



A New Algorithm on Pythagorean Fuzzy-Based Multi-Criteria Decision-Making and Its Application

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Abstract

The rapid growth in information technology (IT) and the implementation of IT tools has aided hospitals in delivering healthcare at an unprecedented pace. However, without the proper knowledge and understanding of software tools, healthcare establishments may find it difficult to select the best hospital management system software solution for their business. In this paper, a problem based on multi-criteria decision-making (MCDM) is modelled to identify the best hospital management software on the basis of a thorough analysis of every aspect of the healthcare needs and required software competencies, so that hospitals can select a robust hospital management software system. This article presents an extended MCDM method for estimating and selecting robust hospital management system alternatives using the Pythagorean fuzzy method based on the removal effects of criteria (MEREK) and stepwise weight assessment ratio analysis (SWARA). To do this, the objective weights and subjective weights are assessed by the MEREK and SWARA models, and the measurement alternatives and ranking according to compromise solution (MARCOS) method determines the order of preference of the alternatives on the basis of the Pythagorean fuzzy set. Moreover, after in-depth analysis of every aspect of healthcare needs and required software competencies in India, the proposed method is designed to identify the best hospital management software tool, so that the hospital can choose a robust hospital management system. Comparative discussion is presented to exhibit the rationality and sustainability of the established approach to prioritize hospital management software options.

Keywords Pythagorean fuzzy set · MEREK · SWARA · Measurement alternatives and ranking according to compromise solution (MARCOS) · MCDM · Hospital management software (HMS)

1 Introduction

These days, contemporary culture, financial systems and critical infrastructure are increasingly reliant on software and network systems. Their impact on the workflow of hospitals, healthcare facilities, doctors, hospital staff, and nurses is also unavoidable. Software that handles all the issues related to hospitals and healthcare centres is known as hospital management software (HMS). HMS allows hospitals to achieve high quality in terms of system

management including data and other records relating to staff, patients, and medications included in the system software. In addition, a hospital management system can reduce general errors on the part of medical officers and staff and provide better strategies for healthcare services by tracking every aspect of the required data. HMS can also be incorporated into revenue management. Balaraman and Kosalram (2013) investigated the qualitative, descriptive nature of performance indicators of e-hospital management and hospital information systems. Later, Arasteh et al. (2018) discussed multi-criteria decision-making (MCDM) methods in the selection of HMS.

HMS is a package of application tools that aids hospitals in the efficient performance of tasks related to patient care, appointment booking, ward management, pharmacy, laboratory and day-to-day operations. Adebisi et al. (2015) established an automatic system employed for managing

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patient information and administration, to improve the overall efficiency of the organization. The tool is designed on HyperText Markup Language (HTML) and My Structured Query Language (MySQL) and provides the best patient amenities and better information. Olivero et al. (2018) discussed a summary of smartphone and tablet applications employed for hospital management and administration, to calculate and explore the characteristics of various management software packages. This coordination eliminates inefficient procedures and helps the hospital operate efficiently. It also provides enormously valuable healthcare analysis that helps hospitals to clearly perceive and further improve their present business. Different MCDM problems have been used in hospital management system software selection, including AHP (Agrawal et al. 2019) and fuzzy ANP-TOPSIS (Zarour et al. 2020; Lin et al. 2021) presented during COVID-19 for smart hospital management.

The present article is organized as follows. In Sect. 2, we have discussed basic definitions of IFSs and PFSs. In Sect. 3, a novel integrated method based on the removal effects of criteria (MEREC)-stepwise weight assessment ratio analysis (SWARA)-measurement alternatives and ranking according to compromise solution (MARCOS) method based on Pythagorean fuzzy sets (PFS) is developed. Thereafter, in Sect. 4, a case study of HMS software selection is presented, which shows the efficiency and utility of the presented model. In addition, a comparison with existing methods is presented to validate the results. Finally, in Sect. 5, conclusions and future outlook are discussed.

1.1 Literature Survey

There are many ambiguous, precise and unfinished problems in the real-life cases. Hence, the fuzzy set (FS) theory developed by Zadeh (1965) has been extensively used to generate new approaches and concepts for dealing with ambiguity and imprecision. However, the fuzzy set has some constraints concerning tackling ambiguous information. Atanassov (1986) established the concept of the intuitionistic fuzzy sets (IFSs), which requires that the sum of membership degree (MD) and non-MD (N-MD) must be less than or equal to 1. Because of its ability to solve practical applications, IFS has been widely employed for a variety of purposes in the literature (Xu and Yager 2006; Xu 2007; Mishra et al. 2019a, b; Rani and Jain 2019; Kumari and Mishra 2020; Kumar and Chen 2022). Nevertheless, there may be difficulties in the decision-making (DM) procedure where neither the FS nor the IFS is capable of addressing unsure and incompatible data. For example, if a decision expert (DE) assigns the value 0.7 as yes and 0.6 as no as their preference regarding the

commodity, in this condition, $0.7 + 0.6 > 1$. Hence, this situation is not handled by IFS. To overcome these shortcomings, firstly, Yager (2013a, b) defined the fundamentals of the PFS. In a Pythagorean fuzzy set, MD and N-MD satisfy the condition that the sum of squares of MD and N-MD is less than or equal to 1. The PFS is a good device for expressing vague information in practical, complicated MCDM problems. It has the same provision as IFSs, but with considerable flexibility and more space to express fuzzy information than IFS. In this regard, the theory of PFS has drawn much attention from scholars in the field of decision-making due to the pervasive changes and growing complexity of today's environment.

After Yager (2013a, b) introduced the basic ideas related to PFS and described the relationship between complicated numbers and PFNs, a sequence of various types of Pythagorean fuzzy aggregation operators were also presented, such as PF-weighted averaging operator. Zhang and Xu (2014) presented basic mathematical operations for PFSs, and also presented the elementary operative laws and score function for PFNs. Further, Peng and Yuan (2017) evolved two new operators and decision-making techniques based on multiple-criteria decision-making (MCDM) problems with PFNs. Gou et al. (2016) generated new PF-functions and basic properties. Ma and Xu (2016) improved the score and accuracy function for PFNs and evolved new averaging and geometric operators based on PFS measures. Peng and Li (2019) discussed new operators and score function on IVPFNs. Peng et al. (2020) generated novel PF-score functions and applied COCOSO and CRITIC approaches to solve MCDM problems under PFSs. Garg (2019) presented the logarithmic operative laws with numerous weighted averaging and geometric operators under PFSs. Wang and Garg (2021) developed some interactive Hamacher power aggregation operators on PFNs, Zeng et al. (2016) explored some aggregation operators under PFN, as well as several researchers working on aggregation operators under PFNs (see Garg 2017; Gao et al. 2018; Wei et al. 2018; Pamucar and Jankovic 2020; Akram et al. 2021; Ali et al. 2021). PF-priority average and geometric operators were introduced by Farid and Riaz (2022) to help handle MCDM problems. Afterward, Rong et al. (2020) presented novel operations for linguistic PFNs based on Einstein's operations. A helpful extension of the handling with uncertainties in information is the PFS, which is one of the greatest frequently employed fuzzy sets in data science. Given these situations, the Aczel-Alsina processes are employed in this study to formulate some PF-Aczel-Alsina aggregation operators (Senapati et al. 2022).

