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Pacheco, Regina Cláudia Soares do Rêgo; Boente,
Diego Rodrigues; Bezerra, Francisco Antônio

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Depreciação e manutenção de equipamentos de alta complexidade e o impacto na
eficiência dos hospitais universitários federais
Depreciación y mantenimiento de equipos de alta complejidad y el impacto en la eficiencia de los hospitales universitarios federales

Regina Cláudia Soares do Rêgo Pacheco
Universidade Federal do Piauí, Brasil
reginaregopacheco@gmail.com
Diego Rodrigues Boente
Fucape Business School, Brasil
diegoboente@gmail.com
Francisco Antônio Bezerra
Evolvi, Brasil
francisco@evolvi.com.br

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Abstract

Objective: This article discusses the relationship between the depreciation and maintenance costs of Medical-Hospital Equipment (MHE) and the efficiency of services provided by Federal University Hospitals (FUHs).
Theoretical framework: Efficient asset management is seen as a critical factor in optimizing the performance and financial sustainability of FUHs.
Methodology: Data Envelopment Analysis (DEA) was used to evaluate the input/output efficiency of the FUHs, and regression analysis was conducted to assess the relationship between maintenance and depreciation costs of MHE and the efficiency of FUHs.
Results: It was found that more than 50% of the Decision-Making Units (DMUs) of FUHs showed efficiency levels above 50% during the observed period. Regarding the relationship between efficiency and costs, it was observed that depreciation costs had a positive and statistically significant correlation with the efficiency of FUHs, while maintenance costs did not show a statistically significant relationship. These findings underscore the need for investment policies in the infrastructure of university hospitals.
Originality: This research stands out by integrating depreciation and maintenance costs of MHE into the analysis of hospital efficiency. This approach provides a broader understanding of the financial and operational variables that impact the efficiency of FUHs, highlighting its relevance in the context of public sector accounting and healthcare resource management.
Theoretical and practical contributions: The contribution of this research lies in providing managers with insights into the variables that affect institutional efficiency and how to optimize results, helping hospitals to properly manage available resources and enhance the provision of services to society, thus fulfilling their social role.
Keywords: Costs; depreciation; maintenance; medical-hospital equipment; efficiency.

Resumo

Objetivo: Este artigo aborda a relação entre os custos de depreciação e manutenção dos Equipamentos Médico-Hospitalares (EMH) com a eficiência dos serviços prestados pelos Hospitais Universitários Federais (HUFs).
Enquadramento teórico: A gestão eficiente de ativos como um fator crítico para otimizar o desempenho e a sustentabilidade financeira dos HUFs.
Metodologia: Utilizou-se a Análise Envoltória de Dados (DEA), para avaliar a eficiência na relação *Inputs/Outputs* dos HUFs; e regressão para verificar a relação entre os gastos com Manutenção e Depreciação dos EMH e a Eficiência dos HUFs.
Resultados: Identificou-se que mais de 50% das Unidades Tomadoras de Decisão (DMU) dos HUFs apresentam eficiência acima de 50% no período observado. A respeito da relação entre a Eficiência e os Custos, encontrou-se que os custos com depreciação têm uma correlação positiva e estatisticamente significativa com a eficiência dos HUFs, enquanto os custos com manutenção

não apresentam relação estatisticamente significativa. Esses achados reforçam a necessidade de políticas de investimento em infraestrutura dos hospitais universitários.
Originalidade: A pesquisa se distingue por integrar os custos de depreciação e manutenção dos EMH na análise da eficiência hospitalar. Este enfoque permite uma compreensão mais ampla das variáveis financeiras e operacionais que impactam a eficiência dos HUFs, destacando-se no contexto da contabilidade aplicada ao setor público e gestão de recursos na saúde.
Contribuições teóricas e práticas: A contribuição desta pesquisa está nas informações que os gestores terão sobre as variáveis que afetam a eficiência das instituições e como otimizar os resultados, ajudando o hospital a administrar adequadamente os recursos disponíveis e a otimizar a oferta de serviços à sociedade, cumprindo, assim, seu papel social.
Palavras-chave: Custos; depreciação; manutenção; equipamentos médico-hospitalares; eficiência.

Resumen

Objetivo: Este artículo aborda la relación entre los costos de depreciación y mantenimiento de los Equipos Médico-Hospitalarios (EMH) con la eficiencia de los servicios prestados por los Hospitales Universitarios Federales (HUF).
Marco teórico: La gestión eficiente de activos como un factor crítico para optimizar el rendimiento y la sostenibilidad financiera de los HUFs.
Metodología: Se utilizaron Análisis Envolvente de Datos (DEA), para evaluar la eficiencia en la relación Insumos/Productos de los HUFs; regresión para verificar la relación entre los gastos de Mantenimiento y Depreciación de los EMH y la Eficiencia de los HUFs.
Resultados: Se identificó que más del 50% de las Unidades Tomadoras de Decisiones (DMU) de los Hospitales Universitarios Federales (HUF) presentan una eficiencia superior al 50% en el período observado. En cuanto a la relación entre la Eficiencia y los Costos, se encontró que los costos de depreciación tienen una correlación positiva y estadísticamente significativa con la eficiencia de los HUFs, mientras que los costos de mantenimiento no muestran una relación estadísticamente significativa. Estos hallazgos refuerzan la necesidad de políticas de inversión en la infraestructura de los hospitales universitarios.
Originalidad: La investigación se distingue por integrar los costos de depreciación y mantenimiento de los EMH en el análisis de la eficiencia hospitalaria. Este enfoque permite una comprensión más amplia de las variables financieras y operativas que impactan la eficiencia de los HUFs, resaltando en el contexto de la contabilidad aplicada al sector público y la gestión de recursos en salud.
Contribuciones teóricas y prácticas: La contribución de esta investigación radica en la información que los gestores tendrán sobre las variables que afectan la eficiencia de las instituciones y cómo optimizar los resultados, ayudando al hospital a administrar adecuadamente los recursos disponibles y a optimizar la oferta de servicios a la sociedad, cumpliendo así su papel social.
Palabras clave: Costos; depreciación; mantenimiento; equipos médico-hospitalarios; eficiencia.

