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The efficiency of Brazilian railway system: an application of Data Envelopment Analysis

Eficiencia del sistema de transporte metro-ferroviario brasileño: una aplicación del Análisis Envolvente de Datos

Eficiência do sistema de transporte metroferroviário brasileiro: uma aplicação da Análise Envoltória de Dados

Authors

Maria Cecilia da Silva Brum
Doctoral Student in Accounting at Universidade do Vale do Rio do Sinos (UNISINOS), Brazil. Address: Dr. Nilo Peçanha Avenue, 1600, Boa Vista, Porto Alegre - RS, Brazil. (51) 3591-1122. Identifiers (ID):
ORCID: https://orcid.org/0000-0002-7222-7381
Lattes: http://lattes.cnpq.br/7455667713175699
E-mail: mceciliabrum@hotmail.com

Tiago Wickstrom Alves
Doctoral Student in Economics at Universidade Federal do Rio Grande do Sul (UFRGS). Professor of Universidade do Vale do Rio dos Sinos (UNISINOS). Address: Dr. Nilo Peçanha Avenue, 1600, Boa Vista, Porto Alegre - RS, Brazil. (51) 3591-1122. Identifiers (ID):
ORCID: https://orcid.org/0000-0002-2813-1550
Lattes: http://lattes.cnpq.br/2532605739636568
E-mail: twa@unisinos.br

Abstract

Purpose: To analyze the technical efficiency of Brazilian railway companies.

Methodology: The technical efficiency of Brazilian railway companies was analyzed through Data Envelopment Analysis (DEA), using the window analysis approach, and considering the Variable Returns of Scale model. The study examined eight companies during a five-year period, which totalizes 90% of the railway passengers in that timespan. The main inputs and outputs of railway systems referred in the international literature were used as variables.

Results: Only railway companies classified as large can be considered technically efficient. Among them, São Paulo’s metro system was the only one that remained efficient throughout the years analyzed. Medium-sized companies were inefficient in all years of the sample, showing the necessity to reduce their inputs by an average of 19% in order to become technically efficient. The inclusion of financial variable as an input did not significantly change the efficiency indexes assessed. The study reveals the prevalence of increasing returns to scale in the Brazilian railway system.

Contributions of the Study: This study identifies potential improvements for the companies considered inefficient and reveals they are medium-sized and state-owned, with high-cost financing from government resources. It is also a benchmark for further research on the topic, given the importance of identifying the effect of funding transport operations with government resources on companies' efficiency. In this context, considering this study identifies the prevalence of increasing returns to scale in the Brazilian railway system, it contributes to the analysis of public policies associated with population access to this means of transportation, as constant returns to scale suggests that production increase, which has the number of carried passengers as the main variable, can generate benefits for the companies in terms of efficiency.

Keywords: efficiency, railway transport, DEA.

Resumen

Objetivo: Analizar la eficiencia técnica de las empresas de metro en Brasil.

Metodología: La eficiencia técnica de las empresas de transporte metro-ferroviario en Brasil fue analizada a través del Análisis Envolvente de Datos (DEA), apoyado por el Análisis de Ventana y considerando el modelo de retornos variables. El estudio abarcó un período de cinco años, para ocho empresas que representan el 90% de los pasajeros transportados en el sistema metro-ferroviario. Como variables se utilizaron los principales insumos y productos del transporte metro-ferroviario referenciados en la literatura internacional.

Resultados: Solo las empresas de metro clasificadas como grandes son técnicamente eficientes y, entre ellas, solo Metrô SP se ha mantenido eficiente en todos los años analizados. Las empresas medianas resultaron ineficientes en todos los años de la muestra, con la necesidad de una reducción promedio del 19% en los insumos para ser técnicamente eficientes. La inclusión de variables financieras como input no tuvo un impacto significativo en los índices de eficiencia calculados. El estudio revela que prevalecen rendimientos crecientes a escala en el sistema de transporte metro-ferroviario brasileño.

Contribuciones del Estudio: El estudio identifica posibles mejoras para las empresas consideradas ineficientes y revela que son empresas públicas de tamaño mediano, con altos niveles de financiamiento de sus costos a través de recursos gubernamentales, sirviendo este estudio de referencia para ampliar la investigación sobre el tema, dada la relevancia de identificar el efecto de costear las operaciones de transporte a través de recursos gubernamentales sobre la eficiencia de las empresas. En esta línea, al identificar que el sistema de transporte metro-ferroviario brasileño es predominante en los rendimientos crecientes a escala, este estudio contribuye al análisis de las políticas públicas vinculadas al acceso de la población a este transporte, ya que los rendimientos crecientes sugieren que el aumento de la producción, que tiene como variable principal el número de pasajeros transportados, puede generar beneficios en cuanto a la eficiencia de las empresas.

Palabras clave: eficiencia, transporte metro-ferroviario, DEA.

Resumo

Objetivo: Analisar a eficiência técnica das empresas metroferroviárias brasileiras.

Metodologia: Foi analisada a eficiência técnica das empresas metroferroviárias brasileiras por meio da Análise Envoltória de Dados (DEA), com suporte na Análise de Janelas e considerando o modelo de retornos variáveis. O estudo contemplou um período de cinco anos, para oito empresas que totalizam 90% dos passageiros transportados no sistema metroferroviário. Como variáveis foram utilizados os principais insumos e produtos do transporte metroferroviário referenciados na literatura internacional.

Resultados: São tecnicamente eficientes apenas as empresas metroferroviárias classificadas como de grande porte e dentre estas somente o Metrô SP se manteve eficiente em todos os anos analisados. As empresas de médio porte apresentaram-se ineficientes em todos os anos da amostra, sendo identificada a necessidade de redução média de 19% nos insumos para que estas se tornem tecnicamente eficientes. A inclusão de variável financeira como insumo não teve reflexo significativo nos índices de eficiência apurados. O estudo revela que prepondera no sistema de transporte metroferroviário brasileiro retornos crescentes de escala.

Contribuições do Estudo: O estudo identifica melhorias potenciais para as empresas consideradas ineficientes e revela que estas são empresas públicas de médio porte, com altos níveis de financiamento dos seus custos por meio de recursos governamentais, servindo este estudo de referência para ampliar a pesquisa sobre o tema, dada a relevância de se identificar o efeito do custeio das operações do transporte por meio de recursos governamentais sobre a eficiência das empresas. Nessa esteira, ao identificar que prepondera no sistema de transporte metroferroviário brasileiro retornos crescentes de escala, este estudo contribui para a análise de políticas públicas vinculadas ao acesso da população a este transporte, uma vez que retornos crescentes sugerem que o aumento da produção, que tem como principal variável o número de passageiros transportados, pode gerar benefícios quanto à eficiência das empresas.

