

## Evaluating Continuous Glucose Monitoring Apps For Type 1 Diabetes Through Fuzzy Mathematical Strategies

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### ABSTRACT

The advancement in continuous glucose monitoring (CGM) devices has greatly enhanced the management of type 1 diabetic (T1D), but there has been inadequate assessment of the CGM apps for use in CGM (i.e. Glimp, xDrip, Diabox, Shuggah, and Libre). This study intends to address that gap by assessing the usability, reliability, effectiveness and user satisfaction with CGM mobile applications for T1D using the Fuzzy Complex Proportional Assessment (F-COPRAS) tool based on the judgments of three healthcare experts. The research will not only identify the areas requiring improvement but it will also provide practical recommendations for developers on how to make the applications more effective for the purpose of self-management and improved health. The evaluation employed ten usability criteria using fuzzy linguistic variables represented through triangular fuzzy numbers. The multi criteria decision model (MCDM) COPRAS method takes into account beneficial and non-beneficial criteria and ranks and evaluates application by considering the user feedback and expert opinions by determining it on the basis of the criteria by using linguistic variables based on triangular fuzzy numbers. A comparative analysis of the applications indicates that there are major differences in their performance as well as usability and the presented data can be useful in making the right choices for developers, medical practitioners, and users. The research highlights areas that require improvement, including efficiency and data privacy to increase the effectiveness and usability of CGM mHealth apps. The conclusion proves that out of all the CGM apps, Glimp is the most effective one.

**Keywords:** Continuous Glucose Monitoring (Cgm), Cgm Apps, Type 1 Diabetes, Usability Evaluation, Fuzzy Complex Proportional Assessment (F-Copras)

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### Introduction:

Long standing and unchanging, T1D requires constant vigilant attention to maintain glucose levels and avoids acute and chronic complications like hypoglycemia, diabetic ketoacidosis, and cardiovascular disease. As an example, T1D is not easy to manage because patients require constant checking of their blood glucose levels and adjusting the dosage of their insulin and their diets, and their levels of physical activities. By giving people with diabetes

access to real-time, continuous glucose monitoring, Continuous Glucose Monitoring (CGM) technologies have transformed the treatment of the condition and enabled better overall disease management. A tiny sensor placed under the skin tracks glucose levels continuously, these systems gather glucose data and transmit real-time readings to receivers or cellphones. In order to present the data, track trends, create alerts for important occurrences (such low or high blood sugar), provide insightful analytics, and facilitate easy data sharing with caregivers or healthcare practitioners, mobile health (mHealth) applications serve as user interfaces that supplement CGM devices. Glimp, xDrip, Diabox, Shuggah, and Libre are known as major mHealth applications of continuous glucose monitoring (CGM) with different functionalities depending on the needs of the individuals with type 1 diabetes mellitus (T1D). These platforms help users to visualize the glucose metric in different modalities, give analytical insights into the temporal glycemic patterns, and help to make better therapeutic decisions.

While CGM technology is still evolving, the usability of the CGM applications is a key factor in the widespread adoption and long-term sustainability of the CGM. Given that decision-making is a frequent activity and can be time-sensitive (relating to real-time measurements of glucose), the usefulness of the tools is dependent on the ability of the users to interact with them effectively. Some of the positive attributes include; ability to provide accurate glucose readings, ease of use, flexibility to be tailored to meet the user's need, compatibility with many devices, ability to share information, capability in providing analytical data which can be useful in making sound decisions and relatively cheap.

It also added that good customer service will also enhance the usage and satisfaction of these applications. However, negative aspects such as high battery consumption, repeated connectivity issues, complex interfaces, and concerns regarding data safety and privacy can act as barriers to adoption and continued use. These issues often arise when the users face difficulties in the setup of the app, understanding of information provided or concern with misuse or breach of their personal health information. In other words, the positive features of CGM applications have to be maximized while the negative aspects have to be minimized for the application to be both clinically useful and easy to use. To meet the many needs of users of CGM apps whether patients, caregivers or medical personnel, addressing these issues and improving on the functionality, security, and design is a must.

This paper uses the Fuzzy Complex Proportional Assessment (COPRAS) approach to assess the

usability and user experience of continuous glucose monitoring (CGM) applications that will therefore cope with intrinsic uncertainties. The evaluation is developed by means of fuzzy logic, with a controlled indeterminacy which allows a more sophisticated definition of subjective dimensions such as user preferences and satisfaction. Weight values are assigned to the factors produced from systematic review and feedback process of users and experts with respect to accuracy, usability, adaptability, data transmission, compatibility, analytical capability and data privacy. By bringing together the positive and negative contributions, the approach provides accurate decisions relevant to all stakeholders (patients, healthcare providers, and software developers), while also suggesting future direction for the further development of CGM applications for patients with T1D.