The MCDM technique is an approach for dealing with a massive quantity of problems and estimating alternatives, and helps the user in mapping the problem. Criteria weights play a vital role in the decision-making procedure,

as the suitable selection of criterion weights is best for ranking alternatives, although the weight information of the criteria in the MCDM problem is occasionally unnamed, so developing a technique to determine the weights is vital. Several techniques are available in the literature. As a result, many researchers have studied the entropy measure on PFSs. Yang and Hussain (2018) presented some probabilistic and non-probabilistic kinds of entropy measure for PFSs and their application in MCDM problems. Xu et al. (2020) proposed an entropy measure on PFS to solve MCDM problems. In incorporating both PF-entropy in terms of membership and non-membership and Pythagorean hesitation entropy in terms of hesitation degree, Wang et al. (2022) presented a new entropy measure of PFS. Chaurasiya and Jain (2022) proposed entropy on PFS, and Rani et al. (2020a, b) proposed a new MCDM technique in PFS for healthcare waste management. Paul et al. (2022) presented a PF-GRA and AHP framework. Yildirim and Yildirim (2022) discussed a picture fuzzy VIKOR method, and MCDM methods and techniques have been presented in the literature. Some popular MCDM methods have been used by many researchers in various fields of study (see He et al. 2020; Mishra et al. 2019a, 2021; Rani et al. 2021a, b; Ashraf et al. 2022).

In addition, criterion weight is very significant in solving MCDM difficulties. Therefore, authors have turned their attention to methods related to criterion weight. The MEREC approach proposed by Keshavarz et al. (2021) is one of the most powerful approaches for defining the objective criterion weights (OCWs). Hadi and Abdullah (2022) presented an integrated MEREC-TOPSIS (technique for order of preference by similarity to ideal solution) for IoT-based hospital place selection. Hezam et al. (2022) proposed an IF-MEREC-ranking sum-double normalization-based multi-aggregation method for evaluating alternative fuel vehicles concerning sustainability. Marinkovic et al. (2022) employed the MEREC-CoCoSo multi-criteria method to evaluate the application of waste and recycled materials to production. An integrated MEREC method on Fermatean fuzzy environment was proposed by Rani et al. (2022), MEREC-MULTIMOORA was proposed by Mishra et al. (2022), and MEREC-MARCOS by Nguyen et al. (2022), whereas innovative techniques for determining criteria weight were presented by Biswas and Sarkar (2019) and Ozdemir and Gul (2019), level-based weight assessment was proposed by Zizovic and Pamucar (2019), and Rani et al. (2021a, b) presented an integrated WDBA criteria weight-based method under PFSs.

Kersulienė et al. (2010) established the SWARA approach as an effective method for calculating the subjective criteria weights (SCWs) and diverse weight methods discussed by Chen (2019), Wang et al. (2019), and Stevic et al. (2022). Other approaches, in addition to

SWARA, are based on pairwise comparisons; however, there are large variances in computing the criteria weights. Some researchers have drawn attention to integrated methods to solve the MCDM problems, such as Rani et al. (2020a, b), who developed a new integrated SWARA-ARAS method on PFS for HCWT problems. Alipour et al. (2021) employed a combined SWARA and COPRAS technique to assess the supplier selection of fuel cell and hydrogen constituents in the PFS domain. Saraji et al. (2022) proposed the hesitant fuzzy-SWARA-MULTIMURA method for online education. In proposing the CRITIC-CoCoSo method, Peng et al. (2020) discussed prioritizing risk in self-driving vehicles, and combining AHP with TOPSIS and VIKOR algorithms with PFS (Bakioglu and Atahan 2021). The extended PF-SWARA-TOPSIS approach for sustainable human resource management was proposed by Saeidi et al. (2022), and the SWARA-VIKOR method was presented by Rani et al. (2020a).

The MARCOS method is a popular MCDM method developed by Stevic et al. (2020). To evaluate the ranking of alternatives by the MARCOS method, Puska et al. (2020) proposed a way to measure alternatives and ranking according to the compromise solution (MARCOS) method for project management software, and the integrated FUCUM-MARCOS model was presented by Stevic and Bekovic (2020). Bakir and Atalik (2021) applied a fuzzy MARCOS approach for the airline industry. Ecer and Pamucar (2021) proposed a MARCOS technique on IFS for insurance companies in the context of health services. Tas et al. (2021) presented the SWARA-MARCOS method on a spherical fuzzy set for green supplier selection. Tesic et al. (2022) presented a DIBR-fuzzy-MARCOS framework, and the MEREC-MARCOS method was proposed by Nguyen et al. (2022). Several researchers have used the MARCOS method for various applications (Kumar et al. 2021a, b). Various academicians have now expanded the traditional MARCOS technique under a range of vague environments, and many scholars have applied the traditional MARCOS method in several areas (see Stankovic et al. 2020; Badi et al. 2020; Chaurasiya and Jain 2021; Kumar et al. 2021a, b).

The motivation for this study is to develop an integrated PF-MEREC-SWARA-MARCOS method that can efficiently deal with the implicit vagueness and uncertainty associated with the judgment of decision experts (DE). Therefore, we first calculate objective weights by the MEREC method and evaluate subjective weights by the SWARA method. Then we calculate the combined criterion weights, and finally compute the ranking of alternatives by the MARCOS method. The benefit of using the Pythagorean fuzzy MARCOS method is that it takes into account Pythagorean fuzzy context points through PF-ideal

and anti-ideal solutions at the start of model construction and proposes utility functions and their aggregation functions and measurements. A new method is likely to consider a large set of criteria and alternatives.

The article can be summarized as follows:

1. A new integrated MCDM model of MEREC-SWARA-MARCOS in a Pythagorean fuzzy environment is developed, and the decision experts' weights in PFS and an aggregate of Pythagorean fuzzy numbers are calculated.
2. Objective criterion weights are calculated by MEREC and subjective criterion weight by SWARA. Thereafter, we calculate the combined criterion weights.
3. An empirical case study of HMS software is presented. Selection is considered to verify the potential and effectiveness of the presented MEREC-SWARA-MARCOS method in the context of PFSs.
4. Finally, a comparative analysis of the proposed method is performed with the existing techniques to verify the validity and rationality of the established PF-MEREC-SWARA-MARCOS method.

2 Methodology

In this section, we provide a brief review of the IFS and the PFS.

Definition 2.1 (Atanassov 1986) For an IFS $I \subset Y$ in a fixed set, let $Y = \{y_1, y_2, \dots, y_n\}$ be given by:

$$I = \{ \langle y_i, \mu_I(y_i), \nu_I(y_i) \rangle | y_i \in Y \}. \tag{1}$$

where $\mu_I : Y \rightarrow [0, 1]$ and $\nu_I : Y \rightarrow [0, 1]$ indicate the MD and N-MD, respectively, $y_i \in Y$, such that $0 \leq \mu_I(y_i) + \nu_I(y_i) \leq 1$. For an IFS $I \subset Y$, $\pi_I(y_i) = 1 - \mu_I(y_i) - \nu_I(y_i)$, we define the hesitancy degree of $y_i \in Y$ as follows: $0 \leq \pi_I(y_i) \leq 1$.