Palavras-chave: eficiência, transporte metroferroviário, DEA.

1 Introduction

The relevance of public transport goes far beyond the need for cities to have public transport networks that qualify the structure of urban mobility, with the definition of the transport system financing model being equally important. (Montañez, 2017). In general, public transport fare revenues are intended to cover its operating costs and, as these revenues are not sufficient, there is a need for subsidies to the transport operation, which is the reality of most cities in the world. (Asensio, Matas, & Raymond, 2003; Kiggundu, 2009).

However, although the importance of the subsidy as a source of financing for the transport system is recognized, it competes with other demands for subsidy in essential services, such as education and health. (Poliak, Senanová, & Mrníková, 2017). Regarding the benefits arising from metro-railway transport, they can be grouped into social, such as inclusion of the low-income population, reduction of accidents, etc., and environmental, such as reduction of pollution, traffic jams, among others. As an example, subway transport in Brazil prevents the entry of more than 1.1 million cars and more than 16,000 buses in urban centers daily. Compared to transport by bus, this transports, in terms of passengers, 6,700 passengers/hour/direction, while rail transport has a ratio of 60,000 passengers/hour/direction. (Associação Nacional de Transportes de Passageiros sobre Trilhos [ANPTrilhos], 2017).

In terms of financing the operating costs of public transport systems by buses in Brazil, they are predominantly financed through fare revenue (Vasconcellos, Carvalho, & Pereira, 2011) and, with this, the variation of operating costs of public transport is fully absorbed by the paying users of this transport. In rail transport systems, however, there are significant levels of financing through public resources (Brinco, 2012), but financing public transport is a challenge faced by large cities around the world (Kiggundu, 2009).

In systems financed by fare revenue, the higher the costs, the greater should be the amount financed by the user directly, whereas, in a financing system through public resources, the higher the costs, the greater the need for public resources (Carvalho, & Pereira, 2011). As a result, inefficient transport systems can generate high fares, reducing access to transport, especially for the low-income population, as well as unduly compromising public budgets. (Ševrović, Brčić, & Kos, 2015).

In this context, it is possible to see the importance of technical and economic efficiency in metro-rail transport, since companies with unsatisfactory performance tend to transfer the cost of this inefficiency to paying transport users or to the government, as the fare revenue is not sufficient to cover operating costs. The efficiency of subway transport becomes even more relevant in the Brazilian context as it competes for public resources in a country in constant fiscal crisis, where there are other fundamental demands still unmet, such as in the areas of health, education and safety, among others, requiring that the government does more and more with less (Alonso, 1999).

Given the relevance of the subway transport system, the restriction of public resources and the need for subsidies for this modal, this study aims to analyze the technical efficiency of Brazilian subway companies. As a methodology to respond to the proposed objective, Data Envelopment Analysis (DEA) was used, supported by Window Analysis.

The analyzes carried out, which considered Brazilian metro-railroad companies with different levels of financing by fare revenue, generated information on potential improvements for the sector that contribute to the enrichment of discussions on public policies aimed at urban transport, in particular, on efficiency and its consequences in financing public transport.

This article is divided into four more sections. The second section presents the theoretical framework. The third section presents the methodology used and, finally, the results and conclusions arising from the research are discussed.

2 Theoretical Reference

This section discusses the theoretical issue associated with efficiency based on Data Envelopment Analysis and summarizes the empirical studies related to the evaluation of efficiency in metro-railway transport as a way to build the theoretical basis and establish the analysis variables.

2.1 Technical Efficiency

The concept of efficiency can take on different meanings depending on the area and object of study, such as: i) economic efficiency, ii) allocative efficiency, iii) technical efficiency and iv) scale efficiency, (Gomes, Oliveira, & Matias, 2017; Mariano, 2007).

Technical efficiency results from maximum production combinations for all possible input combinations. This maximum combination results in what is called the production function, where the companies/analysis units that are on the curve are efficient and those that are below the curve are inefficient, with the degree of inefficiency given by the distance of the unit in relation to the production function, since it could produce more with the same resources (output-oriented) or the same volume with less input (input-oriented). These situations can be graphically represented as shown in Figure 1.

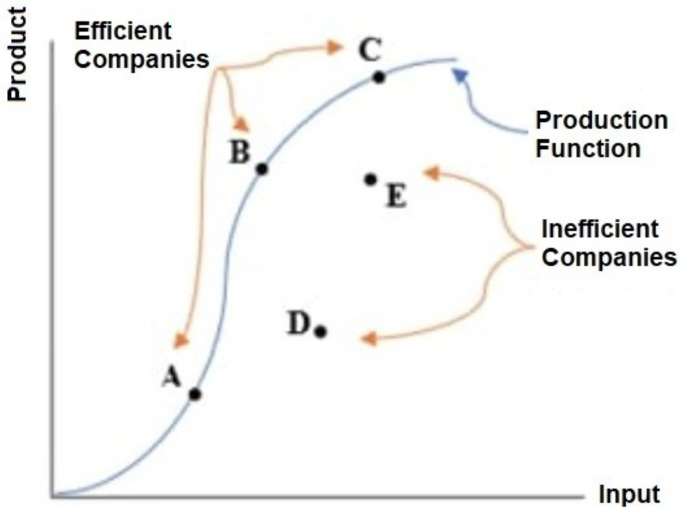

Figure 1 *Production function with variable yields*
Source: *Adapted from Besanko e Braeutigam (2004).*

Mathematically, the production function can be generically defined as Q = f(K,T,τ) where Q is the quantity produced as a function of the capital stock (K), labor (L) and technology (τ). In Figure 1, a production function with variable returns is represented, that is, when changing the input in a constant way, production initially grows at increasing rates and then grows at decreasing rates. If the yield were constant, the production function would be represented by a straight line that starts from the origin (Jehle, & Reny, 2000).

For example, based on Figure 1, if earnings were constant, the production function would be represented by a straight line that starts from the origin and touches the production function in company B so that there would be only one efficient company (Souza, Souza, & Pessanha, 2010; Peña, 2008).

In Data Envelopment Analysis (DEA), the efficiency information is relative, that is, there is no absolutely defined production function, being considered efficient those that "envelop" the companies/units with the best performance. Therefore, companies considered efficient are significantly sensitive to the sample. (Souza, Sousa, & Tannuri-Pianto, 2008). In DEA, it is possible to determine the technical efficiency of companies or their units, the DMUs (Decision-Making Unit), from the relationship between the raw materials (inputs) and the products (outputs), but this efficiency is relative and not absolute and, with that, identify possible input savings or increased production.