1 INTRODUCTION

Federal University Hospitals (FUHs) are healthcare institutions affiliated with Federal Universities. The FUH network consists of 51 hospitals linked to 36 federal universities. Of these, 41 hospitals are affiliated with and managed by the Brazilian Hospital Services Company (EBSERH, 2023).

In both public and private hospitals, medical-hospital equipment represents the most significant assets. Between 2019 and 2022, University Hospitals performed 70,972,008 (seventy million, nine hundred seventy-two thousand and eight) exams, according to DATASUS (2023). These exams were conducted using the equipment available in the hospitals, most of which are operated for two or even three shifts of eight hours, depending on the size of the hospital and the demand. As a result, the depreciation cost of this equipment needs to be recorded.

Regarding depreciation, since 2008, the Brazilian Public Sector Accounting Standards (NBC - TSP) have been implemented through a partnership between the Federal Accounting Council (CFC) and the National Treasury Secretariat (STN). Another outcome of this partnership was the creation of the Technical Group for the Standardization of Accounting Procedures (GTCON) in 2011, through Ordinance No. 109. In 2017, it was restructured by Ordinance No. 767 and renamed the Technical Chamber of Accounting Standards and Fiscal Reports of the Federation (CTCONF). One of CTCONF's responsibilities is to analyze and prepare diagnostics aimed at standardizing accounting procedures across all federal entities (Andrade & Suzart, 2019, p. 3).

In research conducted by Baldez et al. (2022) on the importance of using maintenance when there is a high demand for medical-hospital equipment for corrective maintenance in a University Hospital, which includes equipment with a high level of importance for its operation, the absence of such equipment directly impacts the interruption of procedures, and replacements cannot be made in a short period of time. The authors analyzed two periods: the first from October 2019 to February 2020, and the second from October 2020 to February 2021. Baldez et al. (2022) found that, in the first period, 72% of maintenance performed was corrective, and only 28% was preventive. In the second period, 52% of maintenance was preventive, and 48% was corrective. According to the researchers, this shift occurred due to the use of monitoring tools and the implementation of scheduled preventive maintenance based on the criticality level of the assets (Baldez et al., 2022).

Regarding hospital efficiency, the quality of service delivery is the primary source. Studies have compared two groups of hospitals: one managed by Social Health Organizations and the other by Direct Administration, aiming to assess the level of efficiency achieved by each group, as in the research by Tonelotto et al. (2019).

Garmatz et al. (2021) assessed the technical efficiency of teaching hospitals in Brazil using Data Envelopment Analysis (DEA), although they did not use regression. They found that the study demonstrated DEA's potential to become an important tool for evaluating services and supporting decision-making in healthcare. The research by Oliveira Barros et al. (2021) focused on the performance and capacity of the Spanish healthcare system during the pandemic, an article that also utilized DEA to evaluate the system's efficiency.

The cited studies, although they used DEA to analyze efficiency, have different objectives from this research, which incorporated depreciation and maintenance costs of Medical-Hospital Equipment, as well as variables such as the elderly population, the regions where the hospitals are located, and the number of deaths in a regression analysis.

This research aims to answer the following question: What is the impact of depreciation and maintenance costs of Medical-Hospital Equipment (MHE) on the efficiency of Federal University Hospitals? The econometric methodology indicated that only depreciation costs had an impact on efficiency.

Depreciation costs represent the economic consumption of an asset during its use, while the concern of Federal University Hospitals (FUHs) to keep this equipment fully operational will require investments in maintenance. The general objective of this research was to identify whether depreciation and maintenance costs of Medical-Hospital Equipment impacted the efficiency of FUHs between 2019 and 2022, the period during which data was available.

The data were collected from the EBSERH and DATASUS databases and analyzed using Data Envelopment Analysis (DEA) with variable returns to scale (BCC), referencing the physical and human resources used in the hospitals. Financial and healthcare-related variables were selected to compose the efficiency analysis, which will be detailed later in the study.

To answer the research question, a regression analysis was conducted, with the efficiency level as the dependent variable, while the explanatory variables were the depreciation and maintenance costs of Medical-Hospital Equipment (MHE).

The contribution of this research lies in its two-stage analysis. It provided insight into the evolution of hospital efficiency over four years and highlighted which factors are important for the efficiency of these hospitals. Efficiency is measured in terms of both inputs and outputs, allowing for a better understanding of the factors that determine efficiency.