Definition 2.2 (Yager 2013a, b) A PFS $A \subset Y$ in a fixed set is defined as:

$$A = \{ \langle y_i, \mu_A(y_i), \nu_A(y_i) \rangle | y_i \in Y \}. \tag{2}$$

where $\mu_A : Y \rightarrow [0, 1]$ indicates MD and $\nu_A : Y \rightarrow [0, 1]$ indicates the N-MD that satisfies the condition

$$0 \leq \mu_A^2(y_i) + \nu_A^2(y_i) \leq 1.$$

If the hesitancy degree $\pi_A(y_i)$ is denoted by $\pi_A(y_i) = \sqrt{1 - \mu_A^2(y_i) - \nu_A^2(y_i)}$, then it is a PF-index.

Definition 2.3 (Zhang and Xu 2014) The score and accuracy function of the PFS $\beta = (\mu_\beta, \nu_\beta)$ is defined as:

$$S(\beta) = \mu_\beta^2 - \nu_\beta^2, \tag{3}$$

$$\tilde{h}(\beta) = \mu_\beta^2 + \nu_\beta^2, \tag{4}$$

where $S(\beta) \in [-1, 1]$ and $\tilde{h}(\beta) \in [0, 1]$.

Definition 2.4 (Peng and Li 2019) The modified normalized score function of the PFS $\beta = (\mu_\beta, \nu_\beta)$ is given as:

$$S^*(\beta) = \frac{2(\mu_\beta)^2 + (1 - (\nu_\beta)^2) + ((\mu_\beta)^2)^2}{4}, \tilde{h}^\circ(\beta) = 1 - \tilde{h}(\beta), S^*(\beta), \tilde{h}^\circ(\beta) \in [0, 1]. \tag{5}$$

Definition 2.5 (Yager 2013a, b) Let $\beta = (\mu_\beta, \nu_\beta)$, $\beta_1 = (\mu_{\beta_1}, \nu_{\beta_1})$ and $\beta_2 = (\mu_{\beta_2}, \nu_{\beta_2})$ be PFSs, where the operations on the PFSs are depicted below as:

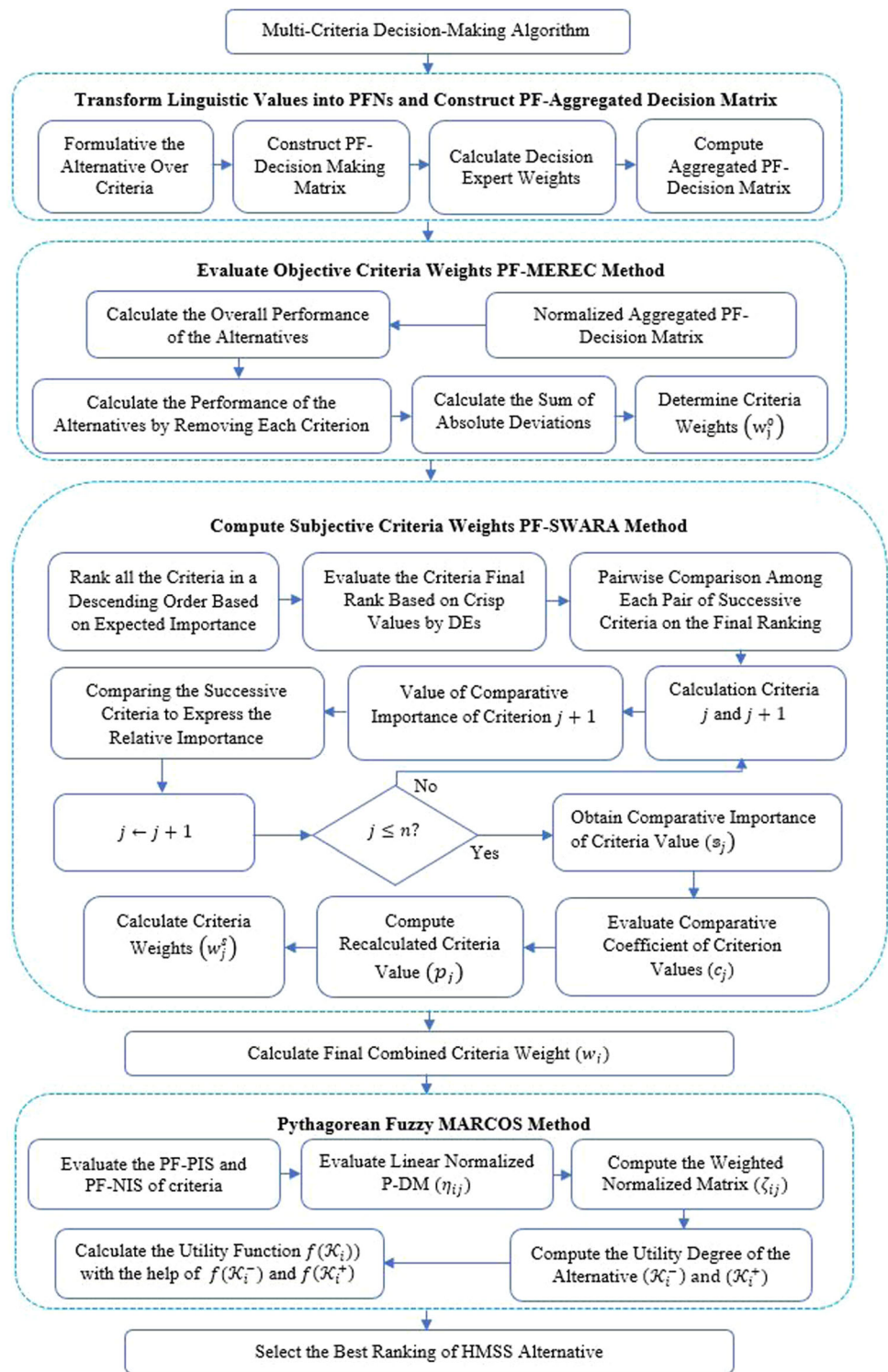
1. $\beta^c = (\mu_\beta, \nu_\beta)$,
2. $\beta_1 \oplus \beta_2 = \left(\sqrt{\mu_{\beta_1}^2 + \mu_{\beta_2}^2 - \mu_{\beta_1}^2 \mu_{\beta_2}^2}, \nu_{\beta_1} \nu_{\beta_2} \right)$,
3. $\beta_1 \otimes \beta_2 = \left(\mu_{\beta_1} \mu_{\beta_2}, \sqrt{\nu_{\beta_1}^2 + \nu_{\beta_2}^2 - \nu_{\beta_1}^2 \nu_{\beta_2}^2} \right)$,
4. $\lambda \beta = \left(\sqrt{1 - (1 - \mu_\beta^2)^\lambda}, (\nu_\beta)^\lambda \right), \lambda > 0$,
5. $\beta^\lambda = \left((\mu_\beta)^\lambda, \sqrt{1 - (1 - \nu_\beta^2)^\lambda} \right), \lambda > 0$.

3 An Integrated Method for MCDM on PFS

Here, we introduce the Pythagorean fuzzy MCDM problem to identify the best alternative. To tackle this complex decision-making problem, in this article, we have presented the PF-MEREC-SWARA-MARCOS method, and a new PF-linguistic variable is installed with quantization in PFNs. The MEREC is a powerful method for determining objective criterion weights, introduced by Keshavarz et al. (2021). The SWARA method is an effective tool for the calculation of subjective criteria weights, proposed by Kersulienė et al. (2010). The main benefit of the SWARA approach is the ability to assess the correctness of the expert's view of the weights allocated by this method. Thereafter, we have calculated criteria weights by a combined formula. Additionally, the MARCOS (Stević et al. 2020) approach is employed to the ranking order of alternatives. The process of the integrated method is described in Fig. 1.

