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Diagnosis of Type-2 Diabetes using Multi-Criteria Decision-Making Techniques with Diverse Operators

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Abstract:

This study applies multi-criteria decision-making (MCDM) techniques to identify and evaluate the risk factors associated with Type 2 diabetes mellitus (T2DM). By leveraging advanced MCDM approaches, the study aims to enhance the decision-making process for T2DM diagnosis and management. The primary objective of this study is to develop a comprehensive framework for ranking and prioritizing various risk factors contributing to the onset and progression of T2DM. The study also aims to compare different MCDM techniques and aggregation operators to provide a deeper understanding of the influence of key factors such as genetics, lifestyle, and environmental triggers. The study integrates four advanced MCDM approaches: Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE-II), Graph Theory and Matrix Approach (GTMA), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), and VIˇsekriterijumsko KOmpromisno Rangiranje (VIKOR). A diverse range of aggregation operators is utilized within the MCDM framework to enhance the evaluation process, including the Einstein aggregation operator, Hamy mean operator, Dombi operator, and arithmetic-geometric aggregation operators. These operators facilitate a nuanced assessment of risk factors, allowing for a more comprehensive and structured evaluation of their impact on Type 2 diabetes mellitus (T2DM). The study provides a detailed comparison between PROMETHEE-II, GTMA, TOPSIS, and VIKOR rankings. Integrating various aggregation operators highlights the relative significance of different risk factors. The results demonstrate how different methodologies influence the prioritization of risk factors, contributing to a more refined approach to decision-making in T2DM management. This study enhances decision-making processes for T2DM diagnosis and management by offering a robust, operator-driven evaluation system for healthcare professionals. The comparative analysis of MCDM techniques and aggregation operators provides valuable insights into the key risk factors affecting T2DM, ultimately aiding in better healthcare strategies and preventive measures.

Keywords: Multi-criteria decision-making, Fuzzy, Multi-attribute decision making, type 2 diabetes and applications of MCDM.

1. Introduction

The WHO has consistently highlighted the increasing global burden of T2DM, with key reports such as the 2016 Global Report on Diabetes showing that 422 million adults were living with diabetes in 2014, the majority with T2DM. This report urged improved prevention strategies, focusing on obesity reduction and physical activity promotion. WHO's GAP (2013-2020) emphasized reducing diabetes-related mortality by 25% by 2025, while their 2019 recommendations provided updated diagnostic guidelines, including fasting plasma glucose and HbA1c tests, and stressed integrated management strategies like lifestyle interventions and insulin access. Other critical medical reports include the ADA guidelines, which emphasize lifestyle changes and treatments like metformin and GLP-1 receptor agonists, and the IDF Diabetes Atlas, which predicted a rise in global diabetes cases from 463 million in 2019 to 700 million by 2045. The NICE guidelines in the UK focus on personalized care and regular monitoring of blood glucose, lipids, and blood pressure. Significant studies like the Framingham Heart Study, UKPDS, and ADVANCE Trial have demonstrated the importance of tight glucose control in reducing complications, such as cardiovascular diseases and kidney issues. These efforts reflect the global push to manage T2DM through lifestyle changes, medical treatments, and complication prevention. Defronzo et al. [19] explained that type-2 diabetes can be a cause of more health issues. Oguntibeju et al. [31] is doing the master role in oxidative stress in tissue, by this problem they explained about the relationship between tissue and T2DM. T2DM is more generally connected with cardio vascular disease by the damage of beta cells. Ke et al. [26] explained about the management of type-2 diabetes in China and India. In that research they explained that half of the adults in both countries are suffering from type-2 diabetes. Soetedjo et al. [43] explained that vaccination also changing the beta cells of type-2 diabetes. Livadas et al. [28] reviewed about type-2 diabetes with risk factors for women. Through this work the authors having an uncertainty about the disease and risk factors. Hence, we need to utilize the fuzzy set and its values. It was originated by Zadeh [48]. Fuzzy set theory is working to find the uncertainty between the variables. Linguistic terms are utilized in fuzzy set theory to represent the membership values of elements. Decision-making is also an important part in this place in choosing the correct risk factor. In this work, we have chosen ten risk factors that are prescribed by WHO and doctors. Gupta et al. [23] utilized two hybrid MADM models that is FAHP-MOORA and CODAS-FAHP. Eghbali et al. [22] provided the result about prioritizing the lower glucose medicines for type-2 diabetes. Ebrahimi et al. [21] explained the sensitivity survey about diabetes-related complications by utilizing the fuzzy hybrid decision-making techniques.

Table 1: Abbreviations and their means

Abbreviations	Means
WHO	World Health Organization
T2DM	Type 2 diabetes mellitus
ADA	American Diabetes Association
UKPDS	UK Prospective Diabetes Study
IDF	International Diabetes Federation
GAP	Global Action Plan
NICE	National Institute for Health and Care Excellence
MCDM	Multi-Criteria Decision Making

PROMETHEE	Preference Ranking Organization Method for Enrichment Evaluations
CODAS	Complex Distributed Assessment
MOORA	Multi-Objective Optimization by Ratio Analysis
FAHP	Fuzzy Analytic Hierarchy Process
MADM	Multi-Attribute Decision Making

1.1 Motivation

Type-2 diabetes is a widespread health issue with increasing prevalence globally, necessitating the development of more effective diagnostic methods. The complexity of the disease, driven by numerous interrelated risks factors, requires advanced analytical approaches beyond traditional techniques. MCDM methods offer a structured framework to address this complexity, enabling more accurate and comprehensive diagnostic assessments.

- The diagnosis of type-2 diabetes involves numerous risk factors. MCDM techniques allow for the integration of these multifaceted criteria into a comprehensive diagnostic model.
- Traditional diagnostic methods may not fully capture the interplay between various risk factors. By employing advanced MCDM methods such as PROMETHEE-II and GTMA, researchers can improve the accuracy of risk assessment and diagnosis.
- Early and accurate diagnosis using MCDM methods can prevent the progression of diabetes-related complications, ultimately reducing the economic burden on healthcare systems.
- By applying MCDM techniques, healthcare providers can make more informed and timely decisions, potentially improving the quality of life and long-term outcomes for individuals diagnosed with type-2 diabetes.

1.2 Contribution

To comprehensively evaluate and prioritize risk factors for type-2 diabetes, this study employs a combination of advanced analytical methods.

- Identifying and analysing the top 10 risk factors for type-2 diabetes is crucial for understanding the disease’s epidemiology and for developing effective preventive strategies. These risk factors could include genetic predisposition, obesity, physical inactivity, poor diet, age, family history, ethnicity, hypertension, high cholesterol levels, and smoking.
- By integrating the risk factors into the analysis using PROMETHEE and GTMA, the study aims to provide a comprehensive assessment of their relative importance and the robustness of their impact on type-2 diabetes risk.
- By integrating PROMETHEE for ranking and GTMA for robustness analysis, the study can offer a nuanced view of how each risk factor contributes to type-2 diabetes risk and how stable these contributions are under different scenarios or assumptions.

- The sensitivity analysis adds another layer of insight by showing how sensitive the risk assessments are to changes in the risk factors, thus highlighting which factors need more precise measurement or management strategies.

The study combines sophisticated methods to analyze and prioritize risk factors for type- 2 diabetes, assesses the stability of these findings, and provides actionable insights for improving diabetes risk assessment and management.

1.3 Literature Review on MCDM methods:

MCDM methods have gained significant prominence in various fields due to their ability to handle complex decision-making problems involving multiple conflicting criteria. Over the past few decades, numerous MCDM techniques have been developed, each tailored to address specific types of decision environments. From traditional methods like the AHP and TOPSIS to more advanced approaches such as the PROMETHEE and the VIKOR, these techniques provide a robust framework for structured decision analysis. This review examines the evolution, strengths, and limitations of various MCDM methods, emphasizing their applications across different domains.

Table 2: Literature Review on MCDM Methods

Ref	Method	Application	Advantages	Limitations
[39]	TOPSIS	Medical Imaging	The use of MCDM algorithms facilitates effective prioritization of diagnostic options, improving decision making processes in clinical settings.	The effectiveness of the framework may be limited by the quality and quantity of the training data used, which can affect generalizability to real world scenarios.
[25]	FDM, FWZIC	Medical Diagnosis	By utilizing integrated fuzzy multi-criteria decision-making methods, the framework accounts for the inherent uncertainties and complexities in diagnosing ASD, improving the reliability of assessments.	The approach has limitations in generalizability, as it could be tailored to specific demographic and cultural contexts, potentially affecting its applicability in diverse settings.
[1]	TOPSIS & ELECTRE- I	Medical Diagnosis and Engineering	By effectively addressing the complexities of decision making, the model can lead to improved outcomes and more informed choices in critical areas, such as healthcare and engineering projects.	Implementing the cubic bipolar fuzzy model may involve significant computational resources, which could be a barrier for use in resource-constrained environments or smaller organizations.

[4]	FWZIC, MAIRCA	Medical Diagnosis	By utilizing fuzzy logic, the framework can better handle uncertainties and ambiguities inherent in medical language, leading to more precise and reliable extraction of clinical concepts.	The framework's effectiveness is highly dependent on the quality and comprehensiveness of the input data, which can vary significantly across different medical domains.
[32]	CWBCM	Medical Diagnosis	The insights gained from this method can assist healthcare professionals and researchers in making informed decisions about which evaluation criteria to prioritize, ultimately leading to better predictive models.	The analysis involved in applying the CW- BCM method may demand substantial computational resources, which could pose limitations for smaller research teams or organizations with fewer technological capabilities.
[41], [40]	TOPSIS & VIKOR	Medical Diagnosis	The application of Einstein aggregation operators enhances the decision-making process by providing a comprehensive way to combine multiple criteria and factors, leading to more informed conclusions.	The advanced techniques employed in the analysis may require significant computational resources, which could pose challenges for smaller research teams or institutions with limited technological capabilities.
[12]	CRITIC, TOPSIS & EDAS	Medical Diagnosis	The proposed methodology can be adapted to various populations and clinical settings, making it a versatile tool for healthcare providers in managing cervical cancer risk.	The reliance on machine learning algorithms may require significant computational resources, potentially limiting accessibility for smaller clinics or healthcare institutions with fewer resources.
[27]	WSM, TOPSIS & VIKOR	Medical Diagnosis	The integration of MCDM allows for a holistic evaluation of multiple criteria, such as accuracy, interpretability, and computational efficiency, ensuring that recommendations align with practical health- care needs.	The effectiveness of the framework relies heavily on the quality and diversity of input data; insufficient or biased data can negatively impact the re-liability of the recommendations.

[7]	AROMAN	Medical Diagnosis	The approach considers multiple criteria, allowing for a holistic assessment of different devolution strategies and their potential impacts on healthcare systems.	The evaluation and analysis involved in the AROMAN method may demand significant computational resources and time, which could be a limitation for smaller organizations or in resource-constrained settings.
[5]	COPRAS	Medical Diagnosis	The method can be adapted to various healthcare settings and can consider multiple criteria, making it a versatile tool for policymakers and healthcare professionals in managing infectious diseases.	Implementing the approach may require significant computational resources, which could limit its feasibility in resource-constrained environments or smaller healthcare institutions.

1.4 Literature Review on GTMA Method:

The GTMA is explained by Rao [36] to expand MADM by using the graph theory approach. The technique was additionally classified as the GTMA as an official decision-making technique [37]. GTMA contributes three works. The first one is finding the performance value between each criterion, second one is making the digraph between every alternative converts the esteem into the representation of the matrix and computes the permanent esteem of each alternative. By this basis, ranking is provided in this technique [35]. Noticeable thing is, at the time of procedure the permanent function and the permutation function are used to give the total information of the evaluated alternative beyond any low value. Few recent articles strongly set on the selection of alternative problems by this technique. By this scope of GTMA, Tuljak et al. [47] utilized the hybrid technique that included AHP and GTMA. Chang et al. [14] found a new approach to MCDM with R Studio techniques by using the GTMA approach. Through that work, they analyzed tariff plans and smartphone selection for taxi service operators, and they compared with AHP and TOPSIS. Chakraborty et al. [13] provided a review of the ap- plications of MCDM techniques of machine learning techniques, through that work they explained that MOORA and GTMA techniques gave the proper results for optimization problems. Hence, this work also included the high-level analysis work of the GTMA technique.

