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Potential effects of expansion of the panama canal on midwest brazilian soybean logistics

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ABSTRACT

This work analyzed the potential impact on the soybean outflow Logistics from Brazilian Midwest to China caused by the Panama Canal expansion, completed in 2016. Scenarios were built out to analyze the use of this route in compare to the traditional route, which skirts the Cape of Good Hope. A mathematical optimization model based on Linear Programming was constructed using the transportation problem, considering the main soybean exporting ports, Brazilian internal logistic infrastructure and new projects to optimize logistics costs. In 2017, there was a low influence of Panama Canal on the soybean transportation between Brazil and China. However, the growth of exported soybean projections aims to the huge potential for demand to export through the North ports, due to their geographical locations, closer to the producing areas, capacity constraints in Brazilians Southern ports and new investments in Brazilian infrastructure, increasing the competitiveness of the route via the Panama Canal.

KEYWORDS: Logistics · Brazilian Soybean · Panama Canal · Costs · Operational Research

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1. INTRODUCTION

Brazil is the global leader in soybean exportation. In the year of 2017, 62 million tons of this product were sent beyond the country's borders [1], [2]. Besides that, Brazil exported approximately 84 million metric tons of the grain. It means that the country kept the first place in the ranking of grain exports [3], [4].

Nowadays, Brazilian soybeans are sent primarily to the global market through the ports in the Southern and Southeastern regions of Brazil. The ports of Santos (SSZ), Paranaguá (PRG) and Rio Grande (RGD) are the main exporting ports [5]; [6]. However, in recent years, due to the great use of traditional ports, not only because soybean but also for cargo competitors, it has been happening a greater flow of soybeans through the northern ports of Brazil, such as Itacoatiara (ITA), Santarém (STM), Vila do Conde (VDC) and Itaqui (ITQ). This group of ports are known as the Northern Arch (in Portuguese, "*Arco Norte*"). The Brazilian federal government plans and has already performed several projects related to the expansion, development and creation of transportation alternatives for grain logistics through these ports. In September 2017, the government announced a package of privatizations and new concessions that included new fuel terminals in STM; a stretch of the North-South railway between Porto Nacional (TO) and Estrela D'Oeste (SP); and the Ferrogrão section between Sinop (MT) and Miritituba (PA). These new concessions have been implemented and it will be used to transport Brazilian soybeans, creating new alternatives for central Brazil, while strengthening the structure of northern ports to receive soybeans and other products that will use new paths [7].

China is the main importing country of Brazilian soybeans, accounting for 79% of all soybeans exported by Brazil in 2017 [1]. Besides that, China is the world leader in soybean consumption, accounting almost 90% of the world soybean. This situation makes the country dependent of the soybean production from other countries [8]. Ports in the North still send a low percentage of exports to China since the routes from the southern and southeastern ports have shorter distances using the traditional route through the Atlantic and Indian Oceans and Western Pacific around the Cape of Good Hope in South Africa. However, the expansion of the Panama Canal was completed in July 2016. This expansion seeks to reduce queues and restrictions on bulk carriers. In this scope, exports from the ports in northern Brazil has been receiving a new alternative for maritime transport. The analysis of this alternative is the scope of this research.

Soy is a commodity priced in the international market Thus, is not possible to control its sale price, with the only controls available being operational and management costs, related to production and logistics. From this explanation and the expansion of the Canal, the question of this research is: What is the influence of the Panama Canal expansion in the export logistics of the Brazilian soybean?

Thus, this study proposes a cost analysis based on the influence of the expansion of the Panama Canal on Brazilian soybean export logistics destined for China. This applied study aims to guide decisions of stakeholders involved in the Brazilian Soybean logistics (Producers, Buyers, Tradings, Logistics and grain transportation companies, Competitors and Brazilian government) in order to minimize costs, increasing the profit over the sale price established in external market. A model focused on the transportation problem and based in Linear Programming was built for the analyses, comparative analyses were carried out in terms of costs between soybean exports through the traditional route (passage around the Cape of Good Hope) and the potential route using the Panama Canal. Comparative scenarios were executed for shipment from the main Brazilian soybean exporting ports in order to evaluate the potential effectiveness of the use of the Panama Canal, while taking into consideration the new investments that are being made in Brazilian infrastructure. The scientific contribution of this work is related to applicability and topicality of the object of study related to the Brazilian soybean logistics with the recent expansion of the Panama Canal.

Besides the introduction, this work is divided in 6 sections. In the section 2 is performed a Background about the Brazilian soybean logistics. The section 3 shows the Panama Canal and its expansion. In the section 4 is showed the research method. The section 5 organizes the breakdown cost that was used. The comparative scenarios are defined in the section 6. The analyses of the results are present in the section 7. Lastly, the conclusions are in the section 8 and then, the references that were used.

2. BRAZILIAN SOYBEAN LOGISTICS

It is possible to divide the Brazilian soybean logistics in two systems: Internal and external logistics. In order to understand the non-use of the current route via Panama Canal and the purpose of this study, it is necessary the presentation and the understanding of these systems.

