricultural production, iron ore, cement and other Brazilian products runoff by sea.

About the alternatives for the runoff/flow of agricultural production, in the State of Mato Grosso, the authors (de Oliveira & Santos, 2004) analyze the multimodal routes (Road- Rail- Water) and make a qualitative comparative analysis of logistic routes and their expenses.

In the production of cement and aggregates the study case evaluated by (Dos Santos & Da Silva, 2015) is based on a multinational company that operates, located in Minas Gerais in the Campo de Vertentes mesoregion. It aims to compare both rail and road transport modes, with their respective historical developments and characterization of advantages and disadvantages through the qualitative approach methodology.

Another study is the analysis of Maritime Alternatives for Iron Ore Flow by (Montilha & Botter, 2015). This study evaluates the alternatives seeking possible difficulties of the respective mode of transport and to propose ways to solve them.

In Brazil, according to the National Land Transportation Agency (ANTT) and the ILOS analysis (Lobo, 2018), iron ore is responsible for 74.2% of the products transported by rail, followed by agricultural bulk, specifically soybeans (in grains and bran), corn and sugar, see Figure 2.

Regarding the use of multimodal transportation, the authors (Dalmás, et al., 2009) compare the options for the transportation of agricultural bulk from the western region of Paraná. There are preferences for road mode due to the lack of logistics infrastructure for the other modes, however the author mentions that the waterway mode becomes more economically efficient resulting in a lower ton/kilometer value.

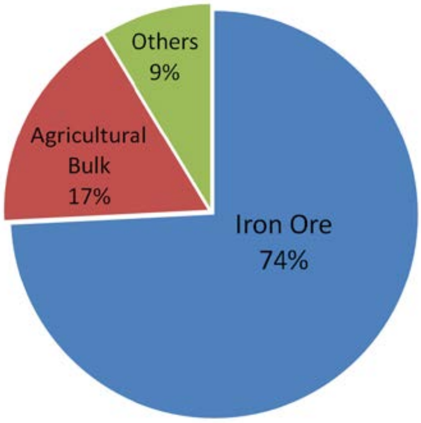

Figure 2 – Distribution of products handled on Brazilian railways by volume, (Lobo, 2018).

The study by (Araújo, et al., 2018) evaluates soybean runoff through a multicriteria decision methodology using the Analytical Hierarchical Process (AHP) where the results are showing a logistic costs reduction using the waterway mode through the Tocantins-Araguaia waterway, a scenario that was more competitive against the other two proposed scenarios.

According to the Brazilian cargo transportation matrix, we can say that two products comparable by their bulk transportation and their transportation logistic versatility are iron ore and agricultural grains such as soybeans.

For these products, the rail and waterway networks are transport modes that consume less energy and may represent lower costs, (CNT : SEST SENAT, 2018), (Lobo, 2018), (Almeida, et al., 2013), see Figure 2 and Figure 3.

Regarding the cost of each mode of transport, the information presented by (Almeida, et al., 2013) classifies the operational characteristics, for the choice of a mode of transport in general terms, using speed, availability, reliability, capacity, and frequency giving greater operational advantage to inland waterways.

About the economic characteristics of the modes, (Almeida, et al., 2013) present three types of cost: fixed, variable and price for the user, where the best classified again is the waterway mode with low fixed costs, average variable costs and lower price for the user.

The study by (Lopes, et al., 2011) evaluate the use of the Araguaia-Tocantins waterway for the flow of granulated iron ore, from the city of Marabá, Pará, via Tucuruí and final destination to the city of Barcarena, Brazil. Vila do Conde industrial district, also in the State of Pará, is near the city of Belém. The study concludes that the waterway mode is the most competitive solution for low value-added products and high cargo volume compared to the predominant modes in the country, road and rail. It is important to notice that the developed model considered as the basis for the input data probability distributions and that the path from the production points to the intermodal point was not evaluated, leaving a gap of analysis in the applied research.

According to the 2016 statistical data and the Statements of some authors such as (Lobo, 2018), Brazil needs to invest in different modes of transport to make its cargo transport matrix more efficient. According to the information presented by (Lobo, 2018) the largest amount of cargo is moved via road mode. (CNT : SEST SENAT, 2018) also indicates that energy consumption in the transport sector by mode for 2016 corresponds to Road 77436, Air 3347, Rail 1129, and Waterway 740 in thousands of tons of oil equivalent (TEP), see Figure 3.

