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Analysis of relative efficiency of vessels of passenger transportation in the Brazilian Amazon: an AHP-DEA approach

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ABSTRACT. Waterway transport is of great importance for the population of the Amazon Region. It is responsible for moving, according to *Agência Nacional de Transportes Aquaviários* (Antaq, 2018), approximately 9.8 million passengers and 3.4 million tons of cargo distributed by state, interstate longitudinal transport interstate and crossing. However, despite the great importance, there are several blockages related to the conditions of the roads and vessels in certain routes. The study in question proposes the use of a mathematical tool to analyze vessels from the relative efficiency involving parameters of input and output for two analysis scenarios: Energy Efficiency Analysis and Modality Analysis, being analyzed variables such as power, consumption, total time of the trip, total distance of the line of action, passenger capacity and ticket price. For that, the data of 652 vessels used in the Amazon region registered in the Brazilian states (Pará, Amazonas, Amapá and Rondônia) were verified, and from these data, a sample space of 148 vessels from the same utilization level was selected. With these data, a model was developed using the Data Envelopment Analysis (DEA) methodology, with the aid of the DEA-Solver software. After the use of the solver, the relative efficiency indexes of each vessel were obtained, allowing to rank and measure the efficient and inefficient Decision Units (DMU'S). Lastly, analysis of the general characteristics of efficient vessels were made in order to stratify the parameters that may have transformed them into efficient DMU`s, making it possible to trace a profile of the type of vessel employed in each type of line, thus helping in decision making of new projects.

Keywords: data envelopment analysis; river passenger transport; energy efficiency.

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Introduction

Brazil has a large part of the largest hydrographic basin in the world, the Amazon River Basin (Santos, Lima, Bassi, Rodrigues, & Maiellaro, 2018a), turning the region one of the largest waterway potentials on the planet. Bearing this in mind, the waters of the Amazon region hold several uses, such as the direct and indirect consumption by the riverside population (Pojo, Elias, & Vilhena, 2014), as well as for the means of transportation, both for the traditional population and for large multinational companies.

The Amazonian river navigation, even if exploited in an inexperienced way, it has historically been the main support for the development of the Amazon economy (Gadelha, 2002). Passenger transportation in the region is characterized, in general, by its low cost to the user, reflecting the low income of the inhabitants, the ones with the lowest per capita household income in the country (*Instituto Brasileiro de Geografia e Estatística* [IBGE], 2019). In 2017, approximately ten million passengers were transported in the region (*Agência Nacional de Transportes Aquaviários* [Antaq], 2018).

Considering that, there is a greater concern related to the quality of those services offered in the region, which, due to the lack of supervision, incentives, and guidelines, are well below the satisfactory level for the user, calling for immediate and clear solution for the development of the region. In addition, Amazonian river navigation also lacks further studies regarding its use, since related studies are almost nonexistent (Lameira, Filgueiras, Botter, & Saavedra, 2020), causing an incipiency in the use of scientific methods that are proven to be efficient for the improvement of its logistical system.

Corroborating with these hypotheses, this study aims to analyze the efficiency of passenger transportation vessels used in the Brazilian Amazon, highlighting those with greater efficiency and, at the same time, evidencing the inefficiency in degrees, based on the Slack-based model DEA (SBM-DEA) in order to analyze qualitative and quantitative influencing factors.

Background

Amazon navigation

According to the Brazilian Ministry of the Environment (*Ministério do Meio Ambiente* [MMA], 2006a; 2006b), the Brazilian Amazon includes a large part of the hydrographic regions of the Amazon and Tocantins-Araguaia rivers. The Amazon alone embraces approximately 44.65% of the Brazilian territory, encompassing an area of 3.8 million square kilometers with approximately 50 thousand kilometers of rivers, being historically and geographically prone to the use of the waterway modal as its main means of transportation. The existence of other modals, are not fully prioritized in the region in view of historical, economic issues and linked to the feasibility of use.

