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Evaluating Healthcare Efficacy: An Exploration Of Grey Relational Analysis And COCOSO In MCDM Framework

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ARTICLE INFO | **ABSTRACT**

The growing intricacies and demand for enhanced care quality in the healthcare sector necessitate robust performance evaluation mechanisms. This study embarks on a comprehensive assessment of healthcare organizations employing three sophisticated Multi-Criteria Decision Making methods. The Mahalanobis distance based GRA TOPSIS, along with Combined Compromise Solution (CoCoSo) is applied in this study.This study underpins the importance of a tailored approach to healthcare organization performance evaluations and provides decision-makers with robust tools tailored for evaluative needs by considering the case study of Twenty Healthcare organization in Andhra Pradesh, India. Also, in order to evaluate the correctness of ranking of the proposed methods, Spearman, Kendall and Rank-Biased Overlap (RBO) are considered as ranking consistency indices.

Keywords: MADM, GRA TOPSIS, CoCoSo

1. INTRODUCTION

The rapidly shifting dynamics of the healthcare sector underscore the urgency for reliable and thorough performance evaluations of healthcare organizations. Such evaluations, given the multitude of intertwined variables at play, require an approach that is both holistic and adaptable. As healthcare facilities grapple with the twin challenges of delivering exemplary patient care and maintaining operational efficiency, they need analytical tools that can seamlessly navigate the complex terrain of healthcare metrics. The realm of Multi-Attribute Decision Making (MADM) offers a promising avenue, with methods such as GRA TOPSIS, Mahalanobis distance based GRA TOPSIS, and CoCoSo (Combined Compromise Solution) standing out for their applicability and depth.

GRA TOPSIS integrates the principles of Grey Relational Analysis with the classical TOPSIS method, facilitating evaluations especially in environments where information might be incomplete or uncertain, as often encountered in healthcare. The method efficiently caters to the multifaceted criteria involved in healthcare performance, offering rankings grounded in both relational coefficients and proximity to ideal solutions.

Mahalanobis Distance based GRA TOPSIS enhances the traditional GRA TOPSIS approach by incorporating the Mahalanobis distance, a measure adept at recognizing and accounting for correlations among variables. By doing so, the method provides a nuanced performance ranking, capturing the inherent complexities of healthcare data and its attributes.

CoCoSo method was developed recently by Yazdani et al. (2019) which is based on two common approaches namely weighted sum model (WSM) and exponentially weighted product model. This method develops three different appraisal scores to evaluate the alternatives. Thus, a final coefficient combining these scores is calculated to obtain more robust results.

To encapsulate, evaluating the performance of healthcare organizations is a multifaceted endeavor, demanding both analytical precision and an intuitive grasp of the healthcare landscape. Through methodologies like GRA TOPSIS, Mahalanobis distance based GRA TOPSIS, and CoCoSo, this evaluation is transformed from an intricate puzzle to a guided journey, charting a course towards healthcare excellence.

For any MCDM method to be reliable, its ranking results should be consistent. This means that with similar input datasets or slight variations, the method should produce similar rankings. Consistent rankings give decision-makers confidence in the method's robustness. Moreover, when comparing the outcomes of various

MADM methods consistency across methods require affirm the consistency of the decisions derived from these rankings.

In this context, there's a need for metrics to assess the similarity and dissimilarity of ranked lists. Three popular methodologies in this regard are the Rank-Biased Overlap (RBO), Pearson's correlation coefficient, and Kendall's Tau. Each offers a unique lens to view and evaluate rank similarity.

Kendall's Tau: Measures the consistency between two rankings by comparing the number of pairs that are in the same order to the number that are in a different order.

Spearman's Rank Correlation Coefficient: It evaluates the strength and relation of direction and the association between any two ranked variables.

Rank-Biased Overlap (RBO): RBO provides a measure that combines the evaluation of top-ranked items with a gradual consideration of the items' depth in the rank

2. LITERATURE REVIEW

Amer et al (2022) made a scientific analysis to discover all the balanced scorecard perspectives which are mostly used in the healthcare sector. Lizarondo et al (2014) made a literature review on performance evaluation under different dimentions and evolved a complete picture of health care sector.Yasar (2008) attempted the Performance evaluation benchmarking methods in health care systemusing Data Envelopment Analysis (DEA).Vainieri et al (2019) did his work on the relationship between top management parameters, information distribution, and organizational efficiency in public health care system. Their work indicated that managerialabilities have high positive influence with the organizational efficiency.Hamilton et al (2007) explored the documentary evidence on the use of performance assessment in health care professionals. Their study, concluded theproposing a multi-method approach to assure effective nursing and midwifery practice.Izadi, et al (2017) evaluates exisisting performance and determines each item's role from the patients' angle through questionnaire using importance performance analysis. From the study, it as observed that tangibility was proved to be by priority as highest and reliability was proved to be by the performance as highest and the Social accountability was proved to be important wise as lowest and also same is the case for performance . Brahim and Youness (2021) have experimented a thematic analysis on the work already researched world wide in case of performance measurement framework on healthcare. The authors confirmed that measurement of performance was in nauseant stage in most of the most organizations.Cheng et al (2023) investigatedorganization efficiency of provincial health-care system in China, by adopting a dynamic network data envelopment analysis (DEA) approach.Their work, attempted to discover the changes in static efficiency and dynamic efficiency Karadayi et al (2014) proposed Fuzy TOSIS and Fuzzy VIKOR for health-care performance assessment. The authors did a comparative analysis toevaluate the health-care performance of six regions in Istanbul.Akdag et al (2014) aggregated using OWA and Compensatory AND operator for measurement of service performance of Turkish hospitals. Santonab Chakraborty et al (2023) reviewed 140 journal articles published in the period 2013-2022 on the area of decision making in health care sector using MCDM methods. It was found subsequently that Healthcare quality evaluation is diversified into 11 application areas. The authors concluded that their study helped the people working in the area health care sector how to apply different MCDM tools in addressing problems in decision making in health care areas. Ahmed El-Araby et al (2022) adopted MCDM methods namely: TOPSIS, EDAS, GRA, CoCoSo methods for evaluation of facility location problem with a numerical example. In a conclusion, it was observed that GRA method has the lowest correlation coefficient especially with CoCo Somethod. among the methods. TOPSIS and EDAS methods has a very strong relation on basis of the spearman`s correlation value. Nemati et al (2020) attempted to compare hospital service quality depended on the HEALTHQUAL model and considering nurses"s trust at university and non-university hospitals in Iran.The data wasgeneratedvia the HEALTHQUAL questionnaire and the Trust in Nurses Scale, and then examinedusing the SPSS. The study concluded that hospital managers and policy-makers have to concentrate on patients to reduce gaps in service quality, and will be able to provide better healthcare services to patients.Quan et al (2019) made aevaluation of different methods like the KE-GRA-TOPSIS, KE-TOPSIS, KE-GRA, GRA-TOPSIS, and TOPSIS and demonstrated the salient merits of the KE-GRA-TOPSIS method in Kanseicomputation using a numerical example of elecrical drill equipment. Dong et al (2022) have concluded that Mahalanobis Distance has enhanced the quality of Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) method when it is coupled with the Grey Relational Analysis (GRA) for evaluation of Thermal Power Generation units in China. Özcan and Çelik (2020) have adopted entropy method and integrated into TOPSIS , GRA and COPRAS methods to compute 7 alternative products and 7 criteria for milk processing. Zhang et al (2021) have simulated the consistency of ranking of six typical multiple attribute decision making methods (SAW,PROMETHEE, TOPSIS, GRA, ELECTREE and VIKOR) using Correlaion, Kendall index and RBO index.