The analysis of the Brazilian logistics corridors is extremely important, with an improvement in the survey, analysis, modeling and monitoring of data. Currently, it is the main concern of the regulators from the sector ANTF (National Agency of Rail Transport), ANTT (National Agency of Land Transport) and ANTAQ (National Agency of Waterways Transport).

The main routes of the export iron ore are three logistics corridors: North-Northeast, Midwest and Southeast, which are a group of 16 routes. For internal supply, four logistic corridors are identified: Northeast, Midwest, Southeast-South and Coastal Corridor, which together present a group of 20 main routes (Ministério dos Transportes, Portos e Aviação Civil, 2018).

The iron ore export corridors use road, rail, water and pipeline modes, with the largest share of railways, which, in terms of length, represent 42% of the total network of identified corridors and carry approximately 85% of the volume of iron ore and pig iron. In domestic consumption corridors, supply is mainly by road, rail, and cabotage.

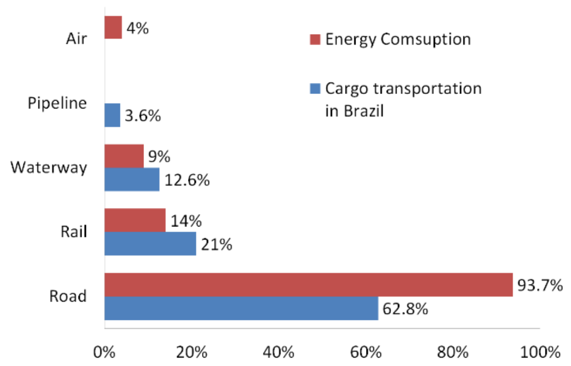

Figure 3 – Cargo transportation matrix of Brazil and energy consumption by modes, in 2016, (Lobo, 2018) and (CNT : SEST SENAT, 2018)

Vale is the world's biggest producer of iron ore and pellets and operates 10,000 kilometers of railroad tracks. Their Valemax vessels are capable of carrying 400,000 metric tons each (2.3 times more than the traditional Capsize ships), (VALE, n.d.).

Vale has deep-draft ports, capable of receiving the Valemax. To service the deeper ports, Floating Transfer Stations were installed, where ore is passed from Valemax vessels to smaller vessels.

This integrated logistics chain allows a reduction in the number of trips made, especially between Brazil and Asia, which reduces not only the costs and times, but also the air emission.

The literature review directs the researchers of this work to propose logistical alternatives as the use of waterway transport. In order to achieve this objective, the production centers of the two largest bulks produced in Brazil (iron ore and soybeans), the multimodal terminals, the waterways and railways were identified, see Figure 4.

Figure 4 represents the soybean (green warehouse) and iron ore (brown tools) production centers, intermodal terminals (red "I''), drainage ports (blue ships). The modes of transport were differentiated by layers of different line colors, road (lila), pipeline (yellow), waterway (blue) and rail (brown).

The northern iron ore flow system is differentiated, including the Ponta Madeira port, the main export port in the northern corridor.

In general, studies of quantitative analysis and comparability viability performed by discrete event simulation (DES), use of Geographic Information System (GIS), and Data Mining studies are considered in the knowledge boundary.

In the present study, an analysis based on Geographic Information System (GIS) is performed using *Transcad 4.5 software*, aiming to compare the railway route from the Carajás complex to the Ponta da Madeira Terminal (Itaqui Port - MA) with another logistic corridor. It also includes the Marabá - Belém waterway route. The comparison is made through minimum paths and cost generation of the respective alternative routes.

3. Methodology

In this paper, georeferenced data are used to develop an analytical approach to estimate modal and alternative modal routes of transport. In this section, the problem overview, parameters and decision variables are presented, the mathematical model defined, a case study with data description, transport mode information, costs and the developed model are introduced.

