

A Fuzzy Multi-Criteria Decision Analysis Model For Decision Support In Diabetes Mellitus: A Proposal Paper

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Abstract— Decisions in healthcare like diabetes mellitus are crucial to a practitioner's decision since it involves people's life. The practitioner is required to consider multiple factors and possible alternatives which can increase the complexity of the decision-making process. Most of the researchers in the diabetes mellitus domain focusing more on how to handle the multiple factors but neglecting on how to ensure that the decision made is certain. In order to address the problem, a Fuzzy Multi-Criteria Decision Analysis (FMCDA) model is proposed in this concept paper, which is able to manage multiple criteria and at the same time avoid uncertainty in the compromise decision. This research will start with analyzing the required criteria and decisions by conducting a comprehensive literature review and interviewing the expert and practitioners in the diabetes mellitus domain. The results acquired from the previous step will be used to formulate the FMCDA model. The evaluation will be conducted to verify and validate the proposed model in the healthcare industry using a case study. The proposed model is expected to assist the practitioner in managing multiple criteria and improve certainty in the decision-making process particularly in the diabetes mellitus domain. This will significantly improve decision quality and sustain the healthcare system.

Keywords— multi-criteria decision analysis, fuzzy multi-criteria decision analysis, diabetes mellitus, decision support

I. INTRODUCTION

The healthcare area faces a big challenge in developing and applying a robust tool in assisting practitioners in making difficult and complex decisions. It became more intricate when it involved human life. Every decision that they make will affect the future and life of the patient. Multi-Criteria Decision

Analysis (MCDA) is a tool that aids decision-makers to summarize complex value process that is steady and transparent [1]. The decision-makers need to consider several criteria before coming out with a compromise result. It will be costly to come out with an ideal solution since the complex criteria decision involved.

The fuzzy set theory has been proposed by Zadeh [2], this theory deal with a problem relating to imprecise judgment and ambiguous variables. FMCDA has been successfully applied countless times to many problems in the case of ambiguous and incomplete data [3]–[5]. The uses of the fuzzy method in MCDA largely were led by the uncertainty of data in any situation. A great number of researches relating to MCDA in the health area have been done. The fuzzy method appears to be one of the most used MCDA principles in healthcare research studies [6]. However, FMCDA methods are unheard-of in the diabetes mellitus scene. Nowadays, diabetes mellitus appears to be one of the most common chronic diseases worldwide. The prevalence of diabetes mellitus has significantly increased over the past decade from National Health and Morbidity Survey 2019 : Health Literacy as shown in Table 1 [7]. Overall, 1 in 5 adults in Malaysia has diabetes which is about 3.9 million people aged 18 years and above. Diabetes Mellitus disorder is caused by an inability of the body to regulate the blood sugar (glucose) level which leads to an improper response of insulin. This condition increases the Cardiovascular Disease (CVD) risk such as stroke, intermittent claudication, cardiac failure, coronary heart disease, myocardial infarction, angina pectoris and coronary mortality [8].

TABLE I. DIABETES TREND IN MALAYSIA [7]

Diabetes	2011 (%)	2015 (%)	2019 (%)
Overall Raised Blood Glucose	11.2	13.4	18.3
Known Diabetes	7.2	8.3	9.4
Raised Blood Glucose Among Those Not Known to Have Diabetes	4.0	5.1	8.9

Type 2 Diabetes Mellitus (T2DM) has become a prevalent non-communicable disease in Malaysia. The latest National Diabetes Registry (NDR) has reported, that 1,698,683 patients registered in the registry and there were raised 902,991 number of patients compared to the year before. The registry dataset shows that 99.33% of diabetes patients were diagnosed with T2DM [9]. With the enormous amount of diabetes patients globally, many country and institution have developed their guidelines for the management of T2DM which referred by the Ministry of Health Malaysia, such as the American Diabetes Association (ADA) Standards of Medical Care in Diabetes, American Association of Clinical Endocrinologists', American College of Endocrinology, International Diabetes Federation (IDF) Global Guideline for Type 2 Diabetes and others [10]. While these guidelines are developed to provide recommendations and assist healthcare professionals in the identification, diagnosis and management of T2DM patients; they are open to making a decision based on the criteria and condition of the patients.

The goal of this concept paper is to present the methodology process of developing a Fuzzy Multi-Criteria Decision Analysis (FMCDA) model for decision-making support in diabetes mellitus. In order to produce the FMCDA model, criteria and decisions that contribute to the decision support need to be analysed. Once the FMCDA model is formulated, it will be evaluated in the healthcare industry to support decision-making in diabetes mellitus.

