Composite Indicators for Performance Evaluation in Healthcare

Najada Firza(✉) and Dante Mazzitelli

Department of Economics and Finance, University of Bari "Aldo Moro", Largo Abbazia Santa Scolastica, Bari, Italy
najada.firza@uniba.it

Abstract. Key Performance Indicators (KPIs) are essential tools for assessing and ensuring high standards of quality and efficiency in the delivery of healthcare services within the National Health System. This study focuses on four critical dimensions of healthcare quality: Accessibility, Equity, Effectiveness and Efficiency each of which must be evaluated using composite KPIs that reflect their inherent complexity and interconnections.

Healthcare quality data includes a mix of quantitative and qualitative variables, often nominal or ordinal in nature, and typically involve large datasets. A major challenge is the dimensionality reduction of this complex data into a manageable set of indicators that retain meaningful insights. To address this, we employ Principal Component Analysis (PCA), a widely accepted statistical technique, alongside Exploratory and Confirmatory Factor Analysis, to identify and extract the most relevant components.

This research aims to develop a structured system of KPIs tailored to evaluate the quality and adequacy of primary care services provided by public health facilities in the Puglia Region. Through multivariate analysis specifically PCA we construct, aggregate, and weight KPIs to build a comprehensive performance evaluation model. This model is designed to highlight the relative importance of each indicator, thereby supporting evidence-based decision-making and continuous improvement in healthcare delivery.

Keywords: Composite Indicators · PCA · Factor analysis · KPI · Health Indicators · Performance Evaluation

1 Introduction

The importance of a system of indicators is given by the fact that the indicator allows us to describe and analyze complex phenomena through a synthetic evaluation of the phenomenon and to make decisions to obtain changes. Again, art. 1, paragraph 2 of the Ministerial Decree of Health of 24 July 1995 states: "the indicators represent information selected for the purpose of measuring the changes that occur in the observed phenomena and, consequently, to guide the decision-making processes of the various institutional levels". In fact, of each detected unit, they represent characteristics that can be measured

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and that are closely associated with the phenomenon of interest that is not directly measurable. A measure or a set of measures constitute an indicator of a given phenomenon when it is able to change as the aspects of the phenomenon itself vary. As is known, the issue of health care provided to protect the health of the citizen is a complex phenomenon that involves various segments of care. It is necessary to define a system of indicators, capable of bringing a fragment of knowledge, such as to compose a synthetic picture of the level of health guaranteed throughout the national territory. The indicators must also reflect compliance with the criteria of equity in access to services, effectiveness and appropriateness of the health care provided. The methodological and applicative characteristics that the indicators must have been reported as follows: Methodological characteristics of the indicators:

- Reproducible
- Accurate
- Sensitive to change
- Specific to the phenomenon investigated.

Applicative characteristics of the indicators:

1) Linked to the potential usefulness:

   - Relevant
   - Scientifically founded
   - Inserted in a decision-making model
   - Easily understandable
   - Simple, not unnecessarily complex.

2) Linked to the methods of detection:

   - Complete
   - Easily detectable
   - Inexpensive to detect and analyze
   - Timely

As for the data source, indicators can be built from current administrative or clinical data sources. While there are undoubted advantages, since the data are collected continuously, they are constantly updated, on the other hand there are some disadvantages such as relatively high costs and frequent need for sampling.

Characteristics of a Health Performance Indicator: Although a health performance indicator can often be expressed as a single numerical value, that figure encapsulates a range of specific characteristics that define its identity typically documented within a technical data sheet.

The technical sheet includes several key components, among which the most important are:

Name, Code, and Reference Year. These elements uniquely identify the indicator, ensuring it can be accurately referenced and tracked over time.

Rationale for Construction and Selection: This is a structured explanation of the reasons behind the indicator's development and the purpose it serves within the monitoring framework.

Numerator, Denominator, and Multiplication Factor: These define the formula used to calculate the indicator, clarifying its quantitative foundation.

Original Data Source: This provides transparency regarding the origin and reliability of the raw data used to derive the indicator.

Evaluation Criteria and Reference Values: These criteria enable interpretation of the indicator's value by comparing it to benchmarks or standardized thresholds, thus giving it meaningful context.

Indicators can be aggregated at various levels to reflect broader trends. Typically, these are composite indicators that synthesize several sub-indicators, allowing for comprehensive evaluations across different system dimensions such as departments, healthcare organizations, network pathways, or geographic areas (regional, national, or international). These aggregated indicators are often incorporated into structured evaluation systems and stored in dedicated reference databases for use by policymakers and decision-makers. However, a key limitation of such systems lies in their tendency to focus primarily on what is easily measurable, potentially neglecting critical aspects of management and service quality that are inherently more complex and less amenable to standardization through indicators.