Considering the vast potential of the waterway modal in the Amazon region, navigation has been the main way of transportation since the beginning of the its occupation process (Gadelha, 2002). The waterway modal continues to be very important nowadays, both in view of the incipience of alternative modals (Santos et al., 2018b) and in the lack of great efforts of the municipalities in planning and analyzing logistical systems (Marques & Kuwahara, 2009). The rivers are navigable in most of their courses, allowing access to great distances in the hydrographic region at a relatively low cost (*Agência Nacional de Transportes Aquaviários* [Antaq], 2013).

Studies regarding current vessel profiles in the Amazon region is extremely scarce when it comes to academic work. We can mention some authors who proposed to work with the subject, (Paula et al., 2019), analyzing from a fuzzy logic the risks of the sanitation of river vessels in the Amazon for the environment; Soares and Vidal Filho (2014) seeking to increase safety in typical wooden vessels, but not having as main focus a general view of the efficiency of the modal. Looking at past studies, we can mention Moraes and Vasconcelos (2001), who characterize river passenger boats in a very specific way, however, already outdated by its time of publication.

The National Waterway Transport Agency of Brazil (Antaq, 2018), updated its report in 2013 (*Agência Nacional de Transportes Aquaviários* [Antaq], 2013), showing the essential characteristics of the supply and demand of fluvial transport of passengers and cargo in the Amazon region. It presented several points of navigation, the profile of vessels used, in addition to drawing the general profile of the types of passengers using the modal. Results indicated that the majority of users are young, between 18 and 40 years of age (58%), and with an average monthly family income of R$ 1,675.00. About 35% of respondents were self-employed. The main reasons for traveling were: leisure or visiting friends and relatives (40%) and work commitments and medical treatment (45%). Regarding the granting of discounts, gratuities and exemptions on the ticket, most passengers interviewed (84.8%) declared to pay the full price of the ticket. Only 15% said they benefited from discounts or exemptions. Furthermore, only 26.7% of respondents lived in one of the four capitals surveyed (Belém 6.8; Macapá 4.1; Manaus 15.4 and Porto Velho 0.4%). The remaining 73.3% lived in municipalities in the interior of the states or were tourists.

According to IBGE data, the North Region of the country concentrates about 9% of the Brazilian population (17,936.201 inhabitants) and 45% of the Brazilian territory. The average monthly household income per capita in 2016 in the North Region was R$ 846.00, about 50% lower than the average income of the state of São Paulo, which has the highest in the country. In the national comparison, the average income of the population of the North Region is 34% lower than the national income registered. Another important socioeconomic aspect in the North Region is the high concentration of its population in the rural area. Approximately 26% of the population (4.2 million inhabitants) lives in the rural area, with emphasis on Pará, which has the fourth largest rural population (2.3 million inhabitants). In Brazil, the percentage of rural population is 15.6% (*Instituto Brasileiro de Geografia e Estatística* [IBGE], 2019).

Slack-based model DEA

Performance analysis has become a vital part of practical management in logistics infrastructure (Wanke & Azad, 2018). Recently, numerous analytical methods have emerged with the purpose of comparing efficiency between similar elements. Thus, the Data Envelopment Analysis appears, which has its linked origin, firstly using the CCR model, by Charnes, Cooper, and Rhodes (1978), and already with the BCC model, by Banker, Charnes, and Cooper (1984). In general, the method is a multivariable technique for monitoring productivity of decision-making units (DMU's), which provides quantitative data on possible directions to improve the status quo of the units, when inefficient. In particular, DEA is a non-parametric technique that allows input and output data to be compared without statistical assumptions (Angulo-Meza, González-Araya, Iriarte, Rebolledo-Leiva, & Mello, 2019).

The DEA has, despite its somewhat young age, a vast bibliography of applications and developments within several fields of knowledge in order to evaluate relative performances of DMU's that consume similar inputs and produce similar outputs (Lin, Lee, & Ho, 2011). Among them, applied to the transport area, we can quote the work of Wanke and Azad (2018) which compares the efficiency between the rail networks of six Asian countries in order to assess how its underlying randomness and imprecision affect the efficiency levels of their operations, from general data related to freight and the network situation. Li, Jiang, and Lin (2018) can also be mentioned applying the DEA to data from 20 coastal ports in China from 2007 to 2012, to assess the ECC mechanism in coastal ports. According to the results, the author provided a guide for policies to be adopted to promote the advancement of sustainable development in ports.