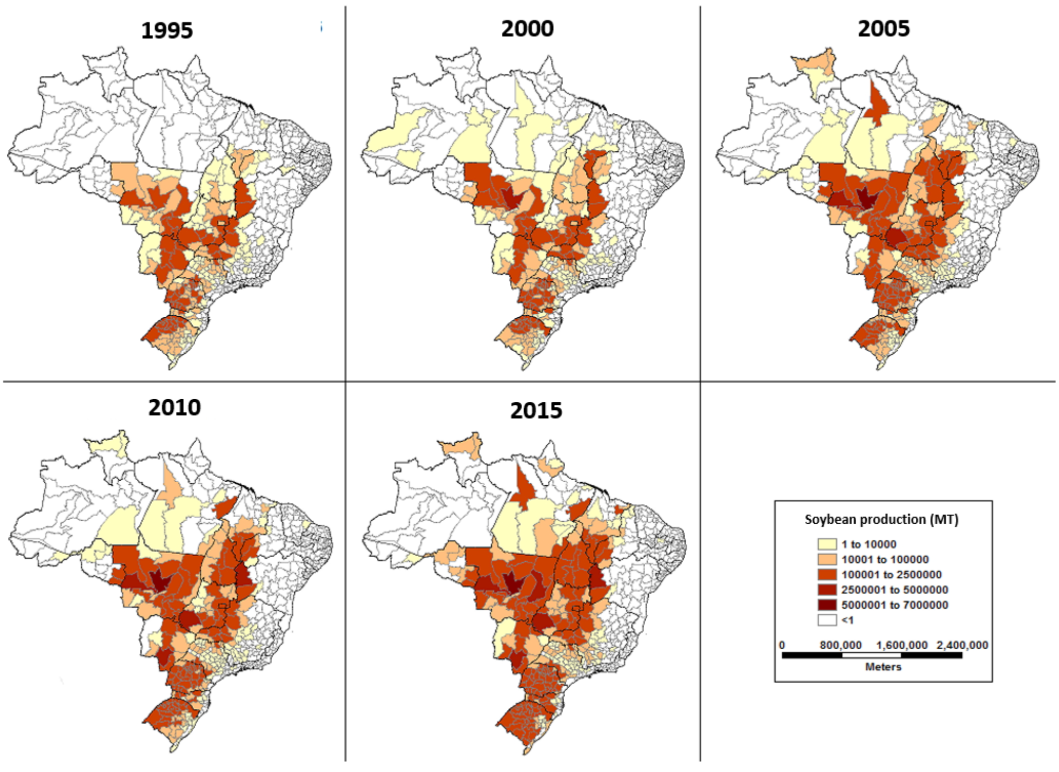

Fig. 1: Soybean production in Brazil per micro region (Source: [10])

2.1. Internal Brazilian soybean logistics

In the latest years, the search for larger territorial for planting grains increased due to population growth and demand increases. Soybean cultivation migrated from the southern region of Brazil to the central regions of the country. It goes especially to the states of Mato Grosso and Mato Grosso do Sul. These areas have fertile soil for grain development [9]. Nowadays, the production of soybeans has become the most economically expressive Brazilian activity. Figure 1 shows the evolution and expansion of soybean cultivation in Brazil from 1995 to 2015 at the level of Brazilian micro regions.

The Figure 1 shows that the soybean is cultivated in all over Brazil but the production is concentrated in the interior regions of the country, far from Brazilian coastlines. The Midwest and Southern regions are the largest soybean producing areas, followed by the Southeast, Northeast and North regions which produce considerably lower volumes. In 2017, the Midwest and Southern regions produced 83% of soybeans in Brazil. It is important to emphasize, as shown in Figure 1, that in the beginning of grain exports, the history of Brazilian soybean prioritized investments in Ports closer or with a better infrastructure to the detriment of farther Ports which the potentialities are just recent for the studied logistics.

Due to the immense volumes of soybeans exported from Brazil to the world market, and based on the fact that the most productive regions are located in the interior of the country – around 1,000 kilometers from the main ports – the logistics becomes fundamental in this system [11]. Internally, the main transportation model that takes soybeans from the producing regions to the main exporting ports in Brazil is the road transportation – around 50% of the soybean transportation in Brazil – followed by waterways and railways [12]. This transportation model is not recommended for long distances. It burdens internal logistics of soybean flow, as well as the lack of storage infrastructure at multimodal terminals and export ports [13].

2.2. External Brazilian soybean logistics

In 2016, there were 16 soybean exporting ports in Brazil [6]. For this model, 10 Brazilian ports and the adjacent port locations were considered. Table 1 shows the ports considered in this investigation, the export of Brazilian soybeans per port, the amount and the percentage bound to China, the main importer country in the year of 2016.

China is currently the main destination for Brazilian soybeans. It imports about 75% of the volume of its exports [6]. China imports 40% of all soybeans grown in Brazil, compared with production data. From data in Table 1, it can be verified that approximately 88% of the Brazilian soybean crop shipped to the country passes through the ports located in Southern and Southeastern regions of Brazil. It happens due to the greater proximity of ports in Southern China which are traditional routes. Besides that, these ports have the best existing port infrastructure and Brazilian internal logistics, which has greater efficiency than the Southern Ports [14].