This study addresses the complex evaluation problem by integrating an MCDM method, i.e., the fuzzy COPRAS method. The Fuzzy Complex Proportional Assessment method determines the relative weight of evaluation criteria based on expert judgments and user feedback even allowing for the uncertainty in the information provided. After weighting the criteria, COPRAS can rank the evaluated applications by the weighted criteria providing the users with an objective evaluation.

### **The primary objectives of this study are to:**

1. Develop a structured methodology of evaluating the usability of CGM apps that involves both positive and negative design aspects evaluation.
2. Use fuzzy logic to deal with subjective decision and uncertainty in usability test.
3. Give recommendations to developers and healthcare stakeholders on what they can do to make CGM applications more design-oriented and performant.

The paper is important in that it provides an elaborate assessment approach and viable analysis of the strengths and weaknesses of Glimp, xDrip, Diabox, Shuggah and Libre. The findings will be used to advise the users on the most appropriate application to use besides showing the areas to work on to improve user experience, functionality, and security.

In section 2 of this paper, an assessment of literature on CGM devices and other strategies of usability assessment is given. Section 3 outlines the Fuzzy COPRAS methodology. Section 4 details the evaluation criteria and data collection process. Section 5 displays the research analysis followed by presentation of obtained results. This paper ends with essential findings and future research recommendations in addition to implications.

### **Literature Review:**

This review looks at usability, effectiveness and user satisfaction of mobile health (mHealth) applications and digital tools in diabetes management with a focus on methodologies such as machine learning, fuzzy evaluation and user-centred, highlighting the key aspects of these

methods.

Nguyen et al. (2015) proposed fuzzy Analytic Hierarchy Process (AHP) and Complex Omission and Process Analysis System (COPRAS) model to solve the vagueness problem of evaluations in machine tool. Their methodology provides a framework for choosing the right tools for the manufacturing sector. Lanzola et al. (2016) was dedicated to the remote monitoring of blood glucose in the sense of integrating Continuous Glucose Monitoring (CGM) systems with telemedicine. They underlined issues of standardisation and real-time data exchange, which are key to helping patients.

Knight et al. (2016) assessed the Rapid Calc app for type 1 diabetes and showed both the benefits of the app to self-management and its limitations with respect to connectivity and data input. Lanzola et al. (2016) reinforced these findings by highlighting the importance of remote monitoring in individual treatment while highlighting ongoing problems of standardisation.

Zhou and Chan (2017) proposed a fuzzy evaluation method integrated with the Analytic Hierarchy Process (AHP) for evaluating the product usability, which allows the conversion of a subjective data set, enabling the conversion of subjective data to a precise usability index. Vettoretti et al (2018) performed an analysis of the use of continuous glucose monitoring (CGM) systems, reporting an improvement in glycaemic control while reporting cost and usability issues, especially in terms of the implementation of personalised treatment plans.

Fernandez-Carames and Fraga-Lamas (2018) created a system using Internet of Things (IoT), Blockchain, and fog computing in CGM that increased the security of data and enabled real-time monitoring. Wang et al. (2019) used fuzzy AHP and evaluation theory to determine the usability of mobile applications to gain insights for design with the aim of enhancing user interaction.

Barata et al. (2019) created and evaluated an inexpensive CGM system that included IoT and Freestyle Libre sensors and showed successful performance in real world environments, while having some accuracy limitations. Georgsson et al. 2019), a diabetes self management application has been evaluated with the Usability and Cognitive Walkthrough (UC-CW) framework and the think aloud methods, and it has been found that UC-CW had a superior efficiency of resolving usability problems.

Stephen et al. (2022) reviewed mHealth apps for type 1 diabetes, noting improvements in

treatment satisfaction but no significant changes in self-efficacy. Eghbali-Zarch (2022) proposed a decision-making model for diabetes therapy, integrating expert recommendations to evaluate treatment options.

Schubert-Olesen et al. (2022) talked about the role of CGM in the management of the physical activity-related hypoglycemia. The most user-friendly mHealth app in the study of Gupta et al. (2022) was mySugr since it was compared with the other 5 apps targeting type 2 diabetes. The application of the DEA and fuzzy COPRAS to estimate the efficiency of wind farms by Yilmaz (2023) demonstrated that the methodology could be applied to various types of assessments.