3. PERFORMANCE EVALUATION OF HEALTHCARE ORGANIZATIONS

The healthcare sector's pivotal role in ensuring societal well-being necessitates rigorous and systematic evaluation mechanisms. Assessing the performance of healthcare organizations provides stakeholders with essential insights into the efficiency, effectiveness, and quality of healthcare services delivered. In the intricate world of healthcare, where multiple parameters influence outcomes, methodologies like GRA TOPSIS, Mahalanobis Distance based GRA TOPSIS, and CoCoSo (Combined Compromise Solution) emerge as significant tools for such evaluations. The proposed methods are discussed in the following sections.

3.1 GRA-TOPSIS

Chen and Tzeng (2004) proposed integrated GRA-TOPSIS to calculate thealternatives performance. In this integrated method the first step is construct a PIS and NIS through the TOPSIS method. In the second step is adopting GRA to evaluate the gray correlation degree. The third step isto evaluate the Euclidean distance by TOPSIS. Then the fourth step is aggregation of the gray correlation degree and the Euclidean distance to get the closeness (Tang et al., 2019). And as per the closeness, the alternatives are graded. The entire procedure shown below in different steps.

Step 1: Building the decision matrix

The decision matrix is generated by considering the alternatives and criteria. In this study, Case study of 20 healthcare organizations are considered as alternatives and 37 measuring items as developed by the author (Bhanutej and Kesava rao, 2023) are considered as criteria

Step 2: Calculate the decision matrix which is weighted

Determine the weights of the criteria through CRITIC method. The weighted decision matrix is determined through following relation.

$z_{ij} = r_{ij} w_j$ (i= 1,2,......,m; j = 1,2,......,n;)

w_j=weight of the jth criteria

Step 3: Determine the Ideal Solutions

The ideal solutions comprises of the PIS $A^+ = (z^+_1, z^+_2, \ldots, z^+_n)$ and NIS $A^- = (z^-_1, z^-_2, \ldots, z^-_n)$. They are evaluated by the following Equations

$z_j^+ = \max z_{ij}$ (i= 1,2,......,m; j = 1,2,......,n;)

$z_j^- = \min z_{ij}$ (i= 1,2,......,m; j = 1,2,......,n;)

Step 4: Determination of the separation of each alternative

Evaluation of extent of separation of each alternative from the PIS and NIS. Euclidean distance is used to determine same using the following relation shown below.

$$D_i^+ = \left\| z_i - A^+ \right\|_2 = \sqrt{\sum_{j=1}^{n} \left(z_{ij} - z_j^+ \right)^2} \quad (i= 1,2,....,m)$$

$$D_i^- = \left\| z_i - A^- \right\|_2 = \sqrt{\sum_{j=1}^{n} \left(z_{ij} - z_j^- \right)^2} \quad (i= 1,2,....,m)$$

where D^+_i shows the separation of each alternative from Ai and A^+. D^-_i shows the separation of each alternative from Ai and A^-.

Step 5: Evaluating the grey relational coefficients.

The grey relational coefficients are determined by the following relation shown below

$$v_{ij}^+ = \frac{\min_i \min_j \left| z_j^+ - z_{ij} \right| + \rho \max_i \max_j \left| z_j^+ - z_{ij} \right|}{\left| z_j^+ - z_{ij} \right| + \rho \max_i \max_j \left| z_j^+ - z_{ij} \right|}$$

$$v_{ij}^- = \frac{\min_i \min_j \left| z_j^- - z_{ij} \right| + \rho \max_i \max_j \left| z_j^- - z_{ij} \right|}{\left| z_j^- - z_{ij} \right| + \rho \max_i \max_j \left| z_j^- - z_{ij} \right|}$$

where ρ is the distinguishing coefficient, ρ [0, 1]; ρ = 0.5 is taken

Step 6: Compute the grey relational degree

The grey relational degrees are determined from the following Equations.

$$v_i^+ = \frac{1}{n} \sum_{j=1}^{n} v_{ij}^+ \quad (i= 1,2,....,m)$$

$$v_i^- = \frac{1}{n} \sum_{j=1}^{n} v_{ij}^- \quad (i= 1,2,....,m)$$

Step 7: Determine dimensionless processing parameters

The dimensionless processing parameters are determined from the following relations

$$s_i^+ = \beta \frac{D_i^+}{\max\left(D_i^+\right)} + \gamma \frac{v_i^+}{\max\left(v_i^+\right)} \quad (i= 1,2,....,m)$$

$$s_i^- = \beta \frac{D_i^-}{\max\left(D_i^-\right)} + \gamma \frac{v_i^-}{\max\left(v_i^-\right)} \ (i = 1,2,....,m)$$

where β representsthe coefficient of influence of the distance between alternative to the ideal solution on the closeness. γ represents the coefficient of influence of the grey relational degree between the alternative and the ideal solution on the closeness. β, γ [0, 1], β + γ = 1.

Step 8: Calculate the closeness coefficient and grading of the alternatives.

The closeness coefficient of each alternative is determined from the following relation.

$$C_i = \frac{s_i^+}{s_i^+ + s_i^-} \ (i = 1,2,....,m)$$

If the alternative Ai is nearer to A + and away from A −, then Ci is more approximate to 1 and it can be considered as the best- among all alternatives

3.2 Mahalanobis Distance based GRA-TOPSIS: The methodology is explained in the steps below

Step 1: Constructing the decision matrix

Construct the decision matrix as discussed in step 1 of section 3.1

Step 2: determine the decision matrix which is weighted

Develop the decision matrix which is weighted as discussed in step 2 of section 3.1

Step 3: Calculate the Ideal Solutions

The Ideal solutions which are both Positive and negative are calculated as discussed in step 3 of section 3.1

Step 4: Determine the Mahalanobis Distance

Determine Mahalanobis distance from the following relations.

$$d\left(z_i, Z_0^+\right) = \sqrt{\left(z_i - Z_0^+\right) \sum^{-1} \left(z_i - Z_0^+\right)^T}$$

$$d\left(z_i, Z_0^-\right) = \sqrt{\left(z_i - Z_0^-\right) \sum^{-1} \left(z_i - Z_0^-\right)^T}$$

Where, ∑-1 is the inverse of the covariance matrix ∑ of n attribute variables

Step 5: Calculating the grey relational coefficients.

