Journal of Artificial Intelligence and Technology, 2023, 3, 53-59
https://doi.org/10.37965/jait.2023.0167

ISTP
RESEARCH ARTICLE

Studies on Multi-Criteria Decision-Making-Based Healthcare Systems Using the Machine Learning

Sk Anamul Hoda and Abhoy Chand Mondal
The Department of Computer Science, The University of Burdwan, West Bengal, India

(Received 16 February 2023; Revised 18 March 2023; Accepted 20 March 2023; Published online 25 March 2023)

Abstract: There is a lot of information in healthcare and medical records. However, it is challenging for humans to turn data into information and spot hidden patterns in today's digitally based culture. Effective decision support technologies can help medical professionals find critical information concealed in voluminous data and support their clinical judgments and in different healthcare management activities. This paper presented an extensive literature survey for healthcare systems using machine learning based on multi-criteria decision-making. Various existing studies are considered for review, and a critical analysis is being done through the reviews study, which can help the researchers to explore other research areas to cater for the need of the field.

Keywords: fuzzy analytical hierarchical process; healthcare: machine learning; multi-criteria decision-making

I. INTRODUCTION

Multi-criteria decision-making (MCDM) can be described as a set of approaches to help in complex decision-making problems. MCDM approaches provide heuristics to determine the best course of action to achieve long-term goals. The motivation toward developing MCDM approaches is to eliminate the limitations of traditional techniques based on single-criterion decisions. Alternatively, MCDM is effective while multiple criteria need to be considered to choose among alternatives. While handling healthcare issues, the success of healthcare decisions lies in comprehensively understanding the choices and considering the future implications to select the best option possible. MCDM helps analyze healthcare issues from various perspectives. MCDM approaches include three parts such as data processing, evaluating the outcomes and selection, and planning. Data processing leads to identifying the healthcare issues, and evaluation helps assess each solution's performance for healthcare management. Planning and design help in setting the goals of healthcare solutions and exploring the relationship structure among multiple criteria. It is challenging for healthcare decision makers with various complex choices due to the ad-hoc decision-making process, which may raise concerns about transparency and comprehensiveness. In such situations, multi-criteria decision analysis (MCDA) can be a promising tool to appraise multiple aspects of unrelated and conflicting information for healthcare decision-making. The healthcare system is responsible for healthy societies and individuals and taking care of their health and diagnosis of disease. Determining the correct diagnosis is crucial to achieving the objective of a sound healthcare system. Proper diagnosis is based on a blend of information about the patient, which can be selected based on the diagnosis established.

Machine learning is used to understand data and find a pattern. The patterns used to understand various health situations are based on the input data. Machine learning utilizes mathematical models to train and learn data through learning algorithms. Machine learning methods can be classified into different types, such as supervised, unsupervised, and reinforcement learning. To obtain solutions for healthcare problems, supervised learning is suitable to determine the relationships in patient's data (input) and defined outcome (output).

There is a huge potential and contribution of machine learning brings to healthcare. Machine learning has the ability to provide an effective approach to healthcare processes. Correct diagnosis is important in healthcare, but getting the proper diagnosis on time is also equally important. Different sensing technologies now enabled to monitor a patient around the clock by measuring and transmitting the information. The information collected by these sensors could be more helpful for medical practitioners in its raw form, but the huge datasets can be processed through machine learning algorithms to generate patterns. For example, machine learning algorithms can detect heart anomalies more accurately based on large datasets. Outcomes obtained from machine learning algorithms can assist doctors. Machine learning and artificial intelligence techniques can save healthcare professionals time, and it has proven that they can forecast health-related issues. Although MCDM has been used in operational research for a long time, recently, it has increased interest while including machine learning techniques in the traditional numerical models.

The rest of the paper is organized as follows. Section II describes the methodology for the review process and search strategy and selection of relevant research work. Section III explores the literature review with salient features and future direction. Section IV demonstrates the analysis of the literature review. The conclusion and future work drawn from the entire discussion are presented in section V.

II. METHODOLOGY

The review of the research topic is aimed to explore the related methods and studies used for healthcare systems using MCDM and

Corresponding author: Abhoy Chand Mondal (e-mail: abhoy_mondal@yahoo.co.in).

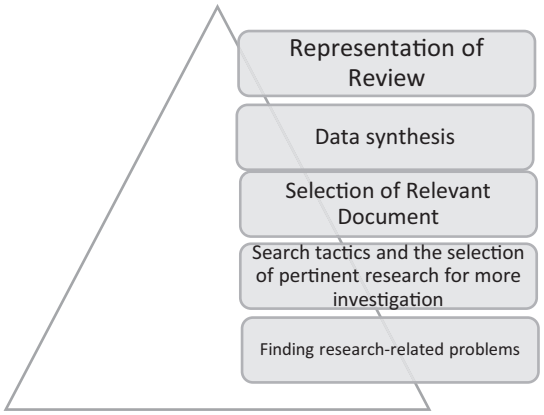

Fig. 1. Methodology for a review process.

