academicJournals

Vol. 11(8), pp. 693-700, 25 February, 2016
DOI: 10.5897/AJAR2015.10653
Article Number: F2DD9F657318
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Evaluating the logistics performance of Brazil's corn exports: A proposal of indicators

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Received 14 November, 2015; Accepted 10 February, 2016

Despite significant advances in the Brazilian agriculture, the logistics costs, particularly transportation and storage costs continue to act as the main barriers that limit the potential of the Brazilian agribusiness. This study analyzes the logistics efficiency of the main flow routes for Brazil's agricultural production and exports - in particular, corn production and exports, among the major producing states and the main ports of Brazil. For this purpose, we develop a performance measurement system based on the Balanced Scorecard (BSC) using four models for efficiency analysis: financial, customer, internal business processes, and learning and growth. Tthe efficiency of the main routes was calculated using the data envelopment analysis (DEA). Our results suggest that the routes from Mato Grosso state to Santarem port using a road-waterway intermodal transport system were the most efficient on three of the four criteria. Thereafter, the relative efficiency of all main Brazilian routes was analyzed based on the four criteria, establishing the references and developing a standard model to evaluate other logistics systems.

Key words: Data envelopment analysis, corn, logistics index, route analysis.

INTRODUCTION

The spatial arrangement change of the Brazilian agricultural production is a recurring phenomenon and agricultural businesses are exploring new frontiers through activities that incorporate modern production technologies (Oliveira, 2014). However, modern agriculture must foster sustainable development, including production systems that promote efficient water management (Valipour, 2015).

Brazil's market share in global corn exports is approximately 17% (22 million tons) which represents 28% of the national produce and supports the Brazilian commercial trade results (USDA, 2014). The productivity of Brazilian corn is approximately 5,051 kg/ha, which is lower than the global average of 5,495 kg/ha (USDA, 2014). Besides the economic importance, corn is an essential component of animal feed for livestock such as poultry, pork, and cattle. On a regional basis, the main Brazilian producer states that export corn are Mato

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Grosso (59% of the total exports), followed by Paraná (13%) and Goiás (12%). Together, they account for over 84% of the national export volume. The most important Brazilian ports used for corn exports are the Port of Santos (SP) and the Port of Paranaguá (PR) with 43% and 15% of the total volume of corn exports, respectively (MDIC, 2014).

The spatial reconfiguration of agriculture in Brazil increases production; nevertheless some weaknesses are becoming apparent, in particular, those related to transportation and storage. Bartolacci et al. (2012) stated that Brazil's agricultural competitiveness can only be increased by directing investments and solving logistical barriers. In the Brazilian case, product competitiveness can be increased by overcoming problems such as the shortage of storage capacity, reducing bureaucracy and increasing port organization, redistributing the cargo transportation matrix, as well as increasing the capacity and efficiency of rail and waterway transport.

Difficulties in the Brazilian infrastructure are not just limited to transportation, but also to the storage network. In addition to the deficit capacity, the storage location is inadequate and largely concentrated in urban centers. The ideal solution would be that the storage units focus on farms and the countryside. As stated by Junqueira and Morabito (2012), storage is a strategic factor in the agricultural sector to correct the seasonality issue in production, and therefore, to meet demand during the off-season period, in addition to maintaining stability in product prices and cargo rates.

According to Oliveira (2014), constant developments in agriculture, increase in productivity, and expansion of domestic corn in areas previously considered unproductive can further increase production. However, aspects such as increasing the efficiency of ports, obtaining international quality certifications for the produced corn, improving logistics network development, and reducing the bureaucracy process and costs are still key elements for the efficiency of this production chain (Amirteimoori, 2011).

Therefore, the overall objective of the study is to develop a performance measurement system that makes it possible to evaluate the relative logistics efficiency of the Brazilian corn export process through the data envelopment analysis (DEA) method in the main logistics routes.

MATERIALS AND METHODS

This study used MDIC (2014) and USDA (2014) data and bibliographical research to build the indicators and data envelopment analysis (DEA) to calculate the logistics efficiency of the main flow routes for Brazil's corn production and exports. Four strategic indices based on the balanced scorecard (BSC) were used to evaluate logistics efficiency. The BSC was developed by Kaplan and Norton (1997) to translate corporate strategy into performance indicators, unfolding it into four perspectives – financial; customer; internal business processes; and learning and growth - not restricting the analysis to financial criteria.