Grey relation coefficients are determined as discussed in step 5 of section 3.1

Step 6: Compute the grey relational degree

Grey relation degrees are determined as discussed in step 6 of section 3.1

Step 7: Determine Normalized Mahalanobis distances

Normalized Mahalanobis distances from the following relations.

$$D_i^+ = \frac{d_i^+}{\max_i d_i^+}$$

$$D_i^- = \frac{d_i^-}{\max_i d_i^-}$$

Step 8: Determine Normalized grey relation degrees

Normalized grey relation degrees from the following relations

$$S_i^+ = \frac{s_i^+}{\max_i s_i^+}$$

$$S_i^- = \frac{s_i^-}{\max_i s_i^-}$$

Step 9: Derive dimensionless Mahalanobis Distance and grey relational degree

Derive above mentioned items from the relations shown below.

$$E_i^+ = \alpha D_i^- + \beta S_i^+$$

$$E_i^- = \alpha D_i^+ + \beta S_i^-$$

Step 10: Obtain closeness coefficient which is Relative

It is derived from the following relation.

$$\gamma_i = \frac{E_i^+}{E_i^+ + E_i^-} \ (i = 1,2,....,m)$$

Grade the alternatives depending on the value obtained from the above relation

3.3 Combined Compromise Solution (CoCoSo)

Step-1: Obtain decision matrix:
Decision matrix is obtained as discussed in step 1 of section 3.1
Step 2: Obtain the weights relating to the criteria
Determine the weights of the criteria through CRITIC method
Step 3: Find weighted sums of comparable sequence scores (S_i)
Weighted sums of comparable sequence scores are determined from the following relation

$$S_i = \sum_{j=1}^{n} \left(w_j r_{ij} \right)$$

Step 4: Find exponentially weighted product of comparable sequence scores (P_i)
Exponentially weighted products of comparable sequence scores are determined from the following relation

$$P_i = \sum_{j=1}^{n} \left(r_{ij} \right)^{wj}$$

Step 5: Find Arithmetic mean of sums of scores
Arithmetic means of sums of scores are determined from the following relation

$$K_{ia} = \frac{S_i + P_i}{\sum_{i=1}^{m} \left(S_i + P_i \right)}$$

Step 6: Find Sum of relative scores compared to the best
Comparison of the Sum of relative scores to the best are determined using the following relation

$$K_{ib} = \frac{S_i}{\min_i S_i} + \frac{P_i}{\min_i P_i}$$

Step 7: Find balanced compromise of scores
Balanced compromises of scores are determined from the following relation

$$K_{ic} = \frac{\lambda S_i + (1-\lambda) P_i}{\lambda \max_i S_i + (1-\lambda) \max_i \mathrm{P}_i}, \lambda \in [1,0]$$

Lambda=Compromise coefficient

Step 8: Evaluate Final ranking of Alternatives
Final Scores of the alternatives are determined by taking sum of Geometric means and arithmetic means of sums of scores, Sum of relative scores compared to the best and balanced compromise of scores. These scores are determined from the following formulae.

$$T_{ia} = \frac{S_i + P_i}{\sum_{i=1}^{m} \left(S_i + P_i \right)}$$

$$T_{ib} = \frac{S_i}{\min_i S_i} + \frac{P_i}{\min_i P_i}$$

$$T_{ic} = \frac{\lambda S_i + (1-\lambda) P_i}{\lambda \max_i S_i + (1-\lambda) \max_i \mathrm{P}_i}, 0 \le \lambda \le 1$$

Calculate the score value T_i using

$$T_i = \left(T_{ia} T_{ib} T_{ic} \right)^{1/3} + \frac{T_{ia} + T_{ib} + T_{ic}}{3}$$

The alternatives are graded based on the final score in decreasing order.

4. CASE STUDY

In the ever-evolving landscape of healthcare, it becomes imperative for stakeholders to evaluate healthcare organizations based on multiple criteria to ensure efficient, effective, and quality patient care. This study aims to evaluate 20 healthcare organizations based on 37 criteria using three different methods. The 37 criteria proposed by the author encompass various dimensions of healthcare quality. The criteria are presented below.

Table 1: List of Criteria

Construct	Measurement Variable
Empathy	employee politeness (EY1)
	Providing details (EY2)
	pay attention to the patient (EY3)
	Recognize and take into account the patient's circumstances (EY4)

Construct	Measurement Variable
	A feeling of proximity and kindness (EY5)
	Hospital is aware of the patient's preferences (EY6)
	The medical facility has empathy for the patient's issues. (EY7)
Tangibles	level of security for sophisticated medical equipment (TA1)
	degree of securing skilled and knowledgeable medical personnel (TA2)
	Amount of practical amenities (TA3)
	Cleaning level of employee uniforms (TA4)
	general cleanliness of the medical facility (TA5)
Safety	The degree to which a therapeutic setting is both cosy and secure (SAl)
	Amount of confidence in medical professionals to avoid mistake (SA2)
	The extent to which nurses are seen to be error-free (SA3)
	Level of assurance regarding this hospital's medical expertise (SA4)
	The degree to which a hospital setting is immune to infection (SA5)
	Patients' level of comfort and safety in the surroundings (SA6)
Efficiency	beliefs towards the avoidance of needless medicine (EF1)
	Efforts made to demonstrate effective treatment options (EF2)
	Affordable medical costs (EF3)
	Cost for medical series prodded is appropriate (EF4)
	Comfort level of treatment procedures (EF5)
	Efforts made to cut out on unneeded procedures (EF6)
Degree of improvement	Efforts made to cut out on unneeded procedures (D1)
	Gratitude and support for the medical staff's finest efforts (D2)
	As a consequence of work and therapy, one's health has improved (D3)
	Degree of patient condition improvement following this hospital treatment (D4)
	Level of justifications for the patent to stop associated sickness (D5)
	Effort level and readiness to prevent disease (D6)
	Disease improvement as a result of care at this hospital (D7)
	Communities' levels of disease prevention (D8)
Operational Performance	Availability of Beds (OP1)
	Waiting time of the Patients (OP2)
	Loyalty of the patients (OP3)
	Length of Stay (OP4)
	Cost of Treatment (OP5)

Each criterion was measured using a 1-5 Likert scale through a questionnaire survey. The study's target population was private hospitals in Andhra Pradesh, India. In the beginning, 400 questionnaires were handed to patients in 50 hospitals in Andhra Pradesh. Out of these, 350 were returned, with 56 being removed due to mistakes. As a result, in the final analysis 294 questionnaires were utilized, yielding a satisfactory of 73.5% response rate. The respondents are asked answer the questionnaire based on their perception on 37 criteria. Each criterion was measured using a 1-5 Likert scale through the questionnaire survey. Descriptive statistics are presented below.

Table 2: Descriptive statistics

Variable	Total	Mean	St.Dev	Min	Max	Variable	Total	Mean	St.Dev	Min	Max
EM1	294	3.1395	1.4397	1	5	EF2	294	3.0612	1.4177	1	5
EM2	294	3.0306	1.4054	1	5	EF3	294	3.017	1.4056	1	5
EM3	294	3.051	1.3170	1	5	EF4	294	3.0782	1.4084	1	5
EM4	294	2.9422	1.4142	1	5	EF5	294	3.085	1.4177	1	5
EM5	294	2.9592	1.4112	1	5	EF6	294	3.0952	1.4278	1	5
EM6	294	3.0612	1.3934	1	5	DI1	294	2.932	1.4174	1	5
EM7	294	2.8946	1.4115	1	5	DI2	294	3.034	1.4041	1	5
TAI	294	3.0272	1.4544	1	5	DI3	294	3.0102	1.4345	1	5

TA2	294	3.0646	1.4983	1	5	DI4	294	2.9456	1.4419	1	5
TA3	294	3.0272	1.4067	1	5	Dl5	294	3.0782	1.4419	1	5
TA4	294	3.0238	1.4439	1	5	DI6	294	3.1565	1.4438	1	5
TA5	294	2.8912	1.4340	1	5	Dl7	294	3.0714	1.3720	1	5
SA1	294	3.0884	1.3369	1	5	DIS	294	2.949	1.4048	1	5
SA2	294	2.9558	1.3928	1	5	OPl	294	2.9796	1.3873	1	5
SA3	294	2.9116	1.4187	1	5	OP2	294	2.9796	1.4237	1	5
SA4	294	2.9218	1.3616	1	5	OP3	294	3.0374	1.4341	1	5
SA5	294	3.0816	1.4094	1	5	OP4	294	3.0442	1.4123	1	5
SA6	294	2.966	1.4425	1	5	OP5	294	2.9048	1.4421	1	5
EF1	294	3.2585	1.4338	1	5						

The decision matrix is obtained by taking the average response from the respondents of the healthcare organization on the criteria.