Among the existing sea routes, the most used between Brazil and China goes around the Cape of Good Hope. This route has few size restrictions for bulk carriers and no charges for passage. Considering that this route is widely used and there are no restrictions for using, this work will describe the route to Panama Canal. It is object of analysis of this study related to Soybean export logistics. Another alternative route uses the Suez Canal. This route also presents few size restrictions for bulk carriers; however, its route is longer than those to

Table 1: Soybean exportation per Brazilian port in 2016 – Total and percentage exported to China (Source: [6])

Brazilian Port	Total Soybean Exported (Ton)	Total Exports to China (Ton)	Percentage of exports to China
Itacoatiara – AM (ITA)	1,974,313	384,371	19.5%
Santarém – PA (STM)	1,695,169	663,868	39.2%
Vila do Conde – PA (VDC)	2,187,261	633,458	29.0%
Itaqui – MA (ITQ)	3,850,196	2,246,318	58.3%
Salvador – BA (SSA)	1,469,611	824,017	56.1%
Vitória – ES (VIX)	2,944,967	2,401,443	81.5%
Santos – SP (SSZ)	14,475,763	11,825,003	81.7%
Paranaguá – PR (PRG)	8,157,251	7,213,409	88.4%
São Francisco do Sul – SC (SFC)	5,027,400	3,957,312	78.7%
Rio Grande – RS (RGD)	9,704,071	8,414,709	86.7%
Other forms of exportation	95,873	-	-
TOTAL	**51,581,875**	**38,563,909**	**74.8%**

Chinese ports. This particular route is used to service imports from the Middle East and some European countries.

3. THE PANAMA CANAL AND ITS EXPANSION

The construction of the Panama Canal has begun in 1880 by the French government. The US government completed it in 1903. Since its opening in 1914, it has been hugely successful in linking maritime traffic between the Pacific and Atlantic Oceans. The man-made channel is approximately 50 miles long and it is comprised of a system of artificial lakes, channels and locks (Figure 2). The Canal is administered by the country of Panama [15]. In 2016, its expansion works were completed. It aims to meet growing demands, ensure the competitiveness of the Canal over other maritime routes and increase the contributions of the Canal to the Panamanian State [16].

Fig. 2: The Panama Canal (Source: [16]).

Bürger and Lisboa [17] point out that the expansion would serve not only the main canal user - the United States of America - but also South American countries in trade with Asia. Since then, a series of trade agreements and alliances have been signed to improve cooperation between Panama and South America. Brazil has international cooperation agreements signed with Panama in the areas of health, science and technology, as well as tourism, which shows the growing proximity of the countries from a diplomatic standpoint [18].

After its amplification, the canal crossing system had its capacity doubled, enabling the passage of larger ships through the Canal [19]. In addition to the larger capacity, there was also a reduction in the average time for the crossing of ships through the canal. For Brazilian soybean logistics, these improvements can make the route through the Canal more attractive due to the reduction of transportation times and costs.

The scenarios performed in this study has compared routes using the vessels that are now able to cross the new canal locks - Neo-Panamax vessels has a capacity of 120,000 DWT (deadweight tonnage - unit of measurement of total ship weight capacity, considering gross weight cargo, fuel, potable water, groceries, crew and belongings). The Neo-Panamax ship has the maximum allowed dimensions in the third and new set of locks. The Panama Canal Authority (ACP) allows only vessels that are up to 366 meters long, 49 meters wide and 15.2 meters deep to cross [20]. According to [21], the greater the capacity of ships the lower the operational costs for maritime fees and charges. Therefore, Neo-Panamax presents itself as the best option in terms of load capacity for loads transportation through the canal. The dimensions of this vessel are shown in Figure 3. Thus, it will be used in the analyses for comparative purposes.

Fig. 3: Neo-Panamax Dimensions (Source: [15])

4. RESEARCH METHOD

The research method adopted for this paper uses mathematical modeling through Linear Programming. Problems involving the distance between origins and destinations are often solved by using the transportation model. It is an optimization model that aims to minimize the total cost required to supply customers (destinations) from suppliers (origin) centers. Linear Programming is a method in Operations Research widely used to solve static problems with deterministic solutions that provide preliminary subsidies from many constraints. The model restrictions are made based on the available quantities or supply of each source and the quantities required, or demand for each destination. The modeling for this study will be based on the methodology proposed by [22]. It incorporates specific variables of the studied system. The model was implemented at Microsoft Excel and solved through the Solver tool.

4.1. Modeling the System under study

Through adaptation of the studied problem to the research method, it is mathematically expected that the lowest result for Z will be presented. It represents the total cost of operation. The purpose is to find the lowest total cost in order to analyze if the Panama route is viable to transport soybean to China.

The cost of each "j" route was calculated in order to find the lowest cost. Each "j" route comes from "i" regions presented in Table 2 and goes toward Shangai port passing through for one of 10 Brazilian ports. The ports are presented in Table 2. Thus, it is totalized 140 possible routes from origins to final destination. The costs of land (cg_j, in USD/ton); sea transportation (cm_j, in USD/ton), canal tolls (Ct, in USD) and waiting time (Cw, in USD) costs (time in queue for crossing the locks).