Furthermore, DEA is a non-parametric model, therefore not using central trend statistics and population variances. (Ferreira, & Gomes, 2009) and can be used to identify the relative efficiency of Decision Making Units (DMUs) which can be companies, organizations, people, or any system that presents a set of measurable inputs and outputs, regardless of these are either quantitative or qualitative (Cavaignac, & Petiot, 2017; Sampaio, Lima, & Sampaio, 2008; Markovits-Somogyi, 2011; Suguiy, 2017).

DEA originated in 1957 with Farrell (1957) and has a significant evolution in 1978 with Charnes, Cooper and Rhodes in the work *Measuring the efficiency of decision making units*, using linear programming techniques, which became known as (CCR) in honor of the authors. This model is also known as *Constant Returns to Scale* (CRS), as it only considers constant returns as mentioned above. A few years later, Banker, Charnes and Cooper included in the analysis the variable income that became known as BCC – also in honor to the authors (Mariano, Almeida, & Rebelatto, 2006).

In Brazil and in the Accounting area, one of the first researches was developed by Cereta and Niederauer (2001) – this article was originally presented at 2000 ANPAD meeting and subsequently by Silvia Kassai (Kassai, 2002), having had an expansion of employment of this methodology from this in Accounting Sciences.

2.2 Analysis of efficiency in public transport

At the national level, 105 articles were identified by the year 2020, from a search carried out on the website of the Capes/MEC Journal Portal, considering as a keyword: “data envelopment analysis”. From these articles, only seven have the area of transport as their theme, with four dealing with air transport, one with cargo, other with transport by bus and one addresses environmental aspects in public passenger transport. Therefore, there are few national studies using DEA method in transport area, and no article was identified with the DEA application in metro-railway transport, which reinforces the contribution of this study to the expansion of the research.

Internationally, the incidence of DEA use in the transport area can be verified through studies by Markovits-Somogyi (2011), Jarboiu, Forget and Boujelbene (2012) and Cavaignac and Petiot (2017). Markovits-Somogyi (2011) analyzed 69 studies with the application of DEA in the transport area, identifying the predominance of applications in airports, ports, public transport companies and railways, with the first two representing more than 50% of the analyzed studies. For the author, the study demonstrates the successful applicability of DEA method in the transport area, with a predominance of input variables linked to labor and capital, and output variables linked to operational and/or fiscal aspects.

Jarboiu et al. (2012) presented a literature review on the efficiency of public road transport through 24 articles published from 2000 and 2011, with reference to the application of DEA and Stochastic Border Analysis, considering these to be the two best known and adopted approaches in analyzing the efficiency of the transport sector. The result of the review reveals the predominance of studies using DEA, as the only way of analysis, and reports the lack of studies with mixed approaches. In addition to it, the study refers to the need to explain the inefficiency found in public transport operators, which may originate from several, such as work practices, operations management and investments.

Cavaignac and Petiot (2017) carried out a systematic review of the literature on aspects of efficiency in public transport, which included 461 articles with the application of DEA in the transport area, identified in the Scopus, Google Scholar and Econlit databases, and covering the period from 1989 to 2016. More than a third of the publications were leveled in Econlit database, which, for the authors, shows the relevance of economic issues in the transport sector, and the possibility of analyzing these issues through DEA application. The significant growth of DEA applications in the transport area from 2008 onwards is notable. The study also offers, based on the analyzed sample, detailed information on the 10 most cited articles, through transport. Table 1 identifies the variables most present in these articles, considering the passenger rail transport.

Table 1

Most used variables most used in DEA analyzes in passenger rail transport

Type	Variables	Nº of Incidence
Inputs	Nº of employees	10
	Nº of vehicles	8
	Track length	6
	Fuel consumption/Electricity	3
Outputs	Passengers/Km	7
	Car.Km	5

Source: *Adapted from Cavaignac and Petiot (2017).*

Among the main studies with DEA application in rail transport mentioned by Cavaignac and Petiot (2017), Kutlar, Kabasakal and Sarikaya's study (2013) stands out, which, unlike the others, included the financial variable operating costs as an input. The study found through DEA the efficiency of 31 railway companies operating worldwide, identifying different levels of efficiency between the companies and pointing out little variation in these over the period analyzed. Furthermore, it identified that the number of passengers transported negatively affects the efficiency.

Other studies in the area of transport, such as the one of Karlaftis (2004), Sampaio et al. (2008) and Tsai, Mulley and Merkert (2015) also show the incidence of the variables pointed out by Cavaignac and Petiot (2017) in measuring efficiency. Among these, the study of Sampaio et al. (2008), which analyzed through DEA the efficiency of 19 European and Brazilian metropolitan public transport systems. The efficiency analysis sought to identify characteristics that could help in the reorganization of the agency system in the metropolitan area of Recife and had as its main contribution the identification of two aspects that contribute to improving efficiency: more equal participation between government and beneficiaries, and diversification of the structure fare.

Karlaftis (2004) assessed the efficiency and effectiveness of 256 US transit systems, using as a product reference for efficiency the variable miles traveled by vehicles and as an effectiveness variable the passengers transported, concluding that there is a positive relationship between the variables. Finally, Tsai et al. (2015) evaluated the efficiency of 20 international urban railway systems in Asia, Australia, Europe and North America, concluding that the results obtained through the DEA over the analyzed period, identify efficiency performance trends and suggest potential strategies to improve the operations of urban rail systems.

Applying the analysis, the measurement of efficiency through DEA in the transport area is also identified with other biases and variables such as in Falcão, Camioto, Silva and Camargo's study (2019), which aimed to compare the efficiency of transport in Brazil with that of other BRICS countries, G8 and South America, considering as variables the Gross Domestic Product (GDP), the human development level (HDI), the population, the mileage of roads, railways and aerodromes. The results of the study show that Brazil has the lowest level of relative efficiency compared to the G8 and South American countries, in addition to a median efficiency in the BRICS group.

3 Research Methodology

This research is documentary one, as it has as reference data obtained through documents made available by metro-railroad companies and agencies linked to transport. The main sources of information were the financial statements and management reports published on the companies' websites and the reports available on the website of Associação Nacional de Transportes Públicos (ANTP).

In addition to it, information was requested through the public information channel of metro-railroad companies. The analysis period was from 2014 to 2018, because the last report published by ANTP until the end of this work is based on the year 2018 and the adopted methodology is based on the year of 2014.