2 Materials and Methods

2.1 Some Health Efficiency Indicators

The National Health Plan aims to optimize resources and improve the cost-efficiency ratio of health services. The model used to measure efficiency and assign a rate to remunerate the services provided by hospital facilities is the D.R.G. This rate reflects an estimate of the average cost of each hospitalization, based on which hospital activity is remunerated; see Annex 2 guidelines no. 1/1995 of the Ministerial Decree 14/12/1994. The D.R.G. is the acronym for Diagnosis Related Group and divides hospital admissions into homogeneous groups in which they present similar characteristics in terms of resource consumption and similar care loads. To measure the complexity of the caseload of each acute hospital facility in relation to a reference standard, the case-mix index is used, which can be expressed either in economic terms (following the directives of Annex 2 to the Guidelines no. 1/1995, issued in application of the Ministerial Decree 14/12/1994 and published in the Official Journal, general series, no. 150 of 29/06/1995), or in terms of hospital resources. The first formulation is therefore

$$ICM_{hr} = \frac{\sum_{d=1}^{D} (a_d \cdot N_{dh}) \Big/ \sum_{d=1}^{D} N_{dh}}{\sum_{d=1}^{D} (a_d \cdot N_{dr}) \Big/ \sum_{d=1}^{D} N_{dr}}$$

where:

D = total number of entries in the tables of the current D.R.G.;

ad = specific weight relative to each D.R.G.;

Ndh = discharged patients belonging to the d-th D.R.G. in the h-th healthcare institution; Ndr = discharged patients belonging to the d-th D.R.G. in the r-th region.

Each specific weight relative to ad indicates the care complexity in terms of consumption of resources associated with the D.R.G. and therefore can be used to indicate the complexity of the pathology in question.

In these terms, the D.R.G. with ad $< = 1$ are generally associated with pathologies of low care complexity. Taking into account that the specific weights of the D.R.G. are calculated on the basis of standardized cost parameters, therefore, the Case-Mix index is given by the quotient between a "cost-output" indicator relating to the healthcare institution under observation and the same "cost-output" indicator relating, however, to the entire territory in which the hospital service is institutionally required to operate. This is a relative index, with a range of variation [0,1], where the upper limit is reached if and only if the healthcare institution considered is the only one to provide the service to which the h.th D.R.G. refers.

The second formulation of the case-mix index is instead the following:

ICM = average weight of the single unit/standard average weight where: average weight of the single unit = sum of weights/total hospitalizations in the unit;

standard average weight = sum of weights/total hospitalizations in the context.

If the case-mix index is greater than 1, the hospital structure's caseload is more complex than the standard, while if the case-mix index is less than 1, it indicates that the caseload is less complex than the standard. In this research, reference will be made to the second formulation. As regards the classic indicators or flow indicators that express the efficiency of hospital structures, they originate from three basic phenomena:

- admissions in a given period
- the total number of days of hospitalization
- the number of beds.

The first four classic reference indicators are:

- the average hospital stay, which defines the days on which on average a patient is hospitalized in a given hospital structure, and is calculated by comparing the total days of hospitalization and the admissions in the same period (DM = GD / R);
- the bed occupancy rate, obtained as the ratio between actual hospital days and theoretical hospital days per period and is expressed as a percentage (TU = GD / GD* %); - the bed rotation index, which is calculated by the ratio between the total number of hospitalizations and the available beds (Ir = R / PL), and provides in detail the number of patients who have occupied a single bed;
- the turn-over interval, calculated by comparing the difference between theoretical and actual hospital days to the total number of hospitalizations:

$$\mathrm{IT} = (\mathrm{GD} * - \mathrm{GD}) / \mathrm{R} = (365 \cdot \mathrm{PL} - \mathrm{GD}) / \mathrm{R}$$

These indicators are used to construct the Barber nomogram, a graphic analysis that allows the comparison between indicators, thus building a comparison metric between different facilities or services provided in the same hospital facility related to time. Specifically, Barber's nomogram is nothing more than a graphic representation using the Cartesian axes system, in which we will find the turnover index placed on the abscissa axis and the average hospital stay placed on the ordinate axis. In this graphic context, the occupancy index and the bed rotation index further divide the plan. In the plan thus

divided, an acceptability area is identified depending on the objectives that the hospital unit sets itself.