All costs are explained in the subsections from 5.2.1 to 5.2.5. The land costs are related to transportation from production areas to Brazilian ports; the rent of the ship and costs of the crew are related to sea costs; canal tolls are paid for the locks use; the costs of waiting time is related to the used fuel while ship is not moving. The purposed model is generic, however, the toll cost and waiting time cost are charged only in the Panama Canal route. It is described in subsections 5.2.3 and 5.2.4. There are not these costs in routes to China which skirts the Cape of Good Hope. The land and sea costs were calculated per ton and the Toll Cost and Waiting Time Cost were calculated per ship needed to match the demand.

The model can be described according to equations (1), (2), (3) and (4) presented below:

$$Minimize\ Z = \sum_{i=1}^{r}\sum_{j=1}^{s}(x_{ij}(cg_j + cm_j) + \frac{x_{ij}}{K_{np}}x_{ij}(ct + cw) \quad (1)$$

Subject to:

$$\sum_{i=1}^{r} x_{ij} \geq D_p; p = 1, \dots, n \quad (2)$$

$$\sum_{i=1}^{r} x_{ij} \geq K_p; p = 1, \dots, n \quad (3)$$

Given that:

$$x_{ij} \geq 0 \quad (4)$$

Where

x_{ij} is the Quantity of soybean transported from 'i' origin, through 'j' route
Di = customer demand per port
Ki = exportation capacity per port
Knp = *Neo-Panamax* ship capacity

5. COST BREAKDOWN

5.1. Ground Transportation Costs

Ground transportation costs were defined based on real transportation cost data from different producing regions of Brazil, calculating the expenses to reach exporting ports, from 2016, published by [2]. Based on these data, the cost for export from the Central-West region – the main soy producing region and the only one without oceanic frontiers – was calculated, taking into account the distances to each Brazilian soybean exporting port. These costs, calculated in dollars per ton, are shown in Table 2.

5.2. Maritime Transportation Costs

Shipping costs were established from data provided by the USDA (United States Department of Agriculture) in [2]. In this report, the costs were derived from sea freight charges for the year 2016, referring to the shipment of one ton from a given Brazilian port to the Port of Shanghai. This cost is based on the transportation of Brazilian soy via the route around the Cape of Good Hope. From this cost, it was also possible to estimate the maritime costs through the Panama

Table 2: Real transportation costs between regions from Midwest to port [2].

	Cost/Ton [USD/ton]									
Region	**ITA**	**VDC**	**STM**	**ITQ**	**SSA**	**VIX**	**SSZ**	**PRG**	**SFC**	**RGD**
Northern MT	98,29	84,22	49,60	98,08	122,26	107,51	75,49	74,42	99,21	117,24
Southern MT	109,20	98,20	84,13	103,17	95,63	86,03	51,29	53,43	76,76	94,79
Northern GO	148,59	62,10	87,21	67,32	65,09	68,84	58,47	74,19	78,23	111,39
Southern GO	128,37	89,31	103,89	94,54	79,03	59,02	34,66	43,78	57,55	90,70
Eastern GO	147,70	86,62	111,73	91,84	64,96	47,35	40,31	55,86	59,87	93,06
Northern MS	122,81	112,69	98,33	117,92	102,42	77,94	39,10	53,25	56,49	74,57
Southern MS	135,66	122,09	111,18	127,31	111,81	82,07	40,68	38,62	47,14	63,32

Table 3: Distances and costs between Brazilian ports and Shanghai. Data Source: Elaborated by paper's authors.

	Distance to Shanghai [nautical miles]		Cost per route [USD/ton]	
Brazilian's Ports	Panama Canal	Cape of Good Hope	Cost through P. Canal	Cost Cape
ITA	11.592	12.880	16,98	22,39
VDC	10.926	12.005	16,01	20,87
STM	11.352	12.389	16,63	21,54
ITQ	11.087	11.708	16,63	19,48
SSA	12.170	10.997	18,31	16,54
VIX	12.587	10.857	18,93	16,33
SSZ	13.043	11.056	22,68	16,63
PRG	13.165	11.111	22,89	18,13
SFC	13.226	11.215	24,36	20,66
RGD	13.564	11.249	24,99	20,72

Canal, considered as being proportional to costs for the distances from each port to Shanghai through the two routes. Table 3 shows the distance between the Brazilian and Shanghai export ports through the two routes, and the cost of actually traveling the route, shown in dollars per ton.

5.3. Canal Toll Costs

This cost refers to the Panama Canal crossing. The value of this cost is determined through the simulator available on the website of the concessionaire that manages the canal. To calculate this, a standard ship is established for the calculation of the tariff from the capacity of the vessel in DWT and the gross load in tons carried by the vessel. As shown in Table 4, this cost is divided between the use of locks and the cost of the canal crossing.

5.4. Waiting Time Costs

Waiting time costs originate on the route used to cross the Panama Canal while waiting to enter the channel locks. According to [24], ships wait on average 24 hours to use the locks. During this time, the costs accumulate related to the ship's daily operating costs, crew payment and diesel fuel, which is only used because the ship is either stationary or moving at low speed, rather than normal seafaring fuel, thus subjecting the ship to different fuel restrictions. From the [24], an average value of US $ 58 thousand is used for each ship that crosses the locks.