3.1 Population and sampling

The population of this study comprised medium and large metro-rail companies that represent 98% of passengers transported in Brazilian metro-rail system, in a total of 11 companies. For the composition of the final sample, CBTU Recife, CCR Bahia and Via Mobilidade were excluded.

CBTU Recife operates in a mixed way using Trains and VLTs, and therefore the operational data are not comparable with other systems. CCR started operating its activities on an experimental basis in 2014 and had its operation effectively consolidated only in 2018, thus having a large variation in costs and revenues in the period under analysis. Via Mobilidade started to operate a stretch of Metrô SP through concession only in August 2018.

Thus, information was collected from eight subway companies representing 90% of passengers transported in the Brazilian system, in the period 2014 to 2018, and are identified in Table 2.

Table 2
Brazilian subway companies analyzed

ABRREVIATION	COMPANY
Metrô SP	Companhia do Metropolitano de São Paulo
CPTM	Companhia Paulista de Trens Metropolitanos
VIAQUATRO	Concessionária da Linha 4 do Metrô de São Paulo S.A.
Metrô RIO	Concessão Metroviária do Rio de Janeiro S.A.
SUPERVIA	SuperVia Concessionária de Transporte Ferroviário S.A.
CBTU BH	Companhia Brasileira de Trens Urbanos
TRENSURB	Empresa de Trens Urbanos de Porto Alegre
Metrô DF	Companhia do Metropolitano do Distrito Federal

Source: Survey data.

Each company was analyzed individually by year, that is, a DMU in this case is company ***i***, in year ***t***.

3.2 Research variables

Transport system variables have three main measures for output production: labor, fuel and capital (Tsai et al., 2015; Karlaftis, 2004). Therefore, considering the main variables identified in the previous studies referenced by Cavaignac and Petiot (2017), the main qualitative components of the costs of metro-rail transport services were used as input variables for this study: the number of employees, representing the work force, the consumption of electricity, representing the fuel and, finally, the length of the road, the number of stations and the number of cars, representing the capital.

The inclusion of the station number in the composition of the variables is in line with the findings of Tsai's study et al. (2015) which indicate that the number of stations significantly influences technical efficiency. As a financial input variable, the cost of services provided was used, which is the cost directly linked to the transport operation and is linked to the main technical variables of the metro-railway system. Operating revenue was not used as a financial variable, as it is strongly influenced by external factors, such as public policies linked to urban mobility and which directly impact the level of cost coverage by fare revenue.

As a product variable, the main operational results of the metro-rail system were used, namely: number of passengers transported and kilometers traveled by trains. In Table 3, all research variables are identified.

Table 3
Survey variables

	Variable Type	Variable	Description
INPUTS	Financial	Custo dos serviços prestados (CSP)	Total costs of services provided, in thousands of Reais (R$).
	Technical	Carros (CAR)	Total number of operational cars.
		Extensão/Estação (EXES)	Route length in kilometers, in relation to the number of stations.
		Consumo de Energia Elétrica (CEE)	Amount of Electric Energy consumed by trains in GWh.
		Empregados (EMP)	Total number of employees.
PRODUCT	Technical	Passageiros/Km (PASK)	Total passengers transported in millions, in relation to kilometers traveled in millions.
		Carro.Km (CARK)	Total kilometers traveled in millions, by the number of cars per train.

Source: *Survey data.*

Once the variables were defined, through the production function and using the Frontier Analyst 4.4 software, the efficiency levels of medium and large Brazilian metro-railroad companies were calculated. First, efficiencies were calculated considering the technical variables and, advancing the analysis, the financial variable was included. The results allow us to observe companies that are working efficiently and also those that are not at this level. Furthermore, they indicate the necessary adjustments to the units that were not characterized as efficient.

3.3 DEA model used in the analysis

The analysis was of technical efficiency based on DEA of variable returns, considering that the model with constant returns presented a smaller distribution of efficiency indices. Still, when estimating by variable returns, it is possible to verify if there are units with returns to scale, which was verified. With regard to the orientation of efficiency, it was through the input, that is, the minimization of the input. Mathematically, then, the efficient DMUs were obtained by:

$$Min\ \theta x_{i0} - \sum_{k=1}^{n} \lambda_k x_{ik} \geq 0\ \forall\ i \qquad i = 1,2,..., r \qquad (1)$$

$$\sum_{k=1}^{n} \lambda_k y_{mk} - y_{m0} \geq 0\ \forall\ m \qquad m = 1,2,..., s \qquad (2)$$

$$\lambda_k \geq 0\ \forall\ k \qquad k = 1,2,..., n$$

Where, y is the product, x the inputs, λ = weights, Ef0 and θ: efficiency based on the weights μj, vi of the m outputs and i inputs respectively and λk the kth coordinate of the DMU based on a reference DMU.

Efficiency levels range from 0.00 to 1.00 (0% to 100%) and the DMU is considered efficient when the indicator is 100%. Thus, the lower the efficiency level, the more inefficient DMU will be. The identification of efficiency ratings provides parameters for inefficient units to seek improvements to achieve efficiency based on comparison with efficient DMUs. (Sheffer, Monteiro, Cardoso, & Ritta, 2021).

The application of DEA was performed through Window Analysis, considering the existence of 8 DMUs and 6 technical variables. Such application is based on the study by Charnes, Clark, Cooper and Golany (1984). For the authors, the application of DEA through Window Analysis is suitable when one intends to introduce more degrees of freedom, in addition to facilitating the verification and interpretation of results.

For this purpose, a set of three years was established as a window and, therefore, the first window includes the first three years of the analysis: 2014, 2015 and 2016. The window moves over a period of one year, eliminating the first year and adding a new one, so the second window is formed by the years 2015, 2016, 2017. Finally, the third window includes the years 2016, 2017 and 2018. In Window Analysis, the same DMU that is in a different time period, is considered as another decision unit, thus, 8 DMUS were evaluated in the study, in 3-year windows, where each analysis window totaled 24 DMUs.

4 Presentation and Result Analysis

The Brazilian metro-railway transport comprises 15 operators and 21 systems, operated in four types of systems: Metro, Urban Trains, Monorails and VLTs, classified as small, medium and large, based on the number of passengers transported/year. The medium and large systems operate by subways and urban trains and are responsible for 98% of passengers transported in the metro-railway system. (Associação Nacional de Transportes Públicos [ANTP], 2020). In Table 4, these systems are identified, six operated by public companies and five by private companies under the concession regime.

