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Multivariate analysis techniques applied for the performance measurement of Federal University Hospitals of Brazil

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ABSTRACT

The presence of teaching hospitals represents a strategic role in improving the quality of life of the Brazil Unified Health System patients, based on the qualified training of health, medical and complementary professionals, which means efficiency in hospital production. Therefore, the purpose of this paper was to apply the multivariate analysis techniques of principal component (PCA) and clusters analysis in the performance measurement of Federal University Hospitals, aiming to contribute for the improving of Brazilian health care services. The research is descriptive, with exploratory purpose, being organized according to three stages of development, that is, the use of principal component analysis; in the second stage, the selection of inputs and outputs for the management of hospital organizations and; in the third, the use of clusters analysis technique, for the inputs and outputs defined. Results show that the groups' formation represented divergences between both techniques applied. Thus, it was verified that two hospitals, of twenty, remained alone in both clusters and PCA, demonstrating that these organizations differentiate from the others, regarding the similarity of their characteristics described by the original variables used in the analysis.

1. Introduction

The great influence that hospitals exert on the health care systems' efficiency of which they are a part, shows the important role they play in this environment they are inserted. Moreover, hospitals are of extreme value, dealing as they do with issues that need to be addressed immediately, while at the same time as they represented, regionally, a large part of health care spending (Ersoy, Kavuncubasi, Ozcan, & Harris Ii, 1997; Flessa & Dung, 2004). The process of managing and allocating scarce resources, by tackling the vulnerability inherent to patients' and financing needs, means that defining improvement priorities is one of the main challenges faced by hospitals and is essential given the importance they represent to health care systems, as well as the difficulties they face (Bell et al., 2004).

In this sense, Ozcan et al. (2010) point out that the efficiency of each hospital unit and achieving the planned objectives are the parameters used for distributing resources, as they are financed mainly by the Ministry of Health, as well as by the Ministry of Education. To that end, teaching hospitals are generally based on three main dimensions, reflecting these institutions' mission and vocation, as the authors suggest, medical care, qualification of labor for the health system, and conducting research with the purpose of contributing to the generation and evaluation of new technologies for the health area.

Instability in the scale and characteristics of demand for hospital services can be considered a result of a series of factors that happen in a fast and unpredictable way. These include changes due to the advent of globalization and in relation to the living standards of the population, producing epidemiological and demographic changes at local and national levels, as well as regulatory changes and technological advances in the medical field. These phenomena, besides reflecting in the demand format, affect and limit the useful life of hospital infrastructure, often developed to last for more than 30 years (Neufville, Lee & Scholte, 2008).

Thus, in order for access rights to public health care services to be guaranteed by the Brazilian Unified Health Care System (*SUS – Sistema*

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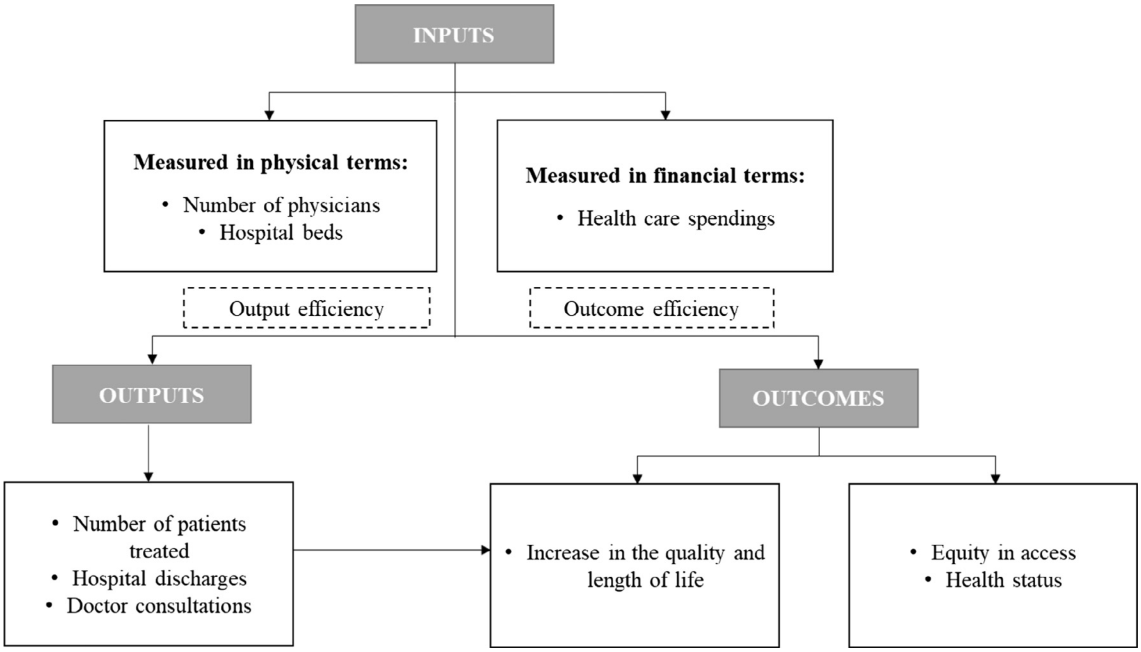

Fig. 1. Process of transforming resources – inputs in outputs and results.
Source: Adapted from Joumard et al. (2010)

Único de Saúde), a valid alternative involves the support on resource allocation methodologies that respect local, municipal and regional needs, as well as the equality criterion (Rosas, Bezerra & Duarte-Neto, 2013). On the other hand, considering the strong social appeal of health organizations, Meyer Júnior, Pascucci and Murphy (2012) point out the great need of transferring the peculiarities inherent to the scenario marked by hospital characteristics, to management theories and practices.

Analyzing the process of measuring hospital efficiency, which enables these organizations to better understand the effectiveness of their management practices, is of great interest to the entire health care sector. To optimize medical resources' allocation, hospitals are supported by performance management and organizational efficiency analysis, important support bases for decision-making processes (Chuang, Chang & Lin, 2011). Another strong appeal reinforcing the importance of evaluating performance in health organizations around the world lies in the constant increase of costs incurred by these organizations, in addition to what the health care sector represents in relation to the countries' Gross Domestic Product (GDP) (Sinimole, 2012).

Considering the scenario presented for health education organizations, there is an essential and characteristic aspect, in line with its strong social appeal, which emphasizes the importance of effective control of its operations. In this sense, it should be mentioned that these are organizations whose objective is not only to save lives, but to act in prevention, as well as to provide a better life quality and to foster the formation of qualified professionals in the medical and complementary fields. Thus, the importance of the use of tools that help in the management of organizational efficiency in these organizations, is accentuated.

Therefore, the purpose of this paper was to apply the multivariate analysis techniques of principal components and cluster analysis in the performance measurement of Federal University Hospitals – Brazilian HUFs (*Hospitais Universitários Federais*) participating in the National Program for Restructuring Brazilian Federal University Hospitals (*Programa Nacional de Reestruturação dos Hospitais Universitários Federais – REHUF*), aiming to contribute for the improving of Brazilian health care services.

2. Management processes in hospital organizations

In the conception of Jones and Northrop (2005), the management of organizations seeks to make the most of the inherent capacity of a production line, resulting in the best positioning of the organization, through support in the necessary areas of action for a given scenario. In this way, managing hospital sector' organizations, based on health care processes, refers to the search to offer, in the best possible way, high quality health care services (Fala, Clayton & Masciantonio, 1995; Jamshidi, Ramezani, Razavi, & Ghalichi, 2017).

Although capacity planning, in the health care area, as pointed out by Ettelt, Nolte, Mays, Thomson, and World Health Organization (2008), represents government levels in health systems, differences in the way this is done on national, regional and local levels are poorly defined in most countries. As Rechel, Wright, Barlow, and Mcnee (2010) point out, in order to find the balance between sufficient capacity and fair price, making it possible to meet future health care needs, it is essential to seek for better ways of planning and operating hospital capacity, bearing in mind the growing global trend for new hospitals.