II. LITERATURE REVIEW

A. Multi-Criteria Decision Analysis

Multi-Criteria Decision Analysis (MCDA) in any approach are intended to improve decisions when conflicting objectives happened [11]. Problem-solving and decision-making processes have been formularized since 1965 by Kepner and Tregoe, and then the decision analysis step was rebranded as MCDA in 2000 [11]–[13]. There are eight stages of applying MCDA [12];

1. Establish the decision context.
2. Identify the options to be appraised.
3. Identify objectives and criteria.
4. 'Scoring'. Assess the expected performance of each option against the criteria. Then assess the value associated with the consequences of each option for each criterion.
5. 'Weighting'. Assign weights for each criterion to reflect their relative importance to the decision.

6. Combine the weights and scores for each option to derive an overall value.
7. Examine the results.
8. Sensitivity analysis.

Multi-Criteria Decision Analysis (MCDA) is a method that supports complex decision-making processes [14]. The decision-maker is required to consider several criteria prior to producing a compromise solution. It is not affordable for the decision-maker to devise a perfect or ideal solution since the criteria involved during the decision-making process are too complex. They have to deal with several processes before any decision can be made. For example, the prioritization, conflicting goals, type of decisions, stakeholder preferences, domain issues and many more [14]–[18]. This is a tedious and long process in which the final decision can be doubted if there is no strategy or method employed to make the decision.

The MCDA method is able to improve the current practices in making the decision which is an ad hoc approach that tends to use the decision maker's preferences [14], [19]. The drawback of the ad hoc approach is the credibility of the produced decisions since strong pieces of evidence are lacking. Contrary to the MCDA method, the process of producing the decisions has its own rationale, transparent and can be justified in more systematic ways [14], [20]–[22]. In the MCDA method, there is a variety of techniques that can be used for example Analytical Hierarchy Process (AHP), Analytic Network Process, Multi-Attribute Utility Theory (MAUT), Multi-Attribute Value Theory (MAVT) and others [14], [18].

As more researchers have been aware of MCDA techniques, various areas of healthcare and medical issues have been applying MCDA. Adunlin et al provided a review of healthcare applications of MCDA which shows 39% of the research done involved diagnosis and treatment [23], Drake et al. present the real-world example of MCDA utilization in various healthcare support from a different country and a systematic review from Frazão et al. demonstrate that majority of the research preferred strategy to define the criteria for structuring the MCDA through literature and specialist [6], [24].

There is a wide variety of domains that have applied the MCDA method to support decision-making according to its own decision problems. This shows the flexibility of the model which can be used in any domain. Examples of domains are transportation [25]–[27], manufacturing [28], [29] and healthcare [17], [25], [30]. The issue in the transportation domain highlighted by Gatta et al. regarding the off-hour deliveries for urban freight transport to avoid traffic congestion during peak hours in Rome [15]. In addition, the off-hour deliveries can also improve the attractiveness and safety of the city [31]. Despite the advantage of the off-hour deliveries, stakeholders can be one of the barriers since they have different interests and preferences.

A study conducted by Kahraman et al. (2003) focused on the fuzzy AHP analysis method to decide on the best supplier firm by considering three important criteria which is divided into eleven sub-criteria [28]. In the healthcare domain, an

MCDA framework was developed by Inotai et al. for off-patent pharmaceutical tender decision-making [32]. The framework consists of seven criteria for assessment. A study conducted by Nutt et al., used MCDA modelling to assess the drug harms which can notify the policymakers in health, policing and social care on the misuse impact and improve the drug classifications [30]. The MCDA modelling involved sixteen criteria in order to assess 20 drugs.

B. Fuzzy Multi-Criteria Decision Analysis

Fuzzy set theory was introduced as a technique that can be used for decision making and it is widely used in multi-criteria decision making [2], [3]. Human knowledge during decision-making involves uncertainty which could not be solved by MCDA alone [3]. Therefore, fuzzy set theory is one of the solutions to handle uncertainty in the decision's parameter. The basic fuzzy MCDA process flow are [33];

1. Identify objectives, criteria or topic of relevance to the decision
2. Identify and select stakeholders
3. Identify and develop alternatives
4. Fuzzy weight criteria and define hierarchy of objectives
5. Review all above items
6. Review quality of data and information available for applying fuzzy weighting and hierarchy
7. Selection of fuzzy mathematical algorithm and procedures
8. Data collection and apply fuzzy algorithm
9. Uncertainty and sensitivity analysis: review data quality and criteria fuzzy weighting and run several iterations
10. Interpret FMCDA calculations, results and finalize recommendations