Table 4
Medium and Large Brazilian Metro Rail System

Operator	City	Operation	Range	Extension (Km)	Transported passengers (millions)
Metrô SP	São Paulo	Public - State	Large	64,7	1.092,0
CPTM	São Paulo	Public - State	Large	270,4	863,3
Via Quatro	São Paulo	Private Concession	Large	12,8	217,0
Via Mobilidade	São Paulo	Private Concession	Large	20,1	38,9
Metrô Rio	Rio de Janeiro	Private Concession	Large	58,0	242,4
Super Via	Rio de Janeiro	Private Concession	Large	270,0	163,0
CBTU	Recife	Public - Federal	Medium	71,4	102,1
CBTU	B. Horizonte	Public - Federal	Medium	28,1	58,4
Trensurb	Porto Alegre	Public - Federal	Medium	43,8	51,8
Metro DF	Brasília	Public - State	Medium	42,4	42,8
CCR	Salvador	Private Concession	Medium	33,4	92,7

Source: *Survey data (2018).*

The rail transport system in 2018 transported 10.9 million passengers per day, has a length of 1,105 km, with 48 lines, 613 stations, 5,444 operational passenger cars and 41 thousand employees. The use of this transport is primarily for work, which is the reason for 70% of trips. (ANPTrilhos, 2019). The metro-railway transport system comprises transport services and support processes.

The transport service is divided into primary and secondary. The primary one constitutes the operating system and is directly related to the transport user, with ticket operations, operational security, train operations and traffic control. Secondary services involve human resources, materials, equipment and facilities to maintain the operating system. Services characterized as support, represent expenses with general administration and involve planning, financial administration, human resources, information technology, among others. (Pezerico, 2002).

Thus, the operational cost of the metro-railway transport companies is made by the transport services, which make up the cost of the services provided, and by the support services, which make up the general and administrative expenses. The costs of services are local to the cost directly linked to the company's main activity and for subway and rail transport, it is composed of costs with personnel, electricity, materials, third-party services, depreciation and amortization. Personnel costs for maintenance and operation employees and the cost of electricity for moving trains are considered the main inputs of the metro-railway transport system. (Ferreira, Brum, & Schreinert, 2019).

The representativeness of the costs of services provided and general and administrative expenses in the composition of the operating cost of the companies in the sample, for the year 2018, is shown in Figure 2.

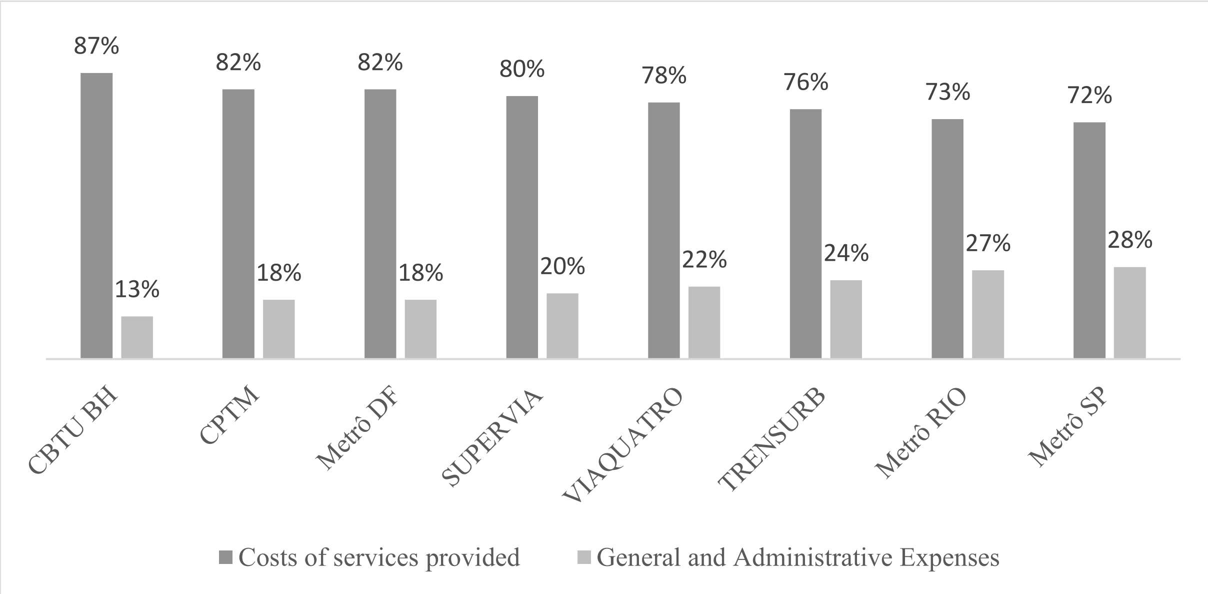

Figure 2 Representativeness of services provided cost
Source: *Survey data (2018).*

In Figure 2, it is identified that Metrô SP has the lowest representation of costs directly linked to the operation in relation to the total operating cost, which is the system that has the largest number of passengers transported. CPTM, on the other hand, which has the second largest number of passengers transported, but four times the size of Metrô SP, represents more than 80% of these costs, in line with the level of medium-sized companies. As for CBTU, which has the lowest rate of general administrative expenses, it is worth noting that it has the administrative management of the systems that it operates centrally, a fact that may have a direct impact on the level of administrative expenses calculated.

As for the revenues to fund the metro-railway transport system, these come from two main sources: own resources and government resources. Fare revenues are the main source of own resources and originate from the charged fare to transport users and represent, on average, 95% of own revenue. Non-fare revenues represent a small portion of own resources and have as their main source the exploitation of commercial and advertising spaces.

Government resources are transferred to transport operators of a subsidy or reimbursement, the latter linked to benefits granted by public policy, such as subsidy for the elderly and students. In Figure 3, the representativeness of the main resources that finance the cost of metro-railway companies can be identified.