The indices for all routes were organized and analyzed using the DEA methodology, thus providing information on which route is the most efficient in which index. The DEA, introduced by Farrel (1957) and generalized by Charnes et al. (1978), is a non-parametric technique that allows the handling of multiple outputs and inputs to facilitate comparative performance measurement of independent units, that is, the efficiency of each unit. DEA allows several inputs and outputs to be used when analyzing the performance of various similar organizational units (DMUs) through a standard linear programming, which seeks to establish the maximum efficiency of a DMU, expressed in the rate of ratio of inputs to outputs, comparing the performance of a unit in relation to the group of similar units. This technique allows us to identify units with relatively more efficient performance (Talluri et al., 2013).

According to Azambuja et al. (2015), DEA models can work under conditions of constant returns to scale (Charles, Cooper and Rhodes (CCR) model, also known as CRS) or variable returns to scale (Banker, Charnes and Cooper (BCC) model, also known as VRS). In this study, we used the BCC model oriented to output, which has its mathematical formulation defined as:

$$Max\ h_o \quad \text{s.t} \tag{1}$$

$$x_{jo} - \sum_{k=1}^{n} x_{ik} \cdot \lambda_k \geq 0, \forall i \tag{2}$$

$$-h_o \cdot y_{jo} + \sum_{k=1}^{n} y_{jk} \cdot \lambda_k \geq 0, \forall j \tag{3}$$

$$\sum_{k=1}^{n} \lambda_k = 1 \tag{4}$$

$$\lambda_k \geq 0, \forall k \tag{5}$$

The proposed model maximizes outputs, keeping the inputs unchanged. In Equation 1 h_o is the efficiency. The Equation 2 guarantees that the reduction in inputs does not get through the frontier defined by the reference DMUs. The Equation 3 guarantees that the reduction in inputs does not affect the output values. The Equation 4 guarantees that the contribution of the DMU does not exceed 1 and Equation 5 guarantees that the contribution of the DMU is not negative. Note that λ_k is the DMU contribution k in the formation of the DMU target o.

Defining routes to analyze the most favorable option

When developing the study, we conducted logistics process mapping for corn and identified the main routes of flow for export, which were defined as the objects of study, the DMUs. Seventeen 17 such routes were defined, of which eight were unimodal, using only the road modal and nine were intermodal, using a combination of road/rail and road/waterway transport systems. Therefore, we have the origins of the routes in the states of Mato Grosso, Paraná, and Goiás and destinations to the ports of Santos (SP), Paranaguá

