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Impact of Vertically Integrated Road Transport on Brazilian Sugar Export Logistics: A Mathematical Programming Application

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Abstract

Brazil currently exports 73% of the sugar produced at harvest. Approximately 75% of those exports are transported to the port of Santos and 18% to the port of Paranaguá for oversea shipment. Transportation to the two ports is mainly through the use of outsourced road transport vehicles. This study analyzes the impact of vertically integrating road transportation operations on the cost to transport raw sugar to the ports. Specifically, the study consists of an evaluation of the economic costs and benefits arising from sugar shippers using their own fleet of vehicles to transport their product to Santos and Paranaguá. Many papers have reduced logistics costs using strategies that involve a change in transport mode, most often to the railways. Although a change in modality may reduce logistics costs, vertically integrating the transport fleet into the producing company may also effectively lower costs. This article aims to (i) assess economic impacts on sugar export logistics in Brazil's South-Central region if agro-industry shippers (mills) vertically integrated their road transport and (ii) identify the optimal regional allocation of vertically integrated logistics operations. The analysis was conducted using a linear programming model designed to identify minimum, multimodal sugar export logistics costs taking into account private and outsourced shipping fleets. The model was programmed and processed with the GAMS modeling system using a CPLEX solver. The results indicate: (i) the competitive economic transportation radius using a mill's private trucking fleet is 420 km or less, (ii) the best strategy to minimize road transportation export logistics costs in Brazil's South-Central region was obtained by using a private fleet 46.30% of the time, which, if all road shipping services had been outsourced, would reduce road transport costs 5.01%, and (iii) there are a number of sugar-producing meso-regions in which the use of vertically integrated transportation operations reduced logistics costs by over 10%, even if all road transportation services were vertically integrated. The results are expected to be used to promote sugar transportation through the optimized use of private shipping fleets and stimulate further discussion of the advantages and disadvantages of vertically integrated product transport operations.

Keywords: Brazilian sugar supply chain, logistics operations, mathematical programming, optimization, vertical transport

1. Introduction

The sugarcane industry in Brazil produced 572.3 million tons of sugarcane in the 2015/2016 season, making the country the world's foremost sugarcane producer. After crushing, this sugarcane yielded 33.8 million tons of sugar. Seventy-three percent of this sugar was exported. Approximately 75% of those exports were transported to the port of Santos and 18% to the port of Paranaguá (UNICA, 2016; Ministery of Development, Industry and Foreign Trade/Secretariat of Foreign Trade-MDIC/SECEX, 2016). Brazil's South-Central region[1], which includes the states of Mato Grosso, Mato Grosso do Sul, Minas Gerais, São Paulo, Goiás and Paraná, is responsible for 92.2% of the country's sugarcane crop (Brazilian Sugarcane Industry Association - UNICA, 2016).

[1]South-Central is a regional designation used by the Brazilian sugar cane industry association (UNICA)

Sugar export logistics involves product distribution from the producing agro-industrial units (mills) to ports using either road or multimodal transportation systems, the latter consisting of road transport from mills to railroads for transshipment to the port (NUNES, 2010). The road segment of sugar transportation is normally outsourced to trucking companies, particularly when the product shipper is operating in the spot market or prefers the security of a long term transportation contract (NUNES, 2010).

A number of studies have used mathematical programming to evaluate agro-industrial product logistics; however, very few of these studies have evaluated the impact of vertical integration strategies on shipping. In this context, two detailed investigations merit emphasis: a study by Oliveira (2005) illustrated the importance of railway terminal expansion and recommended the construction of new facilities to reduce sugar export logistics costs in the state of São Paulo; and a study by Péra et al. (2013) demonstrating the relevance of a private fleet of transportation vehicles in sugar road transport logistics.

The present study aims to (i) assess the economic impact on sugar export logistics in Brazil's South-Central region from the vertical integration of road transport operations by agro-industrial shippers (mills) and (ii) identify optimal vertical strategies of such an operation at the regional level. The assessment is conducted with the aid of a mathematical programming model designed to minimize sugar export logistics costs taking into account private and outsourced road fleets and the multimodal option. This study further develops a discussion proposed by Péra et al. (2013) with the use of updated logistics cost information and optimized regional road transportation strategies.