In healthcare organizations, the decision-making processes in operations management come under the responsibility of a wide range of professionals (Byrkjeflot & Kragh Jespersen, 2014; Vissers & Beech, 2005). Such a scenario can be characterized under the vision of a dual management, involving both managers and business administrators, as well as clinical professionals, creating ambiguous roles and responsibilities, which are not fully defined and may end up overlapping (Aletras, Kontodimopoulos, Zagouldoudis, & Niakas, 2007; Vissers & Beech, 2005). In this context, among the actors involved in managing these organizations, Vissers and Beech (2005) mention managers, physicians, nursing staff, paramedics, and the management team.

According to Langabeer (2008), health care services represent a set of outputs, such as current production and provision of health care services, resulting from the transformation of resources and assets such as labor and capital, represented by money, technology, people, space, equipment and information. According to the author, this is a management process guided by the search for better results, through the intensive use of quality and process improvement techniques, as well as

Table 1
Multivariate statistical methods applied to performance measurement.

Method(s)	Scope	Author(s)
Descriptive statistics, Malmquist index, Mann-Whitney test	An evaluation of the efficiency and quality of public hospitals	Arocena and García-Prado (2007)
Regression analysis	An evaluation of the organizational performance as a result of the combination of information technology (IT) and hospital operations	Devaraj et al. (2013)
Decriptive statistics	A hospital-level performance description considering wait time and visit length on na emergency department (ED)	Horwitz et al. (2010)
Regression analysis and data envelopment analysis and data envelopment analysis (DEA)	An investigation of a health insurance reform on the efficiency of regional hospitals	Hu et al. (2012)
Logistic regression and data envelopment analysis (DEA)	An examination of the efficiency of acute care hospitals through the use of hospital electronic medical record (EMR)	Kazley and Ozcan (2009)
Structural equation modeling	An organizational performance improving proposal to healthcare industry through the examination of supply chain (SC) innovation	Lee et al. (2011)
Correlation analysis	A performance improvement proposal through the management of absorptive capacity stocks in hospitals	Lev et al. (2009)
Univariate and regression analysis	An evaluation of hospital performance through balanced scorecard (BSC)	Lin et al. (2014)
Factorial analysis, Pearson correlation and canonical correlation	An evaluation of the organizational performance of public health-care providers under the impact of factors of quality management systems	Macinati (2008)
Decriptive analysis	An examination of hospital efficiency and performance, considering the information technology (IT) role and its consequences over patient flow	Martini et al. (2014)
Regression analysis and data envelopment analysis (DEA) bootstrapped	An evaluation of public hospitals production and economic efficiency	Mitropoulos et al. (2013)
Descriptive analysis and data envelopment analysis (DEA)	A comparison between high-quality and low-quality health care in hospitals	Mutter et al. (2010)
Regression and correlation analysis	An evaluation of the organizational performance in a general hospital verifying its results through the quality program	Naveh and Stern (2005)
Descriptive analysis and data envelopment analysis (DEA)	An evaluation of hospitals' technical efficiency through performance measures of quality	Nayar and Ozcan (2008)
Descriptive statistics, data envelopment analysis (DEA) and Malmquist method	An evaluation of general public hospitals' operational performance	Sahin et al. (2011)
Correlation analysis, multinomial distribution and qui-square test	An analysis of hospitals' performance involving a broader range of measures	Shwartz et al. (2011)
Principal component analysis (PCA), oblique rotation and Kaiser criterion	A hospital performance dimensions' definition	Simões et al. (2017)
Linear regression analysis and data envelopment analysis (DEA)	A hospital efficiency investigation considering the effects of privatization	Tiemann and Schreyögg (2012)
Principal component analysis (PCA) and logistic regression	An evaluation of the quality of emergency care through factors considered relevant from patient's perspective	Yarney and Atinga (2017)
Regression analysis and Hausman test	An examination of hospitals performance and quality improvement (QI) scope association	Weiner et al. (2006)

analytical and optimization tools. This process of resource transformation, that is, inputs, outputs and outcomes, creates the conditions to effectively meet the demand of its users for higher quality, quantity and level of services desired while, at the same time, reducing and restricting costs (van Sambeek, Cornelissen, Bakker, & Krabbendam, 2010). It can be exemplified through Fig. 1 inspired by the research of Joumard, André and Nicq (2010).

It is known that managing hospital capacity seeks to meet demand, with maximum efficiency, within the established time. To do so, it look for reducing or eliminating customer waiting times and idle capacity, through a series of actions defined and adopted by the managers (Adenso-Díaz, González-Torre, & García, 2002; Barnes, 2008). Thus, the complexity of hospital systems, with complicated and interconnected processes, in which a large number of material and human resources are managed, requires these organizations to be analyzed from a perspective that goes beyond planning approaches involving the "number of beds", in which they are seen as "warehouses" (Bachouch, Guinet, & Hajri-Gabouj, 2012; Rechel et al., 2010).

3. Performance management and performance indicators in hospital organizations

Performance management can be understood as the process of monitoring and controlling how the company organizes itself to achieve its planned goals by making use of interrelated strategies by leaders seeking to provide performance improvements for the people, teams and the organization, as a whole (Walburg, 2006). This is the process of measuring performance and results, which is part of the performance management system, through adopting indicators to support the measurement of the progress (Muller, Muller, Bezuidenhout, & Jooste, 2006; Walburg, 2006).

In order to be able to continue operating, Lied (2001) states that it is the responsibility of health care organizations to ensure results in a cost-effective manner, as well as ensuring that performance requirements may be achieved. Thus, selecting appropriate indicators and approaches for analyzing results may be the ideal projection of a performance measurement system (Purbey, Mukherjee & Bhar, 2007).

Gattnar, Ekinci and Detschew (2011) emphasize the importance of supporting quality indicators, based on the need to ensure an accurate quality measurement and performance indicators, as a bridge to quality improvement. Therefore, knowing what to measure may be a great challenge (Donabedian, 1969). So, health care systems, and the patients who use the services provided by these organizations, can be amended and benefited by performance measurement programs (Mannion & Braithwaite, 2012). In this sense, performance measurement systems are usually applied in public health to bring improvements, which is in line with recent and strong support on performance-based approaches by public service evaluation programs (Degroff, Schooley, Chapel, & Poister, 2010).

An important issue, responsible for disagreement in health care organizations, when it comes to performance measurement processes, refers to the reflection on what should actually be measured, as not everything can or should be. Performance measurement, then, should be incorporated into the routine of this sector, according to public policies supported by regulatory agencies and large corporate buyers (Loeb, 2004). Nakaima, Sridharan and Gardner (2013) illustrate some examples of performance measurement systems based on a variety of hospital activities. Among others, the authors mention the Balanced

Scorecard, patient satisfaction' researches, waiting times, indicators that show users' participation in decisions, educational measures directed at clients and outpatient volumes.

Facing this scenario, it is observed in studies in healthcare performance measurement field, that statistical and/or mathematical decision-making techniques are usually applied as the core methodological procedures of the research. Instead, they are rarely used as a support to fill one of the main gaps related to the lack of formal rigor in variables' selection, as well as regarding to sample definition. This behavior raises questions about the consistency of the results, considering the subjectivity inherent to the support basically in the opinion and experience of the decision makers. Table 1 shows some of these studies (Arocena and García-Prado, 2007; Devaraj, Ow & Kohli, 2013; Horwitz, Green & Bradley, 2010; Hu, Qi & Yang, 2012; Kazley & Ozcan, 2009; Lee, Lee & Schniederjans, 2011; Lev, Fiegenbaum & Shoham, 2009; Lin, Yu & Zhang, 2014; Macinati, 2008; Martini, Berta, Mullahy, & Vittadini, 2014; Mitropoulos, Mitropoulos & Sissouras, 2013; Mutter, Valdmanis & Rosko, 2010; Naveh & Stern, 2005; Nayar & Ozcan, 2008; Sahin, Ozcan & Ozgen, 2011; Shwartz et al., 2011; Simões, Azevedo & Gonçalves, 2017; Tiemann & Schreyögg, 2012; Weiner et al., 2006; Yarney & Atinga, 2017), demonstrating that there is potential for the creation of quantitative, hybrid or sequential combination models, that may fill these gaps noted in the original models.