3.1. Problem Overview

We divided this study basically into three steps. Step 1 (S1) refers to search and treatment of the data from (Fischer Dutra e Mello dos Santos, 2017) and (DNPM, 2017), which includes georeferencing of production points (PP) and outflow point (OP) or export point of iron ore.

The points representing the PP and OP records of iron ore, were assigned to the model and used as input parameters of the mathematical model along with other demographic data. S1 includes data processing, which is an important aspect of all experimentation, being a complete and necessary understanding to conduct the modelling with the correct inferences from the obtained data. This step has a network modelling challenge with external data manipulation which adds complexity to the study.

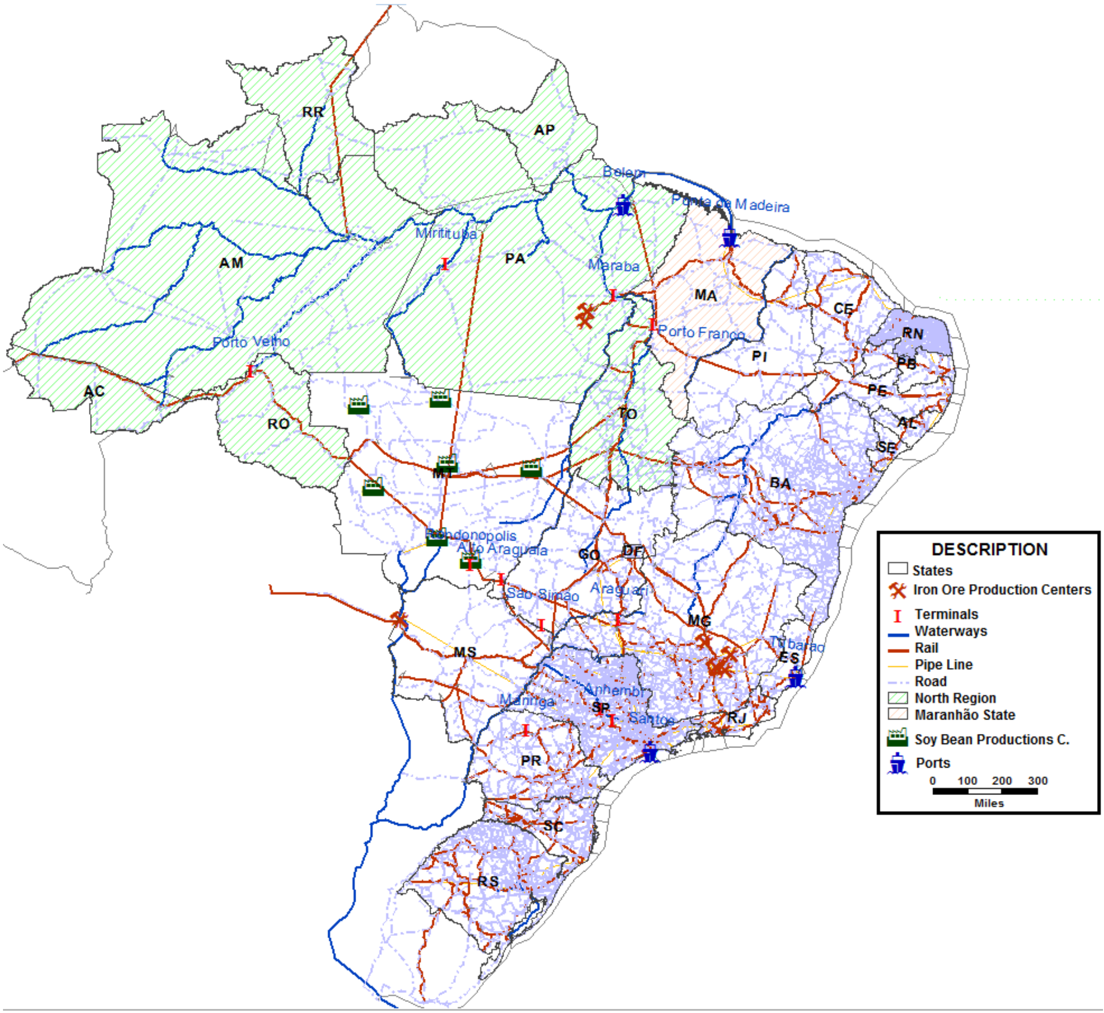

Figure 4 – Representation of soybean and iron ore production centers, intermodal terminals, outlets and transport modes, differentiating the northern iron ore outflow system, (CNT : SEST SENAT, 2018) and (VALE, 2018)

Step 2 (S2) deals with the mathematical modelling, where the information provided by S1 in the construction of a mathematical model of integer linear programming was used. With the mathematical model defined, application scenarios were proposed that allow an evaluation of the results. The scenarios refer to the use of different modes of transport for transporting iron miner from the PP to the OP.