5. ILLUSTRATION OF THE PROPOSED METHODS

The proposed methods are illustrated by considering the case study as discussed in section 4.

5.1 GRA-TOPSIS Method: GRA-TOPSIS Method is illustrated as discussed in section 3.1
5.1.1. Decision Matrix: Decision matrix is formulated by collecting the data through questionnaire. Decision matrix on 37 criteria of 20 healthcare organizationsis prepared and first healthcare organization datais presented below.

Table 3: Decision Matrix

Alt.No	EM1	EM2	EM3	EM4	EM5	EM6	EM7	TA1	TA2	TA3	TA4	TA5
HCO1	3.14	3.14	2.79	2.93	3.00	3.79	2.36	2.50	2.57	3.21	2.36	3.00

Table 3: Decision Matrix(Contd..)

Alt.No	SA1	SA2	SA3	SA4	SA5	SA6	EF1	EF2	EF3	EF4	EF5	EF6
HCO1	3.00	2.93	2.21	2.71	2.93	2.71	3.64	3.00	2.36	2.79	3.21	2.64

Table 3: Decision Matrixt(Contd..)

Alt.No	DI1	DI2	DI3	DI4	DI5	DI6	DI7	DI8	OP1	OP2	OP3	OP4	OP5
HCO1	2.79	3.14	2.79	3.71	3.07	2.79	3.07	2.93	2.86	3.57	2.57	2.71	2.57

5.1.2 Weighted Decision Matrix: In this study, the weights of the criteria determined by CRITIC, MEREC and ENTROPY methods are aggregated. Aggregated weights are presented in the following table

Table 4: Weights of the Criteria

Criteria	Entropy	MEREC	Critic	Norm.wt
EM1	0.1430	0.1430	0.1462	0.0236
EM2	0.1431	0.1468	0.1371	0.0237
EM3	0.1428	0.1356	0.1388	0.0232
EM4	0.1430	0.1497	0.1525	0.0247
EM5	0.1427	0.1408	0.1567	0.0246
EM6	0.1425	0.1397	0.1350	0.0232
EM7	0.1430	0.1444	0.1398	0.0237
TAI	0.1995	0.1870	0.2066	0.0329
TA2	0.2002	0.2066	0.1990	0.0337
TA3	0.2001	0.2046	0.1905	0.0330
TA4	0.2002	0.2096	0.2033	0.0341
TA5	0.1999	0.1922	0.2007	0.0329
SAl	0.1668	0.1668	0.1651	0.0277
SA2	0.1667	0.1627	0.1627	0.0274

SA3	0.1668	0.1697	0.1617	0.0276
SA4	0.1668	0.1634	0.1604	0.0272
SA5	0.1667	0.1670	0.1783	0.0285
SA6	0.1662	0.1705	0.1718	0.0282
EFl	0.1632	0.1618	0.1701	0.0275
EF2	0.1694	0.1717	0.1599	0.0278
EF3	0.1703	0.1656	0.1795	0.0287
EF4	0.1664	0.1730	0.1531	0.0273
EF5	0.1682	0.1677	0.1781	0.0286
EF6	0.1625	0.1601	0.1594	0.0268
DIl	0.1248	0.1217	0.1385	0.0215
DIl	0.1250	0.1240	0.1259	0.0208
DI3	0.1252	0.1289	0.1224	0.0209
DI4	0.1250	0.1253	0.1228	0.0207
Dl5	0.1250	0.1233	0.1218	0.0206
DI6	0.1247	0.1254	0.1234	0.0207
Dl7	0.1252	0.1296	0.1200	0.0208
DIS	0.1250	0.1217	0.1252	0.0206
OPl	0.1997	0.1883	0.1941	0.0323
OP2	0.2003	0.2107	0.1968	0.0338
OP3	0.2001	0.2055	0.1948	0.0333
OP4	0.1997	0.1982	0.2177	0.0343
OP5	0.2001	0.1973	0.1967	0.0330

Weighted decision matrix is determined as discussed in step 2 of section 3.1 and is presented below.

Table 5: Weighted decision matrix

Alt.No	EM1	EM2	EM3	EM4	EM5	EM6	EM7	TA1	TA2	TA3	TA4	TA5
HCO1	0.0743	0.0745	0.0646	0.0723	0.0737	0.0876	0.0559	0.0822	0.0866	0.0849	0.1095	0.0775

Table 5: Weighted decision matrix(Contd..)

Alt.No	SA1	SA2	SA3	SA4	SA5	SA6	EF1	EF2	EF3	EF4	EF5	EF6
HCO1	0.0830	0.0801	0.0612	0.0740	0.0836	0.0766	0.1003	0.0833	0.0676	0.0760	0.0920	0.0708

Table 5: Weighted decision matrix(Contd..)

Alt.No	DI1	DI2	DI3	DI4	DI5	DI6	DI7	DI8	OP1	OP2	OP3	OP4	OP5
HCO1	0.0598	0.0654	0.0583	0.0769	0.0631	0.0578	0.0639	0.0604	0.0924	0.1208	0.0857	0.0932	0.0849

5.1.3 Ideal Solutions: Ideal solutions are determined as discussed in step 3 of section 3.1 and are presented below.

Table 6: Ideal Solutions

PIS/NIS	EM1	EM2	EM3	EM4	EM5	EM6	EM7	TA1	TA2	TA3	TA4	TA5
PIS	0.0878	0.0829	0.0942	0.0895	0.1070	0.0876	0.0830	0.1184	0.1376	0.1210	0.1221	0.1150
NIS	0.0599	0.0569	0.0563	0.0564	0.0537	0.0447	0.0559	0.0702	0.0809	0.0802	0.0818	0.0701

Table 6: Ideal Solutions (Contd..)

PIS/NIS	SA1	SA2	SA3	SA4	SA5	SA6	EF1	EF2	EF3	EF4	EF5	EF6
PIS	0.1068	0.1003	0.0968	0.1017	0.1199	0.1076	0.1141	0.1031	0.1085	0.1073	0.1023	0.1021
NIS	0.0732	0.0606	0.0612	0.0545	0.0685	0.0605	0.0643	0.0642	0.0612	0.0631	0.0634	0.0593

Table 6: Ideal Solutions (Contd..)

PIS/NIS	DI1	DI2	DI3	DI4	DI5	DI6	DI7	DI8	OP1	OP2	OP3	OP4	OP5
PIS	0.0765	0.0763	0.0809	0.0769	0.0767	0.0815	0.0713	0.0756	0.1207	0.1208	0.1167	0.1325	0.1189
NIS	0.0530	0.0520	0.0502	0.0384	0.0488	0.0525	0.0550	0.0471	0.0754	0.0797	0.0800	0.0870	0.0702

5.1.4 Separation Measures of each Alternative: Separation of each alternative from the PIS and NIS are determined as discussed in step 4 of section 3.1 and are presented below.

Table7 : Separation Measures from PIS

Alt	HCO1	HCO2	HCO3	HCO4	HCO5	HCO6	HCO7	HCO8	HCO9	HCO10
Di+	0.1614	0.1400	0.1416	0.1256	0.1408	0.1284	0.1464	0.1465	0.1580	0.1427
norm.Di+	1.0000	0.8675	0.8772	0.7782	0.8724	0.7956	0.9070	0.9077	0.9791	0.8838
Alt	HCO11	HCO12	HCO13	HCO14	HCO15	HCO16	HCO17	HCO18	HCO19	HCO20
Di+	0.1137	0.1471	0.1379	0.1396	0.1311	0.1240	0.1343	0.1362	0.1377	0.1249
norm.Di+	0.7044	0.9115	0.8543	0.8650	0.8119	0.7680	0.8321	0.8440	0.8528	0.7740

Table 7: Separation Measures from PIS(Contd..)