Bearing this in mind, the choice of this method for this study was based on the work of Hilmola (2013) who compared twelve classes of ships for short sea transportation using the basic data of vessels used between Estonia and Finland. On Mantalis, Garefalakis, Lemonakis, Vassakis, and Xanthos (2016) who built a comparative analysis during five years (2007-2011) on the efficiency of Greek cargo navigation, based on data of twenty-two shipping companies operating in the country. Also on Panayides, Lambertides, and Savva (2011) who used the method to compare the relative efficiencies of twenty-seven shipping companies, thus proving the great application efficiency of the method relative to the waterway transport area.

Material and methods

SBM DEA

Incorporating the positive aspects of the additive models is invariant in relation to the measurement unit of inputs and products, allowing easy economic interpretation and, in addition, offering a scale that measures the degree of inefficiency present in the inputs and products (Tone, 2001). It is worth mentioning that the efficiency measured with the SBM is influenced by the reference set and is monotonically decreasing if there are 'looseness' in the objective function.

In this research, the SBM output-oriented model was used, in order to show a trend towards higher quality of service, despite smaller inputs. The relative efficiency obtained follows the Equation 1 and 2:

$$\frac{1}{\rho_o} = max\ 1 + \frac{1}{s}\sum_{r=1}^{s}\frac{S_r^+}{y_{ro}}, \qquad (1)$$

$$x_{io} = \sum_{j=1}^{n} x_{ij}\lambda_j + S_I^- \qquad (i=1, ..., m)$$

$$y_{ro} = \sum_{j=1}^{n} y_{rj}\lambda_j - S_r^+ \qquad (r=1, ..., s) \qquad (2)$$

$$\lambda_j \geq 0\ (\forall j \qquad S_i^{-\geq 0}\ i) \quad S_r^{+\geq 0})$$

where:

x_{io} and y_{ro} are the nth input and nth output, respectively. In order to increase the performance of an inefficient DMU, the objective of the improvement must be established among the efficient DMUs of the analysis (Tone, 2001).

It is important to note that the condition of non-negativity of the inputs and outputs can be relaxed, since negative values can be replaced by small positive values. The efficiency index denominated by ρ, has an amplitude between 0 and 1 and the DMU will be considered efficient when $\rho = 1$.

It is wise to mention that, in future applications of the method here proposed, attention must be paid to the quantity of DMUs evaluated. An insufficient number of DMUs evaluated in a DEA model tends to classify a greater number of them with 100% efficiency, due to the use of an inadequate number of degree of freedom (Sun, Yuan, Yang, Ji, & Wu, 2017).

Data collection

The scarcity of data related to the quality of service employed by passenger vessels used in the Amazon region was one of the main obstacles in this research. Data were collected through field research, considering homogeneous variables, described in **Table** 1. The questionnaires included characteristics that evaluate each criterion in order to ensure the validity of the output data. Data collection included the individual characteristics of each criterion. It was carried out through an open questionnaire applied to the owners of the vessels at two different times (the first from July to September 2015 and the second from March to August 2017). First, the meaning and motivation of using the methodology was explained and then the procedure for the individual development of the research was instructed.

Table 1. Data obtained from field research.

		Power per hour consumption (KW hour^{-1})
		Power by passenger capacity (KW nº of passenger^{-1})
Analysis 1	Energy Efficiency	Power by load capacity (KW ton^{-1})
		Power by speed (KW Knots^{-1})
		Power by vessel size (KW Gross Tonnage^{-1})
		Average distance ticket value (R$ km^{-1})
Analysis 2	Tariff affordability	Average ticket value per hour (R$ hour^{-1})
		Average load value by distance (Cargo R$ km^{-1})

As stated above, the data were divided into two major areas: energy efficiency which aims to analyze technical data of the vessel, focusing on how efficient this DMU is in achieving its objective, and tariff affordability, which seeks to analyze the best way for the consumer to use this vessel. The methodology used proposes to analyze each cited area related to each purpose of the vessel, which will be presented in the next section and, finally, compare them in order to analyze the relative efficiency.