Step 1: For an MCDM problem under Pythagorean fuzzy domain, assume five different alternatives $T = \{T_1, T_2, \dots, T_5\}$ and the set of eight feature criteria

Fig. 1 Procedure of presented integrated PF-MEREC-SWARA-MARCOS method



$F = \{F_1, F_2, \dots, F_8\}$. It is assumed that a collection of decision experts (DEs) $E = \{E_1, E_2, E_3\}$ present their ideas on each alternative T_i with respect to each criterion F_j in terms of linguistic variables (LVs). Let $Z = (z_{ij}^{(k)}), i =$

$1(1)m, j = 1(1)n$ be a linguistic decision matrix recommended by the DEs, where $z_{ij}^{(k)}$ present the appraisal of an alternative T_i regarding a criterion F_j in the form of LVs for k^{th} DE (Fig. 2).

Step 2: Calculate the DEs weights. For the assessment of the k th DE's weight, let $E_k = (\mu_k, \nu_k)$ be a PFN (Liu and Wang 2007).

$$\lambda_k = \frac{\mu_k^2(2 - \mu_k^2 - \nu_k^2)}{\sum_{k=1}^{\ell} \mu_k^2(2 - \mu_k^2 - \nu_k^2)}. \tag{6}$$

Here $\lambda_k \geq 0, \sum_{k=1}^{\ell} \lambda_k = 1$.

Step 3: Define the aggregated Pythagorean fuzzy decision matrix (APF-DM), corresponding to an expert's weight. Let $\mathbb{N} = (\varepsilon_{ij})_{m \times n}$ be the APF-DM, where

$$\varepsilon_{ij} = \left(\sqrt{1 - \prod_{k=1}^{\ell} (1 - \mu_k^2)^{\lambda_k}}, \prod_{k=1}^{\ell} (\nu_k)^{\lambda_k} \right). \tag{7}$$

Step 4: Determine criteria weights.

Step 4.1: Evaluate objective weights (OWs) by the MEREC method.

Step 4.1-A: Normalize the APF-DM. The elements of the normalized matrix are denoted by $\mathbb{N}_{norm} = n_{ij}^x$, where F_b represents benefit criteria and F_c represents cost criteria.

$$n_{ij}^x = (\bar{\mu}_{ij}, \bar{\nu}_{ij}, \bar{\pi}_{ij}) = \begin{cases} \varepsilon_{ij} = (\mu_{ij}, \nu_{ij}, \pi_{ij}), & j \in F_b \\ (\varepsilon_{ij})^c = (\mu_{ij}, \nu_{ij}, \pi_{ij}), & j \in F_c. \end{cases} \tag{8}$$

Step 4.1-B: Compute the overall performance of the alternatives (Ω_i). A logarithmic measure with equal criteria weights is employed to get options overall performance in this step.

$$\Omega_i = \ln \left(1 + \left(\frac{1}{n} \sum_{j=1}^n |\ln(n_{ij}^x)| \right) \right). \tag{9}$$

Step 4.1-C: Compute the performance of the alternatives by removing each criterion. The same logarithmic function as in step 4.1.B is used, and the only difference is that the alternative evaluations are calculated on the basis of eliminating each criterion individually in this step. Hence, we have n sets of evaluations corresponding to n criteria. Assume Ω'_{ij} represents the entire evaluation of i th alternative for eliminating the j th criterion. The following process of appraisal using Eq. (10):

$$\Omega'_{ij} = \ln \left(1 + \left(\frac{1}{n} \sum_{k, k \neq j} |\ln(n_{ik}^x)| \right) \right). \tag{10}$$

Step 4.1-D: Calculate the summation of absolute deviations. We use Eqs. (9) and (10)

$$D_j = \sum_{i=1}^m \left| \Omega'_{ij} - \Omega_i \right|. \tag{11}$$

Step 4.1-E: Evaluate the final weights of the criteria.

$$w_j^o = \frac{D_j}{\sum_{j=1}^n D_j}. \tag{12}$$

Step 4.2: Evaluate the subjective criteria weights (SCWs) by the SWARA method. The procedure for assessment of the criteria weights using the SWARA technique is given as follows:

Step 4.2-A: Determine the crisp values. Initial score values $S^*(\varepsilon_{kj})$ of PFNs by (5) are calculated given in APF-DM.

Step 4.2-B: Calculate the rank of criteria. The appraisal criteria are ranked according to the expert's insight from the most to the least significant element.

Step 4.2-C: Assess the relative significance (s_j) of the average value. Relative position is estimated from the criteria that are placed at second position. The succeeding relative importance is obtained by comparing the criteria located at j th and $(j - 1)$ th places.

Step 4.2-D: Estimate the relative coefficient (c_j) by Eq. (13)

$$c_j = \begin{cases} 1, & j = 1, \\ s_j + 1, & j > 1. \end{cases} \tag{13}$$

Here, s_j represents relative significance.

Step 4.2-E: Compute the recalculated weights (p_j) given Eq. (14)

$$p_j = \begin{cases} 1, & j = 1, \\ \frac{c_{j-1}}{c_j}, & j > 1. \end{cases} \tag{14}$$

Step 4.2-F: Compute scaled weight given as:

$$w_j^s = \frac{p_j}{\sum_{j=1}^n p_j}. \tag{15}$$

Step 4.3: Compute the combined criteria weights.

In the MCDM technique, all criteria have varying degrees of significance. Let $w = (w_1, w_2, \dots, w_n)^T$ be the weights of the criteria with $\sum_{j=1}^n w_j = 1$ and $w_j \in [0, 1]$. It is given as:

$$w_j = \frac{w_j^o * w_j^s}{\sum_{j=1}^n w_j^o * w_j^s}. \tag{16}$$

Step 5: Rank the alternative by MARCOS. Evaluate an expanded initial Pythagorean-fuzzy DM by evaluating the PF-PIS and PF-NIS.

$$PIS = \max_j \varepsilon_{ij} \text{ if } j \in F_b \quad \& \quad PIS = \min_j \varepsilon_{ij} \text{ if } j \in F_c, \tag{17}$$

$$NIS = \min_j \varepsilon_{ij} \text{ if } j \in F_b \quad \& \quad NIS = \max_j \varepsilon_{ij} \text{ if } j \in F_c. \tag{18}$$

Step 6: Compute the crisp values using Eq. (5)

Step 7: Normalize the Pythagorean fuzzy decision matrix $\mathbb{N}' = (n'_{ij})_{m \times n}$, where

$$n'_{ij} = \frac{x_{ai}}{x_{ij}}, \quad \text{Cost type criteria} \tag{19}$$

$$n'_{ij} = \frac{x_{ij}}{x_{ai}}, \quad \text{Benefit type criteria} \tag{20}$$

where F_b is the benefit criterion and F_c is the cost criterion, respectively

Step 8: Create the weighted matrix given Eq. (21), where (w_j) represents combined criterion weights.

$$\zeta_{ij} = n'_{ij} \times w_j. \tag{21}$$

Step 9: Compute the utility degree of the alternatives given as:

$$\mathcal{K}_i^+ = \frac{S_i}{S_{pi}} \quad \text{and} \quad \mathcal{K}_i^- = \frac{S_i}{S_{ni}} \tag{22}$$

where $S_i = \sum_{j=1}^n \zeta_{ij}$.