These scenarios were used in Step 3 (S3), in which computational experiments were performed using *TransCAD 4.5* optimization software.

Figure 5 represents the flowchart of the methodology used in the study where each step is detailed.

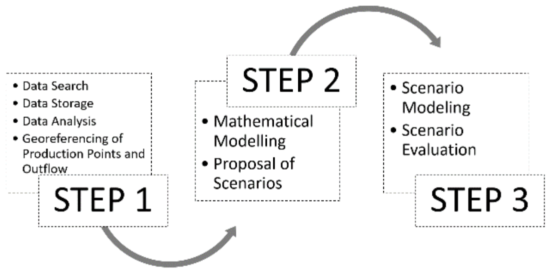

Figure 5 – Flowchart of the methodology used in the study

3.2. Parameters and Decision Variables

(Marins, 2011) has theorized that the transportation problem is represented by a graph $G = \{V, A\}$, being V a set formed by the points of origin V_O and destination V_D, that is $V = V_O \cup V_D$, which are mathematical structures used to model pairwise relations between objects.

The graph is made up of vertices which are connected by edges. A is a set of edges, $A = V_O \times V_D$. We considered that $m = |V_O|$ are origins and $n = |V_D|$ are destinations. The edges represent the routes that connect the origins and destinations, that is (i, j) links the origin $i \in V_O$ and $j \in V_D$ destinations, has a cost per unit transported given by $c_{i,j}$, see Figure 6. The supply quantity of the source product origin $i \in V_O$ is o_i and the quantity of demand at the destination $j \in V_D$ is d_j. The purpose of the problem is to determine the transport flows between pairs $i - j$ (decision variables $x_{i,j}$) that minimize the total cost of transport while respecting all supply and demand constraints, (Mattos Ribeiro, 2014) and (Marins, 2011).

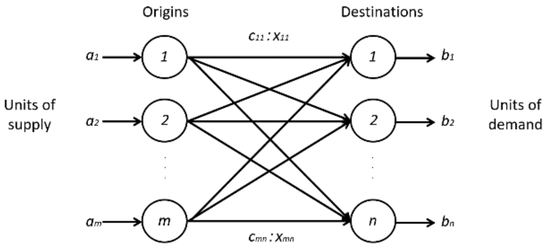

Figure 6 – Graph representation of the transportation problem, (Mattos Ribeiro, 2014)

3.3. Mathematical Model

The description of the cost-effective transportation problem that allows the iron miner to be transported from the place of origin to an export destination, with certain restrictions on the quantity to be transported is shown in Figure 6.

The objective function defined by Equation 1 must minimize the cost and distance between origins (PP) and destinations (OP).

Minimize:

$$z = \sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij} x_{ij} \quad (1)$$

Subject to:

$$\sum_{j=1}^{n} x_{ij} = o_i \quad \forall_i = 1,2,3, \dots, m \quad (2)$$

$$\sum_{i=1}^{m} x_{ij} = d_j \quad \forall_j = 1,2,3, \dots, n \quad (3)$$

$$x_{ij} \geq 0 \quad \forall_i = 1,2,3, \dots, m \quad \forall_j = 1,2,3, \dots, n \quad (4)$$

3.4. Case Study

In this section the study area and the definition of the scenarios of the different modes of transportation are presented.

3.4.1. Study Area

The mathematical model represented by the objective function (Equation 1) and the constraints (Equations 2, 3 and 4) was applied to the Brazilian Northern Region, which more than 12.4 million of people. Its territory of 3.87 billion km^2 is made up of seven states: Acre, Amapá, Amazonas, Pará, Rondônia, Roraima and Tocantins, as can be seen in Figure 7.