The analysis employs a quantitative approach that involves the econometric modeling of freight prices to determine road transportation logistics costs from the use of outsourced transportation services and a road transport costing model to determine road transportation logistics costs from the use of vertically integrated road transportation assets (private fleet). Results from the two models are then used to evaluate cost minimization strategies by means of optimization modeling. Scenarios are then developed and an optimization model is applied to determine the optimum road transportation strategy in each relevant South-Central Brazilian meso-region and this strategy's economic impact on sugar producer road transportation costs.

2. Method

2.1 Specification of Models Input Data

Table 1. Summary of model input data specifications

Model input data	Sources
Sugar production by county (2015)	Anuário da Cana (Sugarcane Annual Report) (2015) and UNICA (2016)
Sugar export by port (2015)	MDIC/Secex (2016)
Sugar railway terminals and cargo-handling capacity (2015)	Agência Nacional de Transporte Terrestres – ANTT (National Land Transport Agency) (2015) and Agroindustrial Research and Extension Group - ESALQ-LOG (2016)
Railway private fleet transport costs (2015)	Agência Nacional de Transporte Terrestres – ANTT (National Land Transport Agency) (2015) e ESALQ-LOG (2016)
Vertical (private) fleet road transport costs (2015)	Lima´s costing model (2003) with parameters obtained from ESALQ-LOG (2016), presented in equation 2 using 37 ton capacity standard type of truck in Brazil ("bitrem basculante").
Outsourced road transport costs (2015)	Linear regression based on database price indicators of road sugar freight actually traded on the market provided by the Freight Information System (ESALQ-LOG, 2016), as shown by equation 1.
Road and rail distance matrices for origin, rail terminal and port combinations	Estimated by a Brazilian multimodal network through TransCAD.
Adopted exchange rate (R$/US$ 3.30)	Thomson Reuters (2015), average annual prices (commercial dollar)

Source: Organized by the authors

The proposed model will be used to identify the logistical impact and economic effect of vertically integrating road transport services, that is, the effect of using the sugar producing units' private fleet in the logistics of sugar transportation to export facilities rather than contracting outside shipping services. In addition, results from the model's run will be employed to identify the impact of a vertically integrated transport strategy on costs in the area's relevant meso-regions. The model is a linear programming mathematical construct structured to minimize sugar producing agro-industries' costs from the use of a unimodal transport system (road) and a multimodal transportation system (road and rail) to ship sugar from mills to the two major Brazilian ports. Table 1 defines the input data adopted for use in the mathematical model and lists the data sources.

2.2 Private and Outsourced Fleet Costs Models

Equation (1) shows the predictive (econometric) model adopted to determine sugar road transport outsourcing costs from a linear regression using traded freight prices for transporting sugar (ESALQ-LOG) and several parameters. Parameter values were obtained from an analysis of 5,374 observations. The results showed an R-squared of 73.40% and a 1 % significance level.

$$Outsourced\ cost_{od} = ɵ\ .dist_{od} + \varphi \quad (1)$$

Where:

$\mathrm{Outsourced\ cost_{od}}$ is the cost of outsourced transportation between the point of origin and destination d in US$ per ton;

ɵ is the slope estimated by the statistical method at US$ 0.0339 per ton-kilometer;

$\mathrm{dist_{od}}$ is the distance between origin *o* and destination *d* in kilometers;

φ is the linear coefficient estimated by the statistical method at US$ 11.2658 per ton;

Equation (2) shows the road transport costing model adopted to determine vertically integrated road transport costs (private fleet), the related fixed costs parameters (depreciation, return on capital, taxes, insurance and salary), and the related variable cost parameters (tires, lubricants and differentials, fuel and maintenance). Data provided by ESALQ-LOG, 2016.

$$VCost_{od} = VC\ .(dist_{od} + dist_{do}) + FC\ .(dist_{od}/s_{out} + dist_{do}/S_{ret}) + FC\ .(LT + UT) + TOLL \quad (2)$$

Where:

$VCost_{od}$ is the cost of sugar company owned vehicle transport between the point of origin *o* and destination *d*, considering the return trip in dollar (US$) per ton;

is the cost of sugar company owned vehicle transport between the point of origin *o* and destination *d*, considering the return trip in dollar (US$) per ton

$\mathrm{dist_{od}}$ is the one-way distance between origin *o* and destination *d* in kilometers;

$\mathrm{dist_{do}}$o is the return distance between point of origin *d* and destination *o* in kilometers;

$\mathrm{s_{out}}$ is the average vehicle speed on the outward stretch in kilometers per hour - a 60 km/h reference was adopted;

$\mathrm{S_{ret}}$ is the average vehicle speed on the return stretch in kilometers per hour - a reference 70 km/h speed was adopted;

LT is the vehicle loading time in hours - a 2.5 hours reference was adopted;

UT is the vehicle unloading time in hours - a 2.5 hours reference was adopted;

VC is the variable cost parameter of US$ 0.0170 per ton-kilometer;

FC is the fixed cost parameter estimated at US$ 0.6323 per ton-hour;

TOLL is the cost of round trip tolls in US$ per ton;

2.3 Mathematical Formulation of the Brazilian Sugar Export Logistics System

The model's decision variables refer to the amount of sugar to be transported using either an outsourced or vertically integrated fleet from producer municipality to export port, including the possible use of multimodal transport (integrated road and rail). The objective function is to minimize logistics costs (LC), for the entire system of sugar mills in Brazil's South-Central region. Equation (3) illustrates the proposed objective function:

$$MIN\ LC = (\textstyle\sum_i^I \sum_j^J \sum_k^K rc_{ijk}\ .RF_{ijk} + \sum_i^I \sum_t^T \sum_k^K rsc_{itk}\ .SRF_{itk} + \sum_t^T \sum_j^J mc_{tj}.MF_{tj}) \quad (3)$$

Where:

Sets:

i: the set of raw sugar producing municipalities in the Central-Southern region of Brazil (154 elements);

j: the set of raw sugar export ports in the country (2 elements);

t: the set of sugar shipment railway terminals in the Central-Southern region of Brazil (17 elements);

k: the fleet to be used for sugar road transport, including either or outsourced fleet (2 elements);

Variables:

$\mathrm{RF_{ijk}}$ is the direct road flow variable in tons between origin *i* and destination *j* using fleet *k*;

$\mathrm{SRF_{itk}}$ is the short road flow variable in tons between origin *i* and rail terminal *t* using fleet *k*;

$\mathrm{MF_{tj}}$ is the rail flow variable in tons between departure terminal *t* and destination *j*;

Parameters:

$\mathrm{rc_{ijk}}$ is the estimated road transport cost between origin *i* and destination *j* using fleet *k*, set as US$/ton, derived from Equation (1) [outsourced fleet)] and Equation (2) [private fleet];

$\mathrm{rsc_{itk}}$ is the estimated parameter of road flow cost between origin *i* and terminal *t* using fleet *k*, set as US$/ton, derived from Equation (1) [outsourced fleet] and Equation (2) [private fleet];

$\mathrm{mc_{tj}}$ is the estimated railway cost parameter between terminal *t* and destination *j*, set as US$/ton;

$\mathrm{production_i}$ is the raw sugar production parameter from each producing municipality *i*, in tons;

$\mathrm{export_j}$ is the raw sugar export parameter of each port *j*, in tons;

$\mathrm{capacity_j}$ is the rail transport capacity of each terminal *j*, in tons.

Minimizing logistics costs is conditioned by the following restrictions:

i. Raw sugar supply restrictions from each producing municipality *i*:

$$\sum_j^J \sum_k^K \mathrm{RF_{ijk}} + \sum_t^T \sum_k^K \mathrm{SRF_{itk}} \leq \mathrm{production_i} \ , \ \forall\, \mathrm{i} \tag{4}$$

ii. Raw sugar export demand restriction at port j:

$$\sum_i^I \sum_k^K \mathrm{RF_{ijk}} + \sum_t^T \mathrm{MF_{tj}} \geq \mathrm{export_j} \ , \ \forall\, \mathrm{j} \tag{5}$$

iii. Transport system solution - restriction that ensures flow continuity from the road portion to the rail terminal *t* and is considered to be zero, i.e., raw sugar losses when changing systems are not taken into account.