Ma et al. (2023) created a fuzzy assessment model of vehicle co-pilot screen usability and emphasised the need to improve its design. Sherazi et al. (2023) evaluated the different mHealth applications, with Diabetes: M meeting the majority of the requirements of pharmaceutical care, which implies that apps may greatly improve the experience of patients. Zivkovic et al. (2024) investigated the SMBG replacement to continuous glucose monitor (CGM) with mySugr that showed enhanced glycemic control. According to Farrahi et al. (2024), the health information system in Iran has 68 usability problems, and the researchers emphasise the need to design it iteratively.

Herrero et al. (2024) tested the Accu-Chek Smart Guide Predict app on CGM with high accuracy in predicting glucose and indicating its ability to provide personalised diabetes treatment. The Diabetes: M app was evaluated by Sherazi et al. (2024) in rural Bosnia-Herzegovina where people were more satisfied with the app mostly with bolus calculators and reporting functionalities.

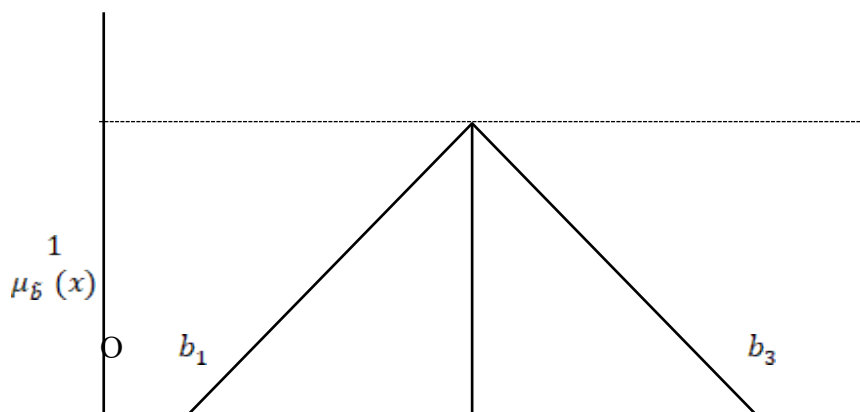
These publications show the increasing role of CGM applications in diabetes management. They emphasise the role of usability, user satisfaction and the data-driven approach towards enhancing patient outcomes. Artificial intelligence, fuzzy appraisal and user-oriented design have been important in the development of the diabetes management tools that have led to the improvement of the self-care and healthcare provision.

### **Research Methodology:**

The analysis shows that fuzzy COPRAS is a good way of ranking CGM apps under uncertainty by weighing between the positive (accuracy, usability, analytics, sharing, compatibility, support) and negative (cost, battery, privacy risks) aspects. The application of

fuzzy numbers based on the T1D educators will retain sensitivity and interpretability but will be sensitive to weights and linguistic scales. The clinical value requires connectivity with the healthcare systems, EHRs, telemedicine, interoperability standards (e.g., FHIR), secure APIs, and consent management are provided as the essential factors to implement the adoption safely and at scale. Regional availability, language support, network quality, regulatory approvals, frequent updates to apps, and platform differences (Android fragmentation, iOS privacy rules, proprietary ecosystems) are some of the contextual issues. The collection of criteria such as localization, stability in updating, performance of the platform, and lock-in of ecosystems is evaluated to make sure that it is accessible and sustainable.

In this present research study, it is proposed that an extended fuzzy formulation be considered for the usability evaluation of CGM apps using the MCDM technique, F- COPRAS due to its balanced handling of beneficial and non-beneficial criteria and superior performance in uncertain environments. The application of fuzzy logic involves applying a very harshly geometric structure, and one that inquires the indefinite conceptual case, a case which can be precisely studied. Additionally, the fuzzy set theory has been extended for decision making and applied to many researchers who have obtained better results. Additionally, it is a modelling language well fitted for a fuzzy environment. Moreover, it allows the type 1 diabetic patients and healthcare providers to optimize and get these applications used. This modelling language, well suited for conditions in a fuzzy environment and mathematically represented as: Set  $U$ , is a non-empty universal fuzzy set. "The set  $s = \langle x, \mu(x) \rangle$ , the grade of membership of  $x$  in  $A$  is represented by  $\mu_A(x): U \rightarrow [0,1]$ . The fuzzy set  $B = \langle b_1, b_2, b_3 \rangle$  on  $R$  is referred to as a TFN, whose membership function can be expressed as shown below in fig.1:"