Alt	HCO1	HCO2	HCO3	HCO4	HCO5	HCO6	HCO7	HCO8	HCO9	HCO10
Di-	0.1131	0.1268	0.1329	0.1451	0.1338	0.1473	0.1280	0.1234	0.1253	0.1337
norm.Di+	0.7176	0.8040	0.8427	0.9203	0.8487	0.9343	0.8121	0.7824	0.7947	0.8480
Alt	HCO11	HCO12	HCO13	HCO14	HCO15	HCO16	HCO17	HCO18	HCO19	HCO20
Di-	0.1577	0.1264	0.1383	0.1337	0.1350	0.1483	0.1274	0.1274	0.1422	0.1553
norm.Di-	1.0000	0.8015	0.8771	0.8478	0.8565	0.9408	0.8079	0.8079	0.9018	0.9851

5.1.5 Grey Relation Coefficients: Grey relation coefficients are determined as discussed in step 5 of section 3.1

Table 8: Grey Relation Coefficients based on Positive ideal solution

Alt.No	EM1	EM2	EM3	EM4	EM5	EM6	EM7	TA1	TA2	TA3	TA4	TA5
HCO1	0.6773	0.7702	0.4893	0.6225	0.4597	1.0000	0.5114	0.4394	0.3576	0.4396	0.6928	0.4302

Table 8: Grey Relation Coefficients based on Positive ideal solution(Contd..)

Alt.No	SA1	SA2	SA3	SA4	SA5	SA6	EF1	EF2	EF3	EF4	EF5	EF6
HCO1	0.5445	0.5840	0.4437	0.5052	0.4387	0.4779	0.6731	0.5885	0.4092	0.4752	0.7350	0.4751

Table 8: Grey Relation Coefficients based on Positive ideal solution(Contd..)

Alt.No	DI1	DI2	DI3	DI4	DI5	DI6	DI7	DI8	OP1	OP2	OP3	OP4	OP5
HCO1	0.6296	0.7222	0.5564	1.0000	0.6758	0.5447	0.7924	0.6507	0.5003	1.0000	0.4780	0.4195	0.4551

Table 9: Grey Relation Coefficients based on Negative ideal solution

Alt.No	EM1	EM2	EM3	EM4	EM5	EM6	EM7	TA1	TA2	TA3	TA4	TA5
HCO1	0.6630	0.6170	0.7741	0.6412	0.5870	0.3974	1.0000	0.7016	0.8308	0.8574	0.5054	0.7941

Table 9: Grey Relation Coefficients based on Negative ideal solution (Contd..)

Alt.No	SA1	SA2	SA3	SA4	SA5	SA6	EF1	EF2	EF3	EF4	EF5	EF6
HCO1	0.7415	0.5920	1.0000	0.5930	0.6528	0.6375	0.4401	0.5977	0.8155	0.6871	0.4976	0.7118

Table 9: Grey Relation Coefficients based on Negative ideal solution (Contd..)

Alt.No	DI1	DI2	DI3	DI4	DI5	DI6	DI7	DI8	OP1	OP2	OP3	OP4	OP5
HCO1	0.8054	0.6794	0.7785	0.4245	0.6645	0.8442	0.7608	0.6814	0.6261	0.4085	0.8322	0.8203	0.6580

5.1.7 Grey relational Degree : Grey Relational degree is determined as discussed in step 6 of section 3.1 and are presented in the table.

Table 10: Grey Relational Degree of alternatives

Alt.No	**vij+**	**Norm.vij-**	**vij-**	**Norm.vij-**	**Alt.No**	**vij+**	**Norm.vij-**	**vij-**	**Norm.vij-**
HCO1	0.5855	0.8637	0.6843	1.0000	**HCO11**	0.6779	1.0000	0.5862	0.8566
HCO2	0.6112	0.9016	0.6386	0.9333	**HCO12**	0.5974	0.8813	0.6675	0.9754
HCO3	0.6229	0.9189	0.6384	0.9329	**HCO13**	0.6397	0.9437	0.6287	0.9187
HCO4	0.6396	0.9435	0.6111	0.8930	**HCO14**	0.6229	0.9188	0.6356	0.9288

HCO5	0.6155	0.9080	0.6445	0.9418	**HCO15**	0.6343	0.9357	0.6111	0.8931
HCO6	0.6531	0.9634	0.6196	0.9054	**HCO16**	0.6668	0.9835	0.5971	0.8725
HCO7	0.6142	0.9060	0.6465	0.9447	**HCO17**	0.6193	0.9136	0.6212	0.9078
HCO8	0.6106	0.9008	0.6435	0.9404	**HCO18**	0.6072	0.8957	0.6326	0.9244
HCO9	0.6127	0.9038	0.6748	0.9861	**HCO19**	0.6517	0.9613	0.6203	0.9064
HCO10	0.6313	0.9312	0.6405	0.9359	**HCO20**	0.6751	0.9959	0.6007	0.8778

5.1.8 Dimensionless processing parameters: The dimensionless processing parameters are determined as discussed in step 7 of section 3.1 Closeness coefficients of the alternatives are determined as discussed in step 8 and the alternatives are ranked. Dimensionless parameters, closeness coefficients and ranking of alternatives are presented in the following table

Table 11: Ranking by GRA-TOPSIS

Alt.No	vi+	vi-	Di+	Di-	si+	si-	Ci	Rank_GRA-TOPSIS
HCO1	0.8637	1.0000	1.0000	0.7176	0.7907	0.8588	0.4793	**20**
HCO2	0.9016	0.9333	0.8675	0.8040	0.8528	0.8358	0.5050	**15**
HCO3	0.9189	0.9329	0.8772	0.8427	0.8808	0.8600	0.5060	**13**
HCO4	0.9435	0.8930	0.7782	0.9203	0.9319	0.8493	0.5232	**4**
HCO5	0.9080	0.9418	0.8724	0.8487	0.8784	0.8605	0.5051	**14**
HCO6	0.9634	0.9054	0.7956	0.9343	0.9488	0.8649	0.5231	**5**
HCO7	0.9060	0.9447	0.9070	0.8121	0.8591	0.8596	0.4999	**16**
HCO8	0.9008	0.9404	0.9077	0.7824	0.8416	0.8451	0.4990	**17**
HCO9	0.9038	0.9861	0.9791	0.7947	0.8492	0.8869	0.4892	**19**
HCO10	0.9312	0.9359	0.8838	0.8480	0.8896	0.8659	0.5067	**12**
HCO11	1.0000	0.8566	0.7044	1.0000	1.0000	0.8522	0.5399	**1**
HCO12	0.8813	0.9754	0.9115	0.8015	0.8414	0.8565	0.4956	**18**
HCO13	0.9437	0.9187	0.8543	0.8771	0.9104	0.8657	0.5126	**8**
HCO14	0.9188	0.9288	0.8650	0.8478	0.8833	0.8564	0.5077	**10**
HCO15	0.9357	0.8931	0.8119	0.8565	0.8961	0.8342	0.5179	**6**
HCO16	0.9835	0.8725	0.7680	0.9408	0.9622	0.8544	0.5297	**3**
HCO17	0.9136	0.9078	0.8321	0.8079	0.8607	0.8200	0.5121	**9**
HCO18	0.8957	0.9244	0.8440	0.8079	0.8518	0.8259	0.5077	**11**
HCO19	0.9613	0.9064	0.8528	0.9018	0.9315	0.8773	0.5150	**7**
HCO20	0.9959	0.8778	0.7740	0.9851	0.9905	0.8796	0.5297	**2**