1.5 Literature Review on PROMETHEE-II Method:

Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) technique designed by Brans [9]. It was expanded by Brans and Vinke [10] in 1986. PROMETHEE technique includes a few research situations like choice, ranking, allocation of resources, and resolution of criterion. Through this technique, alternatives are calculated by the distance with each alternative. PROMETHEE method has subtypes like PROMETHEE-I, PROMETHEE-II, PROMETHEE-III, PROMETHEE-IV, and PROMETHEE-V [8]. The work started with the GAIA plan, each subtype has some specification. They are, PROMETHEE-I provides the partial ranking of alternatives, PROMETHEE-II makes the complete ranking of all alternatives, PROMETHEE-III has a global evaluation process, PROMETHEE-IV is works as a sensitivity tool and it is working like a human brain, PROMETHEE-V can work under some constraints only. By these various levels of process and tools, many works utilized PROMETHEE subtypes, and the works are; effect of promotion on online shopping factors [3], medical diagnosis problems by using Pythagorean fuzzy sets [29], irrigation models analyzed and explained with sorting and ranking [11], multi-scale information systems were analyzed for preference ranking [20]. Hence, by these applications, this paper utilised the hybrid technique GTMAandPROMETHEE-II.

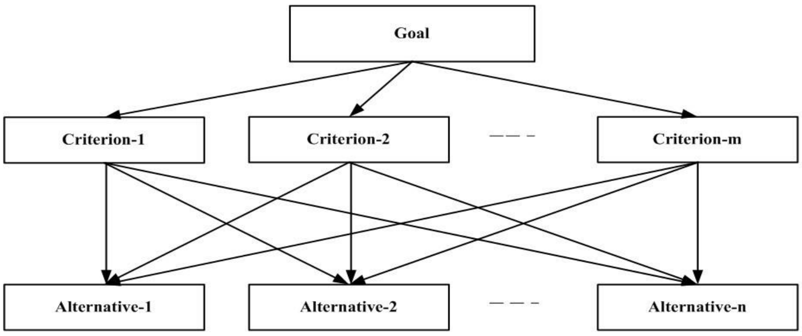

Figure 1: Structure of the MADM problem

2 Preliminaries

In the preliminaries section, we establish the foundational concepts and methodologies pertinent to the study. This includes an overview of key MCDM techniques and their applications, providing the necessary context for understanding the analysis and results.

Definition 1. Lotfi. Zadeh [48] introduced the concept of fuzzy sets in 1965, and it is defined as a set whose elements have a degree of membership. If *U* is a universalthen a fuzzy set

$\widetilde{\mathfrak{X}}$ in *U* is a set of ordered pairs,

$$\widetilde{\mathfrak{X}} = \{(a, \mu_{\widetilde{\mathfrak{X}}}(a)) : a \in \widetilde{\mathfrak{X}}\}.$$

where, $\mu_{\widetilde{\mathfrak{X}}}(a)$ is a membership function. The membership function $\mu_{\widetilde{\mathfrak{X}}}(a)$is defined as

$\mu_{\widetilde{\mathfrak{X}}}(a)$: $\widetilde{\mathfrak{X}} \rightarrow [0, 1]$.

Definition 2. Fuzzy number [49] is defined as a fuzzy set and its membership function should satisfy the following conditions.

A fuzzy set $\widetilde{\mathfrak{X}}$ defined on the set of real numbers $\mathfrak{A}$ is said tobe a fuzzy number if its membership function$\mu_{\widetilde{\mathfrak{X}}}(a)$: $\widetilde{\mathfrak{X}} \rightarrow [0, 1]$ has the following characteristics.

(i) $\widetilde{\mathfrak{X}}$ is convex

$$\mu_{\widetilde{\mathfrak{X}}}(\lambda x_1 + (1-\lambda)x_2) \geq min\left(\mu_{\widetilde{\mathfrak{X}}}(x_1), \mu_{\widetilde{\mathfrak{X}}}(x_2)\right), \forall x \in [0,1], \lambda \in [0,1]$$

(ii) $\tilde{\mathfrak{X}}$ is normal∃ and x∈ $[0,1]$ such that max $\mu_{\tilde{\mathfrak{X}}}(x) = 1$

(iii) $\tilde{\mathfrak{X}}$ is convex is piecewise continuous

Definition 3. A triangular fuzzy number $\tilde{\mathfrak{X}}$ [33] is defined by three parameters $(\mathfrak{p}, \mathfrak{q}, \mathfrak{r})$ with $(\mathfrak{p} < \mathfrak{q} < \mathfrak{r})$ andthe membership function is defined as

$$\mu_{\tilde{\mathfrak{X}}}(\mathfrak{x}) = \begin{cases} \dfrac{\mathfrak{x} - \mathfrak{p}}{\mathfrak{q} - \mathfrak{p}}, & \text{for } \mathfrak{p} \leq \mathfrak{r} \leq \mathfrak{q} \\ \dfrac{\mathfrak{r} - \mathfrak{x}}{\mathfrak{r} - \mathfrak{q}}, & \text{for } \mathfrak{q} \leq \mathfrak{r} \leq \mathfrak{r} \\ 0, & \text{elsewhere.} \end{cases}$$

Definition 4. The arithmetic operations of the triangular fuzzy number [33] are defined

as follows: Let $\tilde{\mathfrak{A}} = (\mathfrak{p}_1, \mathfrak{p}_2, \mathfrak{p}_3)$ and $\tilde{\mathfrak{B}} = (\mathfrak{q}_1, \mathfrak{q}_2, \mathfrak{q}_3)$

Addition: $\tilde{\mathfrak{A}} + \tilde{\mathfrak{B}}$= $(\mathfrak{p}_1 + \mathfrak{q}_1, \mathfrak{p}_2 + \mathfrak{q}_2, \mathfrak{p}_3 + \mathfrak{q}_3)$

Subtraction: $\tilde{\mathfrak{A}} - \tilde{\mathfrak{B}}$= $(\mathfrak{q}_1 - \mathfrak{p}_3, \mathfrak{q}_2 - \mathfrak{p}_2, \mathfrak{q}_3 - \mathfrak{p}_1)$

Multiplication: $\tilde{\mathfrak{A}} * \tilde{\mathfrak{B}}$= $(\mathfrak{p}_1 * \mathfrak{q}_1, \mathfrak{p}_2 * \mathfrak{q}_2, \mathfrak{p}_3 * \mathfrak{q}_3)$

Division;

$$\frac{\tilde{\mathfrak{A}}}{\tilde{\mathfrak{B}}} = \left\{ \left(\frac{\mathfrak{p}_1}{\mathfrak{q}_3}\right), \left(\frac{\mathfrak{p}_2}{\mathfrak{q}_2}\right), \left(\frac{\mathfrak{p}_3}{\mathfrak{q}_1}\right) \right\}$$

3 Risk Factors for Type 2 Diabetes

Risk factors are important for spreading the disease. In this work, ten risk factors are chosen to find out the best risk factor for disease type-2 diabetes.

- A **Sedentary lifestyle** A sedentary lifestyle is a significant risk factor for the development and progression of type-2 diabetes. Lack of physical activity contributes to obesity, insulin resistance, and impaired glucose metabolism, which are key triggers of the disease. Regular exercise improves the body's sensitivity to insulin, allowing for better control of blood sugar levels. Conversely, prolonged periods of inactivity can lead to weight gain, higher blood pressure, and an increased likelihood of developing type-2 diabetes. Physical inactivity also negatively impacts cardiovascular health, which is often compromised in diabetic patients. Engaging in moderate exercise has been shown to help regulate body weight, reduce inflammation, and enhance overall metabolic function. Furthermore, a sedentary lifestyle is linked to higher levels of visceral fat, which is particularly harmful as it increases the risk of insulin resistance. Individuals with a sedentary routine are more likely to experience poor circulation and increased cholesterol levels, worsening diabetic symptoms. Incorporating daily physical activities, even in small amounts, is crucial in both preventing and managing type-2 diabetes. Overall, reducing sedentary behavior plays a vital role in controlling the progression and complications of the disease [18].

- **Obesity** is a major risk factor for the development of type-2 diabetes, as it significantly impacts the body's ability to use insulin effectively. Excess fat, particularly around the abdomen, increases insulin resistance, where the body's cells become less responsive to insulin, leading to elevated blood sugar levels. Obesity is also linked to chronic inflammation, which further exacerbates metabolic disturbances and insulin dysfunction. Over time, this increased strain on the pancreas can lead to its diminished ability to produce insulin, resulting in the onset of diabetes. Maintaining a healthy weight through diet and exercise is critical in reducing the risk of both obesity and type-2 diabetes. Moreover, individuals with obesity are more likely to develop other complications such as high blood pressure, high cholesterol, and cardiovascular disease, which are common comorbidities of diabetes. Weight loss, even in small amounts, can improve insulin sensitivity and glucose tolerance, reducing the likelihood of developing the condition. Public health interventions that promote healthy lifestyles are essential in addressing the obesity epidemic and its role in the increasing prevalence of type-2 diabetes [15].

- **Stress** plays a significant role in the development and management of type-2 diabetes. When the body experiences stress, it releases hormones such as cortisol and adrenaline, which can increase blood sugar levels as part of the ”fight or flight” response. Chronic stress can lead to prolonged periods of elevated blood sugar, contributing to insulin resistance and increasing the risk of developing diabetes. Furthermore, stress often leads to unhealthy coping mechanisms such as overeating, poor dietary choices, and physical inactivity, which are all risk factors for type-2 diabetes. For individuals already diagnosed with the condition, stress can make it more difficult to manage blood sugar levels, exacerbating symptoms and complications. Additionally, stress can negatively impact sleep patterns and mental health, both of which are crucial for maintaining a healthy balance in blood glucose levels. Relaxation techniques, mindfulness, and regular physical activity have been shown to reduce stress and improve diabetes management. Therefore, managing stress effectively is an important component of both preventing and controlling type-2 diabetes. [6].

- **Medicine** is a crucial component in managing type-2 diabetes, particularly when lifestyle changes such as diet and exercise are not enough to control blood sugar levels. There are various classes of medications used to treat the condition, each working in different ways to manage glucose levels. For instance, metformin, a commonly prescribed drug, helps to lower glucose production in the liver and improve insulin sensitivity in cells. Other medications, such as sulfonylureas, stimulate the pancreas to produce more insulin, while DPP-4 inhibitors and GLP-1 receptor agonists help regulate blood sugar by affecting insulin and glucagon hormones. Insulin therapy may also be necessary for individuals whose bodies no longer produce enough insulin on their own. Proper medication adherence is critical to prevent complications such as cardiovascular disease, nerve damage, and kidney problems, which are associated with uncontrolled diabetes. However, medications can sometimes cause side effects like hypoglycemia (low blood sugar) or gastrointestinal issues, which should be carefully monitored. Alongside medication, regular blood sugar testing and healthcare check-ups are important for adjusting treatment and ensuring effective diabetes management [30].

- **Pancreatic disease**can significantly increase the risk of developing type-2 diabetes due to the pancreas's critical role in producing insulin, the hormone that regulates blood sugar levels. Conditions such as chronic pancreatitis, pancreatic cancer, or cystic fibrosis can impair the pancreas's ability to produce insulin effectively, leading to insulin deficiency and high blood glucose levels. In some cases, surgical removal of part or all of the pancreas can also result in diabetes, known as pancreatogenic diabetes or type 3c diabetes. Chronic inflammation of the pancreas, often caused by excessive alcohol consumption or gallstones, can damage insulin-producing cells, further increasing the likelihood of diabetes. Additionally, pancreatic diseases may disrupt the balance of digestive enzymes, leading to poor nutrient absorption, which can complicate blood sugar control. The management of diabetes caused by pancreatic disease can be more complex than typical type-2 diabetes, as it may involve both insulin therapy and enzyme replacement therapy. Early diagnosis and treatment of pancreatic conditions are vital to prevent or delay the onset of diabetes and its associated complications. Proper medical care and lifestyle adjustments can help manage both pancreatic disease and diabetes effectively [46].