Table I. Selection criteria for journal databases

Selection criteria	Journal database
Inclusion of the document	Peer-reviewed journals, research papers and articles, including accepted manuscripts, reputed conference papers, and review papers, also without any time frame constraints
Exclusion of the document	When searching non-English documents, documents with missing abstracts at the time of the study and generic and irrelevant documents are excluded; also, documents that are not peer-reviewed are excluded

machine learning and to analyze their strength and weaknesses. It also aims to provide improved awareness of new developments and challenges in the healthcare system. During the evaluation process, the research papers were identified and examined using machine learning techniques currently in use for MCDM. Figure 1 depicts all phases of the review, and it breaks down the entire review process into several components.

Numerous online journal databases, such as Scopus, IEEE, Science Direct, Web of Science, ACM Digital Library, SpringerLink, and Google Scholar, are utilized to conduct reviews. The terms "MCDM," "Healthcare," and "machine learning techniques" are searched in the document's titles. After gathering enough literature, the documents were refined, emphasizing what to include and what to leave out. The relevant documents that could provide discretionary knowledge of the research domain are included. The papers not focused on enhancing the robustness of machine learning techniques, not having abstracts, and not having significance to our research objective are excluded (Table I).

III. LITERATURE REVIEW

The healthcare decision process is considered to be a low, transparent process. To make a complex decision, the decision process should be able to identify the best alternatives and decision criteria must be weighted and scored for all other options. In [1], the author describes the MCDA framework to identify, approve, and provide guidelines for healthcare solutions. However, various challenges still need to be resolved, such as the selection of appropriate MCDA techniques and quantifying the impact of uncertainty while making a complex decision.

Decision-making in healthcare also involves appraising existing pieces of evidence, societal values, and ethical considerations. MCDA is a supporting tool which can break down a complex problem into multiple components to support decision-making in healthcare. However, author [2] believes that health technology assessment through which data are collected has not fully emerged. Hence, there is a need to merge MCDA and health technology assessment to support informed healthcare decision-making.

While treating patients in hospitals, they serve by considering the urgency and importance of the treatment they desire, an elective admission system that can be established based on evaluating the admission priority. In [3], authors proposed a hybrid MCDM model which integrates a weighted system of evaluating criteria and a fuzzy method to assess the various alternatives. The authors claimed that the proposed model was effective to receive the useful insights for hospital management. Advanced machine learning can be applied to prioritize alternatives and the importance of weights in the future research.

In [4], the issues of selecting the appropriate machine learning algorithm were discussed. Even the process of algorithm selection could utilize MCDM. The author proposed a fuzzy analytical hierarchical approach to the order of preference to the appropriate solutions. A matrix is formed based on the pairwise comparison by taking decision makers judgment and later, it is aggregated and normalized. It is claimed that MCDM techniques help select the best supervised machine learning algorithms.

Study [5] presented an overview of practical insights of MCDA methods and their applications in healthcare. Healthcare applications are based on different aspects such as diagnosis, treatment, resource allocation, and health technology assessment. Each of these healthcare sector segments requires decision-making based on different criteria. MCDA can help in structured and justified analysis for decision makers and stakeholders to make final decisions. Decision-making in the military environment [6] is difficult due to insufficient resources. It is more important to make appropriate decisions for the military healthcare system under different constraints, risks, and situations. In such environment, MCDM may assist with systematic, consistent, and powerful decision-making approaches. Military personnel need to maintain their good health status. MCDM is promising with machine learning techniques to take decisions.

Multifaceted data analysis is required to diagnose and predict tumor grading and cancer detection. The data are collected from multiple sources such as clinical treatments, medical images, and pathology as well. However, processing and classifying the huge clinical data for prediction modeling still need more efficient approaches. In [7], a multi-criterion decision-making-based classifier framework is proposed with experimentation on two clinical datasets. Experimental results claim to be superior predictive performance. However, deciding the importance of various features still needs improvement. COVID-19 has taught us the importance of sudden desires for frontline healthcare services—the study of prioritizing the wastes and various dimensions contributing to these wastes. Analysis [8] uses MCDM to extract and prioritize lean wastes within healthcare.