5.5. Cost Comparisons

Once all the costs are defined, the total number of routes was calculated, departing from one of seven defined origins in Central-West Brazil headed from Shanghai, regardless of which of the 10 Brazilian exporting ports is used, by the two maritime routes previously mentioned.

6. COMPARATIVE SCENARIOS

The scenarios that will be discussed throughout this section will be based on projected soy exports to China in 2017, which is an estimated 43 million tons, as well as in 2026, totaling an estimated 58 million tons [6]. From these values, scenarios will be projected to ship soybeans to China. The scenarios were divided in scenarios for external and internal logistics of the Brazilian Soybean (From C1 to C4) and grouped (From C5 to C7). This division was performed in this study in order to understand the parts of the logistics cost of Brazilian Soybean export. Despite the applied model is based in costs for decision, the understanding of the parts of the system can suggest other alternatives conditions to a better logistics configuration, such as: Viable existing infrastructure, competitiveness to other loads, socio-environmental factors etc. From individual analyzes, it goes to integrated scenarios. The projections of the scenarios are presented in Table 5

Table 4: Canal Toll Costs (Source: [23]).

Rates	Locks [USD]	Canal Crossing [USD]	Total [USD]	USD/ton
Neo-Panamax	244,625	163,750	408,375	4.19

Table 5: Scenario Definitions. Data Source: Elaborated by paper's authors.

Scenarios	Abbreviation	Description
Scenario 1	C1	External logistics scenario in 2017
Scenario 2	C2	External logistics scenario in 2026
Scenario 3	C3	Internal logistics scenario in 2017
Scenario 4	C4	Internal logistics scenario in 2026
Scenario 5	C5	Total logistics scenario in 2017
Scenario 6	C6	Total logistics scenario in 2026
Scenario 7	C7	Total logistics scenario in 2026 without the Santos port

Scenarios 1 and 2 correspond respectively to the years of 2017 and 2026. It will be carried out to evaluate only the cost of external logistics, without considering the ground transportation costs within Brazil. These scenarios show the possibility of soybean flow through the Panama Canal. Both scenarios will be subject to demand restrictions, which require a minimum quantity to be handled per port based on the exports made in 2016, along with capacity, which will limit how much soy can be disposed per port per year. VIX, SSZ and SFC will have limited capacity, both in C1 and C2, to the amount of soybeans shipped in 2015. In this year these three ports reached 100% of their capacity. PRG, which also reached 100% of its operational capacity in 2015, will have capacity limited in C1, but not in C2.

The reason for not limiting PRG capacity in C2 is the investments that will be made up until 2020 to expand this port. VIX will also receive investments; however, this port is predominately used for the outflow of iron ore to China, so there should be no significant increase in the volume of soybeans exported. SSZ and SFC are not yet targets of investments by the Brazilian government in improvements or expansion. Figure 4 shows that in addition to investments in VIX and PRG, and the port of Suape, in Recife, STM and VDC will also undergo improvement projects until 2020. Also, the new railroad projects due to be inaugurated by 2020 are highlighted, standing out the Ferrogrão undertaking that will connect Sinop - MT to the port of Miritituba, located in the state of Pará.

Fig. 4: Planned investments by the Brazilian government for railway and port infrastructure (Source: [25])

Table 6: Production volume in Midwest region of Brazil and respective exportation to China (Source: [6], [26])

	Production Volume [ton]			Export Volume [ton]
Region	**Production 2016**	**2017 Forecase**	**2026 Forecast**	**2016 Exportation**
Northern MT	21,404,383	22,451,091	28,777,219	4,796,805
Southern MT	4,872,920	5,111,214	6,551,419	4,872,920
Northern GO	940,177	986,153	1,264,025	16,977
Southern GO	7,744,050	8,122,746	10,411,523	1,887,519
Eastern GO	1,789,134	1,876,625	2,405,409	877
Northern MS	1,718,680	1,802,726	2,310,687	268
Southern MS	5,671,310	5,948,646	7,624,818	2,418,953
Total	**44,140,654**	**46,299,202**	**59,345,100**	**13,994,320**

Scenarios 3 and 4 will be calculated considering only internal transportation for 2017 and 2026, seeking to understand which direction is cheaper for soybeans to be transported. In C4, the Ferrogrão rail corridor shown in Figure 3 will already be considered in operation, which will reduce the transportation cost between Northern Mato Grosso and STM by 50%, in addition to reducing the cost between other producing regions and Santarém in smaller proportions. The Conceição do Araguaia Terminal in the Araguaia-Tocantins waterway will also be considered as operational, which reduces the cost of transporting soybeans from Northern and Eastern Goiás to VDC by 17%, as well as reducing the cost between the other producing regions and VDC in smaller proportions. For this scenario, one must know the volume of production and exportation from the Brazilian Central-West to China, which is available in Table 6.

It can be seen that in the real scenario in 2016, only 31.7% of the soybean harvested in the Midwest was exported to China and that the largest producing region, northern Mato Grosso, exported a small portion of soybeans. The percentage of exports by state, not by region, was 36.80% for Mato Grosso; 18.19% for Goiás; and 32.74% for Mato Grosso do Sul. For the forecast of exports to China in the years 2017 and 2026 to be inserted in the model, the percentages by state will be respected, representing the volume of soybeans to be exported by region as a result of the cost optimization model.