Step 10: Calculate the utility function (UF) in the relation to the PIS $f(\mathcal{K}_i^+)$ and NIS $f(\mathcal{K}_i^-)$ applying the following Eqs. (23), (24) and (25):

$$f(\mathcal{K}_i^+) = \frac{\mathcal{K}_i^-}{\mathcal{K}_i^+ + \mathcal{K}_i^-}, \tag{23}$$

$$f(\mathcal{K}_i^-) = \frac{\mathcal{K}_i^+}{\mathcal{K}_i^+ + \mathcal{K}_i^-}, \tag{24}$$

$$f(\mathcal{K}_i) = \frac{\mathcal{K}_i^+ + \mathcal{K}_i^-}{1 + \frac{1-f(\mathcal{K}_i^+)}{f(\mathcal{K}_i^+)} + \frac{1-f(\mathcal{K}_i^-)}{f(\mathcal{K}_i^-)}}. \tag{25}$$

Step 11: Find the best ranking of alternatives.

4 Case Study: Hospital Management System Software

HMS is a workflow-based ICT system, especially for government and private sector hospitals. In the public sector, some successful HMS is listed in the Indian National Informatics Centre (NIC, 2013). HMS is a general software system covering the major functional areas, providing an automated tool that streamlines all functions including patient management, medical inventory and regulatory compliance. In this paper, we solve an MCDM problem to identify the best HMS tool T_i under a Pythagorean fuzzy domain.

4.1 MediXcel EMR and HIS Software

MediXcel presently caters to single associated multi-distinctiveness clinics and clinic chains, clinical clusters and different types of hospitals, including an electronic medical report (EMR), inventory and pharmacy, lab and radiology reporting. MediXcel is a good platform for paperless hospitals and is utilized in a multi-location diagnostic chain in Mumbai. It is likewise employed to run genetics labs across the world. MediXcel is easy-to-use electronic medical record and practice management software. It is a browser-based application placed on a cloud server accessible as needed. The software offers accessible, well-timed and

Fig. 2 The comparative analysis of criteria weights

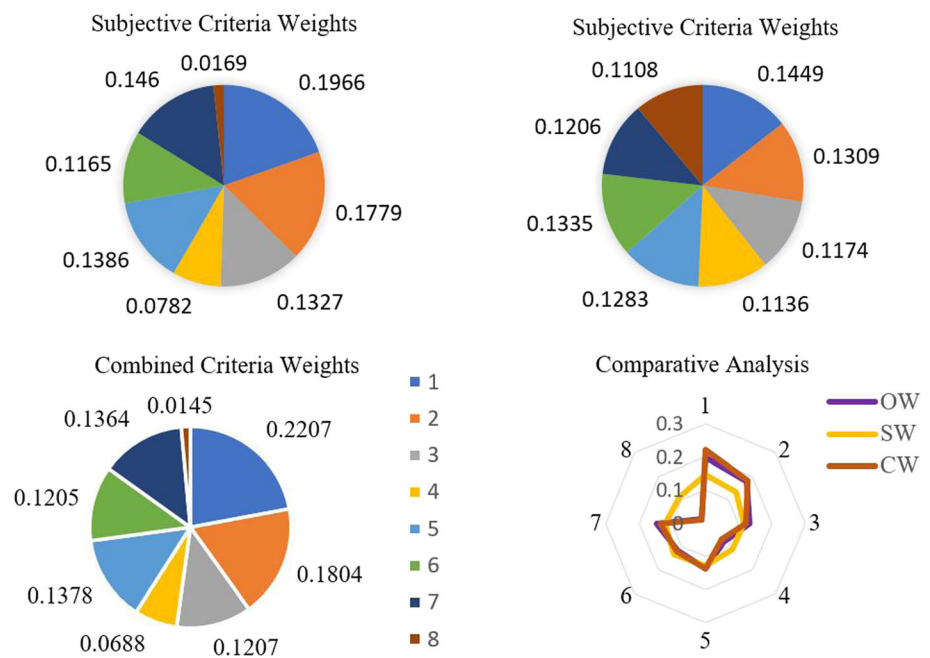


Table 1 Linguistic variables (LVs) in terms of PFNs

LVs	Abbreviation	PFNs
Extremely significant	ES	(0.90, 0.10)
Very significant	VS	(0.80, 0.20)
Significant	S	(0.60, 0.40)
Moderate	M	(0.50, 0.50)
Insignificant	I	(0.45, 0.55)
Very insignificant	VI	(0.30, 0.75)
Extremely insignificant	EI	(0.10, 0.90)

Table 2 Decision expert weights for LVs

Decision experts	LVs	PFNs	Weights λ_k
E ₁	S	(0.6000,0.4000)	0.2592
E ₂	M	(0.5000,0.5000)	0.1825
E ₃	VS	(0.8000,0.2000)	0.4110
E ₄	I	(0.4500,0.5500)	0.1473

Table 3 LV evaluating the alternative (Alt)

LVs	Abbreviation	PFNs
Extremely low	EL	(00,01)
Very low	VL	(0.10, 0.90)
Low	L	(0.20, 0.80)
Slightly low	SL	(0.30, 0.70)
Below average	BA	(0.40, 0.60)
Average	A	(0.50, 0.50)
Above average	AA	(0.60, 0.40)
Slightly high	SH	(0.70, 0.30)
High	H	(0.80, 0.20)
Very high	VH	(0.90, 0.10)
Extremely high	EH	(01, 00)

patient-focused care with controlled workflow and reminders.

4.2 Helmind Software

Helmind is a simple electronic health record and HMS-related software that provides practical, actionable and focused data to automatically manage the day-to-day operations of hospitals.

Table 4 LVs calculating the alternatives given by decision experts

Alt	DEs	Criteria							
		F_1	F_2	F_3	F_4	F_5	F_6	F_7	F_8
T ₁	E ₁	VH	VH	H	H	VH	H	VH	BA
	E ₂	H	SH	SH	A	H	VH	H	SL
	E ₃	H	VH	VH	SH	VH	H	VH	A
	E ₄	VH	VH	H	H	SL	H	H	AA
T ₂	E ₁	VH	H	SH	SH	VH	VH	VH	BA
	E ₂	H	H	A	SH	H	SH	H	AA
	E ₃	VH	VH	H	AA	H	A	H	A
	E ₄	H	H	VH	VH	AA	VH	SH	BA
T ₃	E ₁	VH	H	SH	SH	H	H	VH	A
	E ₂	VH	H	SH	AA	AA	SH	H	SL
	E ₃	H	VH	VH	A	VH	SH	H	BA
	E ₄	VH	AA	BA	VH	A	H	BA	AA
T ₄	E ₁	H	H	AA	SH	H	H	VH	A
	E ₂	VH	H	SH	AA	SL	SH	A	AA
	E ₃	H	H	SH	SH	AA	AA	SH	BA
	E ₄	H	VH	VH	SL	SH	L	BA	A
T ₅	E ₁	VH	H	SH	SH	H	H	H	A
	E ₂	H	H	H	BA	SH	BA	AA	L
	E ₃	H	H	AA	SH	H	H	SH	A
	E ₄	VH	SH	VH	A	AA	AA	AA	SH

4.3 KareXpert Advanced HIMS Software

The KareXpert comprehensive integrated digital healthcare tool, a SaaS-based setup, enables hospitals to achieve end-to-end automated care of their patients transport and deliver the best patient treatment experience. This is unlike chronic technologies, the hospital IT team is fully capable of purchasing and integrating individual products.