2.2 Data Collection

The reference data set is characterized by 38 public hospitalization health facilities in the Puglia Region, within which 523 departments are distributed, classified according to the province they belong to, as can also be seen in table 1. From the data in the table, we note that there is a homogeneous distribution of health facilities in the territory with an average of approximately 5 facilities per province. The exception is the province of Bari with 12 facilities. Furthermore, as regards the departments, we note a greater concentration in the province of Bari with 31%, Lecce with 21% and Foggia with almost 20%. Finally, the province of Brindisi has the lowest number of departments (48) distributed in the territory. Classifying the departments according to the disciplines they deal with, we can state that there are 44, catalogued and distributed in the Region. The departments that we find most in the area are: General Surgery (36 units), Cardiology (34 units), General Medicine (34), Orthopedics and Traumatology (34), Obstetrics and Gynecology (34), Pediatrics (30) and finally Coronary Unit (30) (Table 2).

Table 1. Distribution of the hospitals in the territory, divided into Departments.

Province affiliation ASL	Hospitals	Departments	%
ASL BA	12	162	31
ASL BR	4	48	9,2
ASL BT	4	50	9,6
ASL FG	6	102	19,5
ASL LE	7	109	20,8
ASL TA	5	52	9,9
Total	38	523	100

Source: National Sanitary Informative system, 2019.

Another interesting piece of information that we can draw from a first descriptive analysis of the data is the singularity of some Departments which are located in a single point of the territory, this is the case of the following Departments: Pediatric Cardiac Surgery, Pediatric Nephrology, Pediatric Urology which are located only at the Policlinico of Bari, the Dentistry and Stomatology department is located only in Acquaviva delle Fonti (Bari), the Radiology department is located in San Giovanni Rotondo (Foggia) and finally the Spinal Unit is located in Cassano delle Murge (Bari).

Table 2. Distribution of the hospitals in the territory, divided into Departments.

	PROVINCE						
DEPARTMENT	BR	TA	BT	BA	FG	LE	APULIA
Paediatric Cardiac Surgery	0	0	0	1	0	0	1
Cardiac Surgery	0	0	0	1	1	1	3
Cardiology	3	4	4	10	6	7	34
General Surgery	3	5	4	11	6	7	36
Maxillo-Facial Surgery	0	0	0	1	1	1	3
Paediatric Surgery	0	0	0	1	2	1	4
Plastic Surgery	1	0	1	2	1	1	6
Thoracic Surgery	0	0	0	2	2	1	5
Vascular Surgery	1	1	0	3	1	1	7
Haematology	1	1	1	2	2	2	9
Endocrine Diseases	1	1	0	2	2	1	7
Geriatrics	1	1	1	4	2	3	12
Infectious/ Tropical Diseases	1	1	1	2	1	2	8
General Medicine	3	5	4	9	6	7	34
Spinal Unit	0	0	0	1	0	0	1
Nephrology	2	3	2	6	4	4	21
Neurosurgery	1	1	1	2	2	1	8
Neurology	1	1	2	5	2	3	14
Child Neuropsychiatry	0	0	0	1	1	0	2
Ophthalmology	1	1	2	5	3	2	14
Dentistry and Stomatology	0	0	0	1	0	0	1
Orthopaedics and Traumatology	3	5	4	9	6	7	34
Obstetrics and Gynaecology	3	5	4	9	6	7	34
Otolaryngology	1	1	2	5	3	2	14
Paediatrics	3	4	4	7	5	7	30
Psychiatry	2	1	2	4	3	4	16
Urology	1	2	2	5	3	4	17
Large Burns	1	0	0	1	0	0	2
Intensive Care	1	1	3	7	4	4	20
Coronary Unit	2	3	3	9	6	7	30
Dermatology	1	0	0	2	2	1	6

(*continued*)

Table 2. (*continued*)

	PROVINCE						
DEPARTMENT	BR	TA	BT	BA	FG	LE	APULIA
Recovery and Rehabilitation	1	0	0	4	3	2	10
Gastroenterology	0	0	1	4	3	2	10
Long-Term Patients	2	2	1	5	2	5	17
Neonatology	1	1	0	3	2	2	9
Oncology	1	1	1	3	1	3	10
Paediatric Oncology	0	0	0	0	1	1	2
Pneumology	2	0	0	7	2	4	15
Radiotherapy	0	0	0	0	1	0	1
Rheumatology	0	0	0	1	1	0	2
Neonatal Intensive Care	1	1	0	3	2	2	9
Neurorehabilitation	2	0	0	0	1	0	3
Paediatric Nephrology	0	0	0	1	0	0	1
Paediatric Urology	0	0	0	1	0	0	1
TOTAL	48	52	50	162	102	109	523