### Figure: 1 Membership function in fuzzy set

This study applies a Fuzzy Complex Proportional Assessment (F-COPRAS) approach to rank CGM apps under uncertainty in expert judgments. Linguistic evaluations (e.g., “high”, “average”) were modeled as Triangular Fuzzy Numbers (TFNs) because of their simplicity, intuitive structure, and widespread acceptance in healthcare decision-making studies. Recent studies emphasize that in early-stage decision-support model development—especially in health informatics and mHealth—small, homogeneous expert groups (3–5 members) are sufficient to generate stable fuzzy judgments because the aim is conceptual framework evaluation rather than population-level inference (Yazdani et al., 2019; Rashid et al., 2021; Rezaei et al., 2022). TFNs require only three parameters (lower, modal, upper), which makes them easier for experts to interpret consistently. While Trapezoidal Fuzzy Numbers (TrFNs) can capture more nuance by including an additional plateau region, they also increase elicitation burden and computational complexity. Given that the experts were clinicians rather than mathematicians, TFNs provided an optimal balance between usability and methodological rigor. Table 1 shows the linguistic variables and the fuzzy ratings used to represent the criteria as well as the alternatives.

This paper focuses on Continuous glucose monitoring CGM apps – selecting the best mHealth application based on applying MCDM strategies known as COPRAS in fuzzy environment to determine the best and worst application and also the ratings of the CGM apps in a probabilistic environment based on linguistic terms using triangular fuzzy numbers as decided by the healthcare provider. The evaluation was conducted with the help of three healthcare specialists who provided expert judgments on the usability of five widely used CGM apps, namely Glimp, xDrip, Diabox, Shuggah, and Libre. This expert panel approach ensured that diverse professional insights were incorporated into the decision-making process. A total of ten criteria were considered for evaluation: Accuracy, User-Friendliness, Customization, Data Sharing, Compatibility, Analytics, Cost Efficiency, Support, Battery Consumption, and Data Privacy Risks. These criteria were assessed using fuzzy linguistic variables (Very Low, Low, Average, High, Very High), which were further transformed into triangular fuzzy numbers (TFNs) to capture vagueness and uncertainty in expert opinions.

### Fuzzy copras

The current paper proposes a Fuzzy Complex Proportional Assessment (F-COPRAS) methodology to incorporate the subjective aspect into the usability evaluation of CGM applications. The methodology is used in conjunction with triangular fuzzy numbers and the linguistic variables and it classifies the applications according to attributes including accuracy, convenience of use, data sharing and privacy. This approach encourages a balanced decision-making process, ultimately helping developers to optimise CGM app usability, leading to better diabetes management and user satisfaction. Compared with other MCDM methods, F-COPRAS is preferred to AHP, TOPSIS, and VIKOR as it allows for the assessment of both beneficial and non-beneficial attributes (especially for the usability-cost- data security trade-off in healthcare), and it works as a proportional measure. The natural fuzziness of the approach accurately reflects the uncertainty of the expert. When combined with artificial intelligence (clustering/classification) techniques for pre-processing the feedback, the framework becomes robust, adaptive, scalable and continuously learning, meaning that it can offer sustained decision support for the stakeholders.

### Expert Panel and sample size

The evaluation was carried out with the participation of three diabetes educators based in Delhi NCR, India. Each expert had more than ten years of professional experience in Type 1 diabetes management and patient education, and notably, all three experts themselves were living with Type 1 Diabetes (T1D). This dual perspective as both healthcare professionals and patients allowed for a deeper and more realistic evaluation of CGM app usability. The use of three experts is consistent with recent fuzzy-MCDM studies in health informatics where early-stage model evaluation prioritizes depth of expertise over sample size (Yazdani et al., 2019; Rashid et al., 2021). The choice of specialists was based on how they were actively involved in the T1D management procedure and were aware of the continuous glucose monitoring devices. Their ratings were then done in terms of fuzzy linguistic variables (e.g. Very High, High, Moderate, Low, Very Low) which were then converted into triangular fuzzy numbers to facilitate their subsequent analysis.