- **Blood pressure** is a common comorbidity of type-2 diabetes and plays a significant role in increasing the risk of serious complications. When blood pressure is consistently elevated, it puts additional strain on the heart and blood vessels, leading to cardiovascular diseases, which are already more prevalent among people with diabetes. Uncontrolled high blood pressure can damage blood vessels, reducing circulation and oxygen delivery, especially to critical organs like the kidneys, eyes, and brain. This can worsen diabetic complications such as kidney disease (diabetic nephropathy), vision problems (diabetic retinopathy), and an increased risk of stroke. Elevated blood pressure also contributes to insulin resistance, making it more difficult to control blood sugar levels. Conversely, poorly controlled diabetes can damage blood vessels, further exacerbating hypertension. Managing both conditions simultaneously is crucial for reducing the risk of heart attacks, stroke, and other life-threatening complications. Lifestyle changes such as a healthy diet, regular exercise, and weight management are essential in controlling blood pressure, while medications like ACE inhibitors or beta-blockers may be prescribed to help maintain healthy levels. Regular monitoring and early intervention can significantly improve outcomes for individuals with both diabetes and hypertension [16].

- **Bad habits**, such as smoking, excessive alcohol consumption, poor diet, and physical inactivity, significantly contribute to the development and progression of type-2 diabetes. Smoking, for example, damages blood vessels, increases inflammation, and raises blood sugar levels, making it harder to control diabetes and increasing the risk of complications like heart disease and stroke. Excessive alcohol consumption can lead to weight gain, disrupt blood sugar levels, and impair liver function, all of which negatively affect diabetes management. A poor diet high in processed foods, sugary beverages, and unhealthy fats promotes obesity and insulin resistance, which are key triggers for type-2 diabetes. Physical inactivity is another harmful habit that contributes to weight gain and poor glucose control, further exacerbating the condition. Additionally, these bad habits often interact with each other, creating a cycle of poor health that increases the risk of diabetes-related complications such as nerve damage, kidney disease, and cardiovascular issues. Breaking these habits and adopting a healthier lifestyle, including regular exercise, a balanced diet, and smoking cessation, is essential for preventing and managing type-2 diabetes effectively. Small, positive changes in daily routines can lead to significant improvements in overall health and diabetes outcomes [17].

- **Genetic predisposition** plays a crucial role in the development of type-2 diabetes, as family history and inherited traits can significantly increase the risk of the disease. Individuals with a parent or sibling who has type-2 diabetes are more likely to develop the condition themselves, due to shared genetic factors that influence how the body processes glucose and responds to insulin. Certain genes associated with insulin production, insulin sensitivity, and fat metabolism may predispose individuals to higher risks of insulin resistance, a key factor in type-2 diabetes. Additionally, ethnic groups such as African Americans, Hispanics, Native Americans, and Asians have a higher genetic susceptibility to developing the disease. While genetic predisposition increases risk, it doesn't mean that diabetes is inevitable. Environmental factors, including diet, physical activity, and lifestyle habits, still play a significant role in determining whether or not someone with a genetic predisposition will develop type-2 diabetes. Understanding one's genetic risk can encourage early screening and preventive measures, such as maintaining a healthy weight, staying active, and monitoring blood sugar levels regularly. Combining genetic insights with lifestyle modifications can help reduce the likelihood of developing the disease, even in those who are genetically predisposed [42].

- **Age** is a significant risk factor for the development of type-2 diabetes, with the likelihood of onset increasing as individuals grow older. As people age, their bodies may become less efficient at producing insulin and utilizing it effectively, leading to insulin resistance. This decline in insulin sensitivity is often exacerbated by factors such as decreased physical activity, changes in body composition, and weight gain, which are more common in older adults. Additionally, the cumulative effects of long-term exposure to unhealthy lifestyle choices, such as poor diet and sedentary behavior, can further increase the risk of developing diabetes as one age. Older adults may also face challenges such as managing multiple health conditions, which can complicate diabetes management and increase the risk of complications. Furthermore, age-related hormonal changes can impact metabolism and glucose regulation, contributing to higher blood sugar levels. Preventive measures, including regular physical activity, a balanced diet, and routine health screenings, are essential for older adults to mitigate the risks associated with aging and maintain optimal blood sugar control. Awareness of age as a risk factor highlights the importance of proactive health management and lifestyle adjustments throughout one's life to reduce the likelihood of developing type-2 diabetes [38].

- **Unhealthy food** choices significantly contribute to the risk of developing type- 2 diabetes, as they can lead to obesity, insulin resistance, and poor blood sugar control. Diets high in processed foods, added sugars, unhealthy fats, and refined carbohydrates can promote weight gain and negatively affect metabolic health. For example, sugary beverages, such as sodas and energy drinks, are linked to increased fat accumulation and insulin resistance. Similarly, consuming fast food and highly processed snacks often leads to excessive calorie intake, poor nutrient quality, and an imbalance in essential nutrients, which are vital for maintaining healthy blood sugar levels. Foods high in saturated and trans fats can contribute to inflammation and disrupt insulin signaling, further complicating glucose metabolism. Additionally, a lack of fiber-rich foods like fruits, vegetables, and whole grains can impair digestion and lead to spikes in blood sugar levels. Frequent consumption of unhealthy foods can also establish a cycle of cravings and overeating, making it more challenging to adopt healthier eating habits. To reduce the risk of type-2 diabetes, it is essential to focus on a balanced diet rihjytch in whole, minimally processed foods, including lean proteins, healthy fats, and plenty of fruits and vegetables. Making mindful food choices and promoting healthier eating habits are crucial steps in diabetes prevention and management [34]. For these causes and by the review of these articles this work is integrated with ten risk factors which is indicated with notation in the Table 3.

4 Stages of Type 2 diabetes:

Type-2 diabetes typically progresses through several stages, each marked by increasing severity of insulin resistance and impaired glucose regulation. Initially, individuals may experience prediabetes, where blood glucose levels are higher than normal but not yet diagnostic of diabetes. Without intervention, prediabetes can progress to stage 1 diabetes, characterized by elevated blood sugar levels and symptoms such as increased thirst and frequent urination, eventually advancing to stage 2 diabetes, where the condition becomes more severe with potential complications affecting various organs and systems. This work explains the four stages of type-2 diabetes following as;

4.1 Normal:

In the normal stage of Type-2 diabetes, the body starts to exhibit early signs of insulin resistance. This resistance primarily occurs in muscle, fat, and liver cells, making it more difficult for these cells to effectively absorb glucose from the bloodstream. As a result, glucose remains in the blood, leading to elevated blood sugar levels. However, during this phase, the pancreas compensates for the reduced effectiveness of insulin by producing more of the hormone, particularly from the islets of Langerhans, the specialized cells in the pancreas responsible for insulin production [2].

This compensatory mechanism temporarily helps to maintain normal blood sugar levels, preventing the onset of hyperglycemia. The increased insulin production forces glucose into the cells, allowing them to continue using glucose for energy. Despite this effort, over time, the demand on the pancreas becomes excessive [24]. The continuous overproduction of insulin can eventually lead to pancreatic exhaustion, where the beta cells in the islets of Langerhans begin to lose their ability to produce enough insulin [44].

Although blood glucose levels may appear normal during this stage, the underlying insulin resistance is gradually worsening. The body's cells are no longer responding effectively to insulin, particularly in the liver, where the conversion of glucose to glycogen slows down. As the condition progresses, the compensatory mechanisms fail to keep up with the rising insulin resistance, leading to higher blood sugar levels and advancing the individual toward prediabetes or full-blown Type-2 diabetes [45].

Early detection of insulin resistance at this stage is crucial to prevent further deterioration. Interventions such as lifestyle changes, including diet and exercise, can improve insulin sensitivity and delay or prevent the onset of Type-2 diabetes [50].

4.2 Borderline Diabetes:

This stage, known as pre-diabetes, marks a critical turning point in the progression towards Type-2 diabetes. During pre-diabetes, the body's cells become increasingly resistant to the effects of insulin, and the pancreas struggles to keep up by producing more insulin. However, despite this enhanced insulin production, it is no longer sufficient to bring blood sugar levels back to normal. The cells' ability to respond to insulin continues to decline, causing glucose to accumulate in the bloodstream at levels higher than normal, though not yet high enough to be classified as diabetes.

In this phase, the beta cells of the pancreas, which are responsible for producing insulin, begin to show signs of dysfunction. As insulin resistance worsens, the beta cells are forced to work harder, eventually leading to a decline in their function. Over time, this can result in beta cell exhaustion, where the cells are no longer able to secrete enough insulin to regulate blood sugar effectively. This beta cell disorder is a key factor in the transition from pre-diabetes to Type-2 diabetes.

During pre-diabetes, blood glucose levels are elevated but remain just below the threshold for a diabetes diagnosis. This state is often referred to as "borderline diabetes" because it represents an intermediate stage where the risk of developing full-blown Type-2 diabetes is significantly increased. Without intervention, many individuals with pre-diabetes will progress to Type-2 diabetes within a few years.

However, at this stage, lifestyle interventions such as weight management, dietary changes, and regular physical activity can be highly effective in improving insulin sensitivity and preventing the progression to diabetes. Early detection of pre-diabetes offers a crucial window for taking preventive measures that can delay or even prevent the onset of Type-2 diabetes.

4.3 Early Diabetes:

At this stage, the blood sugar levels become significantly elevated, marking the onset of early Type-2 diabetes mellitus (T2DM). The body's insulin resistance reaches a critical point where the cells, particularly in the muscles, fat, and liver, can no longer efficiently absorb glucose from the bloodstream. As a result, the pancreas is unable to produce enough insulin to compensate for this resistance, leading to persistent hyperglycemia (high blood sugar).

In addition to insulin resistance, the dysfunction and potential infection or damage of the beta cells in the pancreas further exacerbate the problem. These cells, which are responsible for insulin production, become impaired over time, reducing the body's ability to regulate blood glucose levels effectively. The combined effects of beta cell dysfunction and insulin resistance are the primary drivers of the high blood sugar levels characteristic of T2DM.

Without proper management or treatment, these elevated glucose levels can cause long-term damage to various cells and tissues in the body. Prolonged hyperglycemia can lead to complications such as cardiovascular disease, kidney damage, nerve damage, and eye problems (retinopathy), among others. This stage of T2DM, sometimes referred to as "early diabetes," is critical because the damage to the body begins even if symptoms are mild or unnoticed.

While this early stage can be managed with lifestyle changes and medication, failure to control blood sugar can result in the progressive worsening of the condition. Addressing both insulin resistance and beta cell dysfunction through medical intervention is key to preventing further complications and maintaining a healthier long-term prognosis for individuals with T2DM.

4.4 Late Diabetes:

In the late stages of T2DM, persistently high blood sugar levels begin to cause significant complications, particularly affecting the vascular cells that line the blood vessels. Chronic hyperglycemia damages these cells, leading to structural changes in blood vessels that impair their function. This vascular damage is a key contributor to the development of several serious diabetes-related complications.

One of the major effects is diabetic nephropathy, kidney disease. High blood sugar levels damage the tiny blood vessels in the kidneys, reducing their ability to filter waste products from the blood. This can lead to albuminuria, where the protein albumin leaks into the urine, signaling kidney dysfunction. Over time, this may progress to chronic kidney disease or even kidney failure.

The vascular complications also affect arteries, leading to peripheral artery disease (PAD), where narrowed arteries reduce blood flow to the limbs. This condition can cause pain, infections, and in severe cases, require amputations. Additionally, damage to larger arteries raises the risk of atherosclerosis, a condition where the arteries harden and narrow, increasing the likelihood of cardiovascular diseases such as heart attacks and strokes.

Late-stage diabetes can also cause diabetic retinopathy, where the blood vessels in the eyes are damaged, leading to vision problems and even blindness. Heart problems are another serious consequence, as high blood sugar and damaged arteries increase the risk of coronary artery disease, heart failure, and other cardiovascular conditions.