Thus, the identification of deficiencies by hospital organization management benefits from the support of the performance measurement, so that these organizations can achieve better future performance, based on the evidence of existing practices, values, beliefs and assumptions (Lim, Tang, & Jackson, 1999; Purbey et al., 2007). For this, it is up to the performance measurement results to enable the transition between measurement and management, considering the search for organizational efficiency (Purbey et al., 2007).

4. Performance indicators for the National Program for Restructuring Brazilian Federal University Hospitals

Organizational performance indicators can be understood as variables that contribute to achieving strategic goals and objectives, and are used by professionals from different areas, such as engineers, administrators, politicians and the general public. Formulated and implemented to create greater simplicity, quantification and communication, indicators, or performance metrics, refer to easily understood processed information, resulting from data and statistics transformation, whose role involves supporting the processes of assessing progress (Ramani, Zietsman, Knowles, & Quadrifoglio, 2011).

In the scenario of public health organizations, these are structured according to the influence of internal aspects, such as the user and service provider behavior, and the organizational behavior, reflecting the most diverse institutional levels. Moreover, they are influenced by external factors, or those outside the control of health agencies, including religious beliefs, salaries and access to insurance (Hubley, 2008). Patient health care, and programs and services' support, either for high-risk subpopulations or to general users, may be highlighted as some of the responsibilities attributed to the important role of measuring performance in public health (Derose & Petitti, 2003). On the other hand, Beattie, Lauder, Atherton, and Murphy (2014) highlight the great contribution of patients in the condition of resources to measure health service quality. In this sense, they reinforce Hubley's (2008) ideas by arguing that the complexity of the results of current health care systems cannot be translated into a simple performance indicator.

As performance dimensions correspond to the elements used in selecting the indicators involved in measuring performance (Sole, 2009), it is suggested Table 2, which presents the 55 performance indicators proposed by the *REHUF* and, therefore, emphasizes the 5 variables adopted in this paper, as inputs and outputs, within Brazilian federal university hospital.

Therefore, in Table 2, this scenario is represented by the indicators "Supervision of Internship and Residence (SIR)", in the sub-dimension "Faculty", and in the dimension "Teaching and Research"; "Days of hospitalization" (DH), "SUS Care" and "Care Management"; "Specific Projects – Ministry of Health" (SPMH), "Financial Input Data – Ministry of Health" and "Economic and Financial Management"; "Type of Equipment" (TE), "Technological Structure" and "Infrastructure and Management"; Finally, there is "Medical Residence" (MR), "Students" and "Teaching and Research". Thus, due to the research method, translated into the performance measurement model created in this study, Table 2 reinforces the discussion of the results, based on a bibliographical review of authors whose researches complement and contrast the main aspects of the *SUS* management model.

5. Methodology

This paper relied on the performance measurement process based on inter-organizational comparisons, seeking to identify and define successful general practices observed in excellence management model organizations, for the analyzed set. As these practices may also be converted into general parameters to support decision making, in this context of analysis are included the university hospitals of the country. The performance measurement of these units was, therefore, based on the proposition of a general scenario within the reach of maximum organizational efficiency in patient care. In order to do so, the research is descriptive, with exploratory purpose reinforced, based on the bibliographical research, oriented by systematic review requirements (Peixoto, Carpinetti, Musetti, & Mendonca, 2013, 2014; Peixoto, Musetti, & Mendonça, 2016).

The study object involved teaching hospitals registered up to 2015, together with the Integrated System of Monitoring, Execution and Control of the National Program for Restructuring Federal University Hospital (*SIMEC – Sistema Integrado de Monitoramento, Execução e Controle/REHUF*), consisting of an intentional sample of 27 of the 51 hospitals. This is 52.94% of all *HUFs* and of the 27 hospitals, 25 already added the Brazilian Company of Hospital Services (*Empresa Brasileira de Serviços Hospitalares – EBSERH*) management, that is, only *HUFs* 16 and 19 have not yet signed the contract (SIMEC, 2016). In view of the main focus on the use of statistical techniques and the fact that 2014 refers to the most complete year of data in the *SIMEC/REHUF* database, the period of 12 months was set for developing it.

This paper is organized according to three steps of development, as shown in Fig. 2. It summarizes the general model proposed, and applied in this study, emphasizing the theoretical and practical contributions of this paper to performance management literature and to general organizations' management.

Following Fig. 2, the steps' sequence may involve:

- **First step:** Principal Component Analysis (PCA) technique is applied in N performance dimensions; in this paper, it corresponds to four hospital performance dimensions, which are, "Teaching and Research", "Care Management", "Economic-financial Management" and "Infrastructure and Management". In this step, the PCA is used to the selection of the most highly correlated indicators with great explanation power, that is, with eigenvalues over 0.8, in the first, second and third principal components.
- **Second step:** Data Envelopment Analysis (DEA) technique is applied, considering the Superefficiency model of Banker and Chang (2006) for outliers' identification and DMUs' selection; the indicators selected are classified as inputs and outputs; correlation analysis is also used as a complement.
- **Third step:** Cluster analysis technique is used, considering the inputs and the output defined, leading to the performance management of the decision-making units that, in this paper, corresponds to hospital organizations.

Table 2
Bibliographic review of the REHUF performance indicators adopted in this study.

SUS model	Dimensions	Sub-dimensions	Indicators	Authors	Aspects relevant to hospital organizations
National Program for Restructuring Brazilian Federal University Hospitals	Teaching and research	Faculty	Supervision of internship and residency (SIR)	McKee and Black (1992) Kilminster and Jolly (2000) Ilias (2014)	– Absence can lead to incorrect learning of the practice – Qualified production of professionals in Brazil
	Management Assistance	SUS Assistance Training	Days of hospitalization (DH)	Degeling (1994) Stock and McDermott (2011) Capkun et al. (2012) Leleu et al. (2012) Chaudhuri and Lillrank (2013) Fragkiadakis et al. (2014)	– Lower number due to the higher level of specialization of health care services – Improved cost performance in tune with operational performance – Increase can lead to serious operational problems and low patients' flow – Increase due to reduced number of health care professionals
	Economic and Financial Management	Input Financial Data – Ministry of Health	Specific Projects – Ministry of Health (SPMH)	Lins et al. (2007) Ribeiro (2009) Ozcan et al. (2010) Longaray et al. (2015) Ahmed et al. (2017)	– Hospital efficiency, accompanied by the achievement of productivity goals, represents agreement between *HUFs* and MH – Fulfillment of goals defines distribution of resources – Quality performance may be considered lower than that observed in private hospitals
	Infrastructure and Management	Technological Structure	Type of equipment (TE)	Wang and Welsh (2002) David and Jahnke (2005) Decouvelaere (2011) Chu et al. (2012)	– Importance of hospital engineers for safety and care efficiency – Importance of fault-free equipment – Increased patient safety and more reliable medical procedures – Idleness due to lack of policies and planning procedures, procurement and maintenance
	Teaching and Research	Students	Medicine Residency (MR)	Maslach and Jackson (1981) Tzischinsky et al. (2001) Ishak et al. (2009) Macedo et al. (2009) Awa et al. (2010) Korczak et al. (2010) Kaschka et al. (2011) Pérez et al. (2011) Rodger, Stephens, Clark, Ash, and Graves (2011) Johannessen and Hagen (2013) Amigo Vázquez et al. (2014)	– They are more concerned with patients' treatment than teaching doctors are – Profile marked by a high level of care and education, high expectations and excessive workload – High pressure; burnout syndrome – Increase in workload as an unfavorable aspect to obtaining specialized qualification