**Table-1 Expert Panel Profile**

<b>Expert No.</b>	<b>Role/Profession</b>	<b>Background</b>	<b>Years of Experience</b>	<b>Region</b>	<b>App availability</b>
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1	Diabetes Educator	Living with Type 1 Diabetes; provides patient counseling and CGM training	<b>15 years</b>	Delhi NCR, India	Glimp, xDrip, Diabox, Shuggah, and Libre
2	Diabetes Educator	Living with Type 1 Diabetes; specializes in patient education and support programs	<b>11 years</b>	Delhi NCR, India	Glimp, xDrip, Diabox, Shuggah, and Libre
3	Diabetes Educator	Living with Type 1 Diabetes; experienced in digital health and CGM usability guidance	<b>17 years</b>	Delhi NCR, India	Glimp, xDrip, Diabox, Shuggah, and Libre

**Expert Panel, Demographics and Validation of Reliability**

Three healthcare specialists (diabetes educators) working in the healthcare sector in Delhi NCR, India, were recruited based on a purposive sampling strategy, and had over five years of professional experience in Type 1 Diabetes (T1D) management, patient counselling and CGM training. It is worth noting that the three experts were themselves people living with T1D, which gives them a two-sided approach since they were healthcare providers and patients at the same time. The background information, number of years of experience as well as the CGM apps under assessment are summarised in Table 1.

The real expert ratings data (the individual ratings of each of the five apps in all ten criteria) is provided in the Supplementary File S1 to enhance the reproducibility and transparency. To analyse them, these numerical ratings were converted into Triangular Fuzzy Numbers (TFNs) and fuzzy language variables.

The panel determined the usability of five CGM apps (Glimp, xDrip, Diabox, Shuggah and Libre) in relation to ten criteria which are Accuracy, User-Friendliness, Customization, Data Sharing, Compatibility, Analytics, Cost Efficiency, Support, Battery Consumption, and Data Privacy Risks. The fuzzy linguistic variables (Very Low to Very High) were used to express rating which was then converted to Triangular Fuzzy Numbers to analyse the results. This facilitated a systematic and clear method of getting the expert judgement on uncertainty.

**Validation of Reliability:**

Kendall coefficient of concordance was used to estimate the inter-expert agreement to measure reliability of the expert judgement. The analysis that ensued gave a W value of 0.39

at a 95% confidence interval through bootstrapping which shows moderate congruency among the three experts. The level of agreement that has been obtained confirms the strength of fuzzy COPRAS results that are utilised in CGM applications ranking and comparison. The application of diverse opinions of experts, use of fuzzy lingual scales, and concordance testing are incorporated together to enhance the relevance of the findings of the research.

The existing paper employs a Fuzzy Complex Proportional Assessment (F-COPRAS) model to rank CGM applications amidst uncertainty in terms of the expert opinion assessment. Linguistic measurements (i.e. high, average) were transformed to Triangular Fuzzy Numbers (TFNs) because of their simplicity, intuitive form and widespread use in the literature of research into the decision-making of healthcare practitioners. TFNs require only three parameters, lower, modal and upper limits which are easier to use by experts to interpret. Whereas Trapezoidal Fuzzy Numbers (TrFNs) may have a more detailed representation by adding a plateau region to it, they also add to the elicitation burden and computational complexity. TFNs were ideal because the experts were clinicians and not mathematicians in nature.

### **Criteria Weighting**

We clarified that all 10 criteria were equally weighted, based on expert consensus. This approach avoids bias and is consistent with prior fuzzy MCDM studies in healthcare and technology evaluation (Önüt et al., 2009). While equal weighting was appropriate for this exploratory study, we acknowledged that Delphi or AHP could be applied in future work to derive more granular expert-driven weights. Para starting from: “All ten usability criteria were assigned equal weights, as agreed by the expert panel and derived from a systematic review and expert consensus and primary goal is to demonstrate the F-COPRAS framework rather than to derive granular importance weight.

**Importance of evaluating:** The application of fuzzy mathematics for rating CGM apps for Type 1 diabetes gives a novel approach of measuring usability and efficacy. Telemonitoring apps allow minute-to-minute tracking of glucose levels thereby improving self- management and glycaemic control. There is always subjective user feedback in scenarios, and thus fuzzy mathematics helps in making comparisons and ranking. This method ensures better improved app design hence leading to better adoption, user satisfaction, and better health.

We use the conversion scales to convert the linguistic terms to fuzzy numbers using the fuzzy

set theory. Table 1 represents the linguistic variables and fuzzy ratings used for the criteria and the alternatives. The following steps of fuzzy method are proposed:

**Mathematical formulation of F-COPRAS methods:**

**Step 1 - Identification of team of healthcare specialists, mHealth application usability, and mHealth application selection criteria** - The first stage is to assemble a panel of healthcare specialists who will verify the usability of CGM apps and determine the limited parameters that go into selecting the best CGM apps.