Comparisons of the criteria scores for each alternative were used to assist in obtaining the DMU's weights. The Slack-based model DEA identified the weight of each element that comprises the total weight of the factors to be converted into input. The convenience of the method is even more significant due to the number of alternatives used. The classification method, used according to the SBM-DEA, makes it easier to assess large numbers of alternatives. The method reduces the maximum error of each criterion weight, identifying the centroid of all possible weights.

Alternatives

This study used data from 652 vessels (Antaq, 2018) operated in the Amazon region, recorded throughout the states of Pará, Amazonas, Amapá and Rondônia. From this sample, 148 vessels were selected, choosing the ones with the highest number of trips. The selection of vessels started from the level of use, with the fifty most active vessels being selected in order to obtain the greatest possible variation among the DMU's analyzed They were divided, according to their purpose, into three types: crossing vessels (50 vessels), having as main feature short travel distances and consequently short trips; state vessels (50 vessels), those that make medium to long duration routes; and all of which are made within the same state and interstate vessels (48 vessels) that, in general, have long duration routes and cover more than one state. It is worth mentioning that only 48 were selected for the interstate type, since the distance between the degrees of use of the excluded vessels and those that remained in the survey was of a greater value compared to the other types, which could leave the results inconclusive. The general data of the selected samples were exposed in the **Table 2**.

The main characteristic of interstate vessels is relatively high distances and, even with routes of 165 and 261 km (Santana – Santarém and Santana – Vitória do Xingu), the average distance traveled by DMU's of this type is approximately 595 km since they have routes of up to 1648 km (Belém - Manaus). The main feature of this type of DMU is the cost for users, which is relatively higher than previous ones, as well as the trips that are much longer, lasting more than a day.

In this study, for energy efficiency, Power (Pot) and consumption (Con) were considered as input variables, and as outputs the total trip time (TTV), total distance of the line (DTL), and the capacity of passengers (CP) were used. For the analysis of Tariff affordability, the ticket price (PP) was used as input. Consumption (Con), total trip time (TTV) and the total distance of the route (DTR) were used as output. Therefore, the variables can directly reflect the performance of the researched quality. The objective of this research is to maximize the research quality variables; therefore, the applied DEA model is output oriented.

Table 2. Interstate DMU information.