Managing blood sugar levels becomes critical at this stage to prevent further vascular damage and complications. However, without proper control, the cumulative damage to blood vessels and organs can severely impact the quality of life and lead to life-threatening conditions.

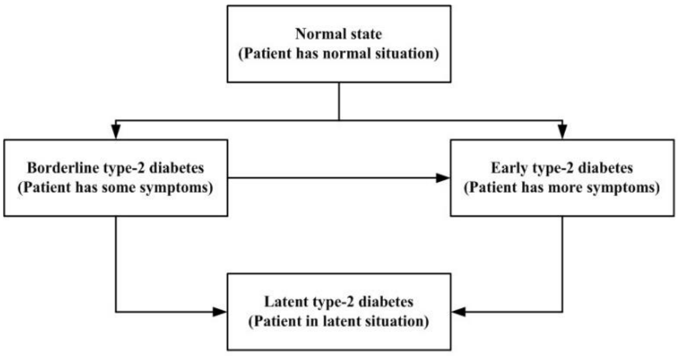

Figure 2: Digraph of each criterion

5 Algorithm

Step-1 Construct the risk factors and stages of T2DM in the alternatives and criteria of the problem. $\mathfrak{A} = \mathfrak{A}_1, \mathfrak{A}_2, \dots, \mathfrak{A}_m$ be the set of risk factors of type-2 diabetes, $\mathfrak{C} = \mathfrak{C}_1, \mathfrak{C}_2, \dots, \mathfrak{C}_n$ be the set of criteria and $\mathfrak{D} = \mathfrak{D}_1, \mathfrak{D}_2, \dots, \mathfrak{D}_k$ is the set of decision makers.

Step-2 Gather the opinions of decision-makers about the risk factors of T2DM. Construct the arrangement matrix with lingual terms with the aid of decision-makers.

$$\begin{bmatrix} \mathfrak{b}_{11} & \mathfrak{b}_{21} & \mathfrak{b}_{31} & \cdots & \mathfrak{b}_{1n} \\ \mathfrak{b}_{21} & \mathfrak{b}_{22} & \mathfrak{b}_{32} & \cdots & \mathfrak{b}_{2n} \\ \vdots & \vdots & \vdots & \cdots & \vdots \\ \mathfrak{b}_{m1} & \mathfrak{b}_{m2} & \mathfrak{b}_{m3} & \cdots & \mathfrak{b}_{mn} \end{bmatrix}$$

where b_{ij} is the relation between i^{th} alternative to j^{th} criterion.

Step-3 Change the lingual terms to a fuzzy decision matrix with triangular numbers. Hence, frame an aggregated fuzzy matrix with triangular number ($\mathcal{T}$) and weighted matrix $\mathfrak{w}$

$$\begin{bmatrix} (\mathbf{u}_{11}, \mathfrak{v}_{11}, \mathfrak{w}_{11}) & (\mathbf{u}_{12}, \mathfrak{v}_{12}, \mathfrak{w}_{12}) & (\mathbf{u}_{13}, \mathfrak{v}_{13}, \mathfrak{w}_{13}) & \dots & (\mathbf{u}_{1n}, \mathfrak{v}_{1n}, \mathfrak{w}_{1n}) \\ (\mathbf{u}_{21}, \mathfrak{v}_{21}, \mathfrak{w}_{21}) & (\mathbf{u}_{22}, \mathfrak{v}_{22}, \mathfrak{w}_{22}) & (\mathbf{u}_{23}, \mathfrak{v}_{23}, \mathfrak{w}_{23}) & \dots & (\mathbf{u}_{2n}, \mathfrak{v}_{2n}, \mathfrak{w}_{2n}) \\ \vdots & \vdots & \vdots & \dots & \vdots \\ (\mathbf{u}_{m1}, \mathbf{v}_{m1}, \mathfrak{w}_{m1}) & (\mathbf{u}_{m2}, \mathbf{v}_{m2}, \mathfrak{w}_{m2}) & (\mathbf{u}_{m3}, \mathfrak{v}_{m3}, \mathfrak{w}_{m3}) & \dots & (\mathbf{u}_{mn}, \mathfrak{v}_{mn}, \mathfrak{w}_{mn}) \end{bmatrix}$$

$$\begin{bmatrix} (\mathbf{a}_{11}, \mathfrak{a}_{12}, \mathfrak{a}_{13}) \\ (\mathbf{a}_{21}, \mathfrak{a}_{22}, \mathfrak{a}_{23}) \\ \vdots \\ (\mathbf{a}_{m1}, \mathfrak{a}_{m2}, \mathfrak{a}_{m3}) \end{bmatrix}$$

Step-4 The fuzzy decision matrix with triangular numbers ($\mathfrak{A}$), is transformed as a matrix that has crisp values to find the matrix that has defuzzified values by using the Converting fuzzy into crisp score (CFCS) algorithm.

a) N
ormalize the fuzzy triangular values:

$$\mathfrak{ru}_{ij} = \frac{\mathfrak{u}_{ij}^{n} - min\{\mathfrak{u}_{ij}\}}{\Delta_{min}^{max}}$$

$$\mathfrak{rv}_{ij} = \frac{\mathfrak{v}_{ij}^{n} - min\{\mathfrak{v}_{ij}\}}{\Delta_{min}^{max}}$$

$$\mathfrak{rw}_{ij} = \frac{\mathfrak{w}_{ij}^{n} - min\{\mathfrak{w}_{ij}\}}{\Delta_{min}^{max}}$$

where Δ_{min}^{max}= max$\{\mathfrak{w}_{ij}^{n}\}$- max$\{\mathfrak{u}_{ij}^{n}\}$

b) F
ind the right and left score:

$$\mathfrak{ruf}_{ij} = \frac{\mathfrak{rv}_{ij}^{n}}{1 + \mathfrak{rv}_{ij}^{n} - \mathfrak{ru}_{ij}^{n}}$$

$$\mathfrak{rwf}_{ij} = \frac{\mathfrak{rw}_{ij}^{n}}{1 + \mathfrak{rw}_{ij}^{n} - \mathfrak{rv}_{ij}^{n}}$$

c) F
inal normalized value:

$$\mathfrak{r}_{ij}^{n} = \frac{\mathfrak{ruf}_{ij}(1 - \mathfrak{ruf}_{ij}) + (\mathfrak{rwf}_{ij})^2}{(1 - \mathfrak{ruf}_{ij} + \mathfrak{rwf}_{ij})}$$

d) C
alculate the separated values:

$$\mathfrak{D}_{ij} = \min\{\mathfrak{u}_{ij}\}^{n} + \mathfrak{u}_{ij} \times \Delta_{min}^{max}$$

Step-5 Normalization of defuzzified matrix

$$\mathfrak{D} = \begin{bmatrix} \mathfrak{e}_{11} & \mathfrak{e}_{12} & \mathfrak{e}_{13} & \cdots & \mathfrak{e}_{1n} \\ \mathfrak{e}_{21} & \mathfrak{e}_{22} & \mathfrak{e}_{23} & \cdots & \mathfrak{e}_{2n} \\ \vdots & \vdots & \vdots & \cdots & \vdots \\ \mathfrak{e}_{m1} & \mathfrak{e}_{m2} & \mathfrak{e}_{m3} & \cdots & \mathfrak{e}_{mn} \end{bmatrix}$$

The defuzzified matrix $\mathfrak{D}$ is getting normalization by $\mathfrak{n}_{ij} = \frac{\mathfrak{e}_{ij}}{\sqrt{\sum_{i=1}^{i=n} \mathfrak{e}_{ij}^2}}$

$$\mathfrak{Y} = \begin{bmatrix} \mathfrak{f}_{11} & \mathfrak{f}_{12} & \mathfrak{f}_{13} & \cdots & \mathfrak{f}_{1n} \\ \mathfrak{f}_{21} & \mathfrak{f}_{22} & \mathfrak{f}_{23} & \cdots & \mathfrak{f}_{2n} \\ \vdots & \vdots & \vdots & \cdots & \vdots \\ \mathfrak{f}_{m1} & \mathfrak{f}_{m2} & \mathfrak{f}_{m3} & \cdots & \mathfrak{f}_{mn} \end{bmatrix}$$

Step-6 Find the weighted normalized matrix $\mathfrak{w}$**:**

Estimate the weighted normalized matrix with the help of decision-maker opinions on weighted values of risk factors.

$$\mathfrak{w} = (\mathfrak{a}_1, \mathfrak{a}_2, \mathfrak{a}_3, \ldots, \mathfrak{a}_n)$$

$$\mathfrak{Y} = \begin{bmatrix} \mathfrak{a}_1\mathfrak{f}_{11} & \mathfrak{a}_2\mathfrak{f}_{12} & \mathfrak{a}_3\mathfrak{f}_{13} & \cdots & \mathfrak{a}_n\mathfrak{f}_{1n} \\ \mathfrak{a}_1\mathfrak{f}_{21} & \mathfrak{a}_2\mathfrak{f}_{22} & \mathfrak{a}_3\mathfrak{f}_{23} & \cdots & \mathfrak{a}_n\mathfrak{f}_{2n} \\ \vdots & \vdots & \vdots & \cdots & \vdots \\ \mathfrak{a}_1\mathfrak{f}_{m1} & \mathfrak{a}_2\mathfrak{f}_{m2} & \mathfrak{a}_3\mathfrak{f}_{m3} & \cdots & \mathfrak{a}_n\mathfrak{f}_{mn} \end{bmatrix}$$

Step-7 Develop the digraph of criteria.

Step-8 Develop the permanent matrix of each digraph.

Step-9 Provide the ranks by the order of permanent of each alternative.

5.1 PROMETHEE-II algorithm

Step-10 Now by the algorithm of PROMETHEE-II, compute the preference degree from one alternative to another alternative. $\boldsymbol{\mathfrak{w}_j}(\boldsymbol{\mathfrak{D}}(\boldsymbol{\mathfrak{U}_i} - \boldsymbol{\mathfrak{U}_j}))$

Step-11 Calculate the preference function,

$$\mathfrak{p}_j(\mathfrak{x}, \mathfrak{v}) = \begin{cases} 0, & \text{if } \mathfrak{S}_{aj} = \mathfrak{S}_{bj} \\ \boldsymbol{\mathfrak{S}}_{aj} - \boldsymbol{\mathfrak{S}}_{bj}, & \text{if } \boldsymbol{\mathfrak{S}}_{aj} > \boldsymbol{\mathfrak{S}}_{bj} \end{cases}$$

Step-12 Calculate the aggregated preference function $\pi(x, y)$,

$$\pi(\mathfrak{x}, \mathfrak{v}) = \frac{\sum_{j=1}^{n} \mathfrak{w}_j \, \mathfrak{p}_j(\mathfrak{x}, \mathfrak{v})}{\sum_{j=1}^{n} \mathfrak{w}_j}$$

Step-13 Determine the leaving and entering outranking flow: Positive (Leaving) flow for

x^{th} alternative,

$$\varphi^{+} = \frac{1}{m-1}\sum_{\mathfrak{v}=1}^{n} \pi(\mathfrak{r},\mathfrak{v})\ (\mathfrak{r} \neq \mathfrak{v})$$
$$\varphi^{-} = \frac{1}{m-1}\sum_{\mathfrak{v}=1}^{n} \pi(\mathfrak{v},\mathfrak{r})\ (\mathfrak{r} \neq \mathfrak{v})$$

Step-14 Calculate the proper outranking flow for every alternative

$$\varphi(\mathfrak{a}) = \varphi^{+}(\mathfrak{a}) - \varphi^{-}(\mathfrak{a})$$

Step-15 Calculate the rankings of each alternative which depends on the value of $\varphi(\mathfrak{a})$.