4.4 Caresoft Hospital Information System Software

Caresoft offers an excellent solution that enables the health workspace to deliver superior patient care with the use of technology. The software is designed and developed in such a way as to face future challenges. It is committed to creating a healthcare method which helps to build a healthcare system, better healthcare for lower cost and higher quality healthcare.

4.5 GeniPulse HMS Software

GeniPulse HMS is the best install-based HMS for all types of hospitals. This software has an inbuilt mechanism that

Table 5 Aggregated Pythagorean fuzzy decision (APF-D) matrix for HMS

	F_1	F_2	F_3	F_4	F_5	F_6	F_7	F_8
T_1	(0.8499, 0.1509)	(0.8789, 0.1222)	(0.8396, 0.1620)	(0.7246, 0.2793)	(0.8550, 0.1512)	(0.8244, 0.1762)	(0.8749, 0.1257)	(0.4673, 0.5394)
T_2	(0.8749, 0.1257)	(0.8504, 0.1504)	(0.7681, 0.2371)	(0.7183, 0.2872)	(0.8173, 0.1851)	(0.7746, 0.2368)	(0.8240, 0.1774)	(0.4869, 0.5170)
T_3	(0.8677, 0.1330)	(0.8359, 0.1666)	(0.7964, 0.2115)	(0.6793, 0.3318)	(0.8108, 0.1954)	(0.7465, 0.2544)	(0.8090, 0.1965)	(0.4526, 0.5545)
T_4	(0.8244, 0.1762)	(0.8199, 0.1806)	(0.7296, 0.2749)	(0.6489, 0.3582)	(0.6568, 0.3548)	(0.6622, 0.3512)	(0.7376, 0.2743)	(0.4865, 0.5174)
T_5	(0.8499, 0.1509)	(0.7881, 0.2123)	(0.7387, 0.2667)	(0.6393, 0.3671)	(0.7632, 0.2385)	(0.7366, 0.2707)	(0.7055, 0.2970)	(0.5087, 0.5053)

Table 6 Normalized aggregated PF-D matrix

	F_1	F_2	F_3	F_4	F_5	F_6	F_7	F_8
T_1	(0.8499, 0.1509)	(0.8789, 0.1222)	(0.8396, 0.1620)	(0.7246, 0.2793)	(0.8550, 0.1512)	(0.8244, 0.1762)	(0.8749, 0.1257)	(0.5394, 0.4673)
T_2	(0.8749, 0.1257)	(0.8504, 0.1504)	(0.7681, 0.2371)	(0.7183, 0.2872)	(0.8173, 0.1851)	(0.7746, 0.2368)	(0.8240, 0.1774)	(0.5170, 0.4869)
T_3	(0.8677, 0.1330)	(0.8359, 0.1666)	(0.7964, 0.2115)	(0.6793, 0.3318)	(0.8108, 0.1954)	(0.7465, 0.2544)	(0.8090, 0.1965)	(0.5545, 0.4526)
T_4	(0.8244, 0.1762)	(0.8199, 0.1806)	(0.7296, 0.2749)	(0.6489, 0.3582)	(0.6568, 0.3548)	(0.6622, 0.3512)	(0.7376, 0.2743)	(0.5174, 0.4865)
T_5	(0.8499, 0.1509)	(0.7881, 0.2123)	(0.7387, 0.2667)	(0.6393, 0.3671)	(0.7632, 0.2385)	(0.7366, 0.2707)	(0.7055, 0.2970)	(0.5053, 0.5087)

Table 7 Computed performance of the alternatives by removing each criterion (Q'_{ij})

	F_1	F_2	F_3	F_4	F_5	F_6	F_7	F_8
T_1	0.0674	0.0729	0.0655	0.0501	0.0675	0.0632	0.0722	0.0331
T_2	0.1105	0.1058	0.0931	0.0872	0.1002	0.0933	0.1013	0.0670
T_3	0.1164	0.1104	0.1039	0.0900	0.1061	0.0982	0.1059	0.0787
T_4	0.1725	0.1718	0.1592	0.1499	0.1505	0.1510	0.1595	0.1371
T_5	0.1599	0.1503	0.1434	0.1325	0.1469	0.1430	0.1398	0.1192

can automatically control the basic workflow of the hospital. Also, it can manage patient data, OPD, and IPD in doctors’ schedules very accurately. The software is very easy to use after minimal training.

The various available HMS systems are as follows: MediXcel EMR and HIS (T_1), Halemind (T_2), KareXpert Advanced HIMS (T_3), Caresoft Hospital Information System (T_4) and GeniPulse HMS (T_5). We have to find the best software tool for any hospital management based on the following features: appointment management (F_1), patient information management (F_2), fast search (F_3), database backup/restore (management)(F_4), multi-user login and role-based access (F_5), security (F_6), electronic medical records, (F_7) and inventory management (F_8).

Table 1 presents the LVs given in PFNs for the relative behavioural rating of weights. Table 2 displays the weight

of each DE as calculated using Eq. (6). For evaluating the alternatives, LVs are transformed in terms of PFNs (Table 3). Here, Table 4 represents the ideas of DEs on each of the alternatives (T_i) with respect to each criterion (F_j) in terms of LVs defined in Table 3. In Table 5, LVs of alternatives given by DEs in Table 4 are converted to APFDM applying Eq. (7).

4.6 MEREC Method

This measure reflects the difference between the performance of the composite alternative and its performance in removing the criterion. The following steps are used to compute the OWs by the MEREC method. We calculate the score matrix using Eq. (5). As $\{F_5, F_8\}$ is a set of cost/non-benefit and others are benefit type of criteria, we

Table 8 Assessment of criteria weights

Criteria	E_1	E_2	E_3	E_4	Aggregated PFNs	Crisp values $S^*(\epsilon_{kj})$
F_1	VH	H	SH	VH	(0.8244, 0.1783)	0.6973
F_2	VH	SH	A	H	(0.7487, 0.2622)	0.5916
F_3	H	AA	A	SH	(0.6564, 0.3511)	0.4810
F_4	SH	H	BA	AA	(0.6265, 0.3865)	0.4474
F_5	VH	A	SH	SL	(0.7339, 0.2806)	0.5721
F_6	H	SH	H	AA	(0.7632, 0.2385)	0.6118
F_7	VH	AA	BA	A	(0.6821, 0.3409)	0.5077
F_8	BA	H	A	SH	(0.6015, 0.4113)	0.4213

normalized-APF-DM using Eq. (8), and it is shown in Table 6. To obtain the OCWs by the MERECE method, we calculate the overall performance of the alternative values (Ω_i) using Eqs. (9) and (5)

$$\Omega_1 = 0.0271, \Omega_2 = 0.0666, \Omega_3 = 0.0740, \Omega_4 = 0.1399, \Omega_5 = 0.1225$$

In Table 7, using Eq. (5), the generalized score values are calculated. Thereafter we computed the absolute

deviations (D_j) using Eq. (11) and objective criteria weights (w_j^o) by the MERECE method in Eq. (12).

$$D_1 = 0.1966, D_2 = 0.1811, D_3 = 0.1350, D_4 = 0.0796, D_5 = 0.1411, D_6 = 0.1186, D_7 = 0.1486, D_8 = 0.0172$$

$$w^o = (0.1932, 0.1779, 0.1327, 0.0782, 0.1386, 0.1165, 0.1460, 0.0169)$$

4.7 Subjective Criteria Weights (SCWs) by the SWARA Method

In the following Table 8, the SCWs are computed using the SWARA method (Table 9):

Thereafter, we calculated the combined criteria weights (w) using Eq. (16),

$$(w) = (0.2207, 0.1804, 0.1207, 0.0688, 0.1378, 0.1205, 0.1364, 0.0145)^T$$

4.8 Pythagorean Fuzzy MARCOS Method

Based on Table 5, evaluation of PIS and NIS of each criterion are concerns for decision experts.