Scenarios 5 and 6 were elaborated in order to integrate internal and external transport, which seek to optimize the cost of transporting soybean production from the Brazilian Midwest to China by defining the best ports and sea routes to do so. In this model the Chinese demand is not a restriction, even because it is greater than the quantity produced in the Midwest. Only the productive capacity of the regions and the port capacity are considered as a restriction. In C6, both port and rail and waterway investments are considered, which were reviewed in previous scenarios.

Furthermore, scenario C7 was carried out, eliminating SSZ from operation in 2026. In other words, the goal was to analyze what the impact on the cost of exporting soybeans to China would be if the main Brazilian port in the market and infrastructure were unable to transport cargo, respecting capacity of other Brazilian ports.

7. RESULTS

Inserting the requirements for C1 in the aforementioned model, the result shows the transportation of approximately 1.9 million tons soybeans to Shanghai through the Panama Canal. The cost and number of ships required for C1 and C2 are shown in Table 7.

It is noteworthy that in both scenarios the transportation of soybeans through the Panama Canal was viable from ITA, VDC and STM. This result indicates that, as soon as the grain transportation reaches the ports of the Northern Arc, the cheapest way to transport soy to China is through the Canal. The result was repeated in C2 because only the export estimate was updated; costs were maintained. The average cost per ton of C1 was US $ 18.93 per ton and C2 was US $ 18.42 per ton.

Continuing the analysis of these scenarios, the model indicates that all soybeans exports retained at the ports that are operating at 100% capacity were carried out by SSA. It is important to have this information, since, according to [6], in 2016, SSA handled only 824 thousand tons of soybeans, while 10 million tons are expected to be transported, representing an increase of more than 1000% in only one decade.

Since the results in C1 and C2 indicate that it is feasible to transport soybeans through the Panama Canal through Northern ports, scenarios C3 and C4 show that at least 36% of the soybean produced in the Midwest region for exportats should follow the ports of Arco Norte. Table 8 shows the results of C3 and C4.

Table 7: Results obtained in C1 and C2. Data Source: Elaborated by paper's authors.

	C1				C2			
Origin	**Quantity shipped through the P. Canal (ton)**	**Quantity shipped through the Cape of Good Hope (ton)**	**Number of ships**	**Total cost [USD]**	**Quantity shipped via the P. Canal (tons)**	**Quantity shipped via the Cape of Good Hope (tons)**	**Number of ships**	**Total Cost [USD]**
ITA	429,365	-	5	9,345,104	581,625	-	6	12,659,032
VDC	741,579	-	8	15,416,892	1,004,555	-	11	20,883,975
STM	707,610	-	8	15,152,296	958,540	-	10	20,525,549
ITQ	-	2,509,269	26	48,880,567	-	3,399,097	35	66,214,420
SSA	-	3,142,668	33	51,983,674	-	10,132,954	104	167,611,782
VIX	-	2,723,894	28	44,483,021	-	2,723,894	28	44,483,021
SSZ	-	11,825,003	122	196,649,805	-	11,825,003	122	196,649,805
PRG	-	7,518,587	78	136,311,994	-	10,915,234	112	197,893,193
SFC	-	4,080,458	42	72,696,284	-	4,080,458	42	84,295,805
RGD	-	9,399,727	97	192,694,411	-	12,733,025	130	263,841,579
Total	**1,878,555**	**41,199,608**	**447**	**783,614,051**	**2,544,721**	**55,809,667**	**601**	**1,075,058,167**

Table 8: Results obtained in C3 and C4. Data Source: Elaborated by paper's authors.

C3				C4			
Region	**Destination Port**	**Volume [tons]**	**Total Cost [USD]**	**Region**	**Destination Port**	**Volume [ton]**	**Total Cost [USD]**
Northern MT	STM	5,269,669	261,375,613	Northern MT	STM	8,127,584	403,128,203
Southern MT	SSZ	4,872,920	249,932,066	Southern MT	SSZ	4,216,606	216,269,722
Northern GO	VDC	16,977	1,054,242	Southern MT	PRG	656,313	35,066,855
Southern GO	SSZ	1,887,519	65,421,420	Northern GO	SSZ	16,977	992,733
Eastern GO	VIX	94,052	4,453,684	Southern GO	SSZ	2,543,833	88,169,280
Northern MS	SSZ	18,122	708,523	Eastern GO	SSZ	877	35,355
Southern MS	PRG	2,418,953	93,413,203	Northern MS	SSZ	267	10,475
Southern MS	RGD	100,449	6,360,415	Southern MS	PRG	3,252,264	125,593,363
Total		**14,678,663**	**682,719,170**	**Total**		**18,814,725**	**869,265,990**

Scenario 3 shows important results: it is cheaper to ship the soybean harvested in the north of Mato Grosso to STM than to SSZ, contrary to what is currently done. Facing a lack of capacity at SSZ and PRG, another northern port - VDC - is also a destination for soybeans harvested in Central-West, reinforcing the fact that northern ports are competitive in relation to cost when up against capacity restrictions in the South and Southeast ports. The PRG operational restriction also directed about 100,000 metric tons of soybeans to the port of RGD from the southern portion of Mato Grosso do Sul. This scenario (C3) has indicated that 36% of the soy available for export is sent to the ports of North.