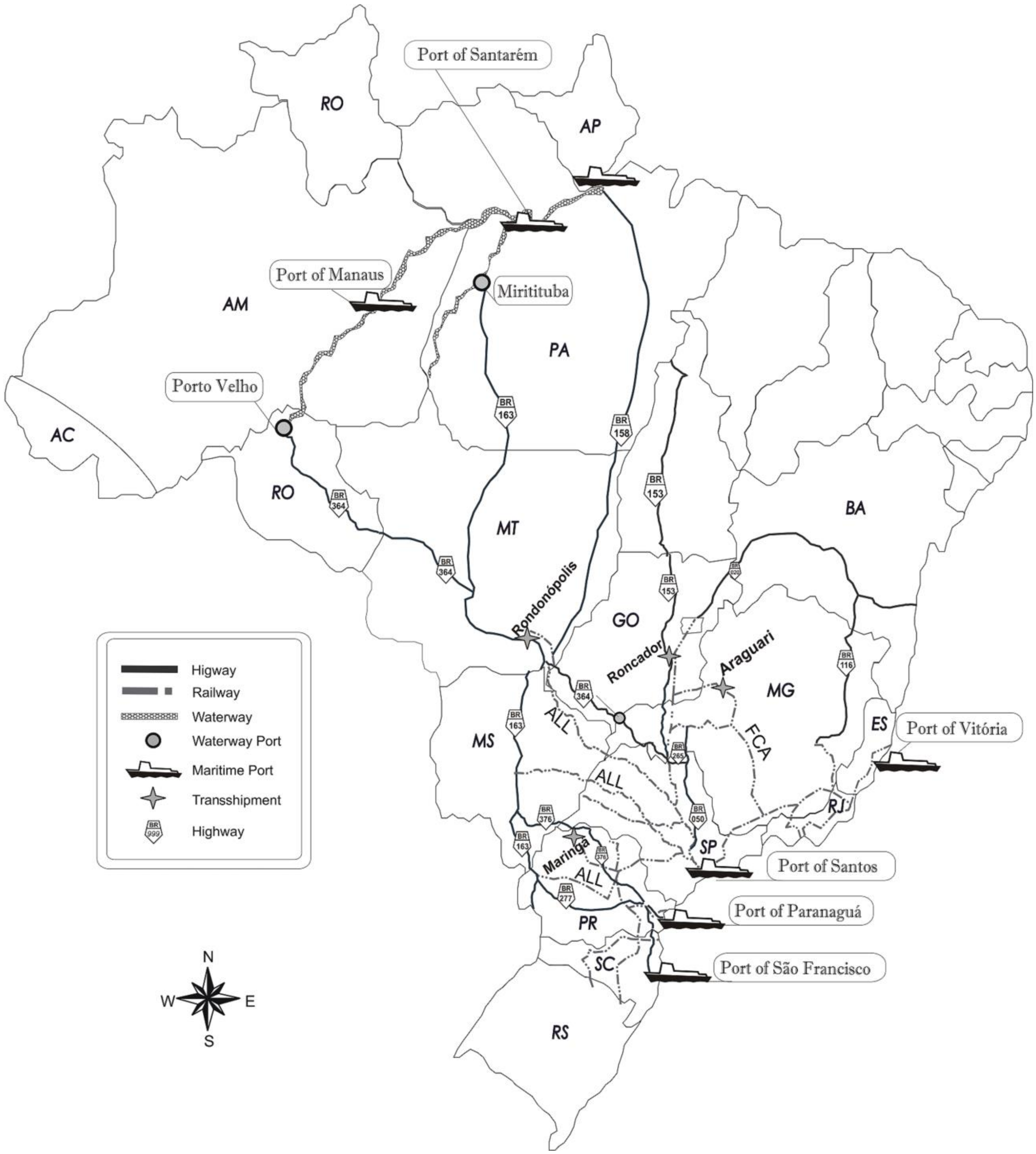

Figure 1. Primary logistics routes for corn in Brazil.

(PR), São Francisco do Sul (SC), Vitória (ES), Santarém (PA) and Manaus (AM) (Figure 1). For example, the MT-SP-ROAD route (DMU01) is characterized by the corn flow between the producing state of Mato Grosso to the Port of Santos (SP) using the exclusive road transport option. The MT-SP-ROAD-RAIL (DMU02) considers the route between the producing state of Mato Grosso to the Port of Santos (SP) using the road-waterway intermodal transport. The produced corn travels a distance of approximately 600 km using the BR-163 and BR-364 highways to the intermodal terminal of Rondonópolis-MT, covering the remainder of the route by rail for 1551 km. The rail transshipment terminals Rondonópolis-MT, Araguari-MG, Maringá-PR, and Roncador-GO were considered. As

Table 1. Measuring efficiency models.

Output	Input
Logistics costs (Financial Dimension)	Composition of the transportation matrix Availability of warehouses Corn production cost Productivity of corn in field
DMU Participation (Customer Dimension)	Transportation cost Queue in the ports/ships Route extension
Lead time delivery (Internal Business Processes Dimension)	Average speed Queue in the ports/ships Route extension
Sustainable development (Learning and Growth Dimension)	Fuel consumption Fleet age Composition of the transportation matrix

for waterway terminals, the Miritituba-PA Terminal (DMU06) and the Porto Velho-RO Terminal (DMU07) were considered (Figure 1).

Definition of variables

To define the variables, the Balanced Scorecard (BSC) based on four dimensions was used as reference:

Financial dimension

This dimension represents the costs and analyzes the contribution of all indicators in minimizing the final cost of the Brazilian corn in the international market. The strategic objective representing this dimension is the Logistics costs, calculated as the total cost of the Brazilian corn delivery in the Port of Shanghai, China, since it is the largest port in terms of activity in the world and the consumer market for Brazilian corn is focused on Asia.

Customer dimension

From the customer's perspective, the DMU Participation indicator was established, which represents the total volume of export by a particular route compared to the total national volume of export.

Internal business processes dimension

In this dimension, the activities that should be developed were evaluated, taking into account the history of bureaucratic procedures of customs and excessive time for delivery. The strategic objective that analyzes these factors is the Lead Time Delivery, which considers the queue of ships in the port and transportation time to the Port of Shanghai, China.