This article is structured into four main sections, in addition to this introduction. Section 2 presents the theoretical framework, discussing aspects related to the depreciation and maintenance of medical-hospital equipment and their implications for hospital efficiency. Section 3 describes the research methodology, including the models used. Section 4 is dedicated to the analysis of the results obtained. Finally, Section 5 presents the final considerations, highlighting the practical implications of the study, its limitations, and suggestions for future research.

2 THEORETICAL FRAMEWORK

2.1 EFFICIENCY IN HOSPITAL MANAGEMENT

Hospitals have been recognized as the primary drivers of cost increases in healthcare systems due to the complexity of their processes and the intensive use of technology in their daily operations (Wolff, 2005). The services provided and the resources consumed by these hospitals are considered interconnected in the rising costs. Therefore, continuous analysis of operational performance and efficiency in resource allocation is necessary (Sediyama et al., 2012; Trivelato et al., 2015).

Efficiency is a measure that assesses the optimization of resources in relation to the outputs produced by the consumption of those resources. It is a relative performance measure, obtained by comparing it with other alternatives or the same alternative over a period of time (Ligarda & Naccha, 2006; Trivelato et al., 2015).

The control of production inputs and services is becoming increasingly necessary in the hospital sector. This is a time when inputs are becoming scarcer, and their prices are constantly rising. It is crucial that hospital organizations are managed with a focus on socioeconomic outcomes (La Forgia & Couttolenc, 2009).

Due to the growing pressure to improve their efficiency, hospitals are significant components of the healthcare sector, as they are considered the primary cost drivers for healthcare systems worldwide. Calculating hospital efficiency is not a simple task, as many variables are involved in this process. One of the tools used for this calculation is DEA, which stands out in the evaluation of the efficiency of healthcare service organizations (Kohl et al., 2019).

Efficiency can be technical, economic, or allocative, and can be measured in healthcare services when a Decision-Making Unit (DMU), such as a hospital, produces a certain level of outputs/inputs. Technical efficiency refers to the relationship between the potential obtained from a given technology and the actual service delivered, allowing for the measurement of efficiency by comparing firms against the “best practice" in production. Economic efficiency can be considered an extension of technical efficiency, involving both physical and monetary aspects, with production requiring maximum technical efficiency to be economically efficient. Allocative efficiency, on the other hand, refers to the manager's ability to choose, among efficient options, the one that brings the best economic outcomes (Peña, 2008, p. 3).

2.2 BRAZILIAN HEALTH SYSTEM

Hospitals can be classified, according to the National Registry of Healthcare Establishments (CNES), by size as follows: small (up to 50 beds), medium (51 to 150 beds), large (151 to 500 beds), and special size (over 500 beds). Other classifications can also be considered, such as financial objectives. Hospitals may be classified as for-profit, when they are private institutions aimed at generating profit; non-profit, when their administrators do not receive compensation or benefits, and they do not aim for profit, but if any is generated, it is reinvested in projects, maintenance, and development; or philanthropic, which refers to private entities that do not aim for profit and allocate or distribute part of their income to provide free services (CNES, 2022).

The current economic reality in Brazil, with either reduced or maintained funding for healthcare, combined with the growing demand for public health services, pandemics, and endemic diseases, makes it difficult for public administrators serving SUS (Sistema Único de Saúde, or Unified Health System) users to consider increasing expenditures in this sector. The available resources must be planned with the scarcity of inputs and the needs of the population in mind (Garmatz et al., 2021).

2.2.1 Federal University Hospitals (FUHs)

The central administration, the headquarters of EBSERH, and the 41 hospital units that make up the EBSERH Network currently have the purpose of "teaching to transform care," carrying out activities of great relevance to society, which align with the public interest (EBSERH, 2022).

EBSERH is a state-dependent company, created by Law No. 12,550 on December 15, 2011, linked to the Ministry of Education (MEC), with its entire capital owned by the Union. It is responsible for managing Federal University Hospitals (FUHs), providing technical support for the development of tools to improve management, allocating resources for development and expansion, and promoting the adoption of best practices in service delivery and hospital management.

In 2012, EBSERH began its activities with the University Hospital of Piauí, with an expansion project aimed at providing healthcare services and conducting teaching, research, extension, and technological innovation activities. The adhesion of other Federal University Hospitals (FUHs) to EBSERH occurred gradually, and the evolution of services offered, focusing on goals and outcomes to be achieved, were key components in the management contracts signed between the Federal Universities and the Brazilian Hospital Services Company. The decision to contract EBSERH rests with each university, within the scope of its autonomy.

In 2018, EBSERH began the strategic planning process in its affiliated hospitals, continuing in 2020 with the monitoring of action plans every four months. All these plans were set to remain in effect until 2023 and, according to the managers, are better aligned with the Network's strategy. They use a management model based on results to be achieved by the Federal University Hospitals (FUHs), which initiated the pursuit of greater efficiency in managing these hospitals, along with the knowledge and analysis of efficiency based on established parameters and conducted research (EBSERH, 2022).

In 2020, based on data from the CNES and DATASUS, Federal University Hospitals had approximately 9.1 thousand beds, conducted 3.7 million consultations, 10.4 million exams, 278 thousand hospital admissions, and 153 thousand surgeries.