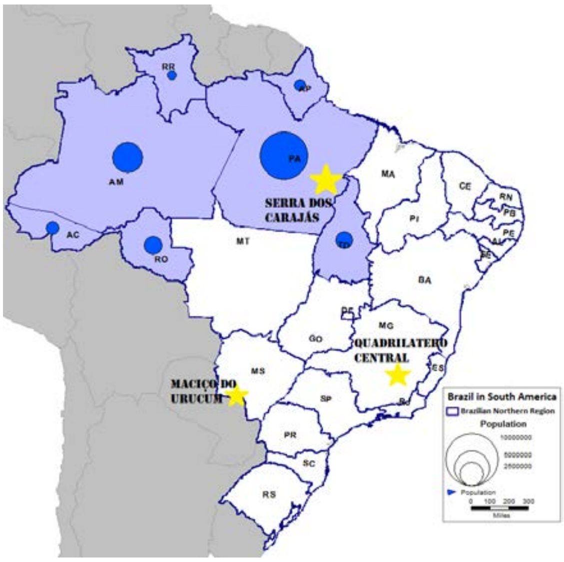

Figure 7 – Representation of the Brazilian Northern Region including the Major Mineral Exploration Areas in Brazil.

Despite being the largest region in Brazil, its demographic density is small (around 4.69 people (pp) per km²). Its main cities are Manaus (capital of Amazonas), Belem (capital of Pará), Porto Velho (capital of Rondônia), Macapá (capital of Amapá), Rio Branco (capital of Acre), Boa Vista (capital of Roraima), Palmas (capital of Tocantins), Ananindeua, Marabá, Santarém, among others, see Table 1. The region's economy is based on industrial activities, mineral and plant extraction, agriculture, livestock and tourism.

Table 1 – Volume-velocity ratio measured on site; *Estimated Population (EP), **Demographic Density (DD)

State	EP* 2018 (pp)	DD** 2010 (pp/km²)	Area of territorial unit 2017 (km²)
Acre	869.265	4,47	164.123,737
Amapá	829.494	4,69	142.828,521
Amazonas	4.080.611	2,23	1.559.146,876
Pará	8.513.497	6,07	1.247.955,238
Rondônia	1.757.589	6,58	237.765,293
Roraima	576.568	2,01	224.300,805
Tocantins	1.555.229	4,98	277.720,412

(Montilha & Botter, 2015) presented a study where it was identified that the largest production point (PP) of iron ore is the Serra dos Carajás zone in the state of Pará, also identified the points of iron ore outflow point (OP) in the state of Maranhão at the ports of Itaqui and Ponta de Madeira, (Montilha & Botter, 2015).

According to this information and the available data, the study area has been delimited by the iron ore flow where the PP is the Carajás Complex (S11D and Carajás) and the PE is Ponta de Madeira, (DNPM, 2017), (Fischer Dutra e Mello dos Santos, 2017), and (VALE, 2018).

As additional data, it is known that the state's main PP is under the responsibility of VALE and the infrastructure used to dispose of the iron miner is the Carajás Railroad. Figure 4 shows the study area including PP and OP.

3.4.2. Definition of the scenarios of the different modes of transportation

For this study, two scenarios are assessed with variation of the transport modal. The scenarios are presented in Table 2.

Table 2 – Iron ore flow modal transport scenarios

Scenario	Origin	Destination	Mode of transport
Base	Carajás Complex	Ponta de Madeira	Rail
Alternative1	Carajás Complex	Belém	Rail + Waterway

The base scenario is the simulation of the transport of iron ore in the current situation that is performed by rail where Ponta da Madeira is the point of export of the product. This base scenario has two production points that are called S11D and Carajás.

Scenario alternative 1, will be the simulation of the transport of the iron ore in rail mode from the Carajás Complex to Marabá, and then sent by Waterway mode by the Tocantins waterway to Belém, where it will be the export point of the product.