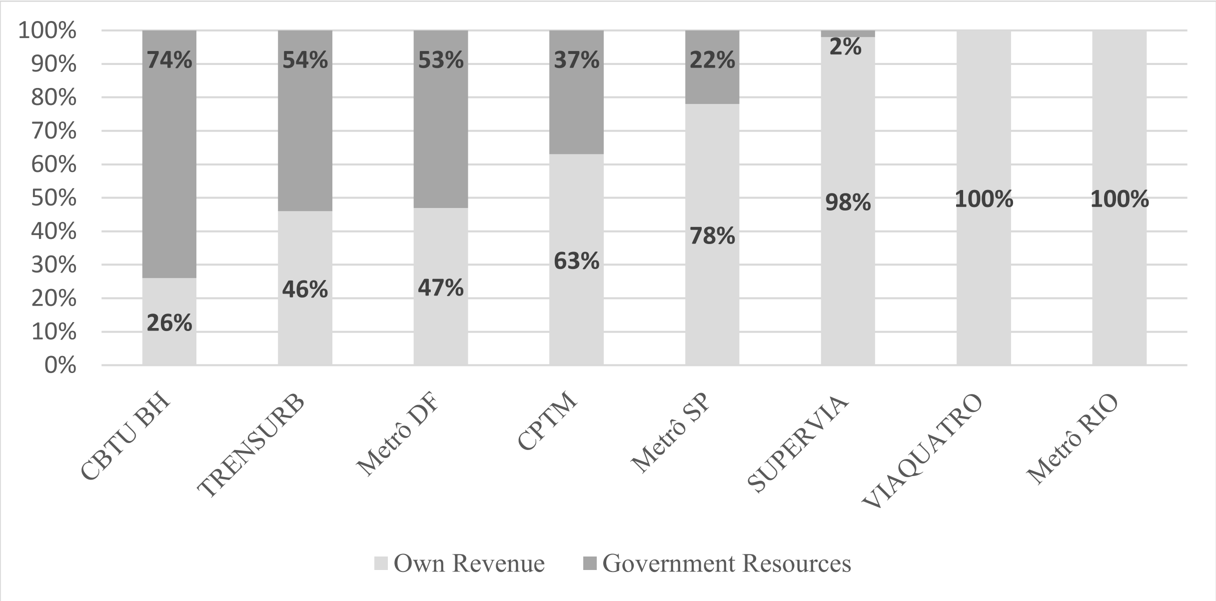

Figura 3 *Sources of funds to operations*
Source: *Survey data (2018).*

Figure 4 identifies the level of coverage of cost of services and operating cost through fare revenue, which ranges from 27% to 201% for the cost of services provided and from 31% to 259% for the operating cost.

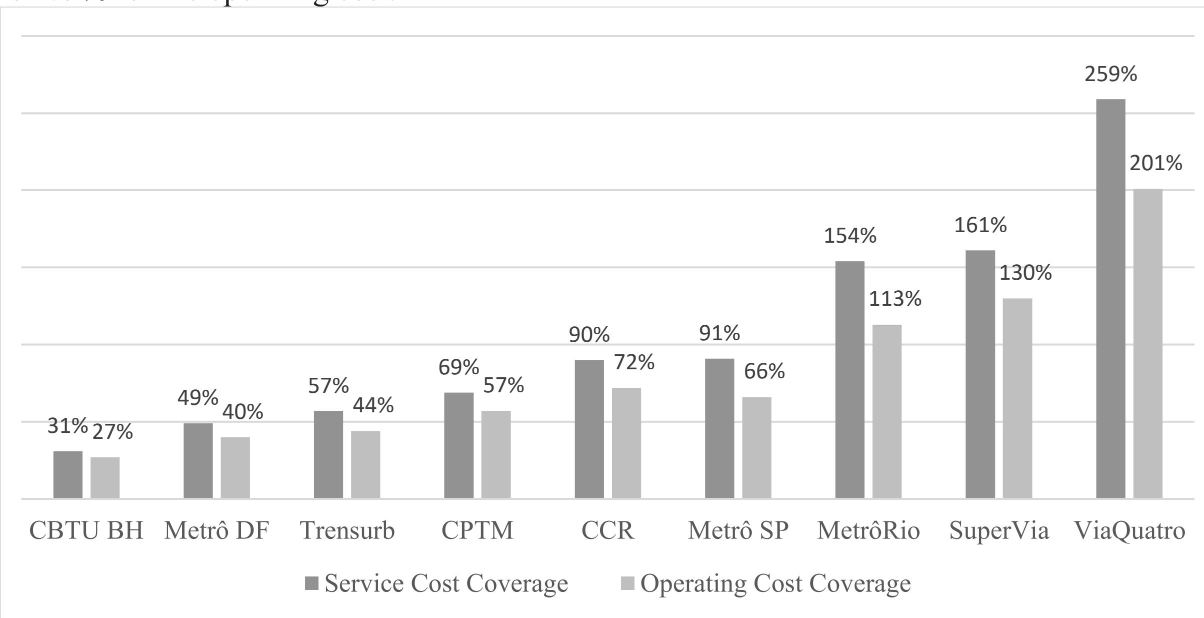

Figure 4 *Cost coverage level by fare revenue*
Source: *Survey data (2018).*

The information presented in Figure 4 shows that large companies have the highest level of coverage of their costs by fare revenues, and that private companies are ahead the others. As shown in Table 4, there are significant variations in the length and number of passengers transported by metro-railroad companies, with large systems being concentrated in systems operated in São Paulo and Rio Janeiro. So, it is worth mentioning the provisions of Tsai et al.

(2015), that the similarities in the production process of urban rail systems, allows the assessment of their efficiency even if they operate at different levels.

4.1 Analysis of subway companies efficiency

Table 5 presents the summary of the research variables values, using descriptive statistics.

Table 5
Descriptive statistics of research variables

REFERENCES	CAR	EXES	CEE	EMP	PASK	CARK	CSP
Medium	513,6	1,8	195,7	3.422,5	35,7	59,4	752,2
Medium	235,0	1,6	146,7	2.017,0	27,9	26,3	358,7
Maximum	1.632,0	2,9	506,1	9.612,0	98,8	211,7	2.273,4
Minimum	84,0	1,1	36,4	924,0	10,1	10,2	129,5
Standard Deviation	488,4	0,6	165,4	3.221,8	25,6	62,5	802,0
N° of Observations	40	40	40	40	40	40	40

Source: *Survey data.*

Regarding the maximum values, the company CPTM stands out, which has maximum values for the variables, CAR, EXES, CEE, CARK and CSP. CPTM company has the largest length of track and the second largest number of passengers transported in Brazilian metro-railway system. The highest rate of passengers per kilometer (PASKM), is identified in VIAQUATRO, which transports the fourth largest number of passengers in the system, however, it has the smallest extension among all the companies in the analysis. As for the minimum values, VIAQUATRO stands out, which has the lowest values for the variables CEE, EMP and CSP.

Using the technical variables, the efficiency indices per window were calculated, and these are presented in a consolidated manner in Figure 5, considering the average efficiency calculated by company in the established time windows.