2.2.2 Costs of maintenance and depreciation of medical-hospital equipment (MHE)

The development of new healthcare technologies and the resulting expansion of services to the population bring about a demand for new sources of information for public health managers to determine the best possible allocation of budgetary and extra-budgetary resources, as well as the levels of efficiency, reliability, and continuity of services provided. This requires consideration of the expenses inherent to the execution of these services, such as costs related to the use of medical-hospital equipment (Stopatto, 2022).

The most evident costs are those related to the depreciation of assets in use within the institutions and the maintenance of these assets. Depreciation is a risk factor for the economic viability of the asset. If, at the beginning of its useful life, depreciation and maintenance costs are underestimated, there will be unrecoverable amounts by the end of the economic life, which will result in losses, even if the equipment is not yet fully worn out physically (Schultz et al., 2008, p. 14).

Hemodynamic devices, for example, are considered high-technology, high-cost, and high-complexity equipment by the Unified Health System (SUS) because they are used in exams and procedures deemed complex by the medical field. Typically, these assets receive special treatment to anticipate risks and prevent or reduce investment losses before failures occur. Avoiding losses from an investment subject to obsolescence involves anticipating its costs or compensating for them during the early phase of its productive life. This can be achieved through accelerated depreciation or even by establishing a special provision (Schultz et al., 2008, p. 15).

Depreciation in a hospital environment is a critical issue that can significantly affect the services provided by a hospital. Depreciation is the gradual loss of value of a fixed asset over time, occurring due to wear and tear from use. This concept is closely related to the accrual accounting principle, which aims to match revenues and the costs incurred to generate them within the same period, as outlined by the Accounting Pronouncements Committee, CPC 00 – Conceptual Framework (CPC, 2019). However, depreciation is inherently an estimate based on three factors: the asset's initial cost, its estimated useful life, and its estimated residual value. These factors are influenced by subjective judgments and forecasts about the asset's future economic use, which introduces a degree of uncertainty in the accuracy of the values reported in financial statements.

On the other hand, maintenance costs are treated differently in accounting. They are recorded as expenses in the period in which they are incurred, according to CPC 27 – Property, Plant, and Equipment (CPC, 2009). This difference highlights the variable and immediate nature of maintenance costs, in contrast to the estimated and systematic nature of depreciation.

The usefulness of these assets over time may change due to factors such as excessive use, time, and lack of proper maintenance. Hospitals must regularly monitor the depreciation of their assets to ensure they can plan for future investments and acquisitions, as well as avoid unpleasant financial surprises in the future.

Although staff members monitor the condition of assets within the institution, the lack of proper depreciation accounting impacts the services provided to the community. It was also demonstrated that calculating asset depreciation is a tool that can assist management in planning the future replacement of assets, as these will become obsolete over time (Silva et al., 2021, pp. 11-29).

In general, it is important for hospitals to adopt good asset management practices and sound financial management to ensure that resources are available for the renewal and acquisition of new assets when necessary. Hospital efficiency is closely related to the equipment used in providing services to patients. These pieces of equipment are subject to depreciation, which is a factor to be analyzed to improve hospital service efficiency. Therefore, an effective analysis of depreciation and equipment replacement is a factor that can impact the efficiency of hospital services (Schultz et al., 2008). Based on the above and considering the nature of depreciation and maintenance costs, the following hypotheses were formulated for testing:

H1: The depreciation cost of high-complexity medical equipment impacts the efficiency of Federal University Hospitals.

H2: The maintenance cost of high-complexity medical equipment impacts the efficiency of Federal University Hospitals.

3 METHODOLOGY

3.1 SAMPLE, DATA COLLECTION, AND DATA PROCESSING

This research is quantitative in nature, utilizing Data Envelopment Analysis (DEA) with variable returns to scale (BCC).

The Federal University Hospitals (FUHs) constitute the research setting. Of the 41 FUHs, 34 are included in the dataset due to data availability, with annual observations from 2019 to 2022, totaling 136 observations. Data collection for the research was conducted through official websites that provide hospital-related indicators and results (CNES, DATASUS, EBSERH, Financial Reports, and Assistance Reports, as well as the websites of the hospitals focused on in the research) and that publish information about medical-hospital equipment.

For the analysis and discussion of the results, descriptive statistics of the variables, Pearson correlation, and model outcomes were used. The models are described in the following subsection.

3.2 ANALYSIS MODELS

3.2.1 Data Envelopment Analysis (DEA)

The variable returns to scale (VRS) model forms a convex efficient frontier with the best-performing units, regardless of their scale of operation, thereby "enveloping" inefficient units at each level of production (Belloni, 2000, pp. 68-69).

The BCC model operates with a convex efficiency frontier and considers units with low input consumption as operating under increasing returns to scale. This model assumes that maximum efficiency varies based on economies of scale and allows for the comparison of units of different sizes, which is important for the evaluation conducted in this study (Belloni, 2000, pp. 68-70).

According to Lins et al. (2007), DEA has been used to analyze the performance of DMUs that utilize the same types of inputs to produce the same goods and/or services (outputs). A DMU is a Decision-Making Unit, and DMUs can be of any nature—companies, countries, schools, ports, stores, etc.—but they must be part of the same production process.