Fuzzy MCDA applications have garnered interest in various areas that have been reviewed a lot since the introduction of fuzzy set theory by Zadeh [2] However, Fuzzy MCDA in healthcare is rare compared to other areas like engineering, computer science and mathematics [3], [4], [34] Only in the recent decade, has the involvement of fuzzy set theory to solve the problem in the healthcare industry rapidly increase as the fuzzy logic-related MCDA intervention appeared second most applied method in the healthcare industry [6]. Few of the notable intervention are, evaluate hospital organization performance [35], renewal of healthcare technologies [35], [36], risk evaluation in healthcare logistics outsourcing [37], evaluating healthcare waste disposal [38] and others. A number of 130 published studies correlated to the processes of fuzzy decision-making in healthcare and medical issue have been reported by A, Mardani et al. Unfortunately, only one study is directly related to the diabetes mellitus domain [33]. This study will be a great opportunity to introduce fuzzy decision-making potential in the diabetes mellitus domain.

III. RESEARCH METHODOLOGY

The overall research methodology process is a multi-method, a combination of two or more research methods. The data collection is conducted through a systematic literature review and interviews with the practitioners. While a case study will be conducted to verify the proposed model.

A. Data Collection

Prior to formulating the FMCDA model, a comprehensive literature review will be led to identify the criteria and decisions that contribute to the decision support in diabetes mellitus. Besides that, an interview with the experts and practitioners also will be conducted to elicit the criteria and decisions that help in the decision support. A guideline from Creswell will be used to conduct the interview session [39].

1) *SLR*: In order to conduct the systematic literature review (SLR), guidelines from Kitchenham[40] and PRISMA[41] are used. The research questions developed before conducting the SLR are;

- Q1: 'What criteria were used for decision support in the diabetes mellitus domain from the MCDA research works?'
 Q2: 'What MCDA technique and implementation have been used in Diabetes Mellitus domain?'
 Q3: 'What is the evaluation technique used and how is the evaluation conducted?'

The basic key string for searching in the online database used is ("Multicriteria Decision Analysis" OR "Multi-criteria Decision Analysis" OR MCDA) AND Diabetes. Pilot searching was conducted several times to identify whether the key search is appropriate to use. The systematic search is conducted in five electronic bibliographic databases to search the criteria of decision support in the diabetes mellitus domain. The search was conducted according to Kitchenham[40] guidelines and following the specific guide from Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [41] on search screening. The searched online databases include PubMed, IEEE, ScienceDirect, ProQuest (Article) and Springer. These are the accessible online databases by the authors.

For the inclusion criteria, only full-text relevant journals, articles and conferences proceeding with English language studies were included. The inclusion criteria also involved the studies that answered the SLR research question. The searches also excluded any review articles and short papers. The details of the inclusion and exclusion criteria can be referred in Table II.

TABLE II. THE INCLUSION AND EXCLUSION CRITERIA

Inclusion criteria	Answering SLR research question
	English only
	Full-text relevant journals, articles and conferences proceeding
Exclusion criteria	Review article and short papers

2) *Interview*: Five experts are selected based on the purposive sampling technique. They are selected based on several criteria which are healthcare professionals that have handled diabetes mellitus patient and who is doing the decision-making process. The experts that participated in this interview are all experienced doctors who specialize in the diabetes mellitus management. After ethical approval and obtaining informed consent, we performed a pilot interview with health practitioner in diabetes management before the actual interview session takes place to see if the information-gathering interview questions are suitable and sufficient. The necessary steps of the qualitative interview from preparing to conducting the interviews of this study were referred to Creswell and Poth approach [42].

- Determine the open-ended research questions to be answered
- Identify interviewees based on purposeful sampling procedures
- Distinguish type of interview based on mode and interactions
- Collect data using adequate recording procedures
- Design and use an interview protocol to guide interaction
- Refine the interview procedures through pilot testing
- Locate a distraction-free place for interviews
- Obtain consent from the interviewee to participate
- As an interviewer, follow good interview procedures
- Decide transcription logistics

The interview setting is performed through a virtual setting via Google Meet in a one-to-one interview. The interview method is designed in a semi-structured qualitative interview. The type of question is exploratory which are open-ended questions. Information Sheet, Consent Form and Interview Questions were given to the interviewee before the actual interview takes place through email. Once the consent form is received, then, the interviews are conducted. The interview recording of the virtual meeting is collected and used for the data collection later. The interview is recorded and transcribed.