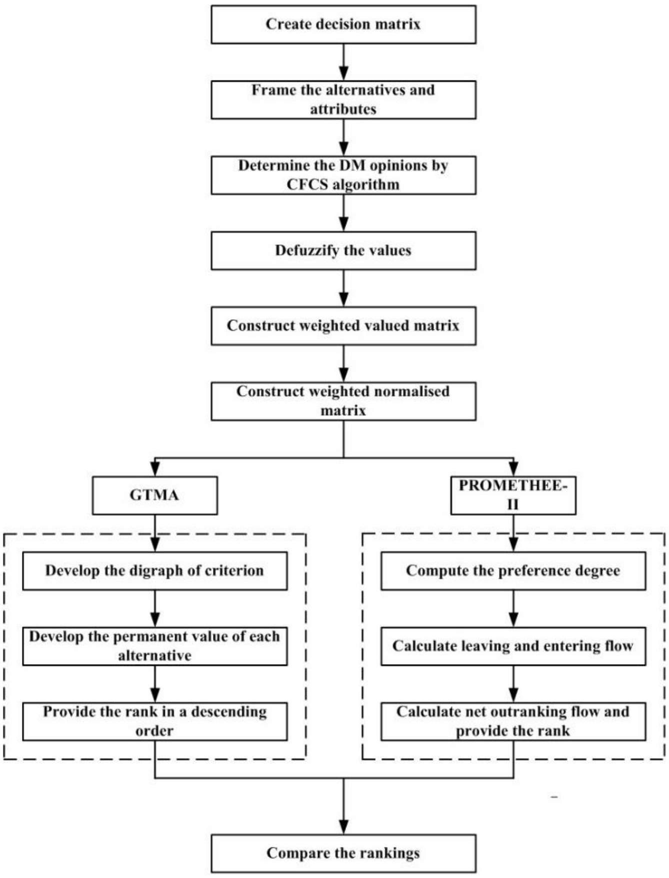

Figure 3: Algorithm of hybrid technique which includes GTMA and PROMETHEE-II

6 Analysing the risk factors of T2DM through the algorithm:

The principal motive of this work is to analyze the leading risk factors of type 2 diabetes by its risk factors. Hence the decision-making methods are used to find the rank of the risk factors of T2DM. According to the decision-makers' opinions analysis of risk factors was started. In the calculation of GTMA, PROMETHEE II techniques, ten alternatives (risk factors) and four criteria (stages) are selected to analyze the dangerous risk factors of T2DM. Table 3 is referred to as the risk factors of type-2 diabetes.

Table 3: Risk factors of Type-2 diabetes

Risk Factors	Notation

Sedentary lifestyle	$\mathfrak{A}_1$
Obesity	$\mathfrak{A}_2$
Stress	$\mathfrak{A}_3$
Medicine	$\mathfrak{A}_4$
Pancreatic Disease	$\mathfrak{A}_5$
Blood Pressure	$\mathfrak{A}_6$
Bad Habits	$\mathfrak{A}_7$
Genetic Predisposition	$\mathfrak{A}_8$
Age	$\mathfrak{A}_9$
Unhealthy Food	$\mathfrak{A}_{10}$

Table 4: Linguistic variables

Linguistic terms	**Notations**	**Triangular Membership numbers**
Very Low	$\mathfrak{VL}$	(0,0,0.10)
Low	$\mathfrak{L}$	(0,0.10,0.30)
Medium Low	$\mathfrak{ML}$	(0.10,0.30,0.50)
Medium	$\mathfrak{M}$	(0.30,0.50,0.70)
Medium-High	$\mathfrak{MI}$	(0.50,0.70,0.90)
High	$\mathfrak{H}$	(0.70,0.90,1.0)
Very High	$\mathfrak{VH}$	(0.90,1.0,1.0)

Table 5: Stages of Type -2 Diabetes

Criteria	**Notation**
Normal (Molecular)	$\mathfrak{C}_1$
Borderline Diabetes (Bio-Chemical Cardio-Metabolic Risk)	$\mathfrak{C}_2$
Early Diabetes (Bio-Chemical Disease)	$\mathfrak{C}_3$
Late Diabetes (Vascular Complications)	$\mathfrak{C}_4$

Table 5 and Figure 2 explaining as the situations of type-2 diabetes patients.

Table 4 provides the details about the triangular membership values of linguistic variables.

By the Table 6 class description values are presented to find the permanent of each alternative.

Table 6: Variance of importance

Class description	$\mathfrak{a}_{ij}$	$\mathfrak{a}_{ji} = 1 - \mathfrak{a}_{ij}$
Both stages having equal importance	0.5	0.5
A stage has marginally more importance than other stages	0.6	0.4
A stage is actively having more importance than other stages	0.7	0.3
A stage is very strongly having more importance over other stages	0.8	0.2
A stage is having an extreme level of importance over other stages	0.9	0.1
A stage is exceptionally having an importance over other stages	1.0	0.0

Table 7, 8 and Table 9 are referred to as the opinions of decision-makers. Table 10 is the weighted values collected by decision-makers.

Table 7: First expert opinion about type-2 diabetes

Alternatives	$\mathfrak{C}_1$	$\mathfrak{C}_2$	$\mathfrak{C}_3$	$\mathfrak{C}_4$
$\mathfrak{A}_1$	$\mathfrak{ML}$	$\mathfrak{ML}$	$\mathfrak{M}$	$\mathfrak{M}$
$\mathfrak{A}_2$	$\mathfrak{MI}$	$\mathfrak{H}$	$\mathfrak{H}$	$\mathfrak{VH}$
$\mathfrak{A}_3$	$\mathfrak{M}$	$\mathfrak{M}$	$\mathfrak{M}$	$\mathfrak{MI}$
$\mathfrak{A}_4$	$\mathfrak{ML}$	$\mathfrak{M}$	$\mathfrak{M}$	$\mathfrak{MI}$
$\mathfrak{A}_5$	$\mathfrak{ML}$	$\mathfrak{M}$	$\mathfrak{M}$	$\mathfrak{MI}$
$\mathfrak{A}_6$	$\mathfrak{L}$	$\mathfrak{ML}$	$\mathfrak{M}$	$\mathfrak{M}$
$\mathfrak{A}_7$	$\mathfrak{M}$	$\mathfrak{M}$	$\mathfrak{MI}$	$\mathfrak{MI}$
$\mathfrak{A}_8$	$\mathfrak{ML}$	$\mathfrak{M}$	$\mathfrak{M}$	$\mathfrak{M}$
$\mathfrak{A}_9$	$\mathfrak{M}$	$\mathfrak{M}$	$\mathfrak{MI}$	$\mathfrak{M}$
$\mathfrak{A}_{10}$	$\mathfrak{ML}$	$\mathfrak{M}$	$\mathfrak{M}$	$\mathfrak{MI}$

Table 8: Second expert opinion about type-2 diabetes

Alternatives	$\mathfrak{C}_1$	$\mathfrak{C}_2$	$\mathfrak{C}_3$	$\mathfrak{C}_4$
$\mathfrak{A}_1$	$\mathfrak{L}$	$\mathfrak{ML}$	$\mathfrak{VL}$	$\mathfrak{ML}$
$\mathfrak{A}_2$	$\mathfrak{VL}$	$\mathfrak{H}$	$\mathfrak{L}$	$\mathfrak{ML}$
$\mathfrak{A}_3$	$\mathfrak{VL}$	$\mathfrak{L}$	$\mathfrak{H}$	$\mathfrak{ML}$
$\mathfrak{A}_4$	$\mathfrak{L}$	$\mathfrak{L}$	$\mathfrak{ML}$	$\mathfrak{L}$
$\mathfrak{A}_5$	$\mathfrak{VL}$	$\mathfrak{ML}$	$\mathfrak{H}$	$\mathfrak{L}$
$\mathfrak{A}_6$	$\mathfrak{ML}$	$\mathfrak{M}$	$\mathfrak{VL}$	$\mathfrak{L}$
$\mathfrak{A}_7$	$\mathfrak{L}$	$\mathfrak{ML}$	$\mathfrak{H}$	$\mathfrak{L}$

$\mathfrak{A}_8$	$\mathfrak{VL}$	$\mathfrak{ML}$	$\mathfrak{ML}$	$\mathfrak{L}$
$\mathfrak{A}_9$	$\mathfrak{VL}$	$\mathfrak{M}$	$\mathfrak{ML}$	$\mathfrak{L}$
$\mathfrak{A}_{10}$	$\mathfrak{VL}$	$\mathfrak{ML}$	$\mathfrak{M}$	$\mathfrak{VL}$

Table 9: Third expert opinion about type-2 diabetes

Alternatives	$\mathfrak{C}_1$	$\mathfrak{C}_2$	$\mathfrak{C}_3$	$\mathfrak{C}_4$
$\mathfrak{A}_1$	$\mathfrak{L}$	$\mathfrak{ML}$	$\mathfrak{M}$	$\mathfrak{H}$
$\mathfrak{A}_2$	$\mathfrak{ML}$	$\mathfrak{M}$	$\mathfrak{MI}$	$\mathfrak{H}$
$\mathfrak{A}_3$	$\mathfrak{M}$	$\mathfrak{M}$	$\mathfrak{MI}$	$\mathfrak{H}$
$\mathfrak{A}_4$	$\mathfrak{L}$	$\mathfrak{ML}$	$\mathfrak{M}$	$\mathfrak{MI}$
$\mathfrak{A}_5$	$\mathfrak{MI}$	$\mathfrak{MI}$	$\mathfrak{H}$	$\mathfrak{H}$
$\mathfrak{A}_6$	$\mathfrak{M}$	$\mathfrak{M}$	$\mathfrak{M}$	$\mathfrak{M}$
$\mathfrak{A}_7$	$\mathfrak{M}$	$\mathfrak{MI}$	$\mathfrak{MI}$	$\mathfrak{H}$
$\mathfrak{A}_8$	$\mathfrak{M}$	$\mathfrak{M}$	$\mathfrak{M}$	$\mathfrak{M}$
$\mathfrak{A}_9$	$\mathfrak{MI}$	$\mathfrak{H}$	$\mathfrak{H}$	$\mathfrak{H}$
$\mathfrak{A}_{10}$	$\mathfrak{M}$	$\mathfrak{MI}$	$\mathfrak{MI}$	$\mathfrak{H}$

Table 10: Opinion of the decision-makers on cr

Decision makers	$\mathfrak{C}_1$	$\mathfrak{C}_2$	$\mathfrak{C}_3$	$\mathfrak{C}_4$
DM_1	$\mathfrak{ML}$	$\mathfrak{M}$	$\mathfrak{M}$	$\mathfrak{MI}$
DM_2	$\mathfrak{L}$	$\mathfrak{L}$	$\mathfrak{L}$	$\mathfrak{M}$
DM_3	$\mathfrak{M}$	$\mathfrak{M}$	$\mathfrak{M}$	$\mathfrak{M}$

Table 11: Weighted value for each criteria

$\mathfrak{w}_i$	0.200	0.250	0.250	0.300

Table 12 referred as the average of decision-makers opinions by utilizing the CFCS algorithm.

Table 12: Aggregated Triangular Fuzzy Matrix

Alternatives	$\mathfrak{C}_1$	$\mathfrak{C}_2$	$\mathfrak{C}_3$	$\mathfrak{C}_4$
$\mathfrak{A}_1$	(0,0.167,0.50)	(0.10,0.30,0.50)	(0,0.333,0.70)	(0.10,0.567,1)
$\mathfrak{A}_2$	(0,0.333,0.90)	(0.30,0.633,1.0)	(0,0.567,1.0)	(0.10,0.733,1.0)
$\mathfrak{A}_3$	(0,0.333,0.70)	(0,0.367,0.70)	(0.30,0.70,1.0)	(0.10,0.633,1.0)
$\mathfrak{A}_4$	(0,0.167,0.50)	(0,0.30,0.70)	(0.10,0.433,0.70)	(0,0.50,0.90)
$\mathfrak{A}_5$	(0,0.333,0.90)	(0.10,0.50,0.90)	(0.30,0.633,1.0)	(0,0.50,1.0)
$\mathfrak{A}_6$	(0,0.30,0.70)	(0.10,0.433,0.70)	(0,0.333,0.70)	(0,0.367,0.70)
$\mathfrak{A}_7$	(0,0.367,0.70)	(0.10,0.50,0.90)	(0.30,0.633,0.90)	(0,0.567,1.0)

$\mathfrak{A}_8$	(0,0.267,0.70)	(0.10,0.433,0.70)	(0.10,0.433,0.70)	(0,0.367,0.70)
$\mathfrak{A}_9$	(0,0.40,0.90)	(0.30,0.633,1.0)	(0.10,0.633,1.0)	(0.10,0.633,1.0)
$\mathfrak{A}_{10}$	(0,0.267,0.70)	(0.10,0.50,0.90)	(0.30,0.567,0.90)	(0,0.533,1.0)

Through Table 13, De-Fuzzified aggregated matrix is explained.