Afonso et al. (2010) define that the results obtained from the model range between 0 and 1, where "0" indicates that the DMU is inefficient, and "1" means that the DMU is efficient in comparison to other DMUs tested in the model. Gavurova et al. (2021) conducted a study showing that it is beneficial for health policymakers to evaluate and compare healthcare systems across countries, develop national and regional health strategic plans, and support the development of international benchmarks in this area. To achieve the general objective, Data Envelopment Analysis (DEA) with variable returns was used, employing both inputs and outputs. This DEA enables the analysis of relative efficiency between hospitals within the same yeari. This analysis assumes that the decision-making units (DMUs), in this case the FUHs, transform inputs into outputs. The combination of these inputs and outputs can have constant or variable returns. For this study, it was assumed that the inputs and outputs have variable returns. The analysis focused on the output.

In the category of inputs/outputs, the inputs and outputs are shown in Figure 1, which references authors who have previously used the same variables in their research, albeit with a different focus than this study. After determining the efficiency scores of the Federal University Hospitals, a regression analysis was applied to demonstrate which variables affect efficiency and which do not. The efficiency level was used as the dependent variable, while the depreciation and maintenance costs of medical-hospital equipment were considered independent variables. As control variables, the number of deaths, the elderly population in the area where each university hospital is located, and the regions where the hospitals are located were included.

Figura 1: Inputs and outputs in the University Hospitals (FUHs)

DEA	
Inputs	**Referencial**
Beds (Thousands)	Marinho and Façanha (2001); Proite and Sousa (2004); Sedivama *et al*. (2012); Tonelotto *et al.*
Doctors (Thousands)	Cesconetto *et al.,* (2008)
SUS (Billion R$)	de Souza *et al.* (2016); Silva et al. (2021); Corrêa (2020)
Outputs	**Referencial**
Consultations (Millions)	Trivelato *et al.* (2015)
Exams (Millions)	Trivelato *et al*. (2015)
Sugreries (Thousands)	Proíte and Sousa (2021)

Source: Research data (2023)

3.2.2 Panel data regression

After the data envelopment analysis, a panel data model was estimated to measure the impact of the variables on hospital efficiency. In the context of the research problem at hand, the application of panel data models offers the opportunity to consider the following aspects: (a) the temporal dimension of the data, associated with the cross-sectional units of hospitals, allows for the evaluation of the effect of control variables on efficiency over time; (b) the ability to control for the effect of peculiar characteristics and unobservable effects specific to each period; and (c) the potential presence of endogeneity in the model can be more easily controlled.

Wooldridge (2002) describes the econometric model with panel data as follows:

$$Y_{it} = X_{it}'\beta + c_i + u_{it} \qquad (1)$$

$$i = 1,2, \ldots, N \qquad t = 1,2, \ldots, T$$

In this notation, the subscript *i* denotes the different cross-sectional units (Federal University Hospitals), and the subscript *t* indicates the time period being analyzed (2019 to 2022).

Figure 2 presents the variables used in the research and their role in the estimation equation.

VARIABLE	TYPE	SOURCE
Product efficiency	Dependent	Estimated
Input efficiency	Dependent	Estimated
Number of deaths	Control	IBGE
Elderly population	Control	IBGE
Maintenance costs*	Independent	EBSERH
Maintenance costs	Independent	EBSERH
Maintenance costs	Dummy	EBSERH

Figure 2: Variables used in the research

Source: Research data (2023)

* The data on maintenance and depreciation costs will be used in the regression in natural logarithmic form to allow for a percentage analysis.

Thus, the equation estimating the impact of these variables on efficiency will have the following structure:

$$Efficiency_{i,t} = \beta_0 + \beta_1.elderly_{\ i,t} + \beta_2.death_{i,t} + \beta_3.ln(maintenance)_{i,t} + \beta_4.ln(depreciation)_{i,t} + \beta_5.region_{i,t} + e \quad (2)$$

The betas ($\beta_0, \beta_1, \beta_2, \beta_3, \beta_4, \beta_5$) represent the coefficients estimated by Equation 2. The inclusion of the number of deaths is based on the relationship between hospital efficiency and mortality rates, as observed in Deily and McKay (2006) and Tonelotto et al. (2019), who found a positive and statistically significant relationship between resource allocation inefficiency and the mortality rates of a DMU. The increase in the elderly population contributes to a higher demand for healthcare services and increases associated costs, with impacts on economic stability, as highlighted by Kernkamp et al. (2016, pp. 1-2). It is expected that the increase in the elderly population will correspond to an increase in hospital efficiency, thus a positive relationship is anticipated.

In turn, the number of deaths can be an indicator of hospital efficiency, as long as the hospital is not primarily dealing with severe or terminal cases. Thus, hospital efficiency may be affected by the number of deaths, and it is expected that the relationship between deaths and efficiency will be negative (Travassos et al., 1999).

Depreciation and maintenance costs are crucial for keeping essential services in good working order. Therefore, it is expected that spending on maintenance and equipment depreciation can help maintain a consistent standard of service delivery. The anticipated relationship between depreciation and maintenance is positive. To ensure the comparability of financial values, all monetary data were adjusted to constant 2019 values using the Broad National Consumer Price Index (IPCA). The IPCA is Brazil's official inflation indicator and is used by government agencies for planning and policy formulation.

Depreciation reflects an estimate of the economic benefit consumption of an asset, and is therefore subject to inaccuracies. There are several methods of depreciation, including the straight-line method, which distributes the cost evenly over time, and the units of production method, which links depreciation to the asset's actual usage. The age of the fixed asset can thus influence the results. It was not possible to identify the age factor in the collected data. Acknowledging this limitation, it is reasonable to state that this could directly impact financial management, influencing how assets are evaluated and how investment decisions are made.