**Step 2 – Determining the weights of the criteria ( $w_j$ )**- The determined mHealth Application usability selection criteria's important weights in this step are given as:

$$w_j = w_1, w_2, \dots, w_n \tag{1}$$

And

$$\sum_{j=1}^n (w_1, w_2, \dots, w_n) = 1$$

**Step 3 – Construction of fuzzy decision matrix**- In this step, a team of specialists constructs the fuzzy decision matrix using triangular fuzzy numbers to represent linguistic words. Let’s say ‘ $k$ ’ healthcare specialists will evaluate ‘ $m$ ’ mHealth application as there are ‘ $n$ ’ criteria that can be translate in the form of the following matrix:

$$\begin{bmatrix} r_{11} & \dots & r_{1n} \\ \vdots & \ddots & \vdots \\ r_{m1} & \dots & r_{mn} \end{bmatrix} \tag{2}$$

**Step 4 – Construction of normalized decision matrix** - In this step, the normalized decision matrix is constructed as:

$$n_{ij} = \frac{r_{ij}}{\sum_{j=1}^n r_{ij}} \tag{3}$$

**Step 5 – Construction of weighted normalized decision matrix** - In this step, the weighted normalized decision matrix is constructed as:

$$N_{ij} = w_j^* n_{ij} \tag{4}$$

**Step 6 – Calculating the sum of the beneficial criteria ( $B_i$ )** - The sum of the beneficial criteria is determined as:

$$B_i = \sum_{j=1}^k N_{ij} \tag{5}$$

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Where  $j = 1, 2, \dots, k$  are beneficial criteria.

**Step 7 – Calculating the sum of the non-beneficial ( $C_i$ )-** The sum of the non-beneficial is determined as:

$$C_i = \sum_{j=k+1}^n N_{ij} \tag{6}$$

Where  $j = k + 1, \dots, n$  are non-beneficial.

**Step 7 – Calculating the relative significance of each alternative ( $S_i$ )** - The relative significance of each alternative is determined as:

$$S_i = B_i + \frac{\min C_i \cdot \sum_{i=1}^n C_i}{C_i \cdot \sum_{i=1}^n (\frac{\min C_i}{C_i})} \tag{7}$$

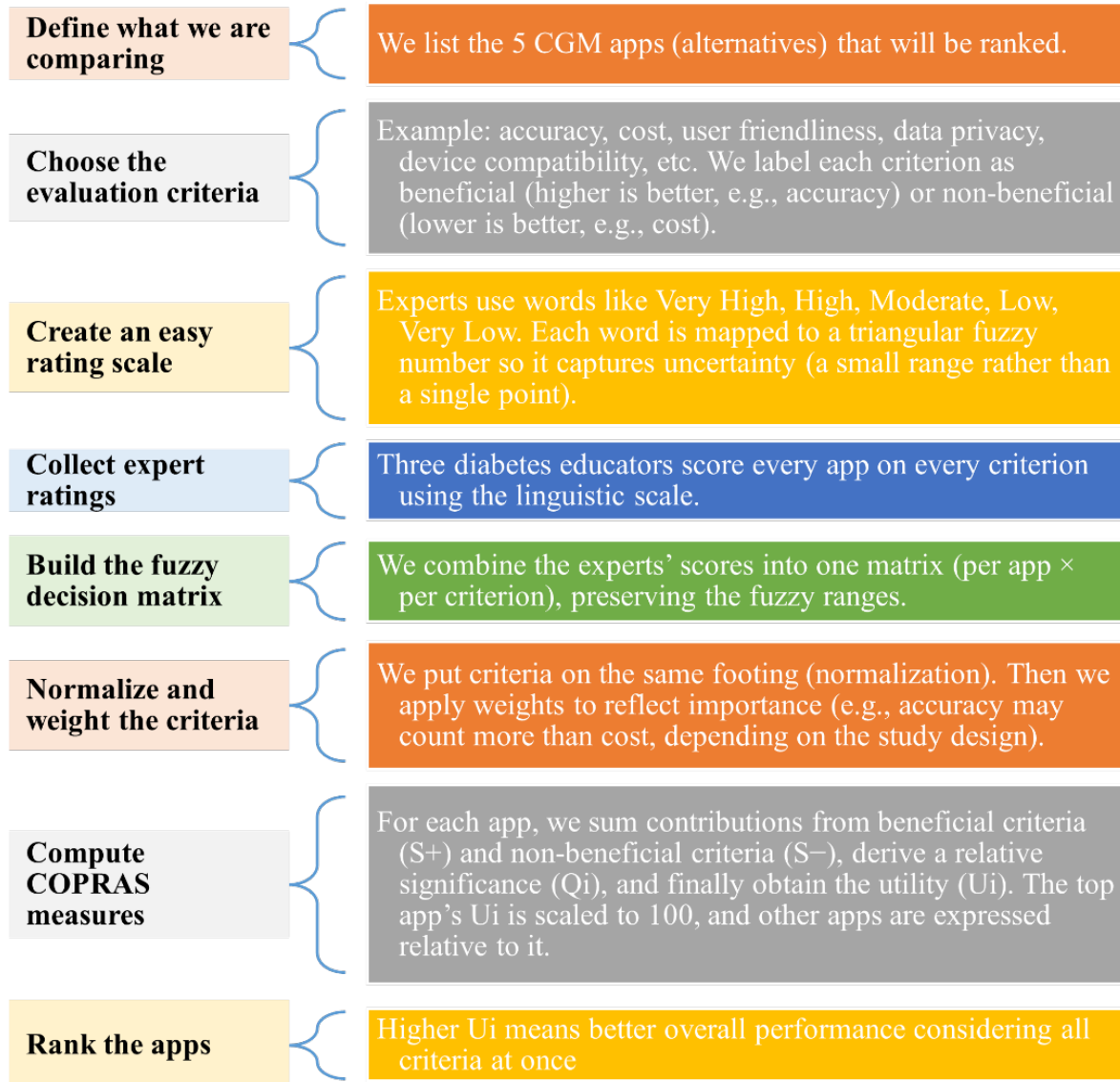
**Step 8 – Calculating the utility degree of each alternative ( $U_i$ )**- The utility degree of each alternative is determined as:

$$U_i = \frac{S_i}{\max(S_i)} * 100 \% \tag{8}$$

**Step 9 – Determination of ranking of alternatives ( $R_i$ )** - On the basis of the values of the utility degree of each alternative, we can obtain the ranking of the alternatives. Thereby, if the value of the utility degree of the alternative is maximum, its rank shall be 1. Thus, the best alternative is found to be:

$$R_i = \max (U_i) \tag{9}$$

**Figure-2 Fuzzy-COPRAS Procedure**



**1. Numerical Analysis**

To facilitate our investigation, we collaborated with healthcare providers, seeking their valuable insights and data for the computational aspects of our research. Our initial step involved the establishment of a decision-making framework specifically tailored to assess the Usability of different mHealth Application options. This framework is intended to define the most important criteria for Usability of various mHealth Application selection. The criteria used above also help in the differentiation of the best and least usability of various mHealth Application as well as setting a ranking system of the mHealth application solutions.

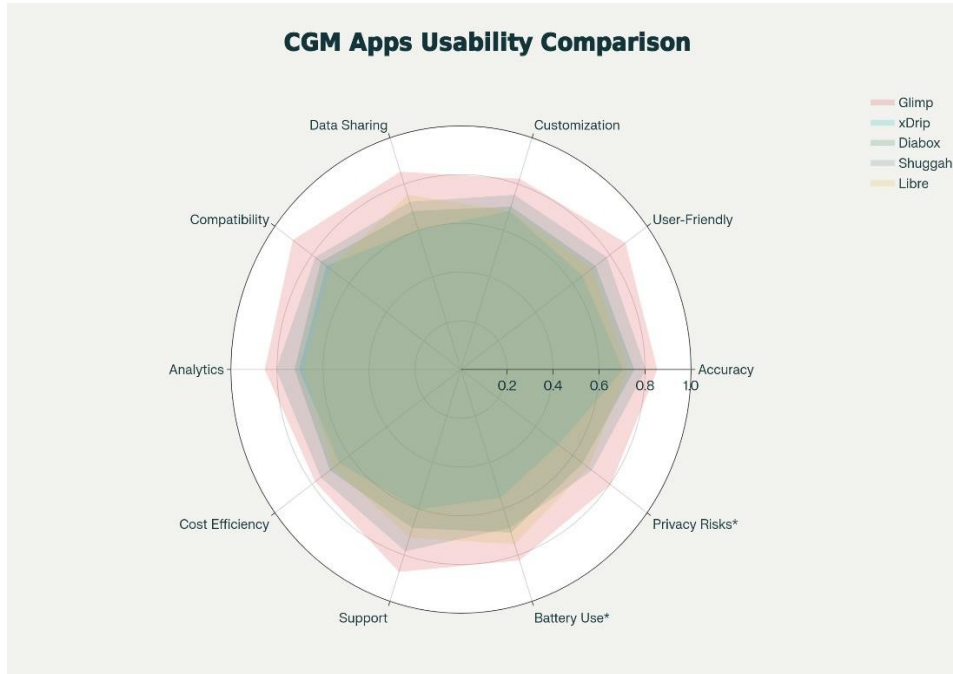
The next step is the selection of criteria. Concerning the selection of the criterion, we adopt previous studies as recommended in the literature, TAM, and UTAUT theories. We have

identified a total of ten criteria from literature review which are as follows:

**Table-2 Criteria for evaluating CGM**

Criteria	Type	Description
Accuracy	Beneficial	Indicates how consistently the program tracks and reports blood glucose levels with no notable variances.
User-Friendliness	Beneficial	Assesses how simple and intuitive the program is for users with different degrees of technical knowledge.
Customization	Beneficial	Evaluates how well the program can adjust to the preferences of specific users, including display settings and notifications.
Data Sharing	Beneficial	Examines how simple it is for users to exchange glucose data with other integrated systems, caregivers, or medical experts.
Compatibility	Beneficial	Checks that the program works with a variety of hardware, operating systems, and CGM sensors.
Analytics	Beneficial	Concentrates on the capacity to offer perceptive data patterns, visual aids, and practical suggestions for improved diabetic care.
Cost Efficiency	Beneficial	Takes into account the application's whole affordability, including subscription fees other unstated expenses.
Support	Beneficial	Examines the availability of community forums, user manuals, and technical support for assistance and troubleshooting.
Battery Consumption	Non-Beneficial	Assesses how the application affects the battery life of the device; less consumption is desirable.
Data Privacy Risks	Non-Beneficial	Assesses the possible danger of user data exposure while guaranteeing adherence to privacy laws and strong security protocols.

After the confirmation of these criteria, we engaged Healthcare specialists to assess and determine the usability of various mHealth application for type 1 diabetics, referred to as mApp1 to mApp 5. Linguistic terms associated with these criteria and the fuzzy performance to evaluate the usability of various mHealth application for type 1 diabetics, based on the judgments of the healthcare specialist panel, are presented in Tables 1 and 2, respectively.



The radar plot of normalized weighted F-COPRAS scores for 5 CGM apps across 10 usability criteria. Glimp demonstrates superior performance across beneficial criteria while maintaining competitive performance on non-beneficial criteria (Battery\*, Privacy\*). \*Non-beneficial: lower values preferred

**Table-3 Linguistic terms of fuzzy performance ratings of usability of mhealth application**

Linguistic Terms	Fuzzy Numbers
Very Low	1,1,3
Low	1,3,5
Average	3,5,7
High	5,7,9
Very High	7,9,9

Table 3 outlines the fuzzy performance ratings of usability for CGM apps, where linguistic terms are mapped to fuzzy numbers to quantify the usability of the applications. The linguistic terms used to describe the performance are: Very Low, Low, Average, High, and Very High. Each term is associated with a specific range of fuzzy numbers, which help in representing the varying degrees of usability. The term **Very Low** corresponds to fuzzy numbers (1, 1, 3), indicating a performance that is mostly poor, with little to no usability. **Low** corresponds to fuzzy numbers (1, 3, 5), reflecting a slightly better but still suboptimal performance. **Average** is represented by the fuzzy numbers (3, 5, 7), signifying a moderate level of usability. **High** is linked to fuzzy numbers (5, 7, 9) and this implies good usability

with some variation whereas **Very High** is linked to fuzzy numbers (7, 9, 9) and this implies excellent usability with little variation. These fuzzy numbers offer a means of giving a more fined and loose expression of the usability of CGM apps in a more definitive way to give a clearer picture as to how the various apps would perform in the various metrics of usability.

**Visual Representations of Evaluated Apps**






To enhance ease of use, Figure 3 provides schematic drawings of the five CGM apps which were used in this study. Both of the apps have their own peculiarities that affect their usability:

**Table-4 Accessibility and App-Specific Limitations of CGM Apps**

<b>App Name</b>	<b>Accessibility / Usability Features</b>	<b>Key Limitations</b>
<b>Glimp</b>	Open-source, flexible, highly customizable; suitable for experienced users seeking configuration control	Limited compatibility with newer smartphone OS; occasional data synchronization issues
<b>xDrip</b>	Advanced customization, cloud synchronization, data sharing options; broad device support	Requires technical expertise for setup; lacks official customer support
<b>Shuggah</b>	Simple design, user-friendly, quick setup; good for beginners	Restricted regional availability; limited language support
<b>Diabox</b>	Supports multiple CGM devices; moderately complex with useful monitoring features	Less intuitive for first-time users; occasional usability challenges due to complex interface
<b>Libre</b>	Proprietary app with polished design, advanced features, and seamless integration with its own devices	Higher cost than alternatives; limited integration with non-proprietary platform

**Figure-3 Visual