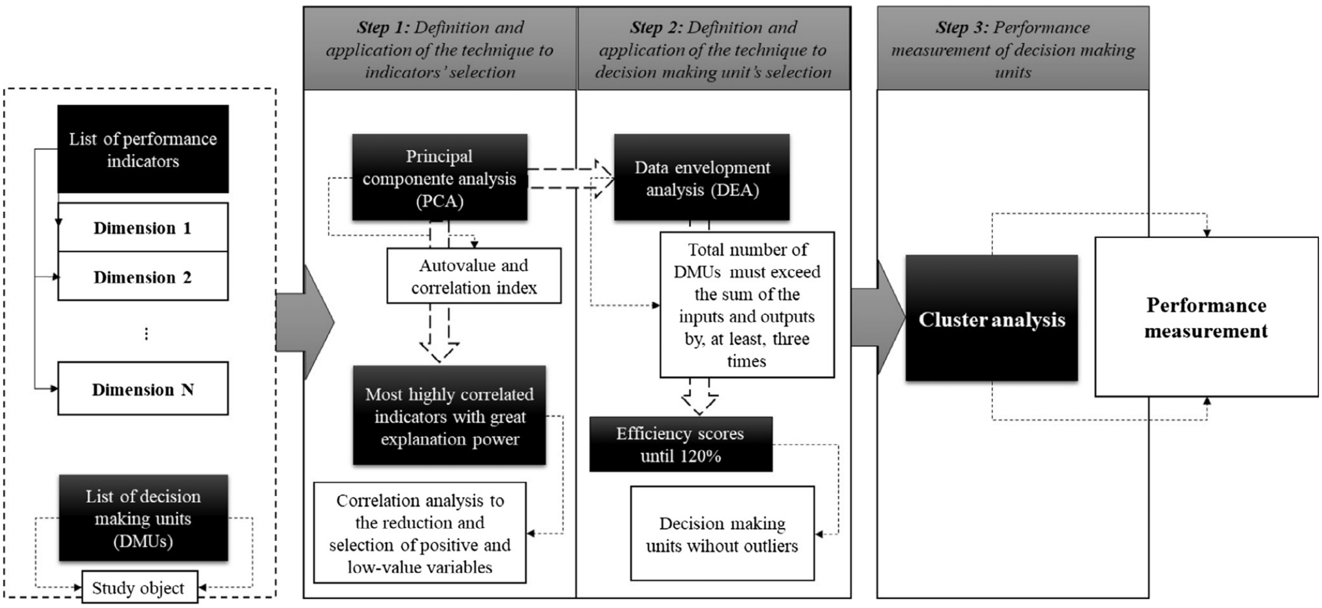

Fig. 2. The principal component analysis-DEA-cluster analysis proposed to support performance measurement.

This paper proposes, in stage 3, the use of cluster analysis for the measurement of organizational performance, as a way to show the similarities and dissimilarities of the performance management of federal university hospitals, in Brazil. However, it is important to highlight and suggest the use of stages 1 and 2 for variables and decision-making units' selection for other statistical and mathematical models, aspect that goes beyond this study proposal and that can also be considered a significant contribution of this research. Besides, as a way to guarantee the success of the present model (Fig. 2), the management model counts with the support of an initial performance indicators' list that may be divided in 1 or N dimensions, or categories, in accordance with the decision making unit's database and the decision makers' opinion. Similar conditions may be attached to the decision-making units' list.

It is also important to reinforce that the main contributions of this paper goes beyond the sequential combination of two multivariate statistical techniques, through the realization of a cluster analysis, which the inputs involve the most significant indicators with great potential to explain hospitals' performance, ensuring the participation of variables from the four dimensions previously mentioned. This study even shows that the use of multicriteria decision-making (MCMD) methods' requirements, notably DEA, for helping on sample definition, may bring satisfactory contributions to organizations, in this case, to hospitals' performance measurement. So, this paper attends to some of the criteria used by Data Envelopment Analysis (DEA); among these, there is the fact that the total number of decision-making units (DMUs) must exceed the sum of the inputs and outputs by, at least, three times (Banker & Morey, 1986; Banker, Charnes, & Cooper, 1984; Banker, Charnes, Cooper, Swarts, & Thomas, 1989; Habibov & Fan, 2010) and the need to define the variables as inputs and outputs.

Considering DEA's criteria, once this research follows the Superefficiency model of Banker and Chang (2006), the presence of 7 identified outliers reduced the set of *HUFs* to 20 hospitals. Taking into account the positive and low values between, at least, the input variables selected after principal component analysis application, correlation analysis was used, in order to ensure that only indicators with correlation up to 0.7 (70%) would compose the model. Correlation analysis also worked as a complement to the reduction of the number of original variables, from 11 to a sum of, at most, 6 input and output conditioners.

As the outliers were eliminated from the analysis and the hospitals were not identified, they are treated as *HUFs* 2, 3, 4, 6, 7, 8, 9, 10, 11, 12, 13, 14, 17, 18, 20, 22, 24, 25, 26 and 27. This information is better described in the next section, "Results and discussion". In addition, it is worth reinforcing, therefore, that the original variables were analyzed, in this paper, as inputs and outputs.

Therefore, the quantitative nature, as a justification, lied mainly in the multivariate statistical techniques, namely, principal component analysis and cluster analysis, and DEA, as a complement. The principal component method's application, as suggested by Zere et al. (2007), assumes that the existence of a correlation between some of the variables can lead to the evaluation of the same aspect, and this fact is justified by a possible redundancy between such collected variables. As can be seen from Eq. (1), the number of principal components must be equivalent to or greater than the number of original variables, with the principal component represented by Yi = 1, 2, …, p (Sharma, Sharma, Irwin, & Shenoy, 2011; Sinha et al., 2011); the eigenvectors correspond to e = 1, 2, …, p, and the original variables are represented by X = 1, 2, …, p. The mathematical formulation expressed by Eq. (1) was supported by authors such as Tadayon and Liu (1993), Hosamani, Hiremath and Sastry (1996), Johnson and Wichern (2007) and Ferreira (2011).

$$Y_i = e_{i1}X_1 + e_{i2}X_2 + \cdots + e_{ip}X_p \tag{1}$$

Cluster analysis was adopted as a way to verify the behavior of hospitals in relation to the analyzed variables, resulting in a satisfactory contextualization of *HUFs*' scenario. For the effective application of cluster analysis in the dimensions of performance, the arithmetic averages for groups formed by the university hospitals, through the 33 original sample data evaluated, were used. In this sense, one of the main tools used by cluster analysis refers to the dendrogram, the quality of which was guaranteed by the cophenetic correlation coefficient, while the cut-off point was validated in the dendrogram, considering the multivariate analysis of variance.

In the context of aspects of hospital management performance, the cophenetic correlation coefficient can be translated into the definition of the correlation between the *HUFs* and the dendrogram of recovered distances, in relation to the matrix of original distances. The processes adopted to carry out this analysis include the Unweighted Pair Group Method with Arithmetic Mean (UPGMA), assuming the condition of a hierarchical agglomerative technique (Ferreira, 2011).

Table 3
Relation of the eigenvectors (ê) and the correlations (r) between principal components I, II and III and the original variables analyzed in the "Teaching and Research" dimension.

Variables	PC1		PC2		PC3	
	$\hat{e}_1$	r	$\hat{e}_2$	r	$\hat{e}_3$	r
DG	0.342902261	0.7231127315	0.12476264	−0.17616491	0.1938048	−0.240454
MR	0.00044253	0.00093321	−0.325457157	0.45954567	**−0.4554174**	**0.5650371**
SRF	0.351998748	0.742295416	0.21389595	−0.30202119	−0.390223	0.4841503
TsP	0.309739452	0.653178958	0.138336514	−0.19533123	−0.3822705	0.4742836
TR	**0.394353995**	**0.831614214**	0.175431664	−0.2477096	−0.1670305	0.2072349
TA	0.362962109	0.765414964	−0.009803036	0.01384189	0.1189473	−0.1475781
MAPS	0.20804361	0.438722633	−0.418449244	0.59085054	−0.1145151	0.142079
POMA	0.270299728	0.570008416	0.208012294	−0.29371346	0.1800682	−0.2234109
MS	0.051692145	0.109008462	−0.462102384	0.6524888	−0.3498561	0.434067
SIR	0.207765677	0.438136527	**−0.477496522**	**0.67422533**	0.2368519	−0.2938625
MD	0.391460338	0.825512068	0.033002508	−0.04659956	0.1407728	−0.1746571
Qty	0.244735968	0.516099525	−0.348929069	0.49268802	0.4131936	−0.51265

DG: Degree; MR: Medical residency; SRF: Sources of research financing; TsP: Techno-scientific production; TR: Type of research; TA: Teaching activities; MAPS: Medical-area professors by specialty; POMA: Professors from other medical areas; MS: Medical servers; SIR: Supervision of internship and residency; MD: Maximum degree; Qty: Quantity.