Table 9 Calculated SCWs by the PF-SWARA method

Criteria	Crisp values	Comparative importance (s_j)	Coefficient (c_j)	Recalculated weight (p_j)	Criteria weight (w_j^s)
F_1	0.6973	–	1.0000	1.0000	0.1449
F_6	0.6118	0.0855	1.0855	0.9212	0.1335
F_2	0.5916	0.0202	1.0202	0.9030	0.1309
F_5	0.5721	0.0195	1.0195	0.8857	0.1283
F_7	0.5077	0.0644	1.0644	0.8321	0.1206
F_3	0.4810	0.0267	1.0267	0.8105	0.1174
F_4	0.4474	0.0336	1.0336	0.7842	0.1136
F_8	0.4213	0.0261	1.0261	0.7643	0.1108

Table 10 PIS and NIS determined for the PF-D matrix

	F_1	F_2	F_3	F_4	F_5	F_6	F_7	F_8
NIS	0.8244, 0.1762	0.7881, 0.2123	0.7296, 0.2749	0.6393, 0.3671	0.6568, 0.3548	0.6622, 0.3512	0.7055, 0.2970	0.5087, 0.5053
T_1	0.8499, 0.1509	0.8789, 0.1222	0.8396, 0.1620	0.7246, 0.2793	0.8550, 0.1512	0.8244, 0.1762	0.8749, 0.1257	0.4673, 0.5394
T_2	0.8749, 0.1257	0.8504, 0.1504	0.7681, 0.2371	0.7183, 0.2872	0.8173, 0.1851	0.7746, 0.2368	0.8240, 0.1774	0.4869, 0.5170
T_3	0.8677, 0.1330	0.8359, 0.1666	0.7964, 0.2115	0.6793, 0.3318	0.8108, 0.1954	0.7465, 0.2544	0.8090, 0.1965	0.4526, 0.5545
T_4	0.8244, 0.1762	0.8199, 0.1806	0.7296, 0.2749	0.6489, 0.3582	0.6568, 0.3548	0.6622, 0.3512	0.7376, 0.2743	0.4865, 0.5174
T_5	0.8499, 0.1509	0.7881, 0.2123	0.7387, 0.2667	0.6393, 0.3671	0.7632, 0.2385	0.7366, 0.2707	0.7055, 0.2970	0.5087, 0.5053
PIS	0.8749, 0.1257	0.8789, 0.1222	0.8396, 0.1620	0.7246, 0.2793	0.8550, 0.1512	0.8244, 0.1762	0.8749, 0.1257	0.4526, 0.5545

Table 11 Computed score values for the PF-D matrix

	F_1	F_2	F_3	F_4	F_5	F_6	F_7	F_8
NIS	0.6975	0.6456	0.5681	0.4624	0.4807	0.4865	0.5387	0.3323
T_1	0.7359	0.7817	0.7213	0.5619	0.7434	0.6975	0.7753	0.2984
T_2	0.7753	0.7367	0.6179	0.5539	0.6869	0.6259	0.6969	0.3158
T_3	0.7637	0.7145	0.6565	0.5064	0.6772	0.5901	0.6748	0.2860
T_4	0.6975	0.6878	0.5681	0.4728	0.4807	0.4865	0.5772	0.3154
T_5	0.7359	0.6456	0.5795	0.4624	0.6118	0.5766	0.5387	0.3323
PIS	0.7753	0.7817	0.7213	0.5619	0.7434	0.6975	0.7753	0.2860

Table 12 PF linear normalized decision matrix

	F_1	F_2	F_3	F_4	F_5	F_6	F_7	F_8
NIS	0.8996	0.8259	0.7876	0.8229	0.6466	0.6975	0.6948	0.8607
T_1	0.9492	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9584
T_2	1.0000	0.9424	0.8566	0.9858	0.9239	0.8973	0.8989	0.9056
T_3	0.9850	0.9140	0.9102	0.9012	0.9109	0.8460	0.8704	1.0000
T_4	0.8997	0.8799	0.7876	0.8414	0.6466	0.6975	0.7445	0.9068
T_5	0.9492	0.8259	0.8034	0.8229	0.8229	0.8267	0.6948	0.8607
PIS	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

Table 13 Weighted normalized PF-D matrix

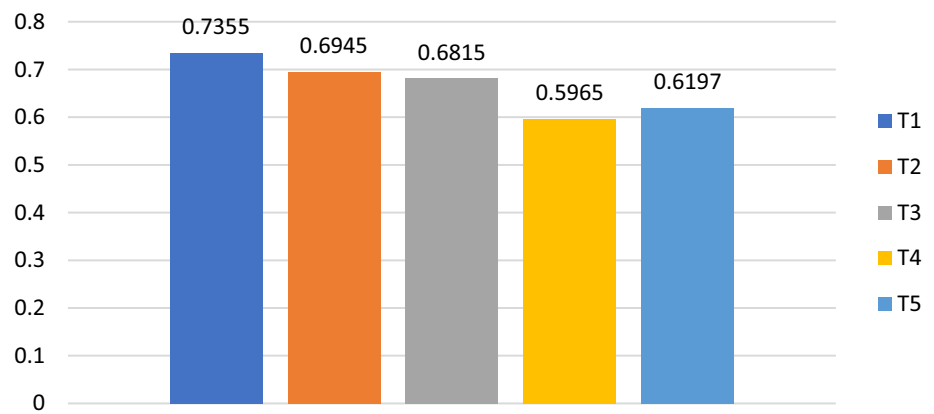
	F_1	F_2	F_3	F_4	F_5	F_6	F_7	F_8
NIS	0.1967	0.1532	0.1069	0.0645	0.0844	0.0746	0.0900	0.0126
T_1	0.2076	0.1855	0.1357	0.0784	0.1306	0.1069	0.1296	0.0140
T_2	0.2187	0.1748	0.1162	0.0773	0.1207	0.0959	0.1165	0.0132
T_3	0.2154	0.1695	0.1235	0.0707	0.1189	0.0904	0.1128	0.0146
T_4	0.1968	0.1632	0.1069	0.0659	0.0844	0.0746	0.0965	0.0132
T_5	0.2076	0.1532	0.1090	0.0645	0.1075	0.0884	0.0900	0.0126
PIS	0.2187	0.1855	0.1357	0.0784	0.1306	0.1069	0.1296	0.0146

Table 14 Ranking order of PF-MARCOS for HMS alternative selection

Alt	Total sum of weighted matrix (S_i)	\mathcal{K}_i^-	\mathcal{K}_i^+	$f(\mathcal{K}_i)$	Rank
NIS	0.7829				
T_1	0.9883	1.2624	0.9883	0.7355	1
T_2	0.9333	1.1921	0.9333	0.6945	2
T_3	0.9158	1.1698	0.9158	0.6815	3
T_4	0.8015	1.0238	0.8015	0.5965	5
T_5	0.8328	1.0637	0.8328	0.6197	4
PIS	1.0000				

The expanded initial P-DM, score values, normalized P-DM and normalized weighted Pythagorean decision matrix are shown in Tables 10, 11, 12 and 13. Using values from Table 13, the S_i , \mathcal{K}_i^- and \mathcal{K}_i^+ values are computed by Eq. (22). Then, $f(\mathcal{K}_i)$, the values are found for utility functions and the score of alternatives is computed by

Eqs. (23), (24) and (25). We determined the ranking of the hospital management system software. As can be seen from Table 14, T_1 is at the highest ranking of HMS (see Fig. 3). Pursuant to the outcomes of the MEREC-SWARA-MARCOS technique, we get the ranking order of alternatives as: $T_1 \succ T_2 \succ T_3 \succ T_5 \succ T_4$.