Machine learning algorithms extensively used for identifying COVID-19 through its various symptoms, such as cough types. In [9], author uses different cough datasets and applies machine learning algorithms to classify them as COVID-19 or non-COVID-19. They also used MCDM to select the best model

through an ensemble the technologies. Feature reduction is done through recursive feature elimination under different estimators. However, the study can be extended by using cross-institutional datasets and involving more symptoms. In [10], author advocates using MCDM in healthcare surgical management. It can help medical practitioners understand causative factors and prioritization for effective decision-making during surgery.

Healthcare sector is keen to improve healthcare services by implementing the latest technological development. In [11], the author investigates various organizational hindrances that can impact the adoption of advanced healthcare technologies. The study highlighted some significant barrier that belongs to effect category. These barriers such as lack of vision from the top management, scarcity of skilled professionals, and the organization organogram are considered critical ones. Identified barriers can help decision makers to make policies for adopting the latest technologies in the health sector.

Waste management and treatment in healthcare entities have become a major issue. It is difficult to select the best option to dispose of healthcare waste. Hence, choosing the best waste disposal method can be considered a complex MCDM problem. In [12], the proposed study complex proportional assessment is done through the proposed entropy measure Pythagorean fuzzy set. However, waste disposal policies also depend on governmental policies, technological innovations, and their effective execution.

During COVID-19, we have seen that proper decisions regarding prevention strategies, and drug and vaccine development helped a lot in combating the disease. Study [13] states that MCDM helps in controlling the COVID-19 patients in terms of the comprehensive analysis of criteria used for precise diagnosing according to guidelines. In the study, future direction is provided to include the fuzzy Delphi method for unifying criteria and MCDM approach for prioritizing alternatives to provide a unique ranking solution.

In [14], different MCDA methods are discussed and the categories of the methods mentioned as outranking methods, value-based methods, and reference level methods. It is also found in the study that hybrid approaches are widely used in healthcare decision-making problems. The selection of MCDA methods depends on the nature and complexity of the healthcare problem. The research study further can be extended to explore the link between the decision-making problem and selected MCDA method.

In [15], the combination of spatial models and machine learning techniques for demonstrating the application of MCDA in healthcare has been discussed. The study investigates the risk factors and quantifies it for disease such as malaria and dengue. Authors claim to minimize the subjective bias while taking decision to quantify the risk. They also claimed that ensemble learning approach. However, there is a need to further explore to couple geographic information systems (GIS) and machine learning to build a robust model. In [16], a framework is proposed to improve the accessibility to healthcare facilities specifically for testing and vaccination sites during the COVID-19 pandemic. To uncover the barriers and their impact on healthcare access, MCDA approach is used. MCDA can also be used to plan preventive measures for future outbreaks of such pandemics. MCDM can be applied to analyze complex decisions to provide appropriate solution.

Treating patient with breast cancer [17] has a better chance of survival if they are diagnosed early. Various supervised machine learning methods and MCDM techniques, which include preference ranking methods, are the reasons for optimism to diagnose breast cancer. However, among multiple supervised learning methods, it is required to select the most efficient method. Due to involvement of fuzziness and ambiguity associated with qualitative decision-making, fuzzy MCDM. However, author [18] presents a critique review of fuzzy methods. In the study, it is found that fuzzy MCDM methods are computationally complex and heavy to obtain clear advantages of fuzzy methods.

Mobile healthcare improves access to health resources for ordinary consumers and even at low cost and conveniently. In [19], a method is developed to examine consumer's adoption of mobile healthcare. Key factors which affect consumer adoption of mobile healthcare are mentioned as product image, social norms, and consumer trust. However, the data collected for analysis involve a limited number of experts in mobile healthcare.

Electronic health record (EHR) technology is the great innovation and need for the hour; however, its implementation is very slow. EHR ensures [20] quality healthcare services by automating procedures with individual health records for sustained development. MCDM model can solve various real-life situations. However, there is a need to further explore the relative weights and their effect on EHR while implementing multiple criteria models.

In [21], authors proposed MCDM approaches based on machine learning algorithms and colliding with evidential reasoning approach. The proposed framework is based on the selection of machine learning algorithm with highest predictive accuracy and connect it with optimization model to minimize the difference between assessment derived and the predicted results. Authors claimed that the proposed method is used to generate accurate and explanatory decisions and to diagnose thyroid nodules. However, proposed method can be explored to diagnose other diseases also.

In [22], various classification techniques such as k-means, logistic regression, and naive Bayes are combined and tested by MCDM to build an ensemble classifier. To diagnose the sleep disorders, sleep scoring is important since it can quantify the quality of sleep. Quality index of sleep helps in identifying the abnormalities in patient. However, the proposed method requires to be tested with electroencephalogram (EEG) data such as epilepsy for further research.