$$\sum_i^I \sum_k^K \mathrm{SRF_{itk}} - \sum_j^J \mathrm{MF_{tj}} = 0 \ , \ \forall\, \mathrm{t} \tag{6}$$

iv. Railway system limitations when dealing with raw sugar transport in observance of rail terminal *t* maximum capacity.

$$\sum_i^I \sum_k^K \mathrm{SRF_{itk}} \leq \mathrm{capacity_t} \ , \ \forall\, \mathrm{t} \tag{7}$$

v. Upper limit for the private fleet portion of the system's total fleet composition (South-Central Brazil). This restriction assures a limitation on the use of a private fleet in the sugar export logistics system, which is import for the simulation of scenarios with fractional parameter β variations.

$$\sum_i^I \sum_j^J \mathrm{RF_{ijk='own'}} + \sum_i^I \sum_t^T \mathrm{SRF_{itk='own'}} \leq \beta \,.\left(\sum_i^I \sum_j^J \sum_k^K \mathrm{RF_{ijk}} + \sum_i^I \sum_t^T \sum_k^K \mathrm{SRF_{itk}}\right), \beta \in (0{,}1) \tag{8}$$

vi. The upper limit of a municipality's rail system freight allotment *i* for rail terminal *t*. This restriction ensures greater adherence to the reality of sugar transport, avoiding "all or nothing" railway flows, rail concession contractual issues, and other factors. This study adopted a maximum railway weight limit for the movement of sugar of 70 % of each municipality's total weight limit (α = 70%).

$$\sum_t^T \sum_k^K \mathrm{SRF_{itk}} \leq \alpha \,.\, \mathrm{production_i}, \ \forall\, \mathrm{i} \ , \ \alpha \in (0{,}1) \tag{9}$$

The model was developed and processed by General Algebraic Modeling System software (GAMS) using the CPLEX solver and involved 5,377 variables and 499 equations. Processing took 2.3 seconds for each scenario with about 450 iterations.

3. Results

Figure 1 shows the calculated road transport costs for private and outsourced fleets depending on distance traveled. The graph indicates that private fleet use is comparatively advantageous within a range of up to 420 km; beyond this distance, the use of an outsourced road transport fleet is more economical: the shorter the sugar transport route, the greater the advantage gained from use of a private road transportation fleet rather than an outsourced road transportation fleet.

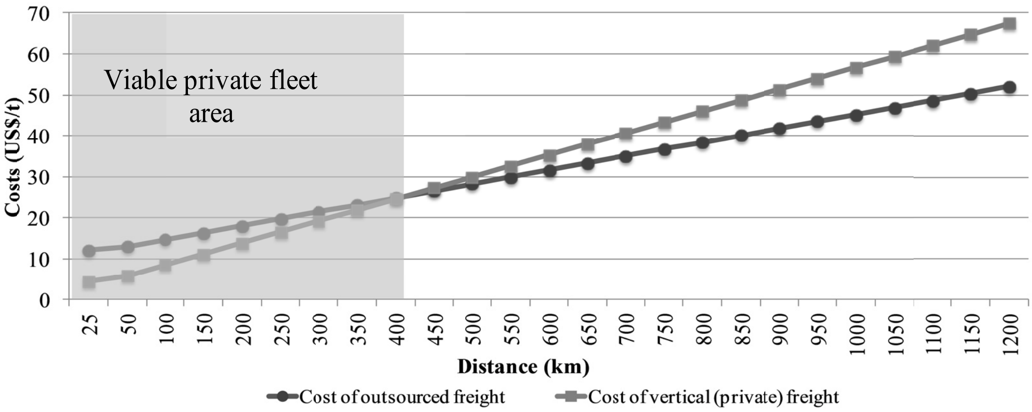

Figure 1. Costs of outsourced and vertical (private) sugar road transport according to distance traveled.
Source: Authors' research

Figure 2 shows sugar mill, port and rail terminal locations in South-Central Brazil. The figure contains a line delineating the 420 km radius within which sugar transportation by roadway to the ports of Santos (SP) and Paranaguá (PR) using a private fleet becomes economically advantageous. There are 114 combinations of sugar-producing municipalities and ports within that radius. Sugar transportation from mill to port can also be accomplished using a combination of road and rail, which can be a competitive shipping option when using a private fleet depending on the distance traveled over roadways.