In C4, when there are no capacity constraints in PRG, the results are different. The port of Paraná exports most of the soybeans produced in Mato Grosso do Sul, which creates space for SSZ to absorb all of the soybean from Goiás, doing away with the need to use VDC and VIX to export the soybeans harvested in the Midwest. Regarding the soybean in northern Mato Grosso, it continues to be transported directly to Santarém, which should be the destination of 43% of all Midwest soybeans produced for export.

It is observed that Scenarios 1 and 2 show that soybeans arriving at ITA, STM and VDC must be transported through the Panama Canal to reach the Chinese market, and that according to Scenarios 3 and 4, STM and VDC are important to sell soybeans from the main Brazilian producing region, the Midwest. In practice, it is known that this logistical arrangement is not used in the Brazil-China trade relationship, and Scenarios 5 and 6 indicate the best way forward to ship from the Midwest to Shanghai. Table 9 shows the results from C5 and C6.

Table 9: Results obtained in C5 and C6. Data Source: Elaborated by paper's authors.

C5					C6				
Region	**Port**	**Route**	**Volume[ton]**	**Total Cost [USD]**	**Region**	**Port**	**Route**	**Volume [ton]**	**Total Cost [USD]**
Northern MT	STM	Canal	5,269,669	349,010,219	Northern MT	STM	Canal	8,127,584	336,725,836
Southern MT	SSZ	Cape	4,661,440	316,605,068	Southern MT	STM	Canal	4,872,920	306,518,053
Southern MT	STM	Canal	211,479	21,308,952	Northern GO	VDC	Canal	16,977	1,146,754
Northern GO	SSZ	Cape	16,977	1,275,061	Southern GO	SSZ	Cape	2,543,833	130,473,236
Southern GO	SSZ	Cape	1,980,695	65,421,420	Eastern GO	SSZ	Cape	877	49,942
Eastern GO	SSZ	Cape	877	49,942	Northern MS	SSZ	Cape	267	14,931
Northern MS	SSZ	Cape	267	14,931	South of MS	PRG	Cape	3,252,264	184,556,926
Southern MS	SSZ	Cape	118,303	6,780,556	**Total**			**18,814,725**	**959,485,681**
Southern MS	PRG	Cape	2,418,953	137,268,826					
Total			**14,678,663**	**933,903,412**					

Scenario C5, while reinforcing the importance of SSZ and PRG, underscores the importance of the STM logistics system. In this scenario, the soybeans in the Southern portion of Mato Grosso should be transported through the Panama Canal, shipping from STM, freeing up space for SSZ to dispose the soybeans from the Cape of Good Hope. The Panama Canal would be the cheapest route to carry approximately 37% of the soybeans produced in the Midwest for export. Compared with C3, it can be seen that STM is a lower cost option in relation to sending soybeans to China through VIX and VDC ports, which were the results of that scenario.

By 2026, the Panama Canal becomes even more important. The reduction of the internal cost of transportation to STM and VDC, due to investments in new railroads and waterways, combined with the cost of making the ship trip faster through the Panama Canal, brought gains to the logistics system in general.

It is worth noting the Ferrogrão railway between Sinop and Miritituba was a determining factor for the increase in soybean exports through the Panama Canal, since the reduction of the internal transportation costs brings positive impacts to the entire state of Mato Grosso, which is the most productive state for Brazilian soybeans and in Scenario 6 has all of its soybeans destined to exportation through the STM to reach the Chinese market by raising the locks of the Canal. The capacity constraints imposed on SSZ and VIX, coupled with the reduction of costs between producer regions and VDC, made the latter become the destination for soybeans produced in northern Goiás, further increasing the amount of soybean to be transported through the Panama Canal, as shown below in Chart 1. In this Scenario 6, the Central-West soybean volume exported to China by the Panama Canal accounts for about 70% of the total exported.

Assessing C6 result more closely, it can be noted that the volume exported through SSZ, which is the main Brazilian port, dropped from 6.78 million tons in 2017 to 2.6 million tons in 2026, indicating that there will be less dependence in relation to this port in the case of the export of soybeans. Scenario 6 indicates that this soybean exportation, which would normally be transported to the southeastern port at SSZ, is being sent to the Northern Arc ports. To confirm this trend, Scenario 7 was set up, in which SSZ is removed from operation to know which ports are needed to replace it. The results of this scenario are shown in Table 10.

Table 10: Results obtained in C7. Data Source: Elaborated by paper's authors.

Region	**Destination Ports**	**Maritime Route**	**Volume [ton]**	**Total Cost [USD]**
Northern MT	STM	Canal	8,127,584.76	336,725,836.49
Southern MT	STM	Canal	4,872,920.00	306,518,053.12
Northern GO	VDC	Canal	16,977.06	1,146,754.98
Southern GO	PRG	Cape	2,543,833.82	157,483,155.10
Eastern GO	VIX	Cape	877.17	55,861.10
Northern MS	PRG	Cape	267.94	19,125.82
Southern MS	PRG	Cape	3,252,264.89	184,556,926.38
Total			**18,814,725.63**	**986,505,712.99**

In C7, the results indicate that the soybeans that should be transported by the port of Santos are mainly transferred to PRG and VIX. This result indicates that these soybeans continue to reach Shanghai bypassing Cape of Good Hope and the importance of the northern ports is limited to the state of Mato Grosso and the northern region of the state of Goiás.