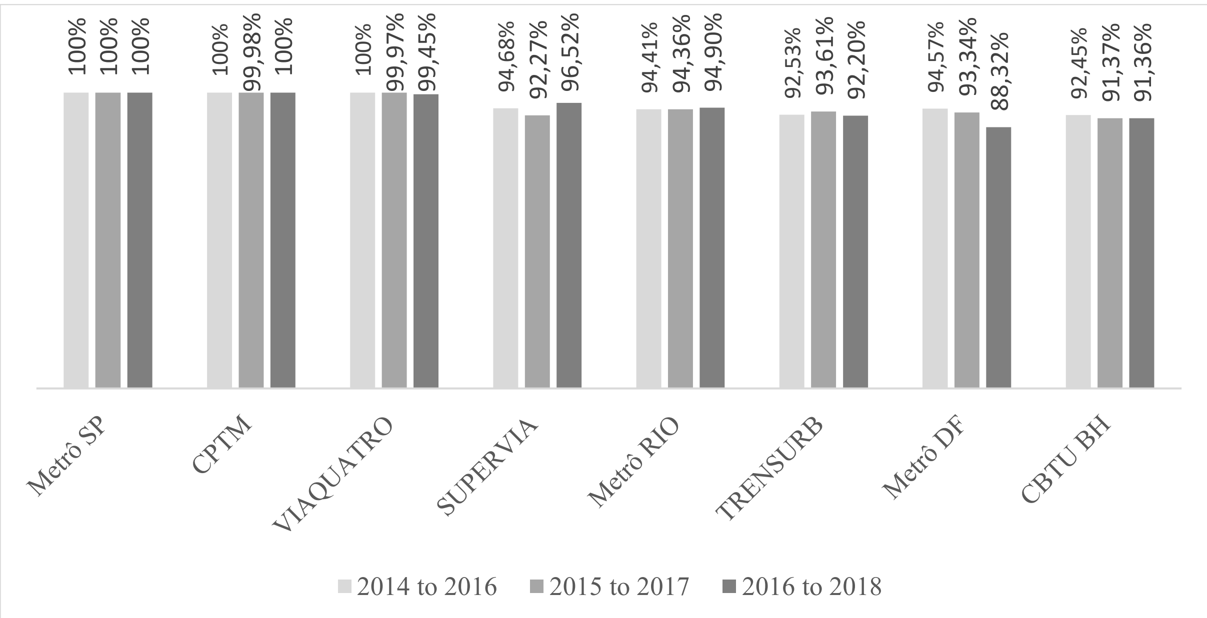

Figure 5: *Average efficiency of metro-railroad companies per window*

Source: *Survey data.*

In Figure 5, the 100% leveles represent efficient companies, those that are on the efficiency frontier. Lower levels than 100% represent inefficient companies, and the average of these range from 88.32% to 99.98% for the analyzed period.

Metrô SP was the only company that maintained an average efficiency of 100% in all analysis windows. CPTM and VIAQUATRO have an average efficiency above 99%. Based on these data, companies operating in São Paulo metro-rail system and representing 73% of passengers transported in Brazilian system, have the highest levels of efficiency, which identifies less need to adjust their inputs and products.

Detailing the efficiency levels, Table 6 shows the efficiency ratios by window, where the efficiency result of the 2014 to 2016 window is represented in the first line of each company, in the second line of the 2015 to 2017 window and in the third line of the 2016 to 2018 window.

Table 6

Efficiency levels of metro-railroad companies per window

COMPANY	2014 (%)	2015 (%)	2016 (%)	2017 (%)	2018 (%)
Metrô SP	100	100	100		
		100	100	100	
			100	100	100
CPTM	100	100	100		
		100	99,94	100	
			100	100	100
VIAQUATRO	100	100	100		
		100	100	99,91	
			100	98,36	100
Metrô RIO	100	86,03	97,21		
		85,73	97,36	100	
			90,82	93,87	100
SUPERVIA	88,08	96,50	100		
		87,74	90,60	100	
			89,55	100	100
CBTU BH	93,81	85,96	97,59		
		85,96	97,59	90,55	
			97,59	90,55	85,94
TRENSURB	85,79	95,75	96,04		
		94,96	95,17	90,70	
			95,17	90,70	90,74
Metrô DF	94,94	95,99	92,79		
		94,87	92,58	92,58	
			92,58	92,58	79,80

Source: *Survey data.*

Through Table 6, it is possible to verify that only the companies classified as Large ones (Metrô SP, CPTM, VIAQUATRO, Metrô RIO and SUPERVIA) present an efficiency rate of 100% at least in one year of the analysis windows concentrated in companies that operate in São Paulo metro-rail system and that present indices ranging from 98.36% to 100%. VIAQUATRO concentrates the inefficiency level in 2017, with its recurrence in the second and third analysis window. Deepening the analysis, it was found that the inefficiency level is impacted by the increase in the number of cars in 2017, but the increase in the number of stations and extension is only identified in 2018, in which the company is again considered efficient .

SUPERVIA and Metrô Rio, which operate in Rio de Janeiro subway system, the second largest subway system in Brazil, have efficiency levels ranging from 85.73% to 100%. SUPERVIA company reached 100% efficiency level as of 2016, and analyzing its input variables from 2014 to 2018, a reduction in electricity consumption and in the number of employees is identified, factors that contribute to this reaching efficiency of 100%.

In Metrô Rio company, an efficiency level of 100% is identified in 2014 and this level is only reached again in 2017. Analyzing its input data, it appears that, from 2015 onwards, there was an increase in the extension, in the number of cars and electricity consumption, however, it was only in 2017 that there was an increase in the number of passengers transported.

For medium-sized companies (CBTU BH, TRENSURB and Metrô DF) there was not 100% efficiency in any of the years analyzed and efficiency rates ranged from 79.8% to 97.59%. This situation reveals the need for improvements to be carried out by these companies.

When the analysis of potential improvements linked to inputs is fragmented, the need is identified for a reduction of around 19% in these, with production maintained, so that these companies can operate efficiently. Individualizing the variables, as it can be seen in Table 7 there is no linearity in the percentage of improvements. In CBTU company, the greatest need for reduction is identified in the variable CAR, in Metrô DF, in the variable CEE and in TRENSURB in the variable EXES.

Table 7
Average of potential improvements per variable

COMPANY	AVERAGE TECHNICAL EFFICIENCY	AVERAGE REDUCTION OF INPUTS	REDUCTION OF INPUTS BY VARIABLE			
			CAR	EXES	CEE	EMP
CBTU BH	91,72%	-19,15%	-35,00%	-14,0%	-8,60%	-18,93%
Metrô DF	92,08%	-20,75%	-15,61%	-26,16%	-33,30%	-7,92%
TRENSURB	92,78%	-17,17%	-13,09%	-31,34%	-17,01%	-7,22%

Source: *Survey data.*

Advancing the analysis of the variables that most contribute to the efficiency indices found in Brazilian metro-railroad companies, considering the input variables, the variables of the length of the road per station (EXES) and the number of employees (EMP), are the most present variables in the composition of the indexes, with frequencies of 34 and 47 respectively, in the set of 72 efficiency assessments (3 windows for 24 DMUs).