In [23], decision-making model is proposed for supplier selection for hospital. Proposed model utilizes MCDM which aims to select the best supplier. Two specific MCDM methods, that is, best worst method (BWM) and decision-making trial and evaluation laboratory (DEMATEL), are used to determine criteria weights. Aggregated criteria weights are used to rank the suppliers. The proposed method can be extended for other verticals used in healthcare such as medical waste management and renewable energy selection.

Various situations in healthcare field occur where multiple criteria play a role to take decisions. These situations [24] may be life threatening or situations in which decisions taken are responsible for reducing health inequalities. In such situations, decision makers need to consider multiple criteria simultaneously. While considering multiple criteria for decision-making in the medical field, priority setting of decision through establishing the weights of these criteria is also important. However, MCDA should not be considered as formulaic or technocratic approach, but it should be considered as assistance in policy making.

Now a days, internet of things (IoT)-based healthcare system plays a vital role in connecting the devices to enable IoT data analytics which could give better insights and results. Various information can be collected through IoT devices like pulse rate, temperature, and oxygen level utilized for decision-making through

machine learning techniques. MCDM methods such as technique for order preference by similarity to ideal solution (TOPSIS) and weighted product model (WPM) help in decision-making as well as in generating informative diagnostic reports. MCDM can be used to develop an expert system which might be more efficient while making any decision for diagnosing and treatment.

Handling decision-making problems can improve the efficiency of hospital management. The proposed error analysis method [25] with hesitant fuzzy linguistic information might be helpful in hospital decision support systems. When choosing the best multi-speciality hospital for surgery, the analytic hierarchy process [26] is used to help obtain the best hospital from the optimal list of hospitals.

To assess the service efficiency of the hospitals, plithogenic MCDM is applied [27], and it can efficiently classify the possible substitute. TOPSIS is also used [28] to determine the ranking of hospitals and helps in disaster preparedness. Machine learning techniques integrated with MCDM [29] can effectively conduct inventory analysis. In an emergency like COVID-19, many health systems worldwide are leading to collapse. To deal with such emergency challenges with many aspects of fuzzy MCDA [30], machine learning can be a great help. Breast cancer patients, if diagnosed early [31], have a better chance of survival. Machine learning and MCDM methods can provide a robust solution in diagnosing breast cancer. The judgments' accuracy will enhance with the employment of two or more MCDM techniques [32]. Further study can combine the fuzzy analytic hierarchy process (FAHP) method with other decision-making techniques and compare the outcomes.

An ensemble-based MCDM technique used for COVID-19 detection in cough specimens. A focus on the difficulty of choosing the optimal classification model [33] when various evaluation factors are considered, and there is diversity in these criteria.

IV. ANALYSIS OF LITERATURE REVIEWED

From Tables II & III, based on different application areas used for MCDA in healthcare, a Pi-chart has been drawn. It shows that the MCDM approach is highly used for healthcare general decision-making for various issues. These issues are related to daily administration issues. Similarly, during COVID-19 it was highly recognizing method to solve various problems such as availability of resources or it may be to decide the urgency and priority of cases. The other areas to use MCDA are cancer detection, surgery decision, thyroid, and sleep disorder management. Another important area in policy management for healthcare institution is also attracting MCDA (Fig. 2).

From Table IV, based on different machine learning techniques/approaches used for MCDA in healthcare, a bar chart has been drawn. It shows that supervised machine learning methods are being preferred for MCDM in healthcare. Similarly, hybrid methods, ensemble methods, and fuzzy methods are also equally used,

Table II. Salient features and future direction from existing work

Referred paper	Salient feature	Techniques/ method used	Application area/disease	Challenges	Gaps identified	Future research direction
[1]	MCDA framework and identification of potential areas to use MCDA	MCDA approach to develop decision support system	Healthcare decision-making	Improve the efficiency under the optimal decisions	Evaluation and assessment of numerous criteria	Methods for weighing and scoring various decision criteria
[2]	Making resource `allocation decisions using MCDA	Uses MCDA evidence matrix	Healthcare reimbursement process	Scoring each criterion of MCDA	Appraising the available evidence	Merging MCDA and HTA (health technology assessment)
[3]	Combines the fuzzy VIKOR method and the 2-tuple DEMATEL methodology	Hybrid multi-criteria decision-making model	Elective admission control of patient	Assessment of qualitative and quantitative criteria	Distinguishing between the important and urgent decision	Weighted score for alternatives might be promising
[4]	Selecting the appropriate machine learning algorithm	Fuzzy analytical hierarchical process	To prioritize the suitable options in order of	Utilizing fuzzy method with analytical hierarchical process	Analytical hierarchical process is not sufficient	Ensemble methods could be more effective
[5]	Provides practical insights of MCDA methods	Case study approach is used	Diagnosis, treatment, and resource allocation	Decision-making on different criteria	Health technology assessment	Selection of suitable MCDA method
[6]	Decision-making in military healthcare	Performance matrix for each criterion	Decision-making for military personnel	Insufficient resources	Numeral expressions indicating the relative weight of the criteria	Improve the efficiency of whole process
[7]	Feasibility study of MCDA decision-making	Fusion of multi-modality feature and multi-classifier model	Prediction of tumor grading and cancer detection	Classify the huge clinical data	Select an appropriate classifier for prediction modeling	Deciding the importance of various features
[8]	Contribution in healthcare management processes	Fuzzy analytical hierarchy process approach	Using a lean approach to healthcare	Efficient delivery of healthcare products	Prioritizing the lean waste	Improvement in fuzzy AHP process