Table 3 – Brazil and United States Cargo Transport Matrix and their costs by modal, based on year 2012, (Lobo, 2018)

Modal	Brazil		United States	
	%TKU	USD/1000 TKU	%TKU	USD/1000 TKU
Road	67	133	31	310
Rail	118	22	37	29
Waterway	11	30	10	10

The cost data is based on the study by (Lobo, 2018), which compares the cost matrices of Brazil and the United States of the year 2012, see Table 3. A relevant data is that Brazil transports 67% of tons per useful kilometer (TKU) of freight by road and the United States a 31% TKU of cargo, (Lobo, 2018).

For calculation purposes it is assumed that production in Para is divided equally between the two points of the Carajás Complex (64,809,963.5 tons), the total production is 129,619,927 tons of iron ore, (DNPM, 2017). For calculation purposes in the base scenario, the demand for the port of Ponta da Madeira is for total production and for scenario alternative 1 this total would be demanded for the port of Belém.

4. Results

According to the information in the Base Scenario, Figure 8, Figure 9, and Figure 10 represent the minimum transport route of iron ore, with a total distance of: Carajás-S11D equal 51.2 kilometers, S11D- Marabá equal 183.5 kilometers, and Marabá- Ponta Madeira equal to 703.9 kilometers. Total is around 938.64 kilometers.

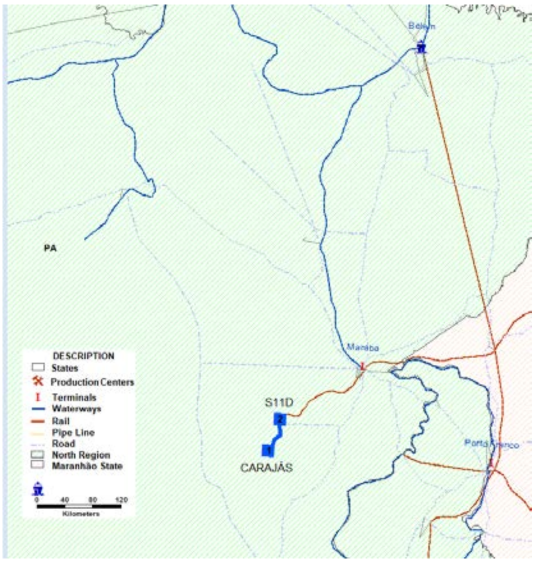

Figure 8 –Minimum route estimation Carajá-S11D by Rail mode

According to the information from Scenario Alternative 1, Figure 8, Figure 9, and Figure 11 represent the minimum transport route of iron ore, with a total distance of: Carajás-S11D equal 51.2 kilometers, S11D-Marabá equal 183.5 kilometers, and Marabá-Belem equal 544.5 kilometers. Total is around 779.3 kilometers.

These minimum routes were calculated using the *TransCAD 4.5* optimization software with the help of the shortest route tool of the mentioned program. This minimum route matrix is described in each of its component sections.