Fig. 3 The ranking of alternatives**Table 15** Comparative study with existing techniques

Techniques	Ranking	Expert's weight	Criterion weights	Utilize the LTs	Alternative assessment information	Optimal selection
Ren et al. (2016)	$T_1 > T_2 > T_3 > T_4 > T_5$	No	Compute	No	PFSs	T_1
Peng et al. (2019)	$T_1 > T_2 > T_3 > T_5 > T_4$	No	Assume	Yes	PFSs	T_1
Kumar et al. (2021a, b)	$T_2 > T_3 > T_1 > T_4 > T_5$	No	Compute	Yes	FS	T_2
Applying hybrid MARCOS method	$T_1 > T_2 > T_3 > T_5 > T_4$	Evaluate	Compute	Yes	PFSs	T_1

4.9 Comparison and Discussion

Currently, with the rapid growth of information technology, selecting the best software for the varied work of hospitals is a complex problem, and MCDM is the best tool to deal with it. In this paper, we have developed an integrated PF-MEREC-SWARA-MARCOS technique for the selection of the best alternative. The empirical results of the proposed method provide significant insights related to the evaluation criteria and the alternative for HMS in India. As may be seen in Table 14, the most significant is the effectiveness of the HMS and software, which we find to be the best alternative among the existing ones. Calculating the results of this paper, the problem of hospital management can be solved to a greater extent. The HMS should not be ignored when selecting the best alternative. We also analysed the performance of HMS alternatives and compared the results for each criterion evaluated. According to the results, T_1 ranks first among all alternatives and T_4 is last in the ranking. Therefore, T_1 can be selected as the best alternative meeting all the evaluation criteria.

In Table 15, the comparative study of the developed hybrid method along with the already prevailing techniques is presented. Results of the comparison show that the proposed method is synchronous with the existing techniques. The preference order of the proposed method and

MARCOS and that given by Peng et al. (2019) is the same, revealing the validity and accuracy of the proposed method. Some of the benefits of the proposed integrated method as visible, in Table 15 are as follows: Initially, PFSs are a resilient preference that is generalized and allows the DM to express their selection on each alternative independently. Thereafter, prevailing methods operate on the supposition that all data are available. However, in applied MCDM problems, this may not always be true. Unlike existing methods, the proposed method considers missing values and applies them systematically using a case-based method. In addition, the criterion evaluated, the criterion alternative and the degree of importance of the DEs are measured as PFNs. On the other hand, in the presented approach, the criterion weights are evaluated by combining MEREC- and SWARA-based formulas, which indicates that the obtained weight is of high precision and optimal. The stability and effectiveness of the integrated method used individually are superior to those of a single technique. In the proposed PF-MEREC-SWARA-MARCOS technique, we have evaluated the weights based on the criteria experts' opinion and calculated the criterion weights after performing the normalization, which leaves no room for ambiguity. The proposed method specifies that the MCDM with more parameters or alternatives for the PF-MEREC-SWARA-MARCOS model can increase the

quantity of operational efficiencies and have better operability.

- In the developed PF-MEREC-SWARA-MARCOS method, we have considered experts, whereas the PF-TODIM (Ren et al. 2016), PF-COCOSO (Peng et al. 2019) and FS-ANP-TOPSIS methods (Kumar et al. 2021a, b) do not.
- In the developed integrated PF-MEREC-SWARA-MARCOS technique, we have evaluated combined expert weights based on expert opinion, leaving no room to treat ambiguity, while PF-TODIM (Ren et al. 2016), PF-COCOSO (Peng et al. 2019) and (Kumar et al. 2021a, b) do not involve expert opinion.
- In the PF-TOPSIS method (Saeidi et al. 2022), to find the distance between two sets, whereas in the PF-MARCOS method we find PF-ideal and PF-anti-ideal solutions. The degree of utility is more precisely determined with respect to both set solutions.
- PF-MARCOS outperformed PF-TODIM (Ren et al. 2016) and PF-TOPSIS (Saeidi et al. 2022) in terms of efficiency and effectiveness. In addition, the Integrated MEREC-SWARA-MARCOS method is more robust and stable in terms of parameter weight variation than PF-COCOSO (Peng et al. 2019).
- The decision delivered by the integrated MEREC-SWARA-MARCOS method is more efficient and less biased than PF-TOPSIS (Saeidi et al. 2022) and PF-TODIM (Ren et al. 2016). Furthermore, in the presence of PF-TOPSIS (Saeidi et al. 2022), there is data variation.

5 Conclusions

With the proliferation of novel opportunities offered through the use of information technology in healthcare, experts have achieved numerous innovations in medical practice, which have led to vast improvements in the delivery of health services. Software packages can be used for information systems for patients, allied business, health operators, and specific HMS functions, especially those planned for hospital management and administration, enabling the analysis and subsequent expansion and dissemination of hospital management applications. An MCDM is a good tool for selecting the best software. In this regard, we developed a hybrid method in a Pythagorean fuzzy environment and combined two new methods to determine the weighting of parameters. Finally, the MARCOS method was employed to obtain the best ranking of alternatives.

- A new normalization score function for PFN is proposed, which minimizes information loss by taking uncertainty into account. Compared to existing score functions, it has a more robust ability to differentiate when comparing two PFNs.
- The combined weight framework is proposed based on the MEREC and SWARA weighted extensive methods, which is considered both objective and subjective.
- MEREC presented a new PF-decision-making technique based on the MARCOS method, which can obtain the best alternative without any adverse events, can obtain the outcome of the decision without segmentation, and has robust ability.

The shortcomings of the projected structure are significant. A practical problem is that the DM must be skilled in the flexibility and ability to properly use the preferred style of PFS. The projected structure will be a useful tool for choosing the best hospital management system software under multi-criteria situations and ambiguous environments. In the future, the developed MCDM method may be further applied to interval-valued PFNs, hesitant PFNs, picture fuzzy sets and q-rung environment. Moreover, researchers can extend our research via numerous MCDM platforms, such as gained and lost dominance score (GLDS), CoCoSo and MAIRCA, to select the most appropriate HMS selection, and more features can be assessed. Therefore, parameters can be identified and selected for easy use and high safety. The limitation of the current study is that only a small number of DEs were included, and it does not take into account the interrelationships among the criteria, which somewhat limits the application scope of the proposed framework. Consequently, further research is still needed that considers a large number of decision experts.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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