When analyzing which companies contribute as a benchmark to achieve the calculated efficiency levels, it appears that VIAQUATRO makes up the reference in 75% of DMUs, being present in the composition of the level of all medium-sized companies. About this information, it is important to highlight VIAQUATRO operates through a private concession on a stretch linked to Metrô SP, which concentrates the largest number of passengers transported in the Brazilian metro-railway system.

Seeking to identify the cost effect of the technical variables used to calculate the efficiency index of metro-railroad companies, the variable cost of services provided (CSP) was inserted, which represents the cost directly linked to the provision of metro-rail transport services, qualitatively represented by the variables input techniques analyzed.

In Figure 6, the distribution of the efficiency levels of the DMUs before and after the inclusion of the financial variables is presented, in a comparative way, considering the total of three windows, with 24 DMUs each.

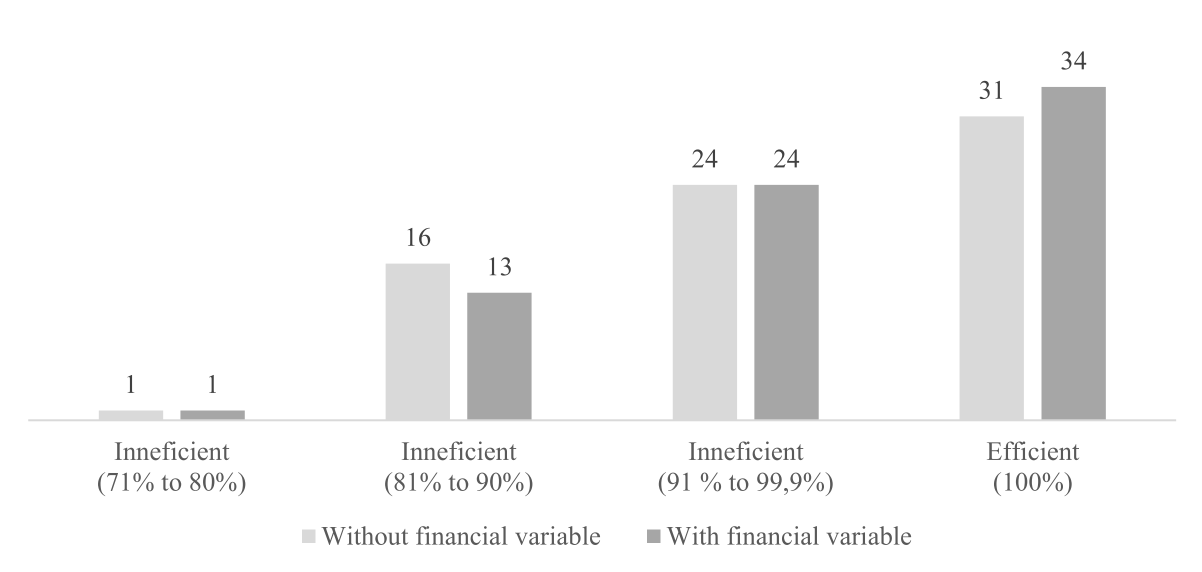

Figure 6: *Distribution of the financial efficiency level with and without financial variable*
Source: *Survey data.*

When comparing the distribution of the efficiency results presented, companies classified as large ones remain efficient. Throughout the analysis period, the companies Metrô SP, CPTM, CBTU BH, TRENSURB and Metrô DF maintained the efficiency ratios previously calculated. Metrô Rio had a small change in two levels, but remained in the same efficiency range. SUPERVIA company had an improvement in three of the five years analyzed, starting to present a maximum efficiency index (100%) for the years 2014 and 2015 in the first analysis window and improving the indexes for the years 2015 and 2016, in the second and third windows, with efficiencies above 94%. VIAQUATRO, had changed the index of the second window for the year 2017, from 99.91% to 100%.

As for the returns to scale, from the 72 efficiency references that make up the three analysis windows with 24 DMUs each, 70% presented increasing returns. All companies that presented decreasing returns during the period of analysis are companies belonging to the large category and, among these, CPTM stands out, which has decreasing returns to scale for 67% of the calculated efficiency indices. All medium-sized companies have increasing returns to scale, as well as most large companies, thus, increasing returns to scale prevail in Brazilian metro-rail transport, which suggests that companies are operating below their productive capacity.

In this scenario, the fact that all medium-sized companies, with increasing returns to scale, are public companies and have high levels of financing through government resources, which are outside São Paulo/Rio de Janeiro area, stands out, which concentrates 87% of passengers transported in the metro-railway transport system. On the other hand, the public companies, CPTM and Metrô SP, have the best technical efficiency indices, and operate with a high volume of transported passengers.

5 Conclusions

Analyzing the efficiency of metro-railway transport gains relevance, as unsatisfactory performance transfers the cost of inefficiency to transport users, or to the government, affecting both the population's access to the transport system, as well as public budgets, already highly compromised. Therefore, this study analyzed the technical efficiency of Brazilian subway companies through Data Envelopment Analysis (DEA), covering eight companies, which account for 90% of passengers transported in Brazilian subway system, from 2014 to 2018. DEA analysis was carried out with support in Window Analysis, oriented to inputs, considering the variable returns model.

The survey results reveal that only companies classified as large are technically efficient and among these only Metrô SP remained efficient in all the years analyzed, being responsible for transporting the largest number of passengers in the metro-railway system. Medium-sized companies were inefficient in all years of the sample, and the need for an average reduction of 19% in inputs was identified for them to become technically efficient. The inclusion of a financial variable as an input did not show any significant impact on the technical efficiencies found.

As a transport system is considered inefficient, discussions on public policies aimed at urban transport, in particular, on financing models for this gain relevance. By identifying that all inefficient companies are classified as medium-sized, and these are public companies with high levels of financing their costs through government resources, the study serves as a reference to expand research on the subject, given the relevance of its identify the effect of costing transport operations through government resources on the efficiency of companies.

Therefore, by identifying that increasing returns to scale prevail in the Brazilian metro-railway transport system, this study contributes to the analysis of public policies linked to the population's access to this transport, since increasing returns to scale suggest that the increase in production, which has as its main variable the number of passengers transported, can generate benefits in terms of the efficiency of companies.

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