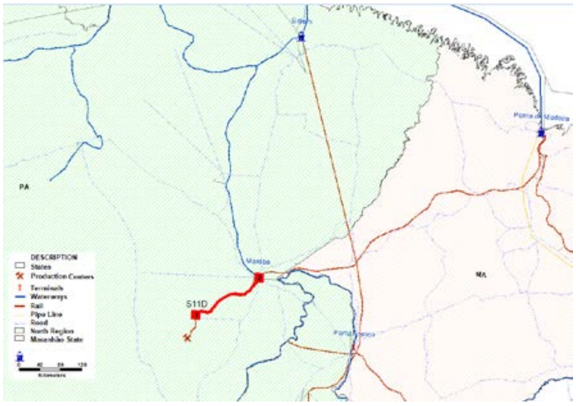

Figure 9 –Minimum route estimation S11D-Marabá by Rail Mode

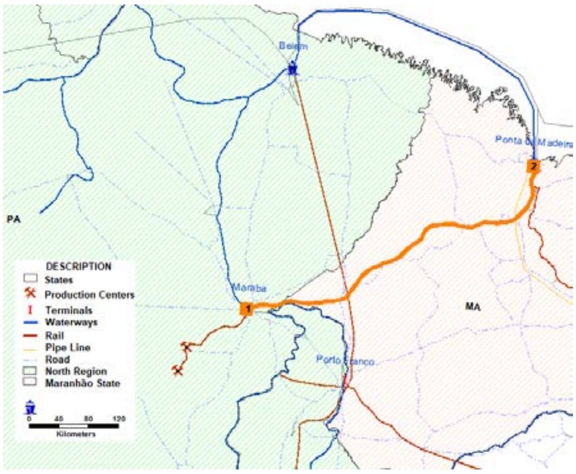

Figure 10 –Minimum route estimation Marabá-Ponta Madeira Rail mode

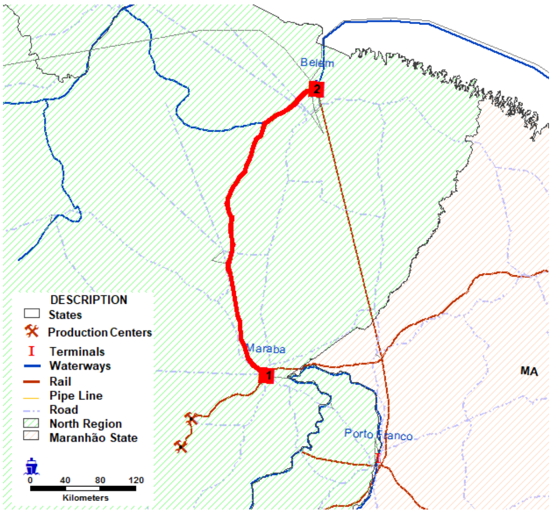

Figure 11 –Minimum route estimation Marabá-Belém Waterway Mode

Table 3 presents the cost matrix that has been used for the simulation. The cost data are coming from (Lobo, 2018) with a base year of 2012. Both Brazil and United States of America cost are compared. It is important to note that in USA the costs of Waterway mode is lower that the Railway mode meanwhile in Brazil it is the opposite. It could be explained partially by the fact that the port and terminals facilities in Brazilian waterways are less developed than in USA.

In order to study this the sensibility of this behavior, a simulation has been performed for the both cases, i.e. one with the USA cost matrix and one with the Brazilian cost matrix, see Table 5, Table 6, Table 7, and Table 8.

Table 4 – Proposed scenario distance matrix with each of the proposed scenario compositions in kilometer

PP/OP	Belém	Carajás	S11D	Marabá	Ponta da Madeira
Belém	0	779	728	545	625
Carajás	779	0	51	235	990
S11D	728	51	0	184	728
Marabá	545	235	184	0	704
Ponta da Madeira	625	990	728	704	0

Table 5 – Brazil base scenario cost matrix 2012 value USD/1000 TKU, (Lobo, 2018)

PP/OP	Belém	Carajás	S11D	Marabá	Ponta da Madeira
Belém	0				
Carajás		0		22	
S11D			0	22	
Marabá		22	22	0	22
Ponta da Madeira				22	0

Table 6 – Base scenario cost matrix United States value in 2012 USD/1000TKU, (Lobo, 2018)

PP/OP	Belém	Carajás	S11D	Marabá	Ponta da Madeira
Belém	0				
Carajás		0		29	
S11D			0	29	
Marabá		29	29	0	29
Ponta da Madeira				29	0

Another of the tools used for the development of this study is the routing/logistics functionality, where, with the data provided by the network about, a distance and time, a distance matrix (PP and OP) can be generated with the help of the vehicle routing tool.

Table 9, is the distance matrix of the PP and OP obtained with a routing algorithm. The distance matrix is calculated based on the geographic information of production and demand points using a routing function where the origin-destination matrix is estimated with distance. The routing algorithm will assess both the minimum distance and the minimum transport cost options.