(continued)

Table II. ***(continued)***

Referred paper	Salient feature	Techniques/ method used	Application area/disease	Challenges	Gaps identified	Future research direction
[9]	Evaluating the effectiveness of the machine learning approaches for classification	Ensemble method for MCDM	Cough classification for COVID-19	Consider performance evaluation metric	Selection of best performance model	Use of cross-institutional datasets
[10]	Understanding causative factors for decision-making	Total interpretive structural modeling methodology	Surgical management	Effective decision-making	Low level of transparency in surgery	Study may be extended by taking more assumptions
[11]	Highlighting three causal factors of organizational hindrances	Healthcare 4.0 adoption	Healthcare policy management	Organizational hindrances to adopt technologies	Cause–effect relationship of the barriers	Environmental, social, and other factors may be considered
[12]	Complex proportional assessment of MCDM technique	Pythagorean fuzzy entropy measure technique	Healthcare waste treatment	Treatment of healthcare waste	Handling disparate qualitative and quantitative features	Technology innovation and their effective execution may be explored
[13]	Review of medical treatment of COVID-19	Review analysis for MCDA methods	COVID-19 diagnosis	Complex decision-making	Multidisciplinary research, i.e., MCDA and COVID-19	Mitigate the shortcomings of weighting technique
[14]	Explore the applications of MCDA in healthcare	Literature review/ case study approach	Healthcare management	Processing relevant literature among the huge one	Assessing the importance of hybrid method	Explore specific MCDA method for specific problem
[15]	Fusion of spatial data model and MCDA in healthcare	Ensemble machine learning methods	Infectious disease outbreaks	Minimizing the subjective bias to quantify risk factor	Quantifying risk factors for disease	Coupling of machine learning and GIS can be explored
[16]	Measuring access to healthcare facilities	Least cost path (LCP) analysis	COVID-19	Uncovering the barriers and their effect on healthcare access	Complex interaction between different factors	Exploration of MCDA for future outbreaks
[17]	Early diagnosing of breast cancer	MCDA and supervised learning	Breast cancer screening	Timely diagnosing the patient	Selection of most efficient supervised learning method	Exploring the fusion of MCDA and supervised learning
[18]	Critique review of fuzzy methods	Fuzzy methods for MCDM	COVID-19 pandemic	Taking deep vision of fuzzy methods	Reducing the computational complexity of fuzzy methods	Needs a deep investigation on fuzzy methods
[19]	Level of consumer adoption for mobile healthcare	Hybrid MCDM methods	Mobile healthcare	Identify MCDM methods and hybridization	Identification of key factor of consumer adoption of mobile healthcare	Wide range of datasets can be utilized for further investigation
[20]	Emphasizing automation procedure in healthcare services	Hybrid MCDM models	Management of electronic health record	Finding influential weights for criteria	Performance measuring of automated procedure	Exploring for improvement in EHR implementation
[21]	Optimization model for ML algorithm and evidential reasoning	Machine learning and evidential reasoning approach	Diagnosis of thyroid nodules	Data-driven decision-making	Learning of criterion weights	Proposed method can be explored for other diseases
[22]	Ensemble models for MCDA	EEG signal analysis	Diagnosing sleep disorder	Formation of ensemble model	Early diagnosis of sleep disorders	Method can be tested for different kinds of EEG signal
[23]	Investigation for a hospital's supplier selection issue	DEMATEL, BWM	Supplier decision-making in healthcare	Weight aggregation, modification of EDAS	Average solution to select supplier	Exploration for waste management, renewable energy selection, etc.
[24]	Decision-making for life-threatening situation	Multi-criteria approach to priority setting	Decision-making in critical health situations	Selection of rational method for priority setting	Priority setting of decision	Comparison of various MCDA methods for priority setting must be done