2.3 Principal Component Analysis

Key Performance Indicators KPI are a set of indicators that measure the efficiency, level and quality of services in general. They are used to define the value of the service offered as a whole. With this method, a global set of information is identified, capable of optimally evaluating the performance and competitiveness of a given service or process under all characterizing aspects, maintaining a small number of components. In order to reflect the characteristics of the KPI, the Principal Component Analysis method is used [1, 2]. Principal Component Analysis (PCA) is an accredited methodology in multivariate analysis to study, summarize and simplify a set of observed features, reducing the complexity of the data through linear combinations of the same [3]. The two essential conditions for carrying out this operation are that:

– Each main component is attributed to the maximum overall variability of the system; - The main components created are independent of each other.

This work aims to create a definition of efficiency of the system subject to the data in our possession, for this reason we are going to calculate a synthetic indicator that provides the importance to the original indices and assigns them weights. Once we have divided the indicators and assigned them weights, we divided them by departments and hospital structures in order to carry out an analysis of the distribution of these indicators [4]. The starting indicators are seven:

– ICM

– Entropy Index
– Beds used/beds available
– Bed occupancy rate
– Turnover interval
– Department utilization rate
– Day hospital admissions/total admissions

We have opted for the normalization of the indicators so that they have the same range of oscillation and consequently assume equal weights within the construction of a synthetic index (Table 3).

Table 3. Total variance explained by the principal components analysis method and results of the subsequent Factor analysis.

	PCA: Extracted eigenvalues			Factor Analysis: Rotated eigenvalues		
Component	Total	% of variance	Cumulate % of variance	Total	% of variance	Cumulate % of variance
1	1.549	25.82	25.82	1.519	25.32	25.32
2	1.354	22.57	48.39	1.381	23.01	48.33
3	1.142	19.03	67.42	1.145	19.09	67.42
4	*0.821*	*13.68*	*81.10*			
5	*0.703*	*11.71*	*92.81*			
6	*0.431*	*7.19*	*100.00*			

Through the analysis of principal components, the 7 indices were examined. We proceeded to identify the indices with a commonality greater than or equal to 0.51 and consequently, using the backward stepwise method we eliminated the indices with poor commonality (<0.51).

In this way we have preserved a set of 4 indices connected to 2 principal components. The two principal components have eigenvalues greater than 1, therefore they are able to explain more variability than the indices that compose them. We also note that the two eigenvalues explain about 80% of the variance. To have better, more robust results and to obtain the solution that interprets the results in a better and simpler way, we started a factor analysis through Varimax orthogonal rotation of the identified principal components [5]. The rotated component matrix is almost identical to the non-rotated component matrix, the results obtained do not improve the model with the rotation. In this way, two distinct ACPs were identified and selected which allowed us to identify the importance of the indices observed within each correlation structure, to identify the existence of significant relationships between them and the latent variables that can best explain the observed phenomenon. We proceeded with the analysis because the Bartlett sphericity test is very significant ($p < 0.0000002$).

Table 4. Factor weights and commonality of the indicators that make up the synthetic performance indicator.

	Factors			
Indicators	Resources efficiency	Organizational efficiency	Internal effectiveness	*Communalities*
Average Length of Stay	–0.824			*0.683*
Rotation Index	0.769			*0.597*
Bed Occupancy Rate		0.827		*0.713*
Outpatient / Inpatient Rate		0.824		*0.703*
Entropy Index			0.733	*0.674*
Standardized HMQ			–0.744	*0.676*

The factorial weights resulting from the previous factorial analysis (Table 4) identify the nature of the three latent dimensions of the healthcare performance in Apulia:

- resources efficiency (explaining 25.3% of the total variance)
- organizational efficiency (23.0% of the total variance)
- internal effectiveness (19.1% of the total variance).

The last column of Table 6 shows the communalities of the selected variables, that is, the proportion of their variance explained by the factorial system. They are all sufficiently high to imply that the factorial solution is reliable.

2.4 Construction of Key Performance Indicators (KPI)

The Key Performance Indicators (KPI) are defined, in general, as a set of indicators measuring the efficiency, the level and the quality of services. Such indicators are used to define the value of the whole service or the success of an organization [6].