Table 7 – Alternative scenario cost matrix 1 Brazil value in 2012 USD/1000 TKU, (Lobo, 2018)

PP/OP	Belém	Carajás	S11D	Marabá	Ponta da Madeira
Belém	0			30	
Carajás		0		22	
S11D			0	22	
Marabá	30	22	22	0	
Ponta da Madeira					0

Table 8 – Alternative 1 scenario cost matrix 1 United States Value 2012 USD/1000 TKU, (Lobo, 2018)

PP/OP	Belém	Carajás	S11D	Marabá	Ponta da Madeira
Belém	0			10	
Carajás		0		29	
S11D			0	29	
Marabá	10	29	29	0	
Ponta da Madeira					0

Table 9 – Distance matrix of the proposed scenario product of the vehicle routing tool in kilometers

PP/OP	Belém	Carajás	S11D	Santos	Ponta da Madeira
Belém	0	634	689	2789	625
Carajás	634	0	87	2320	823
S11D	683	87	0	2408	847
Santos	2789	2320	2408	0	2821
Ponta da Madeira	625	823	848	2821	0

The result of the analysis shows an average transport cost (per 1000 tons) for the base scenarios: Carajás-Marabá-Ponta da Madeira of $20.648 USD per 1000 Tons, and S11D-Marabá-Ponta da Madeira of $19.524 USD per 1000 Tons, using Brazilian cost scenario, see Figure 12.

The same base scenario, Carajás-Marabá-Ponta da Madeira is $27.218 USD per 1000 Tons, and S11D-Marabá-Ponta da Madeira is $25.736 USD per 1000 Tons using United States cost scenario, see Figure 12.

It can be observed that the cost of transport of the base scenario “Carajás-Marabá” is 5% higher than the base scenario “S11D- Marabá”. It can be explained by the higher distance (5%) between Carajás production point and Ponta Madeira outflow point.

The result of the analysis shows an average transportation cost (per 1000tons) for the alternative scenario 1 Carajás-Marabá-Belém of $21.497 USD per 1000 Tons, and S11D-Marabá-Belém is $20.372 USD per 1000 Tons considering Brazilian costs, see Figure 12.

For the same alternative Carajás-Marabá-Belém using the United States base costs, a value of $12.249 USD per 1000 Tons is observed, and for S11D-Marabá-Belém $10.767 USD per 1000Tons is observed, see Figure 12.

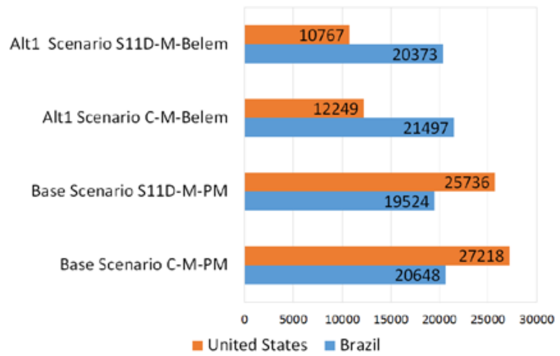

Figure 12 – Cost representation by scenarios in USD/1000Tons

5. Discussions and Conclusions

Comparing the distance matrix between Table 4 and Table 9 we can see that the values are very close. The observed difference is due to the data accuracy in the road network in the GIS model. Indeed, a path has been manually added between S11D and Carajás for the purpose of the simulation causing some inaccuracies.

According to the results we can see that the presented simulation tool is allowing to find the minimum transport cost in function of distance matrix and relative unitary costs of different transport mode. Therefore, it could be a decision-making tool for the implementation of new facilities of multi modal transportation systems.

The current scenario with cost figures based on Brazil 2012 data is more attractive than Alternative 1, but with United States 2012 data costs, Alternative 1 is 50% cheaper.

One of the weakness of this study relies to the availability and accuracy of the GIS data. Moreover, the treatment of the data is highly time consuming.

The data of iron ore production as well as the transportation capacity of each transport mode has been based on an old database State of Pará.

It should be updated in case of any use for further studies.

Other improvements can be considered:

(1) To update the cost data from the Brazilian transportation matrix.

(2) To consider the transshipment costs from one mode of transport to another.

(3) To upgrade the network database (GIS).

This paper is useful to demonstrate the capacity of routing algorithm minimizing distance and/or cost of a multi modal transport network.

The use of this methodology can turn the logistics of an important export material for Brazil more efficient, safer and more profitable for the country. We can conclude that the study has relevance to the area and can be used as a decision-making tool for all stakeholders especially for logistic private companies or governmental institutions including mining sector as well as agrobusiness sector.

6. Acknowledgments

This study was financed in part by the "Coordenação de Aperfeiçoamento de Pessoal de Nível Superior" - Brazil (CAPES) - Funding grant 001.

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