Table III. Summary of different application areas in the review

Reference number	Application area/disease	Count
[9,13,15,16,18]	COVID-19/infectious disease	5
[1–6,14,20],	Healthcare general management/ decision	8
[10,24]	Surgical management	2
[23]	Healthcare supply chain decision	1
[7,17]	Cancer detection/decision	2
[21,22]	Thyroid/sleep disorder	2
[8,10–12,19]	Policy management/decision	4

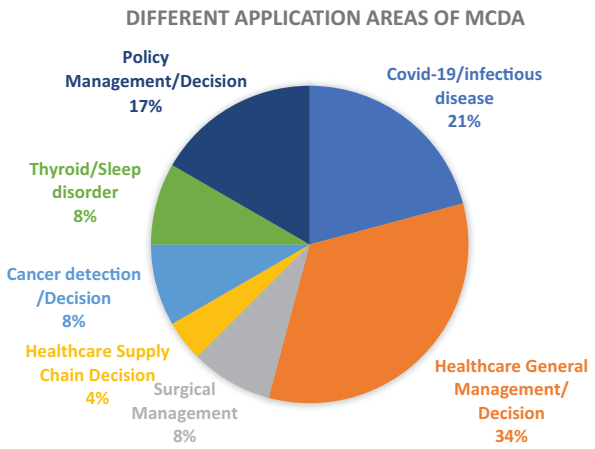

Fig. 2. Different application areas of MCDA in healthcare.

Table IV. Machine learning techniques used in MCDA for healthcare

Reference number	Machine learning techniques/methods	Count
[3,19,20]	Hybrid MCDM	3
[4,8,18]	Fuzzy analytical hierarchical process	3
[9,15,22]	Ensemble method	3
[2,21]	Evidence matrix	2
[5,13,14]	Case study approach	3
[7,17,23,24]	Supervised learning method	4
[10,11]	Causative factors analysis	2
[1,6,12,16]	Other algorithms	4

and the objective of this fusion of methods is to improve the accuracy of decisions (Fig. 3).

V. CONCLUSION AND FUTURE DIRECTIONS

This study aimed to highlight the significance of MCDA in the healthcare sector, while selecting machine learning methods to resolve different issues. To emphasize the significance of considering and picking the appropriate methods for different issues, we did literature review analysis for existing MCDA used in healthcare. Methods like machine learning to identify diseases and make

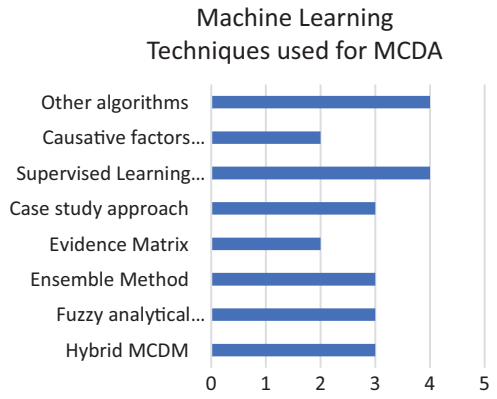

Fig. 3. Machine learning algorithms used for MCDA in healthcare.

diagnosis involve some crucial ethical considerations also. The usage of patient data may have an impact on patients' confidentiality. Therefore, it is crucial to think about the situations in which machine learning could violate patients' privacy and the potential exploitation of generated information about patients. Before beginning the study, it is crucial to get documented ethics approval and permission.

Machine learning models rely on historical data, whereas doctors rely on knowledge and experience. It is quite challenging for a machine to generate precise predictions based on fresh, untested data. A doctor's expertise and experience are extremely useful for medical diagnosis because the practice of medicine is always changing due to new technology and societal issues. It is crucial to note that a doctor cannot be replaced by a machine, but that a machine can be an effective complement that can speed up diagnosis, shorten the duration of a therapy, ease the strain on medical staff, and save money on various resources.

This review's main objective was to emphasize the importance of a complete MCDA in connection to machine learning evaluation. To confirm the feasibility of incorporating machine learning to enhance doctors' diagnosis for various diseases specially heart disease and to ascertain the influence of various machine learning algorithms in healthcare, an experimental design may be employed in future

Acknowledgments

This review work was supported and technical assisted from the Department of Computer Science, the University of Burdwan, West Bengal, India. We specially thank Dr. Sunil Karforma (Professor, B.U) for his guidance.