No.	DMU	Action Line	Distance (km)	Home/ Destination State
1	Amanda Leticia II	Alenquer - Manaus	555	Pará/ Amazonas State
2	Monte Cristo	Alenquer - Manaus	555	Pará/ Amazonas State
3	Amazon Star	Belém - Manaus	1646	Pará/ Amazonas State
4	Catamarã Rondonia	Belém - Manaus	1646	Pará/ Amazonas State
5	Nelio Correa	Belém - Manaus	1646	Pará/ Amazonas State
6	San Marino III	Belém - Manaus	1646	Pará/ Amazonas State
7	Iluminado	Laranjal do Jari - Belém	696	Amapá/ Pará State
8	Pedro Junior	Laranjal do Jari - Belém	696	Amapá/ Pará State
9	Espirito Santo II	Laranjal do Jari - Belém	409	Amapá/ Pará State
10	Hanna Janessa	Laranjal do Jari - Santarém	409	Amapá/ Pará State
11	Almte. Moreira IX	Manaus - Porto Velho	1348	Amazonas/ Rondônia State
12	Stenio Araújo	Manaus - Porto Velho	1348	Amazonas/ Rondônia State
13	Vieira I	Manaus - Porto Velho	1348	Amazonas/ Rondônia State
14	F B São Bartolomeu IV	Monte Alegre - Manaus	866	Pará/ Amazonas State
15	Luis Afonso	Monte Alegre - Manaus	866	Pará/ Amazonas State
16	F B Obidense II	Óbidos - Manaus	650	Pará/ Amazonas State
17	F B Obidense III	Óbidos - Manaus	650	Pará/ Amazonas State
18	Cidade de Oriximiná III	Oriximiná - Manaus	680	Pará/ Amazonas State
19	Lancha Oriximiná	Oriximiná - Manaus	680	Pará/ Amazonas State
20	Letícia Sófia	Oriximiná - Manaus	680	Pará/ Amazonas State
21	Almirante Paulo Arnold	Porto Velho - Manicoré	557	Rondonia/ Amazonas State
22	Marcos Filho III	Porto Velho - Manicoré	557	Rondonia/ Amazonas State
23	São Sebastião	Porto Velho - Manicoré	557	Rondonia/ Amazonas State
24	Bruno	Santana - Santarém	165	Amapá/ Pará State
25	Luan	Santana - Santarém	165	Amapá/ Pará State
26	Quirino Neto	Santana - Santarém	165	Amapá/ Pará State
27	São Bartolomeu II	Santana - Santarém	165	Amapá/ Pará State
28	São Benedito	Santana - Santarém	165	Amapá/ Pará State
29	São Francisco De Assis	Santana - Santarém	165	Amapá/ Pará State
30	Seamar IV	Santana - Santarém	165	Amapá/ Pará State
31	Alice	Santana - Vitória do Xingu	261	Amapá/ Pará State
32	Ana Beatriz V	Santana - Vitória do Xingu	261	Amapá/ Pará State
33	Darcy Junior de São Benedito I	Santana - Vitória do Xingu	261	Amapá/ Pará State
34	Napoleão	Santana - Vitória do Xingu	261	Amapá/ Pará State
35	São Pedro	Santana - Vitória do Xingu	261	Amapá/ Pará State
36	Seamar II	Santana - Vitória do Xingu	261	Amapá/ Pará State
37	Anna Karoline II	Santarém - Manaus	514	Pará/ Amazonas State
38	Cisne Branco	Santarém - Manaus	514	Pará/ Amazonas State
39	Expresso Golfinho I	Santarém - Manaus	514	Pará/ Amazonas State
40	F B Ana Beatriz V	Santarém - Manaus	514	Pará/ Amazonas State
41	Golfinho do Mar II	Santarém - Manaus	514	Pará/ Amazonas State
42	São Bartolomeu III	Santarém - Manaus	514	Pará/ Amazonas State
43	Boa Fé II	Santarém - Parintins	243	Pará/ Amazonas State
44	Cidade de Nhamundá	Santarém - Parintins	243	Pará/ Amazonas State
45	Cidade de Nhamundá III	Terra Santa - Manaus	496	Pará/ Amazonas State
46	Cidade de Terra Santa	Terra Santa - Manaus	496	Pará/ Amazonas State
47	Sereia	Terra Santa - Manaus	496	Pará/ Amazonas State

Results and discussion

Energy efficiency

In order to analyze, in the first place, the energy efficiency of the vessels used in the Amazon region, based on the proposed methodology, **Table 3** presents the input and output data for each vessel divided into crossing, state and interstate vessels.

For the DMU's used in this work, we have an average power of 560 kW ranging from 175 and 1800 kW, and for the second input variable, which is consumption, we have an average of 2500 liters between the range of

120 and 16000 L of diesel. For the output variables, for the Total Travel Time (TTV) an average of 28 hours ranging from 2.5 to 126 hours of travel was obtained, and for the Passenger Capacity variable we have an average of 256 people ranging from 43 to 1400 passengers. It can be seen that there is a great variety within the information, which makes the comparison necessary for the region.

Table 3. Input and output data from interstate DMU's.