Table 13: De-Fuzzified Aggregated Matrix

Alternatives	$\mathfrak{C}_1$	$\mathfrak{C}_2$	$\mathfrak{C}_3$	$\mathfrak{C}_4$
$\mathfrak{A}_1$	(0,0.167,0.50)	(0.10,0.30,0.50)	(0,0.333,0.70)	(0.10,0.567,1)
$\mathfrak{A}_2$	(0,0.333,0.90)	(0.30,0.633,1.0)	(0,0.567,1.0)	(0.10,0.733,1.0)
$\mathfrak{A}_3$	(0,0.333,0.70)	(0,0.367,0.70)	(0.30,0.70,1.0)	(0.10,0.633,1.0)
$\mathfrak{A}_4$	(0,0.167,0.50)	(0,0.30,0.70)	(0.10,0.433,0.70)	(0,0.50,0.90)
$\mathfrak{A}_5$	(0,0.333,0.90)	(0.10,0.50,0.90)	(0.30,0.633,1.0)	(0,0.50,1.0)
$\mathfrak{A}_6$	(0,0.30,0.70)	(0.10,0.433,0.70)	(0,0.333,0.70)	(0,0.367,0.70)
$\mathfrak{A}_7$	(0,0.367,0.70)	(0.10,0.50,0.90)	(0.30,0.633,0.90)	(0,0.567,1.0)
$\mathfrak{A}_8$	(0,0.267,0.70)	(0.10,0.433,0.70)	(0.10,0.433,0.70)	(0,0.367,0.70)
$\mathfrak{A}_9$	(0,0.40,0.90)	(0.30,0.633,1.0)	(0.10,0.633,1.0)	(0.10,0.633,1.0)
$\mathfrak{A}_{10}$	(0,0.267,0.70)	(0.10,0.50,0.90)	(0.30,0.567,0.90)	(0,0.533,1.0)

Through Table 14, the normalised matrix is shown.

Table 14: Normalised Matrix

Alternatives	$\mathfrak{C}_1$	$\mathfrak{C}_2$	$\mathfrak{C}_3$	$\mathfrak{C}_4$
$\mathfrak{A}_1$	0.502	0.494	0.955	0.652
$\mathfrak{A}_2$	0.913	1	0.633	0.555
$\mathfrak{A}_3$	0.836	0.6	0.513	0.611
$\mathfrak{A}_4$	0.502	0.531	0.804	0.774
$\mathfrak{A}_5$	0.913	0.8	0.544	0.72
$\mathfrak{A}_6$	0.758	0.659	1	1
$\mathfrak{A}_7$	0.88	0.8	0.557	0.67
$\mathfrak{A}_8$	0.711	0.659	0.825	1
$\mathfrak{A}_9$	1	1	0.577	0.626
$\mathfrak{A}_{10}$	0.741	0.800	0.593	0.693

Table **15** is the general permanent matrix form of the whole criterion matrix form.

Through the Figure 2, the level of each criterion was estimated.

The permanent value of alternative $\mathfrak{A}_1$ is 1.29177.

The permanent value of alternative $\mathfrak{A}_2$, and the value is 1.71166. The permanent value of $\mathfrak{A}_3$ is 1.26622.

The permanent value is 1.33107.

The permanent value of alternative $\mathfrak{A}_5$ is 1.62443.

The permanent value of $\mathfrak{A}_6$ is 2.10706. The permanent value of alternative $\mathfrak{A}_7$ is 1.56112.

The permanent value of alternative $\mathfrak{A}_8$ 1.87452. The permanent value of $\mathfrak{A}_9$ is 1.81364.

The permanent value of $\mathfrak{A}_{10}$ is 1.51379. By all the permanent of alternative values, we can estimate the higher values and can give the ranks. Table 15 explains the ranks of alternatives we got from the GTMA technique.

Table: 15 Rank of each alternative

Alternatives	**permanent of $[\mathfrak{A}_{ij}]$**	**Rank**
$\mathfrak{A}_1$	1.29177	9
$\mathfrak{A}_2$	1.71166	4
$\mathfrak{A}_3$	1.26622	10
$\mathfrak{A}_4$	1.33107	8
$\mathfrak{A}_5$	1.62443	5
$\mathfrak{A}_6$	2.10706	1
$\mathfrak{A}_7$	1.56112	6
$\mathfrak{A}_8$	1.87452	2
$\mathfrak{A}_9$	1.81364	3
$\mathfrak{A}_{10}$	1.51379	7

Table 16, started the PROMETHEE-II technique by finding aggregated preferences of each alternative. And, in the next table 17 the final column is the sum of each row.

Table 16: Aggregated Preferences

$\mathfrak{A}_{ij}$	$\mathfrak{A}_1$	$\mathfrak{A}_2$	$\mathfrak{A}_3$	$\mathfrak{A}_4$	$\mathfrak{A}_5$	$\mathfrak{A}_6$	$\mathfrak{A}_7$	$\mathfrak{A}_8$	$\mathfrak{A}_9$	$\mathfrak{A}_{10}$
$\mathfrak{A}_1$	-	0.1096	0.1228	0.0375	0.1027	0	0.0995	0.0325	0.1023	0.0905
$\mathfrak{A}_2$	0.2087	-	0.1454	0.1994	0.0722	0.1162	0.0756	0.1256	0.0140	0.0944
$\mathfrak{A}_3$	0.0933	0.0168	-	0.0840	0	0.0156	0	0.0272	0	0.0190
$\mathfrak{A}_4$	0.0458	0.1084	0.1216	-	0.0812	0	0.0929	0	0.1011	0.0243
$\mathfrak{A}_5$	0.1791	0.0495	0.1056	0.1494	-	0.0662	0.0216	0.0756	0.0282	0.0425
$\mathfrak{A}_6$	0.2081	0.2252	0.2532	0.2000	0.198	-	0.2097	0.1377	0.2179	0.1972
$\mathfrak{A}_7$	0.1575	0.0345	0.1667	0.1428	0.0032	0.0596	-	0.0690	0.0132	0.0278
$\mathfrak{A}_8$	0.1874	0.1815	0.2262	0.1468	0.1542	0	0.1660	-	0.1742	0.1501
$\mathfrak{A}_9$	0.2261	0.0387	0.1533	0.2168	0.0756	0.1336	0.3400	0.1430	-	0.1018
$\mathfrak{A}_{10}$	0.1366	0.0414	0.0946	0.1678	0.0122	0.0352	0.0159	0.0412	0.0241	-

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Table 17: Aggregated Preferences-Sum

$\mathfrak{A}_{ij}$	$\mathfrak{A}_1$	$\mathfrak{A}_2$	$\mathfrak{A}_3$	$\mathfrak{A}_4$	$\mathfrak{A}_5$	$\mathfrak{A}_6$	$\mathfrak{A}_7$	$\mathfrak{A}_8$	$\mathfrak{A}_9$	$\mathfrak{A}_{10}$	Sum
$\mathfrak{A}_1$	-	0.1096	0.1228	0.0375	0.10275	0	0.0995	0.0325	0.1023	0.0905	0.6975
$\mathfrak{A}_2$	0.2087	-	0.1454	0.19945	0.07225	0.11625	0.0756	0.12565	0.014	0.0944	1.0517
$\mathfrak{A}_3$	0.0933	0.0168	-	0.08405	0	0.0156	0	0.0272	0	0.019	0.2559
$\mathfrak{A}_4$	0.04585	0.10845	0.12165	-	0.0812	0	0.09295	0	0.10115	0.0243	0.5755
$\mathfrak{A}_5$	0.1791	0.0495	0.1056	0.14945	-	0.06625	0.0216	0.07565	0.0282	0.0425	0.7178
$\mathfrak{A}_6$	0.2081	0.22525	0.2532	0.2	0.198	-	0.20975	0.13775	0.21795	0.1972	1.8472
$\mathfrak{A}_7$	0.1575	0.0345	0.1667	0.14285	0.00325	0.05965	-	0.06905	0.0132	0.0278	0.6745
$\mathfrak{A}_8$	0.18745	0.1815	0.22625	0.14685	0.15425	0	0.166	-	0.1742	0.1501	1.3866
$\mathfrak{A}_9$	0.2261	0.0387	0.1533	0.21685	0.07565	0.13365	0.34	0.14305	-	0.1018	1.4291
$\mathfrak{A}_{10}$	0.1366	0.0414	0.0946	0.1678	0.01225	0.03525	0.0159	0.04125	0.0241	-	0.5691

Table 18 is the final table of PROMETHEE-II technique. In this table leaving (positive) flow and entering (negative) flow is calculated to make the ranking values.

Table 18: Finding the value of ϕ(a)

Alternatives	Positive flow	Negative flow	ϕ(a)	Rank
$\mathfrak{A}_1$	0.69745	1.4427	-0.72525	8
$\mathfrak{A}_2$	1.0517	0.8057	0.246	4
$\mathfrak{A}_3$	0.2559	1.3895	-1.13355	10
$\mathfrak{A}_4$	0.5755	1.3448	-0.76925	9
$\mathfrak{A}_5$	0.7178	0.6996	0.01825	5
$\mathfrak{A}_6$	1.8472	0.42665	1.4206	1
$\mathfrak{A}_7$	0.6745	1.0213	-0.3468	7
$\mathfrak{A}_8$	1.3866	0.6521	0.7345	3
$\mathfrak{A}_9$	1.4291	0.6751	0.754	2
$\mathfrak{A}_{10}$	0.5691	0.74765	-0.1785	6

Table 19: Comparison of rankings

Alternatives	GTMA	PROMETHEE-II
$\mathfrak{A}_1$	8	9
$\mathfrak{A}_2$	4	4
$\mathfrak{A}_3$	10	10
$\mathfrak{A}_4$	9	8
$\mathfrak{A}_5$	5	5

$\mathfrak{A}_6$	1	1
$\mathfrak{A}_7$	7	6
$\mathfrak{A}_8$	3	2
$\mathfrak{A}_9$	2	3
$\mathfrak{A}_{10}$	6	7