Learning and growth dimension

From the learning and growth perspective, the factors that should be developed for the future business success was analyzed. For this, we adopted sustainable development, which represents the adoption of clean practices and which measures the flow impact of corn production in accordance with the modals and the route used. The estimate adopted in this case was the CO_2 emission. After analyzing the indicators proposed in the literature, indicators that reflect the supply chain strategy vision used in the study (Table 1) were selected as inputs. Aiming to verify the relationship of each input indicator with strategic indicators (output), Table 1 was structured, which shows the four models and the respective indicators, constituting the analysis. In the resolution process of the models, we used the BCC method. As a way of dealing with undesirable outputs, the data was treated in order to adjust them through the multiplicative inverse method, which transforms undesirable output indicators (Logistics Costs, Lead Time Delivery, and Sustainable Development) as inputs through the formula $F_{(u)} = -u$. In order to highlight the efficient DMUs, the inverted frontier method was used:

$$Inverted\ Frontier\ Efficiency = \frac{Standard\ Efficiency\ + (1 - Inefficiency)}{2} \quad (6)$$

The final efficiency was obtained by calculating the inverted frontier, which identifies the most efficient DMU and provides a comparative efficiency analysis of the remaining DMUs.

RESULTS AND DISCUSSION

Initially, the results obtained by the routes in each of the four proposed models were analyzed: logistics costs/financial dimension, DMU participation/customer dimension, lead time delivery/internal business processes dimension and sustainable development/learning and growth dimension. Thereafter, the routes were analyzed as a whole.

Table 2. Final efficiency of DMUs (financial/logistics costs model).

DMU/Indicator	DMU	Efficiency	Inefficiency	Inverted frontier efficiency	Final efficiency
MT-SP-ROAD	DMU01	0.572050	0.838137	0.366957	0.482665
MT-SP-ROAD-RAIL	DMU02	1.000000	0.773996	0.613002	0.806293
MT-PR-ROAD	DMU03	0.529067	0.906229	0.311419	0.409616
MT-PR-ROAD-RAIL	DMU04	0.532161	0.944073	0.294044	0.386762
MT-PA/AM-ROAD	DMU05	0.819424	0.585113	0.617155	0.811756
MT-PA/AM-ROAD-WATER	**DMU06**	**1.000000**	**0.479456**	**0.760272**	**1.000000**
MT-PA/AM-ROAD-WATER 2	DMU07	0.767949	0.763861	0.502044	0.660348
MT-ES-ROAD	DMU08	0.479456	1.000000	0.239728	0.315319
MT-ES-ROAD-RAIL	DMU09	0.637890	0.993624	0.322133	0.423708
PR-PR-ROAD	DMU10	0.880385	0.907441	0.486472	0.639866
PR-PR-ROAD-RAIL	DMU11	1.000000	0.798897	0.600551	0.789917
PR-SC-ROAD	DMU12	0.798897	1.000000	0.399449	0.525402
PR-SC-ROAD-RAIL	DMU13	0.893217	0.894404	0.499406	0.656878
GO-SP-ROAD	DMU14	0.891240	0.747728	0.571756	0.752041
GO-SP-ROAD-RAIL	DMU15	1.000000	0.619565	0.690217	0.907856
GO-ES-ROAD	DMU16	0.666405	1.000000	0.333202	0.438267
GO-ES-ROAD-RAIL	DMU17	1.000000	1.000000	0.500000	0.657659

Source: Survey data (2015).

Financial dimension

Following the financial model resolution, the road and waterways intermodal route was analyzed through the Miritituba terminal for obtaining an overall efficiency rate of 76.02% (inverted frontier efficiency), being the most efficient route (MT-PA/AM-ROAD-WATER). From this route, the relative efficiency of others was calculated, highlighting the road and waterways intermodal route to export corn from the state of Goiás to the Port of Santos through the railway, which reached a relative efficiency rate of 90.78% (GO-SP-ROAD-RAIL). Table 2 shows the financial model results.

Customer dimension

As main references in the customer model, the logistics process of corn flow between the producing state of Mato Grosso and the Port of Santos via road (MT-SP-ROAD) was verified, which obtained an efficiency rate of 98.07% (inverted frontier efficiency). This is an expected result, since Mato Grosso is the largest exporter state and Port of Santos is the largest Brazilian port in export volume, with the distribution of 74% of the total transport, according to the Brazilian transportation matrix of CNT (2014). This result demonstrates that the route has reached the maximum limit of its capacity, which calls for the need for distribution by other routes. The main alternative is using the Ports of Santarém and Manaus (MT-PA/AM-ROAD), with relative efficiency rate of 96.39%, followed by alternatives using the highway for transport between the State of Paraná and the Port of Paranaguá (PR-PR-ROAD) and Port of São Francisco do Sul (PR-SC-ROAD) with relative efficiency rates of 94.42 and 87.92%, respectively, as detailed in Table 3.