References

[1] A. C. Mühlbacher and A. Kaczynski, "Making good decisions in healthcare with multi-criteria decision analysis: the use, current research and future development of MCDA," Appl. Health Econ. Health Policy, vol. 14, no. 1, pp. 29–40, 2016. DOI: 10.1007/s40258-015-0203-4.

[2] K. Marsh, M. Goetghebeur, P. Thokala, and R. Baltussen, "Multi-criteria decision analysis to support healthcare decisions," Multi-Criteria Decis. Anal. Support Healthc. Decis., pp. 1–139, 2017. DOI: 10.1007/978-3-319-47540-0.

[3] T. Zhu, L. Luo, H. Liao, X. Zhang, and W. Shen, "Knowledge-based systems a hybrid multi-criteria decision making model for elective

admission control in a Chinese public hospital," Knowledge-Based Syst., vol. 173, pp. 37–51, 2019. DOI: 10.1016/j.knosys.2019.02.020.
[4] J. E. T. Akinsola, "Performance evaluation of supervised machine learning algorithms using multi-criteria decision making techniques," Int. Conf. Educ. Develop., pp. 17–34, 2019.
[5] A. Glaize, A. Duenas, C. Di Martinelly, and I. Fagnot, "Healthcare decision-making applications using multicriteria decision analysis: a scoping review," J. Multi-Criteria Decis. Anal., vol. 26, no. 1–2, pp. 62–83, 2019. DOI: 10.1002/mcda.1659.
[6] B. Ö. Yilmaz, "Multi-criteria decision making (MCDM) applications in military healthcare field," J. Heal. Syst. Policies, vol. 2, no. 2, pp. 149–181, 2020.
[7] Q. He *et al.*, "Feasibility study of a multi-criteria decision-making based hierarchical model for multi-modality feature and multi-classifier fusion: applications in medical prognosis prediction," Inf. Fusion, vol. 55, pp. 207–219, 2020. DOI: 10.1016/j.inffus.2019.09.001.
[8] R. S. Bharsakade and P. Acharya, "A lean approach to healthcare management using multi criteria decision making," OPSEARCH, vol. 58, no. 3, pp. 610–635, 2021. DOI: 10.1007/s12597-020-00490-5.
[9] N. K. C. et al., "An ensemble-based multi-criteria decision making method for Covid-19 cough classification," arXiv:2110.00508v1, vol. Oct, pp. 1–21, 2021.
[10] B. B. Gardas, N. P. Ghongade, and A. H. Jagtap, "Application of multi-criteria decision-making approach in healthcare surgical management," J. Multi-Criteria Decis. Anal., vol. 29, no. 1–2, pp. 92–109, 2022. DOI: 10.1002/mcda.1753.
[11] B. B. Gardas, "Organizational hindrances to Healthcare 4.0 adoption: an multi-criteria decision analysis framework," J. Multi-Criteria Decis. Anal., vol. 29, no. 1–2, pp. 186–195, 2022. DOI: 10.1002/mcda.1766.
[12] R. Chaurasiya and D. Jain, "Pythagorean fuzzy entropy measure-based complex proportional assessment technique for solving multi-criteria healthcare waste treatment problem," Granul. Comput., vol. 0123456789, 2022. DOI: 10.1007/s41066-021-00304-z.
[13] M. A. A. A. H. Alamoodi and O. S. A. K. A. Dawood,Multi – Criteria Decision – Making for Coronavirus Disease 2019 Applications: A Theoretical Analysis Review, vol. 55, no. 6. Netherlands: Springer, 2022.
[14] I. Khan, L. Pintelon, and H. Martin, "The application of multicriteria decision analysis methods in health care: a literature review," Med. Decis. Making, vol. 42, no. 2, pp. 262–274, 2022. DOI: 10.1177/0272989X211019040.
[15] P. Devarakonda, R. Sadasivuni, R. A. A. Nobrega, and J. Wu, "Application of spatial multicriteria decision analysis in healthcare: identifying drivers and triggers of infectious disease outbreaks using ensemble learning," J. Multi-Criteria Decis. Anal., vol. 29, no. 1–2, pp. 23–36, 2022. DOI: 10.1002/mcda.1732.
[16] A. Roy and B. Kar, "A multicriteria decision analysis framework to measure equitable healthcare access during COVID-19," J. Transp. Heal., vol. 24, p. 101331, 2022. DOI: 10.1016/j.jth.2022.101331.
[17] M. T. Mustapha, "Breast cancer screening based on supervised learning and multi-criteria decision-making," Diagnostics, vol. 12, pp. 1–17, 2022.