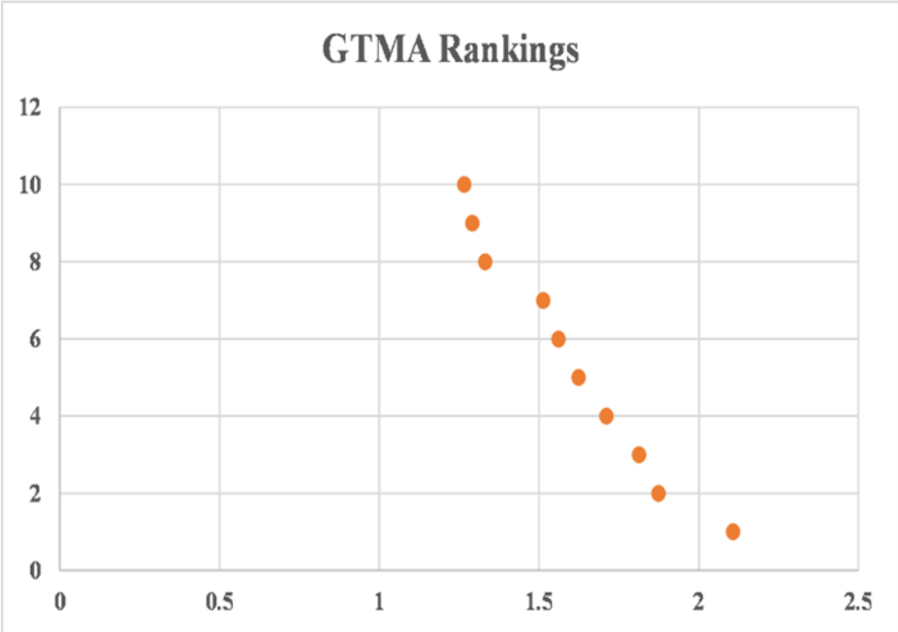

Figure 4: GTMA Rankings

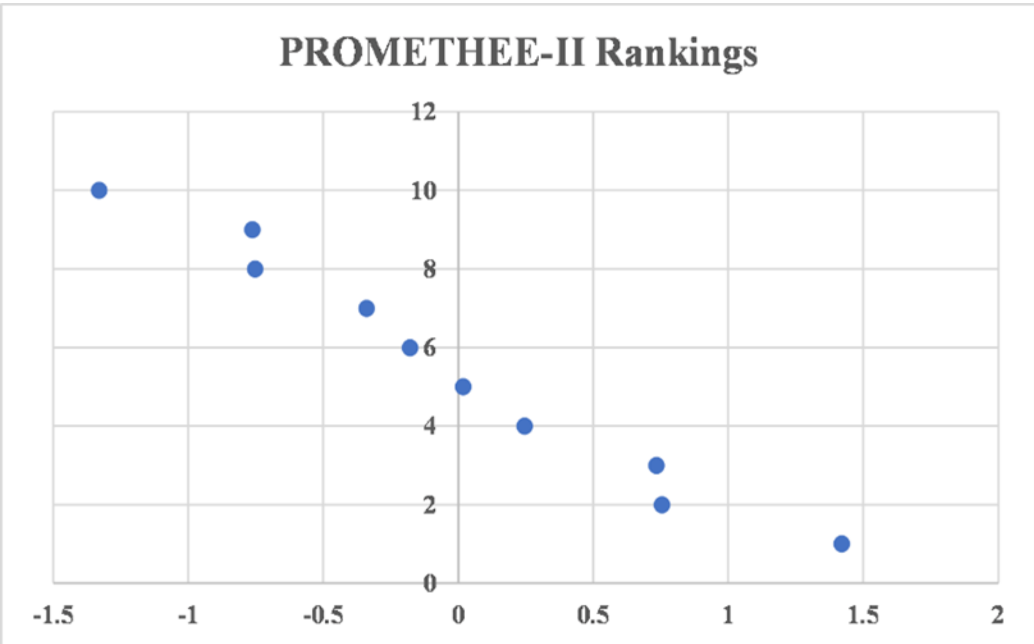

Figure 5: PROMETHEE-II Rankings

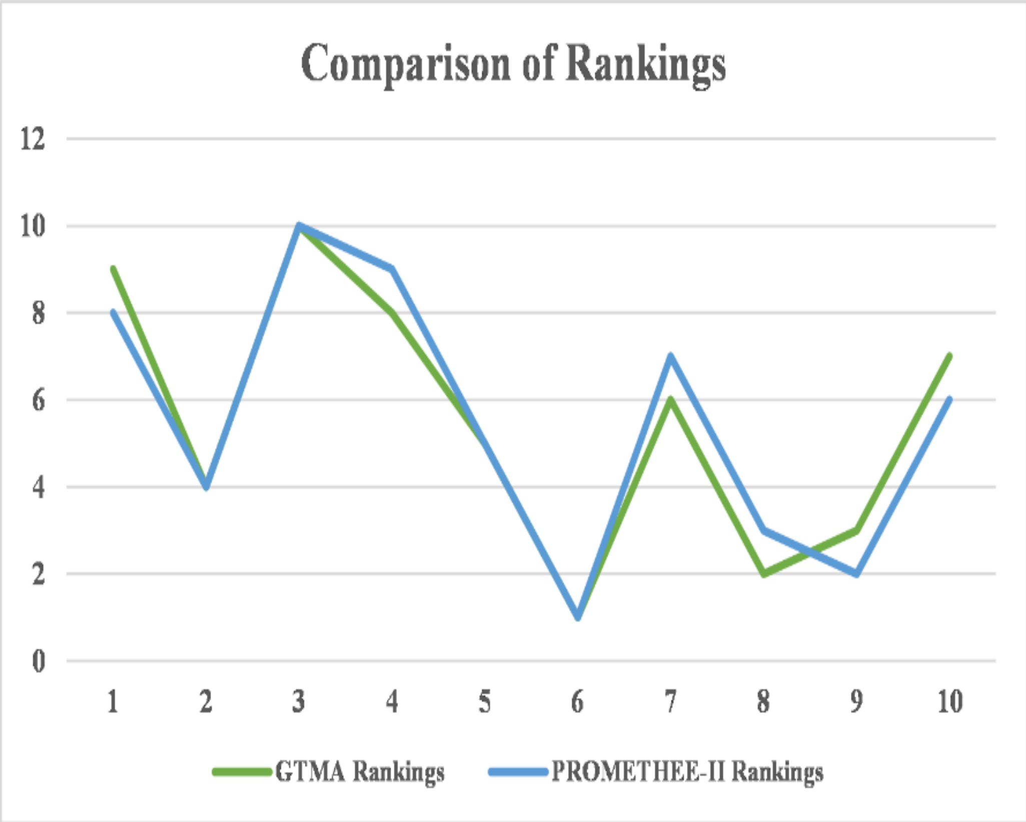

Figure 6: Comparison of Rankings

7 Results and Discussion

With the aim of this technique, the issue of type-2 diabetes was illustrated by the hybrid technique GTMA and PROMETHEE II method. Figure 4 and 5 illustrate the rankings of each risk factor according to their importance, as determined by the GTMA and PROMETHEE-II methods. These figures highlight the relative significance of each risk factor, providing a comprehensive assessment of their impact based on the analysis con- ducted. Every risk factor is connected with the stages of the disease. The judgment of decision makers is taken as linguistic terms and it is converted as a triangular fuzzy number. By utilizing the CFCS algorithm, defuzzied the triangular values. Joined fuzzy matrix got by the hybrid technique. The results of both GTMA and PROMETHEE II methods and their comparative study are shown in Table 19 and in Figure 6. The ranking of both GTMA ($\mathfrak{A}_6$) and PROMETHEE-II ($\mathfrak{A}_6$) methods produces the first rank for blood pressure. Because Blood Pressure is considered to be the best host for type-2 Diabetes. Almost 6 risk factors got the same ranking by the hybrid technique and the remaining risk factors got slightly different values. The joined GTMA and PROMETHEE-II techniques covered a path to apply the particular structure from experts.

7.1 Sensitivity Analysis

To ensure the robustness and reliability of the results obtained in the diagnosis of Type-2 Diabetes using MCDM techniques, a sensitivity analysis was conducted. This analysis evaluates the influence of variations in key parameters on the ranking of risk factors. In this work, the parameter a was systematically adjusted with value $\mathfrak{a} = 1, \mathfrak{a} = 2, \mathfrak{a} = 5$, and $\mathfrak{a} = 100$.

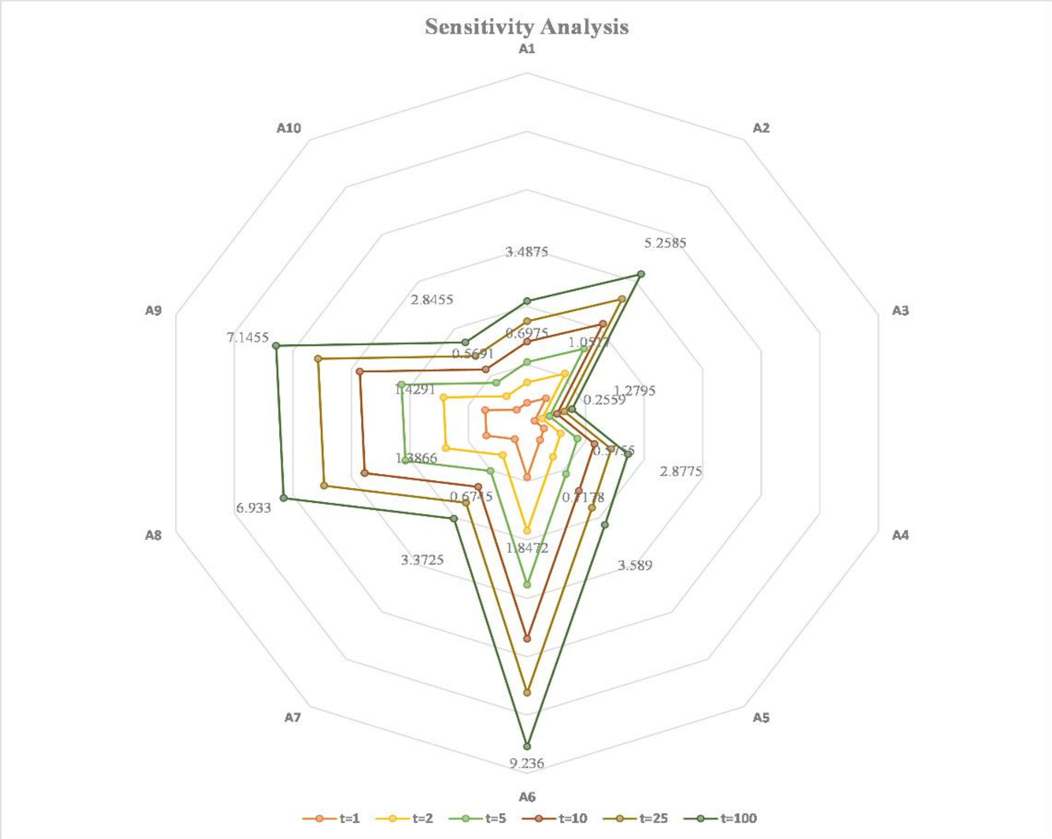

Figure 7: Sensitivity Analysis

The sensitivity of the diagnostic outcomes was assessed through the application of the PROMETHEE and GTMA methods, focusing on the stability and consistency of the rankings across these parameter variations. By testing these values, the analysis aims to identify any significant deviations in the prioritization of risk factors, ensuring the decision-making model's robustness against parameter shifts.

8 Conclusion

This study concludes with the identification of the most significant risk factors for type-2 diabetes, as determined through the application of GTMA and PROMETHEE-II methods. The hybrid technique effectively analyzed and ranked these risk factors, offering valuable insights into their relative importance. By integrating both GTMA's robustness analysis and PROMETHEE-II's multi-criteria decision-making approach, the study provides a nuanced understanding of how different risk factors contribute to the likelihood of developing type-2 diabetes. This dual-method approach enhances the precision of risk assessments and helps prioritize interventions based on their impact. Consequently, the findings offer a clearer picture of how various risk factors should be addressed in patient management and preventive strategies, ensuring that the most critical factors are given appropriate attention in clinical and public health settings.

References

[1] Sagheer Abbas, M Saleem Khan, Khalil Ahmed, M Abdullah, and Umer Farooq. Bio-inspired neuro-fuzzy based dynamic route selection to avoid traffic congestion. *International Journal of Scientific and Engineering Research*, 2(6):284–289, 2011.

[2] Ehtasham Ahmad, Soo Lim, Roberta Lamptey, David R Webb, and Melanie J Davies. Type 2 diabetes. *The Lancet*, 400(10365):1803–1820, 2022.

[3] Iman Ajripour. Applying mcdm technique in analyzing the effect of promotion items based on online shopping factors: A case study. *Proceedings of the European Union's Contention in the Reshaping Global Economy*, pages 9–27, 2020.

[4] AH Alamoodi, Omar Zughoul, Dianese David, Salem Garfan, Dragan Pamucar, OS Albahri, AS Albahri, Salman Yussof, and Iman Mohamad Sharaf. A novel evaluation framework for medical llms: Combining fuzzy logic and mcdm for medical relation and clinical concept extraction. *Journal of Medical Systems*, 48(1):1–12, 2024.

[5] Ahmed M Ali, Ahmed Abdelhafeez, Tamer HM Soliman, and Khaled ELMenshawy. A probabilistic hesitant fuzzy mcdm approach to selecting treatment policy for covid-19. *Decision Making: Applications in Management and Engineering*, 7(1):131–144, 2024.