Internal business processes dimension

As a result of the internal business processes efficiency model, all routes had partial efficiency rates of above 93% owing to the representativeness of the transshipment time between the Brazilian ports and the Port of Shanghai, China, which directly influences the total lead time delivery process. After application of the inverted frontier method, the analyzed routes had a very high inefficiency rate (above 90%). The highlighted routes of this model were that from the state of Mato Grosso to the Ports of Santarém/Manaus, using the road and waterway intermodal route through the Miritituba waterway terminal (MT-PA/AM-ROAD-WATER 2), with a relative efficiency rate of 96.07%. Also, from the State of Paraná to the Port of São Francisco do Sul using the railway (PR-SC-ROAD-RAIL), with a relative efficiency rate of 98.66%. The data on internal business processes model are available in Table 4.

Learning and growth dimension

The highlighted routes were from the State of Paraná,

Table 3. Final efficiency of DMUs (customer/DMU participation model).

DMU/Indicator	DMU	Efficiency	Inefficiency	Inverted frontier efficiency	Final efficiency
MT-SP-ROAD	**DMU01**	**1.00**	**0.03861**	**0.98070**	**1.00000**
MT-SP-ROAD-RAIL	DMU02	0.38	0.11232	0.63270	0.64515
MT-PR-ROAD	DMU03	0.11	0.34375	0.38539	0.39297
MT-PR-ROAD-RAIL	DMU04	0.04	1.00000	0.01968	0.02007
MT-PA/AM-ROAD	DMU05	1.00	0.10938	0.94531	0.96392
MT-PA/AM-ROAD-WATER	DMU06	1.00	1.00000	0.50000	0.50984
MT-PA/AM-ROAD-WATER 2	DMU07	0.11	1.00000	0.05469	0.05576
MT-ES-ROAD	DMU08	0.27	1.00000	0.13569	0.13836
MT-ES-ROAD-RAIL	DMU09	0.09	1.00000	0.04664	0.04756
PR-PR-ROAD	DMU10	1.00	0.14796	0.92602	0.94425
PR-PR-ROAD-RAIL	DMU11	1.00	0.43044	0.78478	0.80023
PR-SC-ROAD	DMU12	1.00	0.27538	0.86231	0.87928
PR-SC-ROAD-RAIL	DMU13	1.00	0.80111	0.59945	0.61125
GO-SP-ROAD	DMU14	0.48	0.18122	0.64713	0.65987
GO-SP-ROAD-RAIL	DMU15	0.19	0.52719	0.33268	0.33923
GO-ES-ROAD	DMU16	0.19	0.33036	0.43078	0.43926
GO-ES-ROAD-RAIL	DMU17	0.06	0.96105	0.04899	0.04996

Source: Survey data (2015).

Table 4. Final efficiency of DMUs (internal business processes/ lead time delivery model).

DMU/Indicator	DMU	Efficiency	Inefficiency	Inverted frontier Efficiency	Final efficiency
MT-SP-ROAD	DMU01	0.94795	0.98711	0.48042	0.86976
MT-SP-ROAD-RAIL	DMU02	0.94247	0.98342	0.47953	0.86814
MT-PR-ROAD	DMU03	0.93573	1.00000	0.46787	0.84703
MT-PR-ROAD-RAIL	DMU04	0.93260	1.00000	0.46630	0.84419
MT-PA/AM-ROAD	DMU05	1.00000	0.93573	0.53214	0.96338
MT-PA/AM-ROAD-WATER	**DMU06**	**1.00000**	**0.89527**	**0.55236**	**1.00000**
MT-PA/AM-ROAD-WATER 2	DMU07	1.00000	0.93869	0.53065	0.96070
MT-ES-ROAD	DMU08	0.95657	1.00000	0.47829	0.86589
MT-ES-ROAD-RAIL	DMU09	0.91415	1.00000	0.45707	0.82749
PR-PR-ROAD	DMU10	1.00000	0.96480	0.51760	0.93706
PR-PR-ROAD-RAIL	DMU11	1.00000	0.96458	0.51771	0.93726
PR-SC-ROAD	DMU12	1.00000	0.95489	0.52256	0.94604
PR-SC-ROAD-RAIL	DMU13	1.00000	0.91000	0.54500	0.98667
GO-SP-ROAD	DMU14	0.97808	0.96604	0.50602	0.91610
GO-SP-ROAD-RAIL	DMU15	1.00000	100000	0.50000	0.90520
GO-ES-ROAD	DMU16	0.97956	0.95525	0.51216	0.92721
GO-ES-ROAD-RAIL	DMU17	1.00000	0.97987	0.51006	0.92342