6. Results and discussion

6.1. Selecting the variables by the principal component analysis

The first of the four dimensions of performance evaluated, considering the technique of principal component analysis, involved the "Teaching and Research" dimension. As mentioned in the topic "Methodology", due to the lack of some data, certain hospitals and variables were eliminated from the database. Thus, of the 15 initial variables, 12 variables that composes this dimension participated of this *HUFs*' performance measurement process.

Total variances of the three principal components (PCs) explain, respectively, 37.06% for PC1 (principal component I), 16.61% for PC2 (principal component II) and 12.83% for PC3 (principal component III). Thus, although the main information regarding the original variables analyzed are represented by the first and second components, it was observed that CP3 also makes an important contribution to the analysis. Thus, it was also chosen to include it, since with PC1 and PC2 the total variance of the three components reaches 66.50% of total variance.

Table 3 describes the numerical values referring to eigenvectors and correlation indexes defined for the first three principal components, considering that a total of 12 components were generated, this number resulting from the quantity of variables addressed in the analysis. The cut-off given to the evaluation of all dimensions encompasses the first original variables represented by the largest eigenvectors which, therefore, assume the highest correlations with the principal components I, II and III.

The table shows that the variable most highly correlated with the first main component involves type of research (TP), which is in the performance sub-dimension named "Research Activities" and refers to the amount of research developed by the *HUF*. On the other hand, the second component refers to the supervision of internship and residency (SIR), the sub-dimension "Faculty", as well as in CP3 there is the original variable, medical residency (MR), with the highest correlations. Therefore, SIR deals with the number of professors and administrative staff (doctors) involved in supervisory processes. The second variable covers the number of medical residents who are active in medical residency programs. Therefore, the variables TP, SIR and MR refer to the first three variables selected in the condition of possible inputs and/or outputs for the BCC model of data envelopment analysis, output oriented.

Regarding "Care Management" dimension, second of the four dimensions used to monitor the public network of teaching hospitals, the original data represented by the information set with the greatest explanatory potential is presented, involving the three principal initial components. In this sense, PC1 refers to 66.07%, whereas PC2 and PC3 present, respectively, 20.82% and 4.98%, so that the components contribute, together, with 91.87% of the total variance. In this sense, the numerical coefficients referring to the eigenvectors and correlation indexes between the original variables and the principal components I, II and III are shown in Table 4.

According to the table, the sum of the total number of days of hospitalization of all patients corresponds to the original variable, days of hospitalization (DH) of the sub-dimension, "*SUS* Assistance", of major importance in the first principal component. In principal component II, the variable with the greatest contribution refers to the number of incident cases of hospital infections (ICHI), in the same sub-dimension as the previous variable. The most highly correlated variable

Table 4
Relation of the eigenvectors (ê) and the correlations (r) between principal components I, II and III and the original variables analyzed in the "Care Management" dimension.

Variables	PC1		PC2		PC3	
	$\hat{e}_1$	r	$\hat{e}_2$	r	$\hat{e}_3$	r
PS	0.3551186	0.7070741	−0.515564976	−0.576161259	**0.70527824**	**0.37386558**
AOBs	0.4106965	0.8177349	−0.433540914	−0.484496602	−0.20038435	−0.08150903
DH	**0.4810855**	**0.9578859**	0.017603026	0.019671975	−0.20243158	−0.10138763
IAHUF	0.3099232	0.6170859	**0.630308650**	**0.704391187**	0.42858449	0.24604497
Dths	0.4164123	0.8291155	0.385469044	0.430774665	0.04676585	0.0054497
QtyAIHs	0.4520225	0.9000187	−0.007055926	−0.007885235	−0.48536426	−0.28547119

PS: Physical structure (SUS); AOBs: Active/operational beds; DH: Days of hospitalization; IAHUF: infections attributed to the HUF; Dths: Deaths; QtyAIHs: Number of inpatient hospital authorization (*Autorização de internação hospitalar* – AIHs).

Table 5
Relation of the eigenvectors (ê) and the correlations (r) between principal components I, II and III and the original variables analyzed in the "Economic-financial Management" dimension.

Variables	PC1		PC2		PC3	
	$\hat{e}_1$	r	$\hat{e}_2$	r	$\hat{e}_3$	r
ReWF grants	**0.343333**	**0.9452381**	0.144164	−0.18553	−0.13753506	−0.1437
SPME	0.081426	0.2241768	−0.49595	0.638245	**0.50591819**	**0.5286**
HCOHP	0.322357	0.8874882	0.041332	−0.05319	0.33887347	0.354066
DCVAC	0.307376	0.8462439	0.06515	−0.08384	0.36756456	0.384044
FAEC	0.311846	0.8585511	0.112759	−0.14511	−0.0802032	−0.0838
MCOHP	0.330807	0.9107523	0.11195	−0.14407	0.28417056	0.296911
SPMH	0.081745	0.2250531	**−0.67415**	**0.867566**	−0.34428766	−0.35972
SCHosp	0.268512	0.7392469	−0.35617	0.458362	−0.10532886	−0.11005
MaE	0.337	0.9278029	−0.14236	0.18321	0.08278016	0.086491
CaE	0.307851	0.8475528	−0.12795	0.164664	−0.37664352	−0.39353
CoD	0.311121	0.8565553	0.188598	−0.24271	−0.21093585	−0.22039
CIGIS_ABC	0.294109	0.8097189	0.220243	−0.28343	−0.2552871	−0.26673

ReWF grants: Residency and workforce grants under the Unique Legal Regime (RJU); SPME: Specific Projects – Ministry of Education; HCOHP: High complexity – outpatient and hospital production; DCVAC: Discrimination of contract values/annual contracts; FAEC – *Fundo de ações estratégicas e compensações*: Strategic actions and compensations fund; MCOHP: Medium complexity – outpatient and hospital production; SPMH: Specific projects – Ministry of Health; SCHosp: Service contracts – hospital; MaE: Materials expenses; CaE: Capital expenses; CoD: Costing expenses; CIGIS_ABC: Consumption items with the greatest impact on spending –ABC curve.

to PC3, SUS physical structure (PS), is in the sub-dimension, "Care Structure" in the *SIMEC/REHUF* database and, together with DH and ICHI, constitutes the set of initial variables to be part of the data envelopment analysis' model.

In the context of managing performance in Brazilian federal university hospitals, another important dimension over which the *EBSERH* also used to support for *HUFs'* monitoring refers to the "Economic and Financial Management". For this, a set of 12 original variables inherent to this dimension was defined, so that, once 12 main components were generated, PC1, PC2 and PC3 were again selected. This fact is justified, since the first three components correspond to 63.16%, 13.80% and 9.10% of explanatory potential, respectively, that is, the three indexes together represent 86% out of the total variance.

Table 5 gives the eigenvectors and the correlation indexes of the original data in relation to the first, second, and third principal components. Therefore, the first principal component showed a greater correlation with the variable of the sub-dimension, "Financial Input Data – Ministry of Health", residency and workforce grants under the Unique Legal Regime (*Regime Jurídico Único – RJU*) (ReWF_grants) is the amount spent by the Ministry of Education (*Ministério da Educação – MEC*) on paying residents and active personnel. The variable most highly correlated to the second component, represented by the highest eigenvector, involves specific projects linked to the Ministry of Health (MH), which relates to the amount transferred by MH to university hospitals. It participates in the sub-dimension "Financial Input Data – Ministry of Education", as well as the original variable corresponding to collecting funds by the *HUFs* from the Ministry of Education was the most important in CP3.

As the last dimension of performance evaluated, it is presented the scenario formed by the original variables, based on the principal component analysis applied in relation to the "Infrastructure and Management" dimension, composed by the sub-dimensions "Technological Structure", which has only one variable and "Workforce", involving six original variables. However, it is important to highlight once again that, due to the lack of some data and to keep as many hospitals as possible, data with complete information and mainly about their reliability, it became feasible, in this dimension, to use only 3 variables, type of equipment (TE), treasury source – expenditure (Staff:TS_expenditure) and staff: treasury source – quantity (Staff:TS_quantity).