[6] Edris Ardeshirlarijani, Ozra Tabatabaei-Malazy, Shahrzad Mohseni, Mostafa Qorbani, Bagher Larijani, and Reza Baradar Jalili. Effect of probiotics supplementation on glucose and oxidative stress in type 2 diabetes mellitus: A meta-analysis of randomized trials. *DARU Journal of Pharmaceutical Sciences*, 27:827–837, 2019.

[7] Mouhamed Bayane Bouraima, Stefan Jovˇci´c, Momˇcilo Dobrodolac, Dragan Pamucar, Ibrahim Badi, and Naibei Dan Maraka. Sustainable healthcare system devolution strategy selection using the aroman mcdm approach. *Spectrum of Decision Making and Applications*, 1(1):46–63, 2024.

[8] Jean-Pierre Brans and Yves De Smet. Promethee methods. *Multiple criteria decision analysis: state of the art surveys*, pages 187–219, 2016.

[9] Jean-Pierre Brans and Ph Vincke. Note—a preference ranking organisation method: (the promethee method for multiple criteria decision-making). *Management science*, 31(6):647–656, 1985.

[10] Jean-Pierre Brans, Ph Vincke, and Bertrand Mareschal. How to select and how to rank projects: The promethee method. *European journal of operational research*, 24(2):228–238, 1986.

[11] Selmin Burak, Funda Samanlioglu, and Duygu Ulker. Evaluation of irrigation methods in stoke plain with hf-ahp-promethee ii hybrid mcdm method. *Agricultural Water Management*, 271:107810, 2022.

[12] Hatice Camgoz Akdag, Akin Menekse, and Fatih Sahin. Cervical cancer risk assessment using machine learning integrated fuzzy mcdm methodology. *Journal of Intelligent & Fuzzy Systems*, (Preprint):1–20, 2024.

[13] Santonab Chakraborty and Shankar Chakraborty. A scoping review on the applications of mcdm techniques for parametric optimization of machining processes. *Archives of Computational Methods in Engineering*, 29(6):4165–4186, 2022.

[14] Ching-Ter Chang, Wen-Xuan Zhao, and Jeyhun Hajiyev. An integrated smartphone and tariff plan selection for taxi service operators: Mcdm and rstudio approach. *IEEE Access*, 7:31457–31472, 2019.

[15] Long Cheng, Jingkang Wang, Hongyu Dai, Yuhui Duan, Yongcheng An, Lu Shi, Yinglan Lv, Huimin Li, Chen Wang, Quantao Ma, et al. Brown and beige adipose tissue: a novel therapeutic strategy for obesity and type 2 diabetes mellitus. *Adipocyte*, 10(1):48–65, 2021.

[16] Martina Chiriaco, Konstantinos Pateras, Agostino Virdis, Marietta Charakida, Despoina Kyriakopoulou, Monica Nannipieri, Michele Emdin, Konstantinos Tsioufis, Stefano Taddei, Stefano Masi, et al. Association between blood pressure variability, cardiovascular disease and mortality in type 2 diabetes: a systematic review and meta-analysis. *Diabetes, Obesity and Metabolism*, 21(12):2587–2598, 2019.

[17] You-jung Choi, Kyung-Do Han, Eue-Keun Choi, Jin-Hyeung Jung, So-Ryoung Lee, Seil Oh, and Gregory YH Lip. Alcohol abstinence and the risk of atrial fibrillation in patients with newly diagnosed type 2 diabetes mellitus: a nationwide populationbased study. *Diabetes Care*, 44(6):1393–1401, 2021.

[18] Utpala Nanda Chowdhury, M Babul Islam, Shamim Ahmad, and Mohammad Ali Moni. Network-based identification of genetic factors in ageing, lifestyle and type 2 diabetes that influence to the progression of alzheimer's disease. *Informatics in Medicine Unlocked*, 19:100309, 2020.

[19] Ralph A DeFronzo, Ele Ferrannini, Leif Groop, Robert R Henry, William H Herman, Jens Juul Holst, Frank B Hu, C Ronald Kahn, Itamar Raz, Gerald I Shulman, et al. Type 2 diabetes mellitus. *Nature reviews Disease primers*, 1(1):1–22, 2015.

[20] Jiang Deng, Jianming Zhan, and Wei-Zhi Wu. A ranking method with a preference relation based on the promethee method in incomplete multi-scale information systems. *Information Sciences*, 608:1261–1282, 2022.

[21] Morteza Ebrahimi and Khatereh Ahmadi. Diabetes-related complications severity analysis based on hybrid fuzzy multi-criteria decision-making approaches. *Frontiers in Health Informatics*, 6(1):11–22, 2017.

[22] Maryam Eghbali-Zarch, Reza Tavakkoli-Moghaddam, Fatemeh Esfahanian, and Sara Masoud. Prioritizing the glucose-lowering medicines for type 2 diabetes by an extended fuzzy decision-making approach with target-based attributes. *Medical & Biological Engineering & Computing*, 60(8):2423–2444, 2022.

[23] Kamaldeep Gupta, Sharmistha Roy, Ramesh Chandra Poonia, Raghvendra Kumar, Soumya Ranjan Nayak, Ayman Altameem, and Abdul Khader Jilani Saudagar. Multi-criteria usability evaluation of mhealth applications on type 2 diabetes mellitus using two hybrid mcdm models: Codas-fahp and moora-fahp. *Applied Sciences*, 12(9):4156, 2022.

[24] Joon Ha and Arthur Sherman. Type 2 diabetes: one disease, many pathways. *American Journal of Physiology-Endocrinology and Metabolism*, 319(2):E410–E426, 2020.

[25] Shahad Sabbar Joudar, AS Albahri, and Rula A Hamid. Intelligent triage method for early diagnosis autism spectrum disorder (asd) based on integrated fuzzy multicriteria decision-making methods. *Informatics in Medicine Unlocked*, 36:101131, 2023.

[26] Calvin Ke, KM Venkat Narayan, Juliana CN Chan, Prabhat Jha, and Baiju R Shah. Pathophysiology, phenotypes and management of type 2 diabetes mellitus in indian and chinese populations. *Nature Reviews Endocrinology*, 18(7):413–432, 2022.

[27] Ajay Kumar and Kamaldeep Kaur. A novel mcdm-based framework to recommend machine learning techniques for diabetes prediction. *International Journal of Engineering & Technology Innovation*, 14(1), 2024.

[28] Sarantis Livadas, Panagiotis Anagnostis, Julia K Bosdou, Dimitra Bantouna, and Rodis Paparodis. Polycystic ovary syndrome and type 2 diabetes mellitus: A stateof-the-art review. *World journal of diabetes*, 13(1):5, 2022.

[29] Mahatab Uddin Molla, Bibhas C Giri, and Pranab Biswas. Extended promethee method with pythagorean fuzzy sets for medical diagnosis problems. *Soft Computing*, 25:4503–4512, 2021.

[30] Qixing Nie, Haihong Chen, Jielun Hu, Songtao Fan, and Shaoping Nie. Dietary compounds and traditional chinese medicine ameliorate type 2 diabetes by modulating gut microbiota. *Critical Reviews in Food Science and Nutrition*, 59(6):848–863, 2019.

[31] Oluwafemi Omoniyi Oguntibeju. Type 2 diabetes mellitus, oxidative stress and inflammation: examining the links. *International journal of physiology, pathophysiology and pharmacology*, 11(3):45, 2019.

[32] Maede Parishani and Morteza Rasti-Barzoki. Cwbcm method to determine the importance of classification performance evaluation criteria in machine learning: Case studies of covid-19, diabetes, and thyroid disease. *Omega*, 127:103096, 2024.

[33] Witold Pedrycz. Why triangular membership functions? *Fuzzy sets and Systems*, 64(1):21–30, 1994.

[34] Rajendra Pradeepa and Viswanathan Mohan. Epidemiology of type 2 diabetes in india. *Indian journal of ophthalmology*, 69(11):2932, 2021.

[35] Attri Rajesh, Dev Nikhil, and Sharma Vivek. Graph theoretic approach (gta)–a multi-attribute decision making (madm) technique. *Research Journal of Engineering Sciences,ISSN*, 2278:9472, 2013.

[36] R Venkata Rao. A material selection model using graph theory and matrix approach. *Materials Science and Engineering: A*, 431(1-2):248–255, 2006.

[37] R Venkata Rao. *Decision making in the manufacturing environment: using graph theory and fuzzy multiple attribute decision making methods*, volume 2. Springer, 2007.

[38] Sathesh, A. L. E., Rajalakshmi, R., Kavitha, T., Prathima, C., & Anitha, G. Novel Methodology to Predict and Classify Liver Diseases Based on Hybrid Deep Learning Strategy. In Deep Learning in Biomedical Signal and Medical Imaging (pp. 129-149). CRC Press.

[39] Sasirekha, D., Kalpana, D. P., Nancy, W., Valarmathi, K., & Anitha, G. (2024). Robust Learning Principle Design to Detect Diabetic Retinopathy Disease in Early Stages with Skilled Feature Extraction Policy. In Deep Learning in Biomedical Signal and Medical Imaging (pp. 55-72). CRC Press.

[40] Rani, A. J. M., Srivenkateswaran, C., Rajasekar, M., & Arun, M. (2023). Fuzzy C-means clustering on rainfall flow optimization technique for medical data. IAES International Journal of Artificial Intelligence, 12(1), 180.

[41] M Sheela Rani and S Dhanasekar. Fuzzy mcdm techniques for analysing the risk factors of covid-19 and flu. In *International Conference on Mathematics and Computing*, pages 159–175. Springer, 2024.

[42] Mahmoud M Sirdah and N Scott Reading. Genetic predisposition in type 2 diabetes: a promising approach toward a personalized management of diabetes. *Clinical Genetics*, 98(6):525–547, 2020.

[43] Nanny Natalia M Soetedjo, Maria Riastuti Iryaningrum, Sherly Lawrensia, and Hikmat Permana. Antibody response following sars-cov-2 vaccination among patients with type 2 diabetes mellitus: a systematic review. *Diabetes & Metabolic Syndrome: Clinical Research & Reviews*, page 102406, 2022.

[44] Carolina Solis-Herrera, Curtis Triplitt, Eugenio Cersosimo, and Ralph A DeFronzo. Pathogenesis of type 2 diabetes mellitus. *Endotext [Internet]*, 2021.

[45] Sopida Thipsawat. Early detection of diabetic nephropathy in patient with type 2 diabetes mellitus: A review of the literature. *Diabetes and Vascular Disease Research*, 18(6):14791641211058856, 2021.

[46] Temel Tirkes, Christie Y Jeon, Liang Li, Aron Y Joon, Ted A Seltman, Meghana Sankar, Scott A Persohn, and Paul R Territo. Association of pancreatic steatosis with chronic pancreatitis, obesity, and type 2 diabetes mellitus. *Pancreas*, 48(3):420, 2019.

[47] Danijela Tuljak-Suban and Patricija Bajec. Integration of ahp and gtma to make a reliable decision in complex decision-making problems: Application of the logistics provider selection problem as a case study. *Symmetry*, 12(5):766, 2020.

[48] Dharmeshwaraan, K., Saravanan, L., Sharmila, P., Krishnan, R., & Anitha, G. (2023, January). An Energy-Efficient Cluster Routing Protocol for Wireless Networks Based on Blended Optimization Technique. In 2023 International Conference on Artificial Intelligence and Knowledge Discovery in Concurrent Engineering (ICECONF) (pp. 1-9). IEEE.

[49] Rajasekar, M., Mukil, A., & Lakshamanan, R. (2024, August). Segmentation and evaluation of multiple sclerosis in flair modality MRI with ResUNet. In AIP Conference Proceedings (Vol. 3161, No. 1). AIP Publishing.

[50] Saijun Zhou, YuLing Zhang, TongDan Wang, Shuai Huang, Siyi Gong, Junmei Wang, and Pei Yu. Canagliflozin could improve the levels of renal oxygenation in newly diagnosed type 2 diabetes patients with normal renal function. *Diabetes & Metabolism*, 47(5):101274,2021.