B. Data Analysis

1) *SLR*: The data extracted from the included articles were organized in an excel spreadsheet for analysis preparation. The screening process could be viewed from the flow diagram in Figure. 1. The quality assessment was conducted on the studies in order to ensure the quality of the selected studies. The questions and checklist of the quality assessment can be referred in Table III. The scoring of each question has three possible scorings; 1 mark for “yes”, 0.5 mark for “partially” and 0 for “no”. A total of 44 studies were identified for further in-depth assessment. Later, the data were summarized and screened based on the research questions.

The list of criteria collected from SLR were summarize and verified by five medical practitioners through interview

sessions. They were asked to identify whether the criteria listed are acceptable or not and categorized the acceptable criteria into pharmacological, non-pharmacological treatment or both.

TABLE III. THE QUALITY ASSESSMENT QUESTIONS

No	Questions
1.	Is there a clear statement of the aims of the research?
2.	Is the article referred?
4.	Is there a clear statement of findings?
5.	Are future works included?

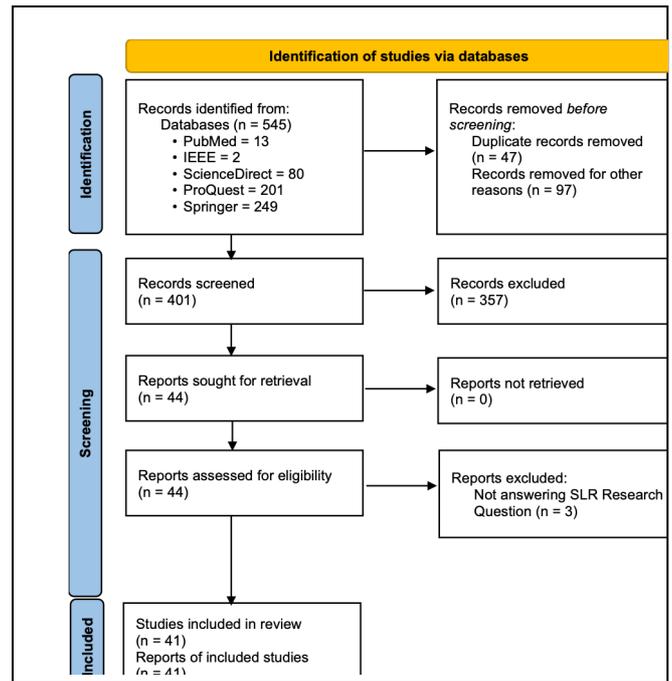


Figure. 1. PRISMA flow diagram of included studies

2) *Interview*: After transcription, a thematic analysis approach is used to analyze the information from the interview. The thematic analysis basic steps are referred to Guest et al. [43];

1. Familiarization with, and organization of, transcripts.
2. Identification of possible themes
3. Review and analysis of themes to identify structures
4. Construction of theoretical model, constantly checking against new data

The main analysis of the interviews is conducted to draw results regarding the criteria and decisions required for the decision-making process for patients diagnosed with diabetes mellitus. In addition, the problems faced by the experts in making a decision in this domain is also analyzed.

C. Development of Model

The criteria identified in the previous phase will be used to formulate the FMCDA model. In order to formulate the model, a guideline from Thokala et al. is referred [17]. Generally, there are eight steps to be followed to formulate the MCDA model which is defining the decision problem, selecting and structuring

criteria, measuring performance, scoring alternatives, weighing criteria, calculating aggregate scores, dealing with uncertainty and reporting and examination of findings.

D. Model Evaluation

Validation and verification will be conducted to evaluate the proposed model. The steps carried out in the model formulation during phase two are iterative and validation will take place accordingly by the selected experts and practitioners. In order to verify the proposed model, a case study will be employed. A guideline from Yin will be used to conduct the case study[44]. The healthcare industry practitioners will be selected to perform the evaluation stage.

IV. CONCLUSION

This paper focuses on the methodology process of developing the FMCDA model. The fuzzy set theory is able to deal with uncertainty data after calculation or scoring in the MCDA method has been done. Meanwhile, the MCDA approach is able to handle multiple criteria prior to producing a compromise decision. This is important in the decision-making process when the criteria are varied and at the same time decision should be certain especially in the critical field that involves people's life. The proposed research FMCDA model is expected able to be used in the healthcare industry specifically for practitioners in diabetes mellitus domain for decision support purposes. This model is expected to assist the practitioners to make a complex decision regarding multi-objectives in diabetes mellitus. This model also expected to improve transparency and consistency in decision-making by structuring the acquired information.

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