The spatial factor is another characteristic to be tested in relation to hospital efficiency. Hospital facilities and socioeconomic conditions differ depending on the region where the hospital is located, as found by Duarte et al. (2002). Therefore, it is plausible that hospital efficiency is affected differently based on the region of the country.

To ensure the robustness of the model, the Hausman Test was used to choose between fixed-effects and random-effects models. The test results suggest that the random-effects model is more appropriate. Subsequently, the Breusch-Pagan and Wooldridge tests, as well as the Durbin-Wu-Hausman test, were applied to check for heteroscedasticity, autocorrelation, and endogeneity, respectively. The results of these tests indicated that there are no significant issues that could compromise the statistical inferences.

4 ANALYSIS AND DISCUSSION OF RESULTS

4.1. DESCRIPTIVE STATISTICS

The data used for the DEA estimation method included SUS funding, the number of doctors, and the number of hospital beds as inputs. For the outputs, data on consultations, surgeries, and exams were used for the 34 selected university hospitals. Table 1 below presents the means and standard deviations of these variables over the four years of the sample.

TABLE 1: MEAN AND STANDARD DEVIATION OF INPUT AND OUTPUT VARIABLES OF UNIVERSITY HOSPITALS BETWEEN THE YEARS 2019 AND 2022

Classification	Variable	Mean	Standard Deviation
	SUS (Billion R$)	1.74	0.07
Inputs	Doctors (Thousands)	18.32	2.11
	Beds (Thousands)	8.11	0.13
	Consultations (Millions)	4.03	0.93
Outputs	Exams (Millions)	15.06	2.11
	Surgeries (Thousands)	100.32	17.10

Source: EBSERH and DATASUS (2023)

The 34 hospitals in the sample received, on average, 1.74 billion reais in SUS funding over the four years. There was an average of 18,000 doctors working in these hospitals, and an average of 8,000 beds. On the output side, there were, on average, 4 million consultations and 15 million exams. Regarding surgeries, an average of 100,000 were performed. As for the standard deviation, only the number of surgeries showed a high index, indicating that significant fluctuations occurred between the years.

According to the data, the total volume of resources was higher in 2019 and 2020ii, with R$1.81 billion in the first year and R$1.79 billion in the second. However, this amount decreased in the following years, dropping by R$120 million in 2021, reaching a total of R$1.67 billion. Finally, it remained stable in 2022 at R$1.68 billion.

The number of doctors remained relatively stable between 2019 and 2020. However, in the second year of the pandemic, 2021, there was a significant increase of 2,900 doctors, bringing the total to 19,700 doctors across the 34 Federal University Hospitals. In 2022, there was another increase, and the total number of doctors rose to 20,600.

During the COVID-19 pandemic, the number of hospital beds was a crucial input to accommodate the influx of patients. Between 2019 and 2020, there was an increase of 270 beds in the hospitals analyzed. In 2021, there was a slight reduction in the number of beds, and by 2022, the number of beds had dropped to a level below that of 2019.

Consultations were drastically affected by the pandemic. In 2020, the number of consultations was nearly half of those conducted in 2019, with a drop of 2.2 million consultations. Starting in 2021, the number of consultations increased to 3.9 million, and in 2022, 4.4 million consultations were conducted, a figure still below the total number of consultations in 2019.

The number of surgeries was another service offered by Federal University Hospitals that was impacted by the pandemic, showing a reduction in the first year of the crisis. Between 2019 and 2020, surgeries decreased from 17.3 million to 12.2 million, a drop of over 5 million. Gradually, the number of surgeries increased, reaching 14.9 million in 2021 and 15.8 million in 2022. However, these figures still amount to nearly 2 million fewer surgeries than those performed in 2019.

In 2020, 5,000 fewer exams were performed compared to 2019, totaling 102,800 exams. However, in 2021, there was a drastic reduction of approximately 25%, with only 75,800 exams conducted. In 2022, there was a significant increase in the number of exams performed, reaching a total of 114,800 exams.

The scenario presented indicates that the outputs were most negatively affected by the pandemic, while on the input side, an increase in resources was necessary to address this critical period. Thus, two DEA models were chosen: one focused on inputs and another on outputs. Regarding the returns to scale, the decision was made to use variable returns to scale (VRS), which is more consistent with the behavior of the variables used.

For each year, two efficiency scores will be estimated for each hospital: one focused on inputs and the other on outputs. This represents the first stage of the empirical strategy. The second step is to estimate the impact of certain variables on this efficiency.

4.2. RESULTS OF THE DATA ENVELOPMENT ANALYSIS (DEA)

The results of the BCC (Banker, Charnes, and Cooper) model, which accounts for variable returns to scale with an input-oriented approach, show the ranking of efficiencies based on the year 2022. In that year, 18 hospitals achieved the highest level of efficiency in terms of input usage compared to other units. However, only 8 hospitals maintained the highest level of efficiency across all four years analyzed.