For the analyses carried out with the other performance dimensions, it was established that the first three principal components would be evaluated as they explained the highest percentages of the total variance. In this case, only three components were generated due to the existence of only three original variables. Therefore, although it is not so common to perform PCA on a small number of variables, it was decided to do so as a way of complementing the general proposal of this paper, as well as observing the behavior of this particular small set of variables.

Considering that the first three main components explain 100%, 73.62% for PC1, 18.87% for PC2, and 7.51% for PC3, Table 6 gives a general outline of the reached for the principal components I, II and III.

The evaluation process of the only three principal components resulted from the application of PCA in a set formed of three original variables allowed, as already mentioned, the obtaining of only three PCs. Thus, maintaining the pattern for selecting variables, in the first component the variable with the principal contribution is the quantitative referring to the number of personnel under the Unique Legal Regime (*RJU*) and staff paid with *MEC* resources, represented by Staff: TS_quantity. This data constitutes the "Workforce" sub-dimension, while the variable type of equipment (TE), with the highest correlation index in component II, refers to the number of support equipments of HUF hospital procedures. In CP3, the presence of the variable, Staff: TS_quantity, is reinforced as the data with the highest correlation with

Table 6
Relation of the eigenvectors (ê) and the correlations (r) between principal components I, II and III and the original variables analyzed in the "Infrastructure and Management" dimension.

Variables	PC1		PC2		PC3	
	$\hat{e}_1$	r	$\hat{e}_2$	r	$\hat{e}_3$	r
TE	0.5340199	0.793633	**−0.7833525**	**0.58936307**	0.3180907	0.1509896
Staff:ST_quantity	**0.6232969**	**0.926312**	0.1105626	−0.0831829	**−0.7741298**	**−0.36746**
Staff:ST_spendings	0.5712475	0.8489589	0.6116656	−0.4601927	0.5473038	0.2597913

TE: Type of equipment; Staff:ST_quantity: Staff: treasury source – quantity; Staff:ST_spendings: Staff: treasury source – spendings.

Table 7
First original variables most highly correlated to principal components I, II and III.

Performance dimension	Variables	PC1	Variables	PC2	Variables	PC3
Teaching and Research	RT	0.831614214	SIR	0.67422533	MR	0.5650371
Care Management	DH	0.9578859	IAHUF	0.704391187	PS	0.37386558
Economic-financial Management	ReWF_grants	0.9452381	SPMH	0.86756615	SPME	0.52859998
Infrastructure and Management	Staff:TS_quantity	0.926312	TE	0.58936307	Staff:TS_quantity	−0.36746

TP: Type of research; SIR: Supervision of internship and residency; MR: Medical residency; DH: Days of hospitalization; IAHUF: Infections attributed to the HUF; PS: SUS physical structure; ReWF_grants: Residency and workforce grants under the Unique Legal Regime – *RJU*; SPMH: Specific projects– Ministry of Health; SPME: Specific projects – Ministry of Education; Staff:TS_quantity; Staff: treasure source – quantity; TE: Type of equipment.

Table 8
Correlation between the original variables for applying principal component and clusters analysis techniques.

Correlation	SIR	MR	DH	SPMH	TE
SIR	1	0.12190539	0.6628751	0.142293631	0.566694
MR	0.1219054	1	0.194993	0.066344815	0.1490712
DH	0.6628751	0.19499301	1	0.155206458	0.5707594
SPMH	0.1422936	0.06634482	0.1552065	1	0.3593853
TE	0.566694	0.14907125	0.5707594	0.359385316	1

SIR: Supervision of internship and residency; MR: Medical residence; DH: Days of hospitalizations; SPMH: Specific projects – Ministry of Health; TE: Type of equipment.

this component. Therefore, it was decided to construct Table 7, which contains a brief general summary of the 11 variables selected, involving the four performance dimensions.

On the other hand, it should be mentioned that, based on the application of the analysis of principal components, in this work, the participation of variables in the four performance dimensions of SIMEC/REHUF to feed the DEA model was considered. Table 8 shows the use of correlation analysis to guarantee indexes with values up to 0.7 (70%), between inputs and outputs, as a whole. In other words, through this adopted cut-off, it became possible to define a low correlation between the input variables, although not necessarily their high correlation with output variables. In this way, we reached an ideal set of variables: SIR (internship and residency supervision), ID (days of hospitalization), PEMS (specific projects – Ministry of Health), TE (type of equipment) for inputs and RM (Medical residency) as output, classified according to the opinion and experience of the authors.

Finally, Table 9 gives a definitive view of the original variables involved in this research, their respective types, the performance dimensions they make up, to which principal components they are most highly correlated, reinforced by the values of the corresponding eigenvectors and correlation indexes.

As Table 9 shows, the performance indicator, days of hospitalization, adopted as input, stood out with a correlation index in the order of 0.96, for the first principal component, followed by the input variable, SPMH, highly correlated, in module, with the principal component II, through a correlation index equivalent to 0.87. Although the output, medical residency, represented the lowest value for correlation (0.57), when compared to the other numeric values contained in the table, this stood out in the scope of CP3.

6.2. Cluster analysis applied to Federal University Hospitals

The initial application of principal component analysis in the performance dimensions “Teaching and Research”, “Care Management”, “Economic-financial Management” and “Infrastructure and Management” enabled a set of inputs and an output. Thus, it should be emphasized that these data respected the low correlation between them, for the effective use of this mathematical technique, as well as meeting the minimum assumption of 15 DMUs, considering the 5 input and output variables. In this sense, cluster analysis is of a complementary character in relation to PCA and DEA, contributing to the identification of the most outstanding characteristics in the scenario formed by federal university hospitals.

From the cluster analysis, it was possible to verify that the composition of 5 distinct groups formed by homogeneous units was significant, as shown by the cophenetic correlation corresponding to 88.32, a fact that indicates the consistency of the results, within the range of the matrix of distances of the dendrogram (cophenetic) and the matrix of original distances. Thus, the construction of the dendrogram enabled a cut-off point to be defined equivalent to 31.33% of the total distance, corresponding to the value of 7.12, as shown in Fig. 3. This criterion was adopted taking into account the scales of the distances from the dendrogram. In order to validate the 5 cluster formed, as well as the cut-off point chosen, it was verified that the groups of hospitals also differed significantly in relation to their centroids, in this case supported by multivariate analysis of variance. The results obtained showed p-value < 0.05, as well as level of significance below 1%.

Once consolidated the main aspects inherent to the reliability of cluster analysis, the description of the hospital characteristics, starting from the dendrogram, can be considered of great interest in decision-making processes for managing the performance of public teaching hospitals, from the production of medical residents. Thus, the distribution of *HUFs* into 5 groups can be reinforced by Fig. 3, so that Group I involves only hospital 2, likewise groups IV and V, which also have only one *HUF* each. Thus, in Group IV, *HUF*12 is included and hospital 20 is in Group V. In the second group, 70% of the *HUFs* can be found, that is, 3, 4, 7, 8, 9, 10, 11, 13, 17, 18, 22, 24, 26 and 27; finally, *HUF*6, *HUF*14 and *HUF*25 correspond to Group III.

Table 9
Selection of inputs and outputs for applying principal components and clusters analysis techniques.

Variables	Type of variables	Performance dimension	Principal component	Eigenvector	Correlation
SIR	*Input*	Teaching and Research	PC2	−0.47749652	0.67422533
MR	*Output*		PC3	−0.455417	0.5650371
DH	*Input*	Care Management	PC1	0.4810855	0.957886
SPMH		Economic-financial Management	PC2	−0.6741469	0.86756615
TE		Infrastructure and Management		−0.7833525	0.589363

SIR: Supervision of internship and residency; MR: Medical residency; DH: Days of hospitalization; SPMH: Specific projects – Ministry of Health; TE: Type of equipment.