DMU	Input data		Output data		
	Pot (kW)	Con (l hour^{-1})	TTV (hour)	DTL (km)	CP
1	915	5000	31	555	836
2	818	5000	28	555	490
3	600	9000	72	1646	756
4	600	16000	96	1646	838
5	367	10000	96	1646	254
6	800	13000	96	1646	763
7	300	2500	40	696	276
8	175	2250	58	696	90
9	180	1200	24	409	91
10	420	1400	24	409	93
11	830	8000	126	1348	95
12	315	7000	124	1348	175
13	360	7000	124	1348	135
14	820	9000	32	866	1324
15	600	9000	30	866	300
16	1200	350	26	650	1330
17	915	3600	24	650	821
18	800	2500	25	680	770
19	950	400	12	680	90
20	915	3000	30	680	1002
21	360	800	15	557	124
22	315	400	13	557	134
23	240	2400	36	557	124
24	600	3600	30	165	680
25	420	2000	36	165	280
26	290	4000	30	165	100
27	600	4500	36	165	290
28	315	2500	40	165	228
29	570	2500	36	165	340
30	600	2000	28	165	200
31	220	800	22	261	250
32	440	800	24	261	151
33	180	900	20	261	155
34	190	500	20	261	98
35	300	1600	30	261	170
36	220	1400	20	261	100
37	829	7500	28	514	520
38	400	9000	27	514	231
39	1800	5000	13	514	171
40	829	8000	30	514	1400
41	440	10000	28	514	700
42	840	6500	28	514	650
43	200	825	7	243	65
44	315	700	7	243	96
45	697	2400	27	496	258
46	600	2000	28	496	362
47	550	2000	32	496	513
48	500	120	2,5	75	43

Table 4 shows the correlations between the variables of inputs and outputs. The fact that the correlations between the inputs and the outputs between them suggest validity for the proposed model. It is observed that the greatest relations between the variables analyzed are Total Route Distance (DTL); Total Travel Time (TTV); Total Route Distance (DTL) and Consumption. All of them are partially dependent variables. The

lowest correlation found was between Total Travel Time (TTV) and Power, this fact in itself shows a tendency towards transportation inefficiency, since they should be partially dependent variables.

Table 5 shows the ranking of vessels in relation to energy efficiency analysis.

Table 4. Correlation matrix between energy efficiency inputs and outputs for state-type DMU's.

	Pot (kW)	Con (l)	TTV (hour)	DTL (km)	CP
Pot (kW)	1				
Con (l)	0.247776042	1			
TTV (hour)	-0.044210576	0.62789929	1		
DTL (km)	0.179702304	0.731938986	0.81400515	1	
CP	0.534060508	0.424743566	0.041419872	0.269134067	1

Table 5. Energy efficiency of interstate DMU's.

No.	Name of the vessel	Score	Rank
3	Amazon Star	1	1
4	Catamarã Rondonia	1	1
5	Nelio Correa	1	1
8	Pedro Junior	1	1
12	Stenio Araújo	1	1
14	F B São Bartolomeu IV	1	1
16	F B Obidense II	1	1
19	Lancha Oriximiná	1	1
22	Marcos Filho III	1	1
31	Alice	1	1
34	Napoleão	1	1
40	F B Ana Beatriz V	1	1
41	Golfinho do Mar II	0.8928	13
7	Iluminado	0.8617	14
33	Darcy Junior de São Benedito I	0.85	15
13	Vieira I	0.7841	16
9	Espirito Santo II	0.7589	17
47	Sereia	0.677	18
23	São Sebastião	0.6755	19
6	San Marino III	0.6585	20
21	Almirante Paulo Arnold	0.6465	21
35	São Pedro	0.5767	22
46	Cidade de Terra Santa	0.5623	23
20	Letícia Sófia	0.5557	24
18	Cidade de Oriximiná III	0.5452	25
36	Seamar II	0.5315	26
32	Ana Beatriz V	0.5237	27
45	Cidade de Nhamundá III	0.4199	28
17	F B Obidense III	0.3992	29
43	Boa Fé II	0.3896	30
28	São Benedito	0.3874	31
44	Cidade de Nhamundá	0.3805	32
25	Luan	0.3801	33
10	Hanna Janessa	0.3795	34
1	Amanda Leticia II	0.3539	35
24	Bruno	0.3339	36
2	Monte Cristo	0.3166	37
38	Cisne Branco	0.2988	38
29	São Francisco De Assis	0.2913	39
15	Luis Afonso	0.2787	40
30	Seamar IV	0.2684	41
42	São Bartolomeu III	0.2651	42
26	Quirino Neto	0.254	43
11	Almte. Moreira IX	0.2416	44
37	Anna Karoline II	0.2323	45
27	São Bartolomeu II	0.2002	46
48	Rita Helena	0.175	47
39	Expresso Golfinho I	0.1131	48

From the above, it is visible that, for the group analyzed in relation to energy efficiency, twelve efficient DMU's were found. Of these said to be energy efficient, 58% have routes between the states of Pará and Amazonas States, 25% between Amapá and Pará States and 16% between Amazonas and Rondônia States. Only 41% of the vessels have interconnected routes in large urban centers. The average efficiency of DMU's was 0.55. It is worth mentioning that the average found did not reach the acceptable value of 0.7 (Tone, 2001), and it is much lower than expected. The relative inefficiencies indicated by this research suggest a high energy inefficiency related to the Amazon waterway transport.