As is widely known, 2020 and 2021 were atypical years for society as a whole. Consequently, many hospitals fluctuated in their relative efficiency positions compared to other hospitals during these years. The Lagarto University Hospital (HUL-UFS), located in Sergipe, and the Climério de Oliveira Maternity Hospital (MCO-UFBA), located in Salvador, are examples of such changes. The University Hospital of the Federal University of Piauí (HU-UFPI) is another DMU that experienced a significant drop in ranking among the hospitals. This may have occurred because input factors increased during this period, while some output factors, such as exams and surgeries, decreased in these hospitals.

Given these brief considerations regarding input-oriented efficiency, the following section will assess product-oriented efficiency. The results are based on the BCC model, which accounts for variable returns to scale.

The DEA estimation from the product-oriented perspective was similar to the results from the input-oriented perspective. In 2022, 18 hospitals achieved the highest level of efficiency, while in 2019, 19 hospitals reached this level. The year 2020 was a disruption, with only 13 hospitals showing high efficiency. However, in 2021, there was a recovery, with 18 hospitals achieving the highest level of efficiency.

TABLE 2: DESCRIPTIVE STATISTICS OF EFFICIENCIES FROM 2019 TO 2022

Year	Variable	Observations	Mean	Standard Deviation	Minimum	Maximum
2019	Input efficiency	34	0.90	0.16	0.53	1
2019	Product efficiency	34	0.90	0.17	0.42	1
2020	Input efficiency	34	0.86	0.15	0.49	1
2020	Product efficiency	34	0.87	0.16	0.46	1
2021	Input efficiency	34	0.84	0.21	0.32	1
2021	Product efficiency	34	0.84	0.22	0.32	1
2022	Input efficiency	34	0.90	0.13	0.62	1
2022	Product efficiency	34	0.91	0.11	0.67	1

Source: Research data (2023)

The results presented in Table 2 reveal significant variations in the operational efficiency of Federal University Hospitals over the period from 2019 to 2022. Efficiency showed an increasing trend in 2022 compared to the previous periods. This improvement can be attributed to adaptations and enhancements in hospital operations following the challenges posed by the COVID-19 pandemic.

In 2019, the average efficiency was 90% for both input-oriented and product-oriented efficiency, as shown in Table 2. The minimum efficiency values were 53% for input-oriented efficiency and 42% for product-oriented efficiency. In 2020, there was a decline in the average efficiency across hospitals for both variables. The average efficiency for inputs was 86%, while for products, it was 87%. The minimum efficiency values for inputs were 49%, and for products, 46%.

The estimation of a DEA is important for understanding which hospitals are utilizing their resources more effectively and offering better services. However, this analysis does not allow for a causal relationship to be established regarding this efficiency. For such a task, a regression model is recommended to enable an analysis of which variables impact the degree of efficiency in these hospitals.

4.3. RESULTS OF THE PANEL DATA REGRESSION ESTIMATION

Following this, Table 3 presents the descriptive statistics of the variables used in the estimated regression.

Year	Variable	Observations	Mean	Standard Deviation	Minimum	Maximum
2019	Input efficiency	34	0.90	0.16	0.53	1.00
	Product efficiency	34	0.90	0.17	0.42	1.00
	Elderly (Millions)	34	1.24	1.06	0.25	3.30
	Deaths	34	323.38	223.70	2.00	982.00
	Maintenance[iii] (Millions)	34	2.43	2.25	0.07	11.50
	Depreciation (Millions)	34	1.25	0.85	0.15	4.04
2020	Input efficiency	34	0.86	0.15	0.49	1.00
	Product efficiency	34	0.87	0.16	0.46	1.00
	Elderly (Millions)	34	1.29	1.10	0.26	3.40
	Deaths	34	342.65	234.85	6.00	1015.00
	Maintenance (Millions)	34	2.31	2.03	0.14	10.50
	Depreciation (Millions)	34	1.65	1.31	0.26	6.85
2021	Input efficiency	34	0.84	0.21	0.32	1.00
	Product efficiency	34	0.84	0.22	0.32	1.00
	Elderly (Millions)	34	1.31	1.08	0.27	3.30
	Deaths	34	295.03	182.03	6.00	745.00
	Maintenance (Millions)	34	2.26	1.98	0.28	11.00
	Depreciation (Millions)	34	1.17	0.83	0.11	4.08
2022	Input efficiency	34	0.90	0.13	0.62	1.00
	Product efficiency	34	0.91	0.11	0.67	1.00
	Elderly (Millions)	34	1.39	1.19	0.28	3.70
	Deaths	34	272.97	196.20	9.00	845.00
	Maintenance (Millions)	34	2.19	1.73	0.09	9.50
	Depreciation (Millions)	34	1.96	2.34	0.17	12.80

TABLE 3: DESCRIPTIVE STATISTICS OF REGRESSION VARIABLES
Source: Research data (2023)

The year 2022 showed an average efficiency of 0.9, which was also observed in 2019. Although it is not possible to directly compare efficiency between these years, this distinct average compared to 2020 and 2021 suggests that hospitals faced significant challenges in providing services during the two waves of COVID-19.