5.2 Mahalanobis Distance based GRA-TOPSIS: The methodology is illustrated in the following sections.

5.2.1 Mahalanobis Distance: Mahalanobis distances are determined from the step 4 of section 3.2 and also normalized mahalanobis distances are determined Themahalanobis distances and normalized mahalanobis distances are presented in the following table

Table 12: Mahalanobis Distances

Alts	di-	Di-	di+	Di+	Alts	di-	Di-	di+	Di+
HCO1	3.3559	0.8023	36.3024	0.9379	**HCO11**	4.0656	0.9720	23.8813	0.6170
HCO2	3.3099	0.7914	36.4725	0.9423	**HCO12**	3.4654	0.8285	19.5134	0.5041
HCO3	3.5319	0.8444	38.7068	1.0000	**HCO13**	3.6115	0.8635	25.6355	0.6623
HCO4	3.7293	0.8916	28.4713	0.7356	**HCO14**	3.6794	0.8797	27.1888	0.7024
HCO5	3.5817	0.8563	32.2482	0.8331	**HCO15**	3.7610	0.8992	26.5912	0.6870
HCO6	4.0191	0.9609	30.4734	0.7873	**HCO16**	4.1679	0.9965	28.3602	0.7327
HCO7	3.5476	0.8482	31.7506	0.8203	**HCO17**	3.5814	0.8563	23.6350	0.6106
HCO8	3.3871	0.8098	20.4860	0.5293	**HCO18**	3.4076	0.8147	23.2333	0.6002
HCO9	3.5439	0.8473	21.6072	0.5582	**HCO19**	3.9539	0.9453	24.7746	0.6401
HCO10	3.6412	0.8706	22.8515	0.5904	**HCO20**	4.1826	1.0000	26.1460	0.6755

5.2.2 Fused dimensionless Mahalanobis distance and Grey Relational grades: The values of fused dimensionless mahalanobis distances and grey relational grades are determined as discussed in step 9 of section 3.2. Also Relative closeness coefficients and ranks of the alternatives are determined as discussed in step 10. These values are presented in the following table.

Table 13: Ranking by Mahalanobis distance based GRA-TOPSIS

Alts	vi+	vi-	Di+	Di-	E+	E-	Gamma	Rank_MD based GRA-TOPSIS
HCO1	0.8637	1.0000	0.9379	0.8023	0.8330	0.9689	0.4623	20
HCO2	0.9016	0.9333	0.9423	0.7914	0.8465	0.9378	0.4744	19
HCO3	0.9189	0.9329	1.0000	0.8444	0.8816	0.9664	0.4771	18
HCO4	0.9435	0.8930	0.7356	0.8916	0.9176	0.8143	0.5298	13
HCO5	0.9080	0.9418	0.8331	0.8563	0.8822	0.8875	0.4985	16
HCO6	0.9634	0.9054	0.7873	0.9609	0.9621	0.8463	0.5320	11
HCO7	0.9060	0.9447	0.8203	0.8482	0.8771	0.8825	0.4985	17
HCO8	0.9008	0.9404	0.5293	0.8098	0.8553	0.7348	0.5379	7
HCO9	0.9038	0.9861	0.5582	0.8473	0.8755	0.7721	0.5314	12
HCO10	0.9312	0.9359	0.5904	0.8706	0.9009	0.7632	0.5414	5
HCO11	1.0000	0.8566	0.6170	0.9720	0.9860	0.7368	0.5723	1
HCO12	0.8813	0.9754	0.5041	0.8285	0.8549	0.7398	0.5361	9
HCO13	0.9437	0.9187	0.6623	0.8635	0.9036	0.7905	0.5334	10
HCO14	0.9188	0.9288	0.7024	0.8797	0.8992	0.8156	0.5244	15
HCO15	0.9357	0.8931	0.6870	0.8992	0.9175	0.7900	0.5373	8
HCO16	0.9835	0.8725	0.7327	0.9965	0.9900	0.8026	0.5523	3
HCO17	0.9136	0.9078	0.6106	0.8563	0.8849	0.7592	0.5382	6
HCO18	0.8957	0.9244	0.6002	0.8147	0.8552	0.7623	0.5287	14
HCO19	0.9613	0.9064	0.6401	0.9453	0.9533	0.7732	0.5522	4
HCO20	0.9959	0.8778	0.6755	1.0000	0.9980	0.7767	0.5624	2

5.3 Combined Compromise Solution (CoCoSo): The methodology is illustrated in the following sections

5.3.1 Weighted Comparable Sequence Scores: Weighted Comparable sequence scores are determined and the scores are presented in the following table.

Table14 : Comparable Sequence Scores

Alts	EM1	EM2	EM3	EM4	EM5	EM6	EM7	TA1	TA2	TA3	TA4	TA5
HCO1	0.073	0.072	0.064	0.074	0.078	0.085	0.055	0.086	0.085	0.082	0.109	0.079

Table 14 : Comparable Sequence Scores (Contd..)

Alts	SA1	SA2	SA3	SA4	SA5	SA6	EF1	EF2	EF3	EF4	EF5	EF6
HCO1	0.083	0.079	0.060	0.073	0.087	0.078	0.103	0.080	0.071	0.071	0.095	0.070

Table 14 : Comparable Sequence Scores (Contd..)

Alts	DI1	DI2	DI3	DI4	DI5	DI6	DI7	DI8	OP1	OP2	OP3	OP4	OP5
HCO1	0.064	0.066	0.057	0.076	0.062	0.057	0.061	0.061	0.092	0.117	0.083	0.098	0.084

5.3.1 Exponentially Weighted Comparable Sequence Scores: Exponentially weighted Comparable sequence scores are determined and the scores are presented in the following table.

Table 15: Exponentially weighted Sequence Scores

Alts	EM1	EM2	EM3	EM4	EM5	EM6	EM7	TA1	TA2	TA3	TA4	TA5
HCO1	1.027	1.027	1.024	1.028	1.029	1.030	1.020	1.032	1.032	1.030	1.040	1.029

Table 15: Exponentially weighted Sequence Scores (Contd..)

Alts	SA1	SA2	SA3	SA4	SA5	SA6	EF1	EF2	EF3	EF4	EF5	EF6
HCO1	1.031	1.030	1.022	1.027	1.032	1.029	1.037	1.030	1.026	1.026	1.035	1.026

Table 15: Exponentially weighted Sequence Scores (Contd..)

Alts	DI1	DI2	DI3	DI4	DI5	DI6	DI7	DI8	OP1	OP2	OP3	OP4	OP5
HCO1	1.024	1.024	1.021	1.027	1.023	1.021	1.023	1.023	1.035	1.043	1.031	1.037	1.031

5.3.2 Weighted and exponentially weighted Sum of Sequence scores: Weighted sums of comparable sequence scores and Exponentially weighted products of comparable sequence scores are determined as discussed in step 3 and Step4 of section 3.3. The scores are presented in the following table.