This method identifies a global set of information, able to assess optimally the performance and competitiveness of a specific service or process. The characterizing aspects are kept, but a lot of information in the data are excessive and should be removed.

The KPI is defined as a synthetic indicator with specific weights given to each index, computed as follows for each department of each health facility:

$$KPI = \frac{\sum_{i=1}^{N} w_i x_i}{\sum_{i=1}^{N} w_i}$$

where z_i: standardized value of the elementary index i;

w_i: weights attributed to each elementary indices.

Here the KPI (defined as a synthetic indicator with specific weights given to each index) is built by using the Factorial Analysis findings, giving w_i = communality of each original variable multiplied by the sign of its main factorial weight.

Therefore, the empirical formulation of KPI for the Apulian health facilities is:

$$KPI = \frac{-0,683z_1+0,597z_2+0,713z_3+0,703z_4+0,674z_5-0,676z_6}{-0,683+0,597+0,713+0,703+0,674-0,676}$$

This formula highlights those increments of Average Length of Stay, as well as increments of Standardized Hospital Mortality Quotient, cause the worsening of the healthcare department/facility performance. This is surely a correct outcome.

All things being equal, the KPI here computed can be used to assess also the performance of elementary units and any combination of them, in this case each hospital department, each healthcare facility or each territorial area.

Thus, aggregating the KPI of healthcare departments and hospitals according with the Apulian provinces[1], the Table 5 is obtained. The table highlights that healthcare facilities in the province of Brindisi have a minimum KPI, so here organizational changes are required urgently, while the best results are obtained by the structures of the provinces of Foggia and B.A.T.

Table 5. Final computing steps of provincial and regional KPI of Apulian healthcare facilities in 2019.

	Sum of		
Provinces	KPI_j*$Admissions_j$	Admission	KPI
Bari	42,041.71	143,039	0.294
Barletta-Andria-Trani	19,332.34	35,160	0.550
Brindisi	113.53	36,173	0.003
Foggia	55,738.53	99,467	0.560
Lecce	37,273.03	83,666	0.445
Taranto	13,555.39	37,836	0.358
Apulia	168,054.53	435,341	0.386

3 Conclusion

The construction of a composite Key Performance Indicator (KPI) for Apulian healthcare facilities has enabled a standardized, data-driven evaluation of departmental and territorial performance across the region. By applying Factorial Analysis to assign weights

[1] The KPI of each department of each structure is initially weighted for admissions recorded in itself, and then the sum of these values is divided, for each territorial area, the relative number of admissions.

based on the communalities and dominant factor loadings of original variables, the resulting KPI effectively captures the multidimensional nature of healthcare service quality.

The model's sensitivity to critical factors such as Average Length of Stay and Standardized Hospital Mortality Quotient reinforces its validity, as increases in these variables appropriately correspond to poorer performance outcomes. Furthermore, the KPI proves flexible and scalable, allowing performance assessment at multiple levels: from individual departments to entire facilities and provincial systems.

The application of this methodology in the Apulia Region reveals significant variability in healthcare performance. Notably, Brindisi shows the lowest KPI, indicating an urgent need for organizational intervention, while Foggia and B.A.T. provinces achieve the highest scores, suggesting more effective resource allocation and operational efficiency.

This KPI framework not only provides a robust tool for comparative analysis but also serves as a foundation for targeted improvements and strategic planning in regional healthcare systems.

The results of this work demonstrate the importance of statistical techniques in order to derive information from data of a different nature and optimize their use.

The Factor Analysis (by using PCA) allowed us to take off the less relevant indicators, leading to a division into three groups of performance indicators. The first group (dimension) is composed by resources efficiency indicators, while the second group is composed by organizational efficiency indicators, and the third one is composed by internal effectiveness indicators.

The construction of performance indicators, especially in health services, is a practice of significant utility, not only to use a strategy of spending review in the provision of specific services but mainly to rationalize working methods of projecting to the results. The synthetic index KPI was built weighting each relevant indicator according with specific weights that are obtained from the Factorial Analysis.

The proposed model can be used for the efficient and profitable management of health departments and whole hospitals, paying attention also to the wellbeing of admitted patients.

This scientific study, however, is still experimental, and it was applied to non-date data. In the further developments this method will be finalized based on the latest data, and then their dynamics over time will be verified, as part in designing of a more complete performance measurement system. Potential developments include the integration of clinical outcome and user satisfaction indicators and the use of the model as a support for regional decision-making.

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