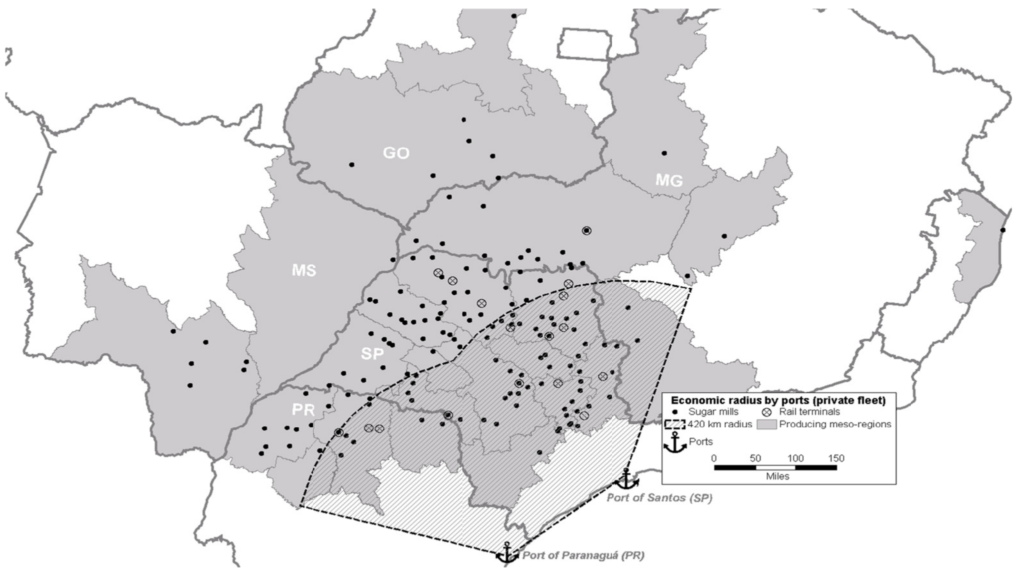

Figure 2. Mill, port and rail terminal locations and the economic radius for sugar transport to the ports of Santos (SP) and Paranaguá (PR) using a private fleet
Source: Authors' research

Figure 3 shows results from the first set of scenarios analyzed to determine the average cost of multimodal logistics (US$/ton) using combinations of private and outsourced truck fleets to transport sugar in South-Central Brazil. In the scenario that simulates using only outsourced road transport services, average logistics costs were US$ 25.73/ton. In the scenario that simulated using only private, vertically integrated road transport services, average logistics costs were US$ 27.47/ton. An allocation of 46.30% of the road shipments to private fleets and 53.70% to outsourced shipping services was found to be the best strategy to reduce average exported sugar transportation logistics costs. This optimum combination of road shipping services results in an average cost of US$ 24.44/ton, a 5.01% savings when compared to 0% use of vertically integrated shipping services.

A second set of scenarios was employed to determine the effect of vertically integrating road transport services on logistics costs for sugar transportation in individual meso-regions of South-Central Brazil. In this context, two different situations were evaluated: (i) operating with outsourced road transportation fleets only and (ii) operating with an optimal mix of outsourced and private fleets. Table 2 shows the savings generated in each meso-region by using road shipping services optimally allocated by the mathematical model between outsourced and vertically integrated operations rather than using only outsourced services. In this regard, full vertical integration of road transport operations (both road to port and road to rail terminal) is strategically recommended in the meso-regions of Piracicaba, Campinas, central-northern Paraná state and south-southwestern Minas Gerais state. Some other meso-regions also showed potential logistics cost reductions through the use of a mixed composition logistics strategy involving both private and outsourced fleets. In other regions, not listed, there was no cost benefit derived from any use of a vertically integrated transportation fleet.

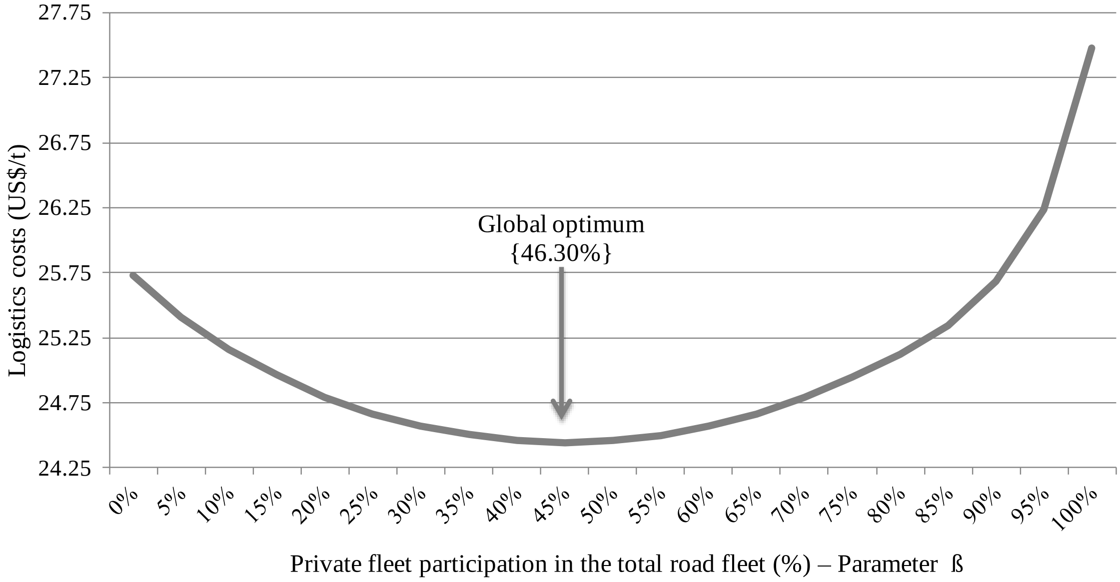

Figure 3. Multimodal logistics average sugar export costs in South-Central Brazil with reference to private fleet participation in the total road fleet (%).

Note. This curve is derived from successive optimizations considering changes in parameter β in Equation (8) ranging from 0% to 100%, under equal mathematical condition.

Source: Authors

Table 2. Logistics costs reduction potential from the optimal allocation of vertically integrated transportation operations in selected sugar producing meso-regions of South-Central Brazil

Meso-region	**Optimal vertical fleet allocation in total fleet (%)**	**Average logistics costs (US$/ton) [1]**		**Logistics cost reduction potential (%)**
		Outsourced fleet only	**Mill's own fleet (Optimal)**	
Piracicaba	100.0%	18.85	15.12	19.77%
Itapetininga	52.0%	19.17	15.62	18.50%
Northern coast of ES	70.8%	32.96	28.20	14.46%
Campinas	100.0%	20.42	17.61	13.78%
Ribeirão Preto	70.0%	25.88	23.08	10.81%
Central-northern Paraná	100.0%	26.87	24.05	10.48%
Southeastern MS	53.3%	30.67	29.50	3.82%
Paraná's "Pioneer" North	62.0%	24.82	24.45	1.49%
Bauru	77.7%	24.18	23.86	1.33%
South/Southwestern Minas Gerais	100.0%	25.32	25.03	1.17%
Central MG State	57.7%	27.37	27.25	0.43%

Notes. [1]Average logistics cost is the ratio between a meso-region's transport costs taking into account both road and multimodal transport and sugar production in the region. Other meso-regions in Central-Southern Brazil were excluded from Table 2 as there was no cost reduction from the use of any portion of a vertically integrated fleet.

Source: Study model results

4. Conclusion

This study evaluated the impact of vertically integrated road transportation strategies on sugar mill costs to transport raw sugar from mills in South-Central Brazil to multimodal export facilities using mill owned assets. A linear programming mathematical model was structured to assess these impacts and identify the integration strategies. The study also identifies major vertical integration logistics cost minimization strategies on a meso-regional basis.

Road transport costs using the mill's fleet rather than a shipping company's fleet were found to be economically advantageous for road transport of up to 420 km, i.e., the shorter the road distance between origin and destination, the greater the economic advantage from using a vertically integrated fleet rather than an outsourced service. Moreover, after analysis of results from modeling different scenarios, it was found that the optimal strategy to minimize sugar export logistics costs when transporting sugar by roadway in South-Central Brazil was to use a mix of road shipping options, with 46.30% of the road shipments allocated to vertically integrated assets owned and operated by the product shipper (mill) and 53.70% outsourced. This ratio can bring about a 5.01% cost reduction from the cost of using only outsourced shipping services.

It was found that sugar export logistics costs on a meso-regional level can be reduced by up to 19.78% through use of an optimal mix of vertically integrated and outsourced road transportation services. Results also indicated that the use of a 100% vertically integrated road transportation fleet is recommended in four South-Central Brazilian meso-regions: Piracicaba, Campinas, central-northern Paraná state, and south-southwestern Minas Gerais state.

It is expected that the study's results will promote improvements in sugar transportation strategies through fleet optimization and will encourage further discussion of the advantages and disadvantages of vertically integrated transport systems. It is recommended that future studies on this topic should include productivity indicators for different routes in their proposed mathematical structures. One factor that influences sugar transportation productivity in Brazil that was not addressed in this study is the delay unloading trucks at ports and rail terminals and the associated effects of recent legislative changes in the fee schedule for parking while waiting to unload. The impact of these delays and charges on sugar export route choice and vertically integrated road logistics strategies should be investigated.

References

ANTT - National Land Transport Agency. (2015). *Estatísticas Ferroviárias*. Agência Naiconal de Transporte Terrestres. Available at: http://www.antt.gov.br/. Access on the 26th of August, 2016.

Anuário da Cana - Procana. (2015). *Anuário da Cana 2015*. Ribeirão Preto, Brazil.

ESALQ-LOG – Agroindustrial Logistics Research and Extension Group. (2016). *Sistema de Informações de Fretes (SIFRECA)*. Piracicaba, Brazil. Available at: http://sifreca.esalq.usp.br/sifreca/pt/index.php

Lima, M. P. (2003). Custeio Rodoviário de transporte de cargas. In: Fleury, P. F.; Wanke, P.; Figueiredo, K.F. (Org). *Logística e gerenciamento da cadeia de suprimentos: planejamento do fluxo de produtos e dos recursos.* São Paulo, Brazil: Atlas, 2003.

MDIC/SECEX – Ministery of Development, Industry and Foreign Trade / Secretariat of Foreign Trade. (2016) Sistema AliceWeb – Estatísticas de exportação. *Ministério do Desenvolvimento, Indústria e Comércio Exterior*. Brasília, DF. Avaliable at: http://aliceweb.mdic.gov.br/. Access on the 24th of August, 2016.

Nunes, P. B. (2010). Caracterização logística do sistema agroindustrial da cana-de-açúcar no Centro-Sul do Brasil. *Monografia de Bacharelado em Ciências Econômicas*. Piracicaba, Brazil: ESALQ/USP, 225.

Oliveira, A. M. K. (2005). Potencial da logística ferroviária para a movimentação de açúcar para exportação no estado de São Paulo: recomendações de localização para armazéns intermodais concentradores de carga. *Dissertação de Mestrado em Ciências: Economia Aplicada*. Piracicaba: ESALQ/USP, 166.

Péra, T. G., Silva, R. F., Bartholomeu, D. B., Cugnasca, C. E., & Caixeta-Filho, J. V., (2013). Modelo, de otimização da logística de açúcar para exportação com o objetivo de avaliar impactos econômicos da frota própria. *In: XXVII Congresso de Pesquisa e Ensino em Transportes (ANPET)*, Belém, Brazil.

Thomson Reuteurs. (2016). Exchange Rate – Currencies Quote. *Thomson Reuteurs.* Available at: http://www.reuters.com/finance/currencies/quote?srcCurr=BRL&destCurr=USD. Access on the 24th of August, 2016.

UNICA – Brazilian Sugarcane Industry Assossiation. (2016). *Estatísticas de dados.* São Paulo, Brazil. Available at: http://www.unica.com.br. Access on the 25th of August, 2016.