Table 16: Exponential weighted Scores

Alts	Si	pi	Alts	Si	pi
HCO1	2.8737	38.0630	HCO11	3.1578	38.1625
HCO2	2.9881	38.1051	HCO12	2.9438	38.0857
HCO3	2.9992	38.1086	HCO13	3.0389	38.1208
HCO4	3.0755	38.1342	HCO14	3.0051	38.1099
HCO5	2.9936	38.1034	HCO15	3.0526	38.1288
HCO6	3.0810	38.1340	HCO16	3.1137	38.1480
HCO7	2.9740	38.0983	HCO17	3.0135	38.1150
HCO8	2.9695	38.0978	HCO18	2.9928	38.1089
HCO9	2.9279	38.0804	HCO19	3.0559	38.1266
HCO10	3.0082	38.1079	HCO20	3.1248	38.1488

5.3.2 Arithmetic means of sums of scoress: Arithmetic means of sums of scores are determined as discussed in step 5 of section 3.3. The scores are presented in the following table 17.

5.3.2 Final ranking of Alternatives: Initially, Arithmetic means of sums of scores are determined as discussed in step 5 of section 3.3. Sum of relative scores compared to the best are determined as discussed in step 6 of section 3.3. Balanced compromise scores are determined as discussed in step 7 of section 3.3. Final score is determined as discussed in step 8 of section 3.3 and final ranking is presented based on the final scores.

Table 17: Ranking by CoCoSo

Alts	Tia	Tib	Tic	Ti	Rank	Alts	Tia	Tib	Tic	Ti	Rank
HCO1	0.0498	2.0000	0.9907	1.4755	20	HCO11	0.0502	2.1015	1.0000	1.5232	1
HCO2	0.0500	2.0409	0.9945	1.4948	15	HCO12	0.0499	2.0250	0.9930	1.4872	18
HCO3	0.0500	2.0449	0.9949	1.4966	12	HCO13	0.0500	2.0590	0.9961	1.5032	8
HCO4	0.0501	2.0721	0.9973	1.5094	5	HCO14	0.0500	2.0470	0.9950	1.4976	11
HCO5	0.0500	2.0428	0.9946	1.4956	14	HCO15	0.0501	2.0640	0.9966	1.5056	7
HCO6	0.0501	2.0740	0.9975	1.5102	4	HCO16	0.0502	2.0857	0.9986	1.5158	3
HCO7	0.0499	2.0358	0.9940	1.4923	16	HCO17	0.0500	2.0500	0.9954	1.4990	9
HCO8	0.0499	2.0343	0.9939	1.4916	17	HCO18	0.0500	2.0427	0.9947	1.4956	13
HCO9	0.0498	2.0193	0.9924	1.4845	19	HCO19	0.0501	2.0651	0.9967	1.5061	6
HCO10	0.0500	2.0480	0.9951	1.4980	10	HCO20	0.0502	2.0897	0.9989	1.5176	2

6. RESULTS AND DISCUSSION

This study delves into the performance evaluation and ranking of healthcare organizations through three multi-criteria decision-making methods: GRA (Grey Relational Analysis) TOPSIS, Mahalanobis distance-based GRA-TOPSIS, and CoCoSo (Combined Compromise Solution) from a specialized healthcare perspective. Rankings of the proposed methods are presented in the following table.

Table18 : Ranking of Healthcare Organizations by the proposed Methods

Alts	GRA-TOPSIS	MD Based GRA_ TOPSIS	CoCoSo	*Alts*	GRA-TOPSIS	MD Based GRA_ TOPSIS	CoCoSo
HCO1	20	20	20	HCO11	1	1	1
HCO2	15	19	15	HCO12	18	9	18
HCO3	13	18	12	HCO13	8	10	8
HCO4	5	13	5	HCO14	12	15	11
HCO5	14	16	14	HCO15	6	6	7

HCO6	4	11	4	**HCO16**	3	3	3
HCO7	16	17	16	**HCO17**	9	7	9
HCO8	17	8	17	**HCO18**	10	14	13
HCO9	19	12	19	**HCO19**	7	4	6
HCO10	11	5	10	**HCO20**	2	2	2

HCO1 consistently ranks least in all three methods, signifying its poor excellence in healthcare quality. HCO11, HCO20 and HCO16 are consistently among the top performers across all methods, suggesting their strong performance from the healthcare metrics considered in the study.
HCO2 and HCO3 perform well in the GRA-TOPSIS and CoCoSo. This suggests that when considering the data distribution nuances, these organizations fare better, perhaps due to having strengths in correlated performance metrics.
HCO8 has a drastic difference in ranking between MD-Based GRA-TOPSIS and the other two methods. It ranked 8th in MD-Based GRA-TOPSIS but 17th in both GRA-TOPSIS and CoCoSo. This divergence may point towards the unique evaluation criteria of MD-Based GRA-TOPSIS, emphasizing certain metrics where HCO8 may have a shortcoming.
HCO4 and HCO6 are consistently middle among organizations across all methods, indicating areas of improvement in both traditional and modern healthcare metrics.

While both Euclidean based GRA-TOPSIS and Mahalanobis distance based GRA-TOPSIS are valuable tools for multi-criteria decision-making, the choice between them depends on the specific dataset and the nature of the decision problem. In scenarios where variable independence can be safely assumed, the simpler Euclidean distance might suffice. In contrast, when dealing with correlated data or seeking a more nuanced evaluation that captures intricate relationships among variables, the Mahalanobis distance offers a distinct advantage. CoCoSo method is based on two common approaches namely weighted sum model (WSM) and exponentially weighted product model. This method develops three different appraisal scores to evaluate the alternatives.

For Hospital Administrators: Given the variability in rankings based on the chosen method, it's crucial to understand the strengths and weaknesses of each facility using multiple lenses. This could guide resource allocation and strategic development.
For Patients and Consumers: While these rankings provide insights, they shouldn't be the sole basis for choosing a healthcare provider. They can be used as a supplementary tool to guide decisions in conjunction with personal preferences, needs, and recommendations.
For Policymakers and Regulators: Recognizing that no single evaluation method can capture the entirety of a healthcare organization's performance, a hybrid approach might be valuable. Combining the strengths of all three methodologies can yield a comprehensive and robust assessment system for the healthcare sector.

6.1 Ranking Consistency Analysis

Ranking consistency analysis is an essential aspect of Multiple Criteria Decision Making (MCDM) methods. MCDM is employed in situations where decision-makers are faced with several alternatives evaluated based on multiple criteria or attributes.Ranking consistency is at the heart of MADM, ensuring that the decision-making process is robust, fair, and reliable. By ensuring consistent rankings, decision-makers can be more confident in their choices, leading to better outcomes and more efficient use of resources.
Ranking consistency methods are crucial tools in multiple Criteria decision-making (MCDM) and other fields where the reliability of ranking outcomes is of paramount importance. In this study, three notable methods to measure ranking consistency are the Correlation Coefficient, the Kendall index (often referred to as Kendall's Tau), and the RBO (Rank-Biased Overlap) index. The average ranking consistency index of the each MCDM method is determined. In order to express the consistency of ranking conveniently, this study considered the value range of consistency index from the literature (Lixia Zhang , Beibei Qu , Huisheng Gao and Jianliang Zhang, 2021). The consistency results are presented below.