8. CONCLUSIONS

After carrying out this study, it is verified a limited influence of the Panama Canal on Brazilian soybean logistics stands out. Nowadays, the Brazilian soybean destined to China does not cross the Panama Canal. However, the potential for the use of the Canal is presented, considering the increase in Chinese demand, the need for faster transportation, the capacity limit of some Brazilian ports and the series of investments in infrastructure planned and in progress in the country.

The first set of scenarios, C1 and C2, which consider only the transportation problem between Brazilian ports and Shanghai, show that the influence of the Panama Canal on the logistics of Brazilian soybean flow into the Chinese market begins with the expansion of the canal itself, the passage of larger *Neo-Panamax* vessels and reduces the cost of crossing. From this cost reduction, it is perceived that by the distance to Shanghai, it is beneficial for the system to ship all the soybeans that arrive at ITA, STM and VDC through the Panama Canal, making the latter the seaway for 4.36% of all Brazilian soybeans destined to China.

It can be seen that the toll charges are an obstacle to this route from the use of ITQ and the most eastern and southern ports of Brazil. For example, if the Canal tariff were reduced by 46%, the cheapest route to the port of Itaqui would be the Panama Canal. However, this reduction depends on large trade agreements and cooperation between countries, which is not tangible in the short term.

Continuing on the results of C1 and C2 and seeking to understand why so little Brazilian soybeans are destined to ITA, STM and VDC, even though there is maritime viability to transport via the Panama Canal. This issue is answered by the optimization of Brazilian internal logistics costs.

Considering only Brazilian internal logistics, it is noted that the result for 2017 is the need to send more soybeans to the northern ports, given the lower cost of shipping the soybeans produced in northern Mato Grosso, the main Brazilian producing region, STM. The volume of soybeans harvested in northern Mato Grosso in 2016 was 22 million tons, while only 5 million tons were exported to China through SSZ. Another reason that increases the need to send soybeans from the Midwest to the northern ports is the capacity limitation of VIX, PRG and SFC, requiring Brazilian surplus production to be transported to VDC and STM.

By 2026, despite the reduced cost of shipping soybeans through the STM and VDC ports, the increase in PRG capacity relieves the logistics system, and in turn reduces the need for receiving soybeans from northern Mato Grosso, at a lower cost due to the railway linking Sinop to the Miritituba fluvial port. Therefore, a scenario that considers only Brazilian internal logistics, VDC, as well as VIX and RGD, would consequentially be repressed by PRG.

Given that it is feasible to ship soybeans from Mato Grosso to STM and from STM to China through the Panama Canal, this model addresses the total logistics of soybean yield and confirms these results, showing that the importance of the Panama Canal can be much larger than it is today. By 2017, the results show that 37% of the 14 million tons of soybeans produced for export in the Midwest should be sent through the Panama Canal. This volume would increase the total share of the canal in Brazil-China soybean sales from 4.36% to 16.23%. The low cost of internal transport from northern Mato Grosso to Santarém, associated with maritime cost, becomes the main element to increase the importance of the Panama Canal in the operation.

By 2026, the importance of the Panama Canal will be even greater. STM and VDC are intermediate points in soybean logistics from the Brazilian Midwest to China, which will have the Panama Canal as a sea route, given the capacity constraints of the South and Southeast ports and the new modes of transportation that will come into operation by 2020. In 2026, the participation of the Panama Canal in the transportation of all soybeans exported from Brazil to Shanghai is estimated at 25%. The reduction of costs of the integrated chain is essential to keep the Brazilian product competitive, and the projection of this scenario in 2026 is $50.99 per ton in transportation, compared to the value of $63.62 dollars per ton that represents the average cost of transportation in 2017. Further studies on the best routes for the disposal of soybeans produced in the region of MATOPIBA, comprised of the states of Maranhão, Tocantins, Piauí and Bahia, are suggested to increase the estimate of the participation of the Panama Canal in the Brazilian soybean logistics in 2026.

It is well known that Brazilian investments in transport infrastructure are underway – albeit at a slow place – thus indicating a change in the profile of Brazilian logistics, which will also stretch greater accessibility and more options to the North while offering lower costs than the current logistics systems. It will be up to Brazil to maintain its focus on these projects in order that they are completed within the stipulated timelines. Furthermore, it is important to continue improving relations with Panama in order that the expansion of the Canal will be able to increase the competitiveness of Brazilian soybeans from Brazilian farm gates to Chinese soybean ports and, ultimately, consumers.

This study is particularly applied to the Brazilian soybean destined to China in order to evaluate the influence of the Panama Canal in the Brazilian soybean logistics. However, similar studies should be done, linking other subjects, not only the Brazilian agribusiness but also the Latin American agribusiness since similar products share similar logistics structures. Other studies for other countries and other agricultural products such as: Corn, coffee, sugar cane and ores can approach the reality of the costs and improve the decisions about investments and competitiveness of the Brazilian and Latin American soybean logistics.

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