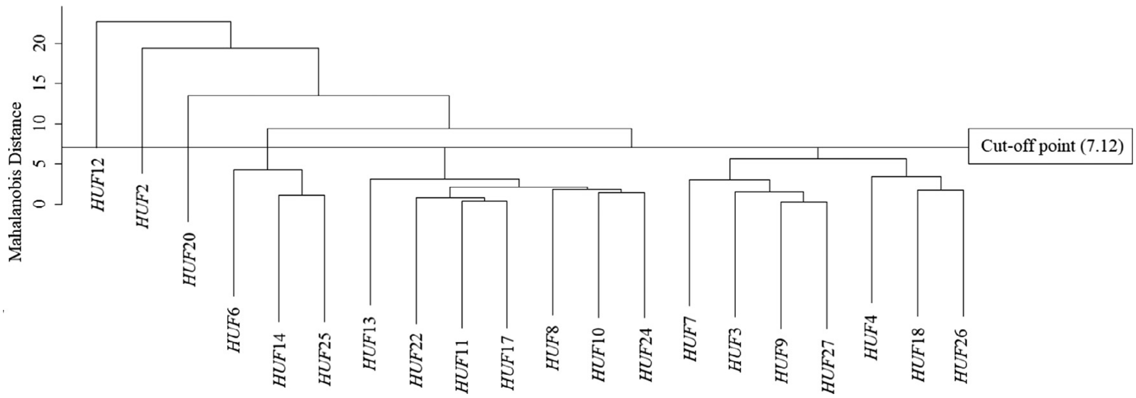

Fig. 3. Dendrogram of the similarities of the variables classified as inputs and output.

Initially, it should be pointed out that, from the application of the data envelopment analysis technique, the cluster formation demonstrated that Groups V and III refer to hospitals with efficiency scores equal to 100%, considering *HUF*4 with 99.75%. In Groups I and IV are the hospitals that can be considered among the less efficient on the scale resulting from the DEA, for production of training programs, by areas of specialty, represented by *HUFs* 2 and 12. Following this reasoning, it can be noted that 50% of the second cluster are inefficient *HUFs*, and the other half are borderline. Thus, it became possible to establish a comparison between two efficient groups, two inefficient ones and another containing hospitals with both classifications, for student's training.

Thus, Table 10 shows the mean values calculated for the second and third groups, as the other groups have only one hospital, so that, for these, the initial averages generated for the original variables were considered, as a whole. Thus, the data contained in the table represent the performance management scenario of *HUFs*, considering the cut-off established for the selected input and mainly the output data. In addition, it is necessary to reinforce that 70% of hospitals are in the second group, corresponding to a total of 14 homogeneous *HUFs*.

It can be observed that Group I stood out for the input, supervision of internship and residency (SIR), days of hospitalization (DH) and type of equipment (TE). Thus, an unfavorable aspect to medical residents obtaining specialized qualification refers to the increased workload related to the treatment of routine patients in a hospital with a higher number of residents, when compared to that of internship and residence supervisors (Johannessen & Hagen, 2013). However, it is desirable to hospital efficiency that the patient's stay time do not be so high, once otherwise, the hospital may suffer serious operational problems, creating low flow (Chaudhuri & Lillrank, 2013; Degeling, 1994; Fragkiadakis, Doumpos, Zopounidis, & Germain, 2014).

It is also desirable that the organization has equipments free of failures and poor performance, avoiding the interruption of medical treatments due to the suspension in the use of this equipment (Chu, Lee, & Wu, 2012). According to Chu et al. (2012), the extent of hospital efficiency goes beyond the greatest number of available medical resources, as well as the difficulty of measuring the loss of medical equipments. Among the main challenges faced by healthcare organizations are devices left unused due to the absence or scarcity of policies and procedures related to planning, obtaining, using and maintaining this technological structure (Wang & Welsh, 2002).

Regarding Group IV, it stood out with regard to specific projects – Ministry of Health (SPMH). This scenario corroborates with the fact that the efficiency inherent in each federal university hospital, accompanied by the achievement of productivity goals based on, health care areas, SUS priority policies, activities to improve hospital management, education, research, technological evaluation and integration, as well as financing, represents the agreement signed between *HUFs* and the Ministry of Health. This was in order to obtain certification, guaranteeing the transfer of funds to these institutions (Lins, Lobo, Silva, Fiszman, & Ribeiro, 2007; Longaray, Ensslin, Ensslin, & da Rosa, 2015; Ozcan et al., 2010).

However, the fourth and first groups, composed of 20 and 45 medical specialties, respectively, presented basically the same values for the output variable, medical residency, which were, respectively, 3.86 and 3.67 units, by area, with Group III exceeding them, on average, in only one unit (4.52). It is known that the profile of the health care professional is marked by high dedication to care and education, high expectations, as well as excessive workload (Pérez, Andreu, Alvarez, & Martinez, 2011). In the context of medical residents, such pressure is more pronounced (Tzischinsky, Zohar, Epstein, Chillag, & Lavie, 2001), especially in the case of a smaller number.

In other words, they are professionals in direct contact and engaged in helping other people being, therefore, subjected to work-related syndrome, known as burnout (Amigo Vázquez, Asensio, Menéndez, Redondo, & Ledesma, 2014; Maslach & Jackson, 1981; Pérez et al., 2011). This involves emotional exhaustion (worn out professionally), depersonalization (cynicism and distancing from people) and low professional efficiency (lack of self-efficacy and self-negativity) (Awa, Plaumann, & Walter, 2010; Kaschka, Korczak & Broich, 2011; Korczak, Huber, & Kister, 2010; Maslach & Jackson, 1981).

Through this comparison of two inefficient hospitals, it can be seen that the number of medical residents in *HUF*2 reflected the higher values this hospital made available, in 2014, for vacancies in the areas of

Table 10
Mean values of the performance indicators for the groups formed by the inputs and the output from the cluster analysis application.

Variables		Group I	Group II	Group III	Group IV	Group V
Inputs	SIR	87.67	13.66	8.22	17.37	3.33
	DH	4.598.14	1.532.25	2.224.54	2.369.52	159.44
	SPMH	R$754125.71	R$386008.75	R$494448.43	R$4091272.47	0.00
	TE	26.53	6.47	8.91	20.70	11.62
Output	MR	3.67	3.41	4.52	3.86	2.14

SIR: Supervision of internship and residency; DH: Days of hospitalization; SPMH: Specific projects – Ministry of Health; TE: Type of equipment; MR: Medical residency.

anesthesiology, general surgery, medical clinic, pediatrics and psychiatry. In the case of *HUF*12, it was very close to the general average of 3.55 medical residents, considering the highest concentrations of professionals in general surgery, medical clinic, obstetrics and gynecology, as well as in pediatrics.

In the scope of the SIR, the table suggests that Group V (*HUF*20) presented the worst amount of internship and residency supervision, by means of the average of 3.33 faculty and technical administrative personnel in the most varied hospital sectors. The process of minimizing inputs is important in this case, as long as the lack of supervisors of internship and residency does not prejudice the practice learning due to the lack of supervision. It can also be seen that some residents take advantage of this opportunity, mistakenly believing they can benefit from this condition, reflecting on patient's suffering being, therefore, unfavorable to health care (Kilminster & Jolly, 2000; McKee & Black, 1992).

However, the group with the highest input (Group I) for this variable had 96.20% more than the fifth group, that is, twenty-six times more supervisors, being represented by hospital 2, with 87.67 units. The supervision of internship and residency evidenced by the *HUF*2 turns on the highest average number of technical-administrative personnel involved in the area of medical practice. The other hospitals presented reduced (below 20) or relatively approximate values for this input variable.

The longest period of hospitalization in *HUFs* in 2014 was found by checking this characteristic for Group I. Thus, hospital 2, considered inefficient by DEA, is the *HUF* with the highest mean value of hospitalization days when compared with the other 19 organizations evaluated. *HUF*2 presented 48.47% more DHs than *HUF*12, a member of Group IV, also inefficient and occupying the second place on this scale unfavorable to the average MR production and, therefore, to hospital performance. According to Stock and McDermott (2011), improvement in cost performance is in line with operational performance, as evidenced by the indicator days of hospitalization. Intensive care of patients can be hampered by the reduced number of health professionals, which also leads to an increase in the patient's hospital stay (Leleu, Moises, & Valdmanis, 2012).