The number of deaths was high in 2019 but increased further in 2020, with a maximum of 1,015 deaths in a single hospital. Maintenance expenses decreased between 2019 and 2022, while depreciation expenses increased during the same period, noting that these are real values, not nominal. Table 4 presents the Pearson correlations between the variables, which help identify potential relationships and multicollinearity among the factors affecting hospital efficiency.

	input_eff.	product_eff.	elderly	deaths	maintenance	deprec.	south
Input efficiency	1						
Product efficiency	0.9645*	1					
Elderly	0.0399	0.0530	1				
Deaths	-0.0411	-0.0202	0.3948*	1			
Maintenance	0.1382	0.1775*	0.3673*	0.3889*	1		
Depreciation	0.1530	0.1850*	0.1025	0.3136*	0.1878*	1	
South Region	-0.3309*	-0.3058*	0.1984*	0.1857*	-0.0734	-0.04631	1

TABLE 4: PEARSON CORRELATION BETWEEN VARIABLES
Source: Research data (2023)

Note: The symbol '*' indicates a significant relationship at the 5% level.

Both input and product efficiency suggest a negative and significant relationship with the Southern region. Product efficiency showed a positive and significant correlation with maintenance and depreciation expenses. The number of elderly people and the number of deaths did not show any correlation with the efficiency variables.

Variable	Coefficient	Standard Error	T	P>|t|
Elderly	0.000	0.000	0.920	0.360
Death	0.000	0.000	-0.220	0.827
Ln (Maintenance)	-0.001	0.018	-0.050	0.957
Ln (Depreciation)	0.039	0.021	1.900	0.057
South Region	-0.174	0.062	-2.790	0.005
Constant	0.350	0.330	1.060	0.288
R^2				
Within	0.03			
Between	0.23			
Overall	0.13			
Breusch-Pagan	4.401	p-valor = 0.493		
Wooldridge	1.969			
DWH	0.000	p-valor = 1.000		

TABLE 5: REGRESSION MODEL RESULTS

Source: Research data (2023)

The results from the panel data regression with random effects indicate that the number of elderly people and the number of deaths do not impact the efficiency index among the University Hospitals in the sample. Among the expenses, only depreciation costs had an effect on the efficiency level. Specifically, a 1% increase in depreciation expenses results in a 0.03 percentage point increase in efficiency.

The results of this study are consistent with Kohl et al. (2019), who identified a positive correlation between efficient depreciation cost management and improved operational efficiency in hospitals. It is observed that hospitals implementing asset management practices tend to record better performance in terms of economic efficiency.

The findings also reinforce the trend observed by Schultz et al. (2008) regarding the importance of investment in healthcare technologies and equipment. The correlation between investments (in this case, captured by depreciation) and efficiency suggests that the modernization of equipment enhances long-term operational capacity. This is significant for the formulation of policies related to hospital infrastructure and operational sustainability.

In turn, the coefficient for the binary variable representing the Southern region was also statistically significant at the 5% level. Therefore, being located in the Southern region, on average, reduces hospital efficiency. The results indicated that the Southern region had a negative impact, while depreciation expenses positively influenced efficiency.

Although the results provide insight into the efficiency of university hospitals, it is important to acknowledge the data limitations, which may have impacted the significance of some variables. Additionally, unobserved factors (such as management quality, quality of care, among others) are difficult to observe and measure but may have influenced the findings.

5 FINAL CONSIDERATIONS

This article aimed to analyze the efficiency of University Hospitals managed by the Brazilian Hospital Services Company (EBSERH). To achieve this, data on inputs and outputs were collected to calculate the efficiency levels of these hospitals.

The distinguishing feature of this article, compared to others that have used the DEA methodology in hospital institutions, was the use of efficiency as a dependent variable in a regression, with depreciation and maintenance expenses as independent variables. In the first stage, the efficiency levels of these hospitals were estimated over a four-year period. The data allowed for the observation of changes due to the pandemic period.

Panel data was estimated to understand which variables impact hospital efficiency. The results showed that depreciation costs help improve efficiency. It was also determined that the regional factor influences efficiency, with hospitals in the Southern region found to be less efficient than hospitals in other regions.

When it is stated that depreciation costs positively impact hospital efficiency, it refers to the effect of these costs, rather than depreciation itself. This means that when depreciation costs are calculated and recorded, reflecting the net values of assets in the institution's financial reports, hospital efficiency increases. Thus, the hypothesis that depreciation costs positively impact efficiency is confirmed. Conversely, the hypothesis regarding maintenance costs was not supported by the estimation. This indicates that maintenance expenditures serve a different purpose for efficiency than depreciation expenses or may not receive the same level of attention from managers. As seen in Table 5, maintenance expenditures decreased between 2019 and 2022.

When assets are of high complexity, alongside the prevalence of high costs, there is also the risk of obsolescence. This encompasses the possibility that the asset may reach the end of its useful life before the expected timeframe due to a loss of technological capability, even while it still possesses physical capacity.

The findings underscore the necessity for investment policies in the infrastructure of university hospitals. Efficient asset management practices impact long-term operational capacity. Furthermore, proper and timely depreciation allows hospitals to more accurately reflect the value and cost of their assets, facilitating better investment and budgeting decisions.

Finally, one of the limitations of this article was the access to data from the University Hospitals managed by EBSERH. For future research, it is suggested to expand the temporal scope to capture long-term trends, as well as to utilize additional variables.

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[i] Since the objective was to use this efficiency in a panel in the next step of the research, DEA relative to the efficiency between hospitals was applied, rather than between years, as happens in Malmquist DEA.

[ii] It is important to note that these are real data, at 2022 price levels, and not nominal data.

[iii] The maintenance and depreciation expenditure data were deflated by the IPCA to 2022 levels.