6.1.1 Correlation Analysis: Correlation coefficients of the proposed methods are presented in the following table

Table19: Correlation Coefficients

Method	GRA_MD TOPSIS	GRA-TOPSIS	CoCoSo
GRA_MD TOPSIS	1.000	0.663	0.672
GRA-TOPSIS	0.663	1.000	0.989
CoCoSo	0.672	0.989	1.000

From the table it is observed that, there is a moderate positive correlation at p=0.05, very close to the correlation with GRA-TOPSIS. Both the GRA_MD TOPSIS and CoCoSo methods have similarities in their rankings.
A very high positive correlation of 0.989 at p=0.05 indicating that the rankings from GRA-TOPSIS and CoCoSo are extremely similar

6.1.2 Kendall index: Kendalls index of the proposed methods are determined and presented in the following table.

Table 20: Kendal index values

Method	GRA_MD TOPSIS	GRA-TOPSIS	CoCoSo
GRA_MD TOPSIS	1.000	0.537	0.537
GRA-TOPSIS	0.537	1.000	0.958
CoCoSo	0.537	0.958	1.000

From the results, it is observed that A very high ordinal association. The rankings from GRA-TOPSIS and CoCoSo are extremely similar, with only minor differences in ordinal placements. A moderate ordinal association. GRA TOPSIS and Mahalanobis distance based GRA-TOPSIS rank alternatives in a somewhat similar manner, but there are noticeable discrepancies in their ordinal placements. Similarly , there's a moderate ordinal association between GRA_MD TOPSIS and CoCoSo. They have similar rankings.

6.1.3 RBO index: In this method the overlap of ranking depth is determined through Matlab code to arrive the RBO Index and the results are presented below.

Table 21: RBO Index Values.

Method	GRA_MD TOPSIS	GRA-TOPSIS	CoCoSo	Index value
GRA_MD TOPSIS	1.000	0.667	0.625	0.764
GRA-TOPSIS	0.667	1.000	0.908	0.858
CoCoSo	0.625	0.908	1.000	0.844

6.1.4 Average Ranking Consistency Index: **Average consistency index** of each MCDM method,is determined by averaging the values in the i^{th} row and the i^{th} column (excluding the diagonal element which will always be 1 as it's the comparison of the method with itself). Average Consistency index values are presented in the following table.

Table 22: Average Consistency index values.

Index Values	Consistency Method			Average
MCDM Method	**Correlation**	**Kendall**	**RBO**	
GRA_MD TOPSIS	0.6675	0.5368	0.6461	0.6168
GRA-TOPSIS	0.8260	0.7474	0.7877	0.7870
CoCoSo	0.8305	0.7474	0.7667	0.7815

From the above table it is observed that the ranking methods are consistent since the average value of each method is more than 0.6. However, they may differ slightly in ranking of individual alternatives. Hence aggregate ranking of alternatives is determined by considering, Optimistic rank, mean rank and pessimistic rank. The aggregate rank(Te) is presented in the following table.

Table 23: Aggregate Rank of Alternatives.

Alts	GRA-TOPSIS	MD Based GRA_ TOPSIS	CoCoSo	To	Tm	Tp	Te
HCO1	20	20	20	20	20.0	20	20
HCO2	15	19	15	15	17.0	19	19
HCO3	13	18	12	12	15.0	18	16
HCO4	5	13	5	5	9.0	13	10
HCO5	14	16	14	14	15.0	16	16
HCO6	4	11	4	4	7.5	11	7
HCO7	16	17	16	16	16.5	17	18
HCO8	17	8	17	8	12.5	17	11
HCO9	19	12	19	12	15.5	19	17

HCO10	11	5	10	5	7.5	10	7
HCO11	1	1	1	1	1.0	1	1
HCO12	18	9	18	9	13.5	18	14
HCO13	8	10	8	8	9.0	10	10
HCO14	12	15	11	11	13.0	15	12
HCO15	6	6	7	6	6.5	7	5
HCO16	3	3	3	3	3.0	3	3
HCO17	9	7	9	7	8.0	9	8
HCO18	10	14	13	13	13.5	14	14
HCO19	7	4	6	4	5.0	6	4
HCO20	2	2	2	2	2.0	2	2

From the results it is observed that, HCO11, HCO20, HCO16, HCO19 and HCO 15 are obtained the best ranks of 1,2,3,4 and 5 respectively. HCO1, HCO2, HCO7, HCO9 and HCO3&HCO5 are obtained the poor ranks of 20,19,18,17 and 16 respectively. Comparison of rankings is presented in the figure1

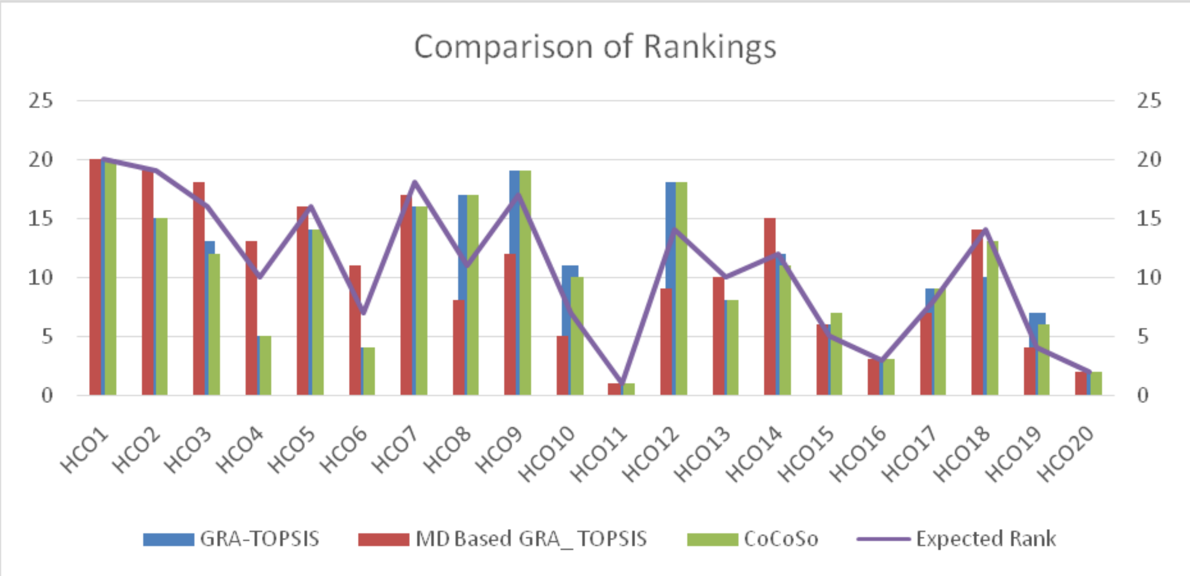

Figure 1: Comparison of Rankings

CONCLUDING REMARKS

The study provides insights into the capabilities of different methodologies in evaluating the performance of healthcare organizations. Each method has its unique advantages and drawbacks, which makes them suitable for specific scenarios. Decision-makers in healthcare should consider the characteristics of each method before settling on a particular one for performance evaluations.

While each evaluation method offers a unique perspective on the performance of the healthcare organizations, it's crucial for stakeholders to interpret these rankings in context. The consistent high performers indicate well-rounded excellence, while discrepancies in rankings can provide insights into specific strengths or areas of improvement. For a comprehensive understanding, it might be beneficial to employ a hybrid approach, combining insights from all three methodologies.

The rigorous evaluation of healthcare organizations is crucial for stakeholders, patients, and policymakers to make informed decisions. In this endeavor, the application of diverse methodologies – GRA-TOPSIS, Mahalanobis distance-based GRA-TOPSIS, and CoCoSo – has offered rich insights.

As the healthcare landscape continues to evolve, adapt, and innovate, the tools we use to evaluate it must also progress. These three methods, with their diverse emphases, remind us of the multifaceted nature of healthcare and the importance of a nuanced, comprehensive approach to its evaluation.

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