Tariff affordability

To analyze the second area of this research, tariff affordability, the related data of the inputs and outputs of each DMU are shown in **Table 6.**

Table 6. Input and output data of tariff affordability of the interstate DMU's.

DMU	Variables of input	Variables of output		
	PP (R$)	Con (l hour^{-1})	TTV (hour)	DTL (km)
1	250	5000	31	555
2	200	5000	28	555
3	650	9000	72	1646
4	550	16000	96	1646
5	645	10000	96	1646
6	771	13000	96	1646
7	175	2500	40	696
8	190	2250	58	696
9	265	1200	24	409
10	280	1400	24	409
11	450	8000	126	1348
12	450	7000	124	1348
13	350	7000	124	1348
14	365	9000	32	866
15	315	9000	30	866
16	300	350	26	650
17	290	3600	24	650
18	285	2500	25	680
19	240	400	12	680
20	260	3000	30	680
21	100	800	15	557
22	60	400	13	557
23	150	2400	36	557
24	370	3600	30	165
25	320	2000	36	165
26	130	4000	30	165
27	255	4500	36	165
28	290	2500	40	165
29	320	2500	36	165
30	330	2000	28	165
31	280	800	22	261
32	280	800	24	261
33	200	900	20	261
34	340	500	20	261
35	230	1600	30	261
36	315	1400	20	261
37	330	7500	28	514
38	390	9000	27	514
39	260	5000	13	514
40	390	8000	30	514
41	365	10000	28	514
42	340	6500	28	514
43	90	825	7	243
44	90	700	7	243
45	225	2400	27	496
46	250	2000	28	496
47	315	2000	32	496
48	60	120	2,5	75

For the vessels used in this research, the tariff affordability analysis shows the average value for the Ticket fare of 287.50 reals ranging between 60.00 and 771.00 reals. It is noticed that this group also has a wide variation between the values of their variables.

Regarding analysis of energy efficiency, **Table** 7 shows the relationship between all variables for the analysis of tariff affordability. As for the first analysis, energy efficiency, the fact that the correlations between the inputs and the outputs with each other suggest validity for the proposed model. It can be seen that the group follows the small variation trend, between 0.62 and 0.81, showing a high degree of interconnection between the variables and having the two highest values in the relation between the Total Distance of the Route and the Total Time of Travel, 0.81, and between Consumption and Ticket Price, 0.75.

Table 8 displays the ranking of vessels in relation to the analysis of tariff affordability.

Table 7. Correlation matrix between inputs and outputs of tariff affordability for DMUs of the interstate type.

	PP (R$)	Con (l)	TTV (hour)	DTL (km)
PP (R$)	1			
Con (l)	,	1		
TTV (hour)	0.6761744	0.6278993	1	
DTL (km)	0.7190672	0.731939	0.8140051	1

Table 8. Tariff affordability of DMU's interstate type.