[18] A. Sotoudeh-anvari, "The applications of MCDM methods in COVID-19 pandemic: a state of the art review ☆," Appl. Soft Comput., vol. 126, p. 109238, 2022. DOI: 10.1016/j.asoc.2022.109238.
[19] Y. Liu, Y. Yang, Y. Liu, and G. Tzeng, "Improving sustainable mobile health care promotion: a novel hybrid MCDM method," Sustainability, pp. 1–29, 2019. DOI: 10.3390/su11030752.
[20] J. J. H. Liou, M. Lu, S. Hu, C. Cheng, and Y. Chuang, "A hybrid MCDM model for improving the electronic health record to better serve client needs," Sustainability, pp. 1–13, 2017. DOI: 10.3390/su9101819.
[21] C. Fu, C. Xu, M. Xue, W. Liu, and S. Yang, "Data-driven decision making based on evidential reasoning approach and machine learning algorithms," Appl. Soft Comput., vol. 110, p. 107622, 2021. DOI: 10.1016/j.asoc.2021.107622.
[22] S. Abdulla, M. Diykh, R. Luaibi, and K. Saleh, "Sleep EEG signal analysis based on correlation graph similarity coupled with an ensemble extreme machine learning algorithm," Expert Syst. Appl., vol. 138, p. 112790, 2019. DOI: 10.1016/j.eswa.2019.07.007.
[23] A. E. Torkayesh, "An integrated decision-making model for supplier evaluation in public healthcare system: the case study of a Spanish hospital," J. Enterp. Inf. Manag., vol. 33, no. 5, pp. 965–989, 2020. DOI: 10.1108/JEIM-09-2019-0294.
[24] R. Baltussen and L. Niessen, "Priority setting of health interventions: the need for multi-criteria decision analysis," Cost Eff. Resour. Alloc., vol. 4, pp. 1–9, 2006. DOI: 10.1186/1478-7547-4-14.
[25] H. Wu, Z. Xu, P. Ren, and H. Liao, "Hesitant fuzzy linguistic projection model to multi-criteria decision making for hospital decision support systems," Comput. Ind. Eng., vol. 115, pp. 449–458, 2018. DOI: 10.1016/j.cie.2017.11.023.
[26] H. Petwal and R. Rani, "An optimal multi-criteria decision-making framework to select best multispecialty hospital for surgery," PDGC 2020–2020 6th Int. Conf. Parallel, Distrib. Grid Comput., pp. 471–475, 2020. DOI: 10.1109/PDGC50313.2020.9315760.
[27] M. Abdel-Basset, M. El-hoseny, A. Gamal, and F. Smarandache, "A novel model for evaluation hospital medical care systems based on plithogenic sets," Artif. Intell. Med., vol. 100, no. July, p. 101710, 2019. DOI: 10.1016/j.artmed.2019.101710.
[28] M. Ortiz-Barrios, M. Gul, P. López-Meza, M. Yucesan, and E. Navarro-Jiménez, "Evaluation of hospital disaster preparedness by a multi-criteria decision making approach: the case of Turkish hospitals," Int. J. Disaster Risk Reduct., vol. 49, p. 101748, 2020. DOI: 10.1016/j.ijdrr.2020.101748.
[29] H. Kartal, A. Oztekin, A. Gunasekaran, and F. Cebi, "An integrated decision analytic framework of machine learning with multi-criteria decision making for multi-attribute inventory classification," Comput. Ind. Eng., vol. 101, pp. 599–613, 2016. DOI: 10.1016/j.cie.2016.06.004.
[30] V. J. Clemente-Suárez *et al.*, "Performance of fuzzy multi-criteria decision analysis of emergency system in covid-19 pandemic. An extensive narrative review," Int. J. Environ. Res. Public Health, vol. 18, no. 10, 2021. DOI: 10.3390/ijerph18105208.
[31] M. T. Mustapha, D. U. Ozsahin, I. Ozsahin, and B. Uzun, "Breast cancer screening based on supervised learning and multi-criteria decision-making," Diagnostics, vol. 12, no. 6, 2022. DOI: 10.3390/diagnostics12061326.
[32] F. Rajabi, H. Molaeifar, M. Jahangiri, S. Taheri, S. Banaee, and P. Farhadi, "Occupational stressors among firefighters: application of multi-criteria decision making (MCDM)Techniques," Heliyon, vol. 6, no. 4, p. e03820, 2020. DOI: 10.1016/j.heliyon.2020.e03820.
[33] N. K. Chowdhury, M. A. Kabir, M. M. Rahman, and S. M. S. Islam, "Machine learning for detecting COVID-19 from cough sounds: An ensemble-based MCDM method," Comput. Biol. Med., vol. 145, p. 105405, 2022. DOI: 10.1016/j.compbiomed.2022.105405.