On the other hand, Group IV was above the general average of 1762.61 days, at 25.61%, when compared to other hospitals, while the fifth group represents the lowest value for this performance indicator, with an average length of stay of 159.44 days. This group had the lowest value for days of hospitalization in the areas of medical clinic, psychiatric, emergency, day-hospital, burn and isolation units, adult, pediatric and neonatal ICUs (Intensive Care Units), adult and pediatric intermediate care units, as well as other specialties. Thus, the increase in the level of services' specialization contributes to the improvement in efficiency and standardization of processes, resulting mainly in the reduced number of hospitalization days, which may represent a greater number of patients whose characteristics influence this performance indicator (Capkun, Messner, & Rissbacher, 2012).

The analysis of the input variable, specific projects – Ministry of Health (PEMS) indicates the contrast between Group IV and the other four groupings, especially Group V. Thus, it can be seen that, in 2014, the group consisting of the inefficient *HUF* 12 received the highest amount, R$ 4091272.47, from the Ministry of Health for *REHUF* improvements. Meanwhile, hospital 2, also inefficient, collected R$ 754125.71 in that year, focused on the cost and capital of the *REHUF* Program.

The financing provided by the Ministry of Health to Brazilian federal teaching hospitals corresponds to, at least, 25% more than the amount collected by hospitals not linked to universities considering, in public management, the adoption of polities based on achieving goals. In this sense, meeting goals, together with the relative efficiency of each hospital, translated into the need for efficiency gains, defines the process of resource distribution. Therefore, it also reflects the best use of installed capacity, resulting in patient care services' quality, as hospital supply expansion processes (Ozcan et al., 2010; Ribeiro, 2009). Besides, it is verified that the quality performance of healthcare service in public hospitals may be considered lower than of observed in private ones (Ahmed, Tarique, & Arif, 2017).

After *HUFs* 2, and 6, 14 and 25 (Groups I and III), whose SPMH values were high, Group II corresponds to the hospital grouping which received the smallest amount of government resources to improve teaching infrastructure for training medical professionals and, therefore, better public health care, as Group V did not receive SPMH, in 2014. Thus, these results enable the hypothesis that inefficient hospitals in the second and fifth groups, may not have met the targets set, according to their performance indicators, so that the amount received was insufficient to meet the real needs of these hospitals, in 2014.

The lack of structural improvements in these hospitals could have been unfavorable to resident training, by specialty, through training programs. Another hypothesis covers borderline *HUFs*, suggesting that these organizations were efficient in allocating these financial resources, reducing wastes, through maximizing available resources, in order to produce medical residents.

The quantitative of medical procedure equipments was elevated for Group I (*HUF*2), while Groups V, III and II were below 50% of this average and the fourth grouping had a mean of 20.70 units. Far beyond the number of medical equipments available in hospitals and their best allocations, it's relevant to reflect on the quality of these resources in the scope of these organizations' efficiency. In this context, the presence of hospital engineers acting as risk management agents and of the hospital equipments' performance, contributing to the technological structure of the organization to meet hospital's objectives (David & Jahnke, 2005). According to Decouvelaere (2011), such position observed for these professionals is accentuated, once it can mean misdiagnosis, putting the patient life under risk.

Therefore, the technological structure of hospital 2 can be represented, in general, by the mean value of 89.44 pieces of life-support equipments, although on average only 1 radiotherapy device was observed in this hospital, as well as low values for the others. The TE numbers for Groups V, III and II were relatively close, that is, Group V had 11.62, Group III, 8.91 and Group II, 6.47. Therefore, it can be deduced that the *HUFs* with the greatest values for this input correspond to the most inefficient ones in the analysis.

Finally, medical residency output can be understood as an output variable in which 60% of the groups had an average of around 4 residents for the different areas of specialty. Only the third group had, in 2014, an average value of 4.52 residents, mainly in clinical obstetrics, and neonatal intermediate care unit (*HUF*6), surgical and medical clinic, emergency and day hospital (*HUF*14), and surgical and medical clinic (*HUF*25). Thus, it can be observed that both hospitals that consumed more and less DH, SPMH and TE, and Group I, with the greatest number for SIR, showed practically the same values, weighted by their respective numbers of specialties, in training residents through *HUF* residency programs.

In this context, the severe emotional damages incurred by medical residents, as a result of dissatisfaction with educational medical residency programs result from a high demand, competitiveness and high levels of stress (Ishak et al., 2009; Macedo et al., 2009; Tzischinsky et al., 2001). This evidence demonstrates the existence of possible bottlenecks inherent to the training processes of future health professionals, through medical residency programs, with hospitals consuming high amounts of inputs for greater and/or lesser concentration, or lack of residents in certain areas, and this may reflect in work overload for some, damaging medical residents' physical and mental health.

Considering the scenario of federal university hospital management, marked by high quantitative variables, supervision of internship and residence and type of equipment and low values for MR, as a reflection of the number of areas, it is important to re-evaluate the increase of this production, as well as the quality of life of these residents (Macedo et al., 2009). So, it is necessary to increase residents' performance and to reverse this situation in patient care services, of high quality, excellence and safety (Ishak et al., 2009; Macedo et al., 2009).

In addition, the need to formulate strategies and support on counseling services is verified, through creating mental health and educational programs (Ishak et al., 2009; Macedo et al., 2009), so that hospitals can achieve efficiency, by managing the quantity and quality of their products. However, in spite of these problems, it is noted in Brazil, a qualified production of top-level professionals, and the country stands out in both the quality of its postgraduate students and medical residency programs (Ilias, 2014).

7. Conclusions

Facing a scenario marked by scarcity of infrastructural, human and material resources, the Federal University Hospitals (*HUFs*) emerge, supported by the National Program for Restructuring Brazilian Federal University Hospitals (*REHUF*), which philosophy is based on restructuring and revitalizing these institutions in the search for better conditions to support the health of the country's population. In this sense, the importance of the process of measuring these hospitals' organizational performance is accentuated. Thus, it is sought to verify to what extent and in what way such institutions have been able to organize themselves, given the reflexes of public hospital management, considering the importance of optimizing their available resources.

The implemented sequence of internships culminated in a hospital performance measurement process under students' training panorama by *HUF* medical residency programs. This fact was due to the compliance and respect with each of the defined stages, so that the input and output variables represented the constraints correlated with each other by up to 70% and, on the other hand, highly correlated to the first three principal components. In this sense, possible redundancies and variables explaining similar information were avoided, and a set of variables capable of explaining 91.69% of the total variance was obtained. In other words, it can be concluded that the general cut-off defined for this paper made it possible to achieve variables with high explanatory potential, regarding the scenario studied. This fact suggests, therefore, that there is an adequate combination of these to be part of the context of hospital performance management of federal university hospitals in Brazil.

Among the evaluated organizations, it is noted, in *HUF*20, a hospital located in the Northeastern region of the country, corresponding to only 2.2% of the *HUF*2 area. Moreover, although these hospitals were evaluated separately in the principal component analysis and cluster, it was possible to verify the formation of groups containing hospitals differing mainly in terms of their respective sizes. This fact corroborates even more with the maintenance, established here, among the hospitals participating in the analysis, of all the *HUFs* with complete data in *SIMEC/REHUF*, regardless of the type, management, unit, state, region and contractual adherence, or not, to the *EBSERH*.

Also regarding the benefits inherent in the parallel application of cluster and principal component analysis, it was possible to verify that the formation of the groups represented divergences between both techniques. Thus, it was verified that *HUFs* 2 and 12 remained alone in both cluster and PCA, demonstrating that these hospitals differentiate from the others with regards to the similarity of their characteristics described by the input and output variables, namely SIR, DH, SPMH, TE and MR. In this way, it was possible to observe, by cluster analysis, that the most homogeneous group (Group II) of *HUFs* is formed of hospitals 3, 4, 7, 8, 9, 10, 11, 13, 17, 18, 22, 24, 26 and 27, so that *HUF*2, *HUF*6, *HUF*12, *HUF*14, *HUF*20 and *HUF*25 distance themselves from this set, as well as differ from each other.

Finally, for future research, an important contribution to teaching hospitals' scenario, notably the Brazilian federal university hospitals associated with the *REHUF*, refers to a general comparison between groups resulting from the application of multivariate statistical techniques, that is, principal component analysis and cluster analysis. It was observed, through combining both models, that this process makes it possible to generate a high quantity of information, contributing with assumptions to complement the decision-making processes in organizations.

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