Source: Survey data (2015).

which is closest producing state for all export routes. The reference is the railway route from state of Paraná to the Port of Paranaguá with a final efficiency rate of 97.55% (PR-PR-ROAD-RAIL), followed by the road route from state of Paraná to the Port of Paranaguá (PR-PR-ROAD) (91.76% relative efficiency), and intermodal route

Table 5. Final efficiency of DMUs (learning and growth/sustainable development model).

DMU/Indicator	DMU	Efficiency	Inefficiency	Inverted frontier efficiency	Final efficiency
MT-SP-ROAD	DMU01	0.06084	0.80321	0.12882	0.13204
MT-SP-ROAD-RAIL	DMU02	0.13159	0.49400	0.31880	0.32678
MT-PR-ROAD	DMU03	0.05544	0.88153	0.08696	0.08913
MT-PR-ROAD-RAIL	DMU04	0.06696	0.80806	0.12945	0.13269
MT-PA/AM-ROAD	DMU05	0.11830	0.55221	0.28304	0.29013
MT-PA/AM-ROAD-WATER	DMU06	0.13664	047907	0.32878	0.33702
MT-PA/AM-ROAD-WATER 2	DMU07	006317	0.78861	0.13728	0.14072
MT-ES-ROAD	DMU08	0.04887	1.00000	0.02444	0.02505
MT-ES-ROAD-RAIL	DMU09	0.06944	1.00000	0.03472	0.03559
PR-PR-ROAD	DMU10	1.00000	0.20964	0.89518	0.91760
PR-PR-ROAD-RAIL	**DMU11**	**1.00000**	**0.04887**	**0.97557**	**1.00000**
PR-SC-ROAD	DMU12	0.73216	0.23976	0.74620	0.76489
PR-SC-ROAD-RAIL	DMU13	0.80549	0.06067	0.87241	0.89426
GO-SP-ROAD	DMU14	0.23325	0,40161	0.41582	0.42624
GO-SP-ROAD-RAIL	DMU15	0.24990	019556	0.52717	0.54037
GO-ES-ROAD	DMU16	0.11389	0.56225	0.27582	0.28273
GO-ES-ROAD-RAIL	DMU17	0.20136	0.28717	0.45709	0.46854

Source: Survey data (2015).

(roadway and railway) from state of Paraná to the Port of São Francisco do Sul (PR-SC-ROAD-RAIL) (89.42% relative efficiency). Detailed results of all routes are shown in Table 5.

Conclusions

This study analyzed the logistics efficiency of the main flow routes of the Brazilian corn production for export among the major producing states and the main Brazilian ports. In the evaluation process, the input and output indicators that influenced the final process outcome were defined.

By analyzing the four proposed models - financial, customer, internal business processes, and learning and growth, it was found that the export route DMU06, which represents the flow from the state of Mato Grosso to the ports of Santarém/Manaus using the road and waterway intermodal route through the waterway terminal Miritituba in the Tapajós-Amazonas Waterway (MT-PA/AM-Road-Waterway-DMU06) was the most efficient route, both in the financial and the internal business processes models. Moreover, in the sustainable development model, it was the most suitable alternative when the origin of corn was from the state of Mato Grosso - the largest producing state. When we use the state of Paraná as the reference, it was possible to highlight the road and rail route to the port of Paranaguá, and when corn comes from the state of Goiás, the road and waterway intermodal route through the port of Santos was used as the reference.

Through the financial efficiency evaluation model, the influence of the participation of rail and waterway modes in the process of defining efficient routes was observed; four of the five most favorable results were part of this intermodality. It is also important to note that the flow to the ports of Santarém and Manaus were the most suitable alternatives to the already overloaded port of Santos. In the efficiency analysis model in sustainable development, the routes with lower extension between the producer state and the export port were privileged, such as the state of Paraná route to the port of Paranaguá through intermodal road-rail. This study allows for a route-level logistics efficiency analysis. Moreover, the results imply targeting of investments on routes that had unsatisfactory results, that is, low levels of efficiency. The proposed models become relevant owing to their replication potential in other logistics process efficiency analyses for other agricultural commodities, as well as their abilities in facilitating comparison with competing countries in the corn chain.

Conflict of Interests

The authors have not declared any conflict of interests.

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