No.	Name of the vessel	Score	Rank
4	Catamarã Rondonia	1	1
13	Vieira I	1	1
22	Marcos Filho III	1	1
26	Quirino Neto	1	1
11	Almte. Moreira IX	0.7955	5
23	São Sebastião	0.7936	6
8	Pedro Junior	0.7691	7
7	Iluminado	0.7664	8
12	Stenio Araújo	0.7482	9
2	Monte Cristo	0.7369	10
15	Luis Afonso	0.7288	11
21	Almirante Paulo Arnold	0.5947	12
5	Nelio Correa	0.5665	13
14	F B São Bartolomeu IV	0.5372	14
1	Amanda Leticia II	0.5365	15
6	San Marino III	0.501	16
41	Golfinho do Mar II	0.501	16
3	Amazon Star	0.4867	18
20	Letícia Sófia	0.478	19
45	Cidade de Nhamundá III	0.4531	20
37	Anna Karoline II	0.4373	21
46	Cidade de Terra Santa	0.3945	22
17	F B Obidense III	0,3942	23
18	Cidade de Oriximiná III	0.3782	24
38	Cisne Branco	0.3764	25
42	São Bartolomeu III	0.3761	26
43	Boa Fé II	0.3675	27
40	F B Ana Beatriz V	0.3589	28
44	Cidade de Nhamundá	0.3508	29
47	Sereia	0.3303	30
39	Expresso Golfinho I	0.2978	31
35	São Pedro	0.2787	32
10	Hanna Janessa	0.2786	33
9	Espirito Santo II	0.2772	34
33	Darcy Junior de São Benedito I	0.2743	35
27	São Bartolomeu II	0.2505	36
32	Ana Beatriz V	0.1944	37
31	Alice	0.1918	38
36	Seamar II	0.1861	39
28	São Benedito	0.1676	40
29	São Francisco De Assis	0.1479	41

25	Luan	0.1429	42
48	Rita Helena	0.1367	43
19	Lancha Oriximiná	0.1355	44
30	Seamar IV	0.135	45
24	Bruno	0.1334	46
34	Napoleão	0.1126	47
16	F B Obidense II	0.1036	48

The last analysis of this research reached the number of four efficient DMU's, two of them with routes between the states of Amazonas and Rondônia States, one between the states of Pará and Amapá States and one between the states of Pará and Amazonas States. About 50% having routes with the distance greater than the average for the 565 km per group. The average efficiency score related to moderacy is 0.37, varying between 0.1 and 1. Two of the DMU's considered efficient in this category, Catamarã Rondônia and Marcos Filho III, were also considered the most energy efficient in the first analysis of this group, the other two DMU's, Vieira I and Quirino Neto, presented position 16 with a score of 0.78 and position 43 with a score of 0.25, respectively.

The results related to tariff affordability proved a high degree of inefficient manpower, extreme lack of infrastructure and ineffective services as a general trend of the relative efficiencies of quality of vessels in the Amazon region. The results also show that the quality of service of the Amazonian vessels fails to meet the passengers regional demand. In other words, the terminals in the region need improvements in the quality of the services provided on transportation of essential cargo.

Conclusion

Based on the work in question, which proposed the development of a methodology for analyzing relative efficiency in passenger transport in the Amazon region, it was possible to evaluate DMU's, through a case study on existing river vessels in the Amazon from the DEA-CCR decision aid tool.

Based on the results found, some conclusions regarding the application of the methodology can be considered:

- The Data Envelopment Analysis (DEA) methodology proved to be a tool that is easy to apply and interpret. From the selection of decision-making units (DMU’s) it was possible to gather variables with different types of nature, presenting coherent results and enabling a clear interpretation in relation to DMU’s classified as efficient and inefficient.
- The methodology in question is evidenced as a tool capable of improving the transport system, generating significant gains in trips and vessels based on the constant monitoring and analysis of the efficiency of DMU's, allowing to evaluate the factors that influence relative efficiency losses. In addition, it shows the possibility of proposing analyzes which enable the generation of information that allows to find possible tangible technical solutions that can be applied to the problems encountered.

Still based on the results obtained, it was possible to obtain conclusions linked, not directly to the applied model, but to the efficiency results obtained, to be noted:

- Energy Efficiency: The results obtained were consistent with what was expected with respect to the analysis of energy efficiency for interstate and state, with values below enough to consider most vessels as efficient. For Interstate vessels, 12 vessels reached the benchmark, with the sample space obtaining an average energy efficiency of 0.55. Therefore, it is evident that of all the averages found, none reached the determined acceptable efficiency value of 0.7.
- Tariff affordability: On the results regarding tariff affordability, even lower average efficiency values were observed, with few vessels reaching the benchmark and the others reaching significantly low efficiency values. For Interstate vessels, 2 vessels reached the benchmark, with the sample space obtaining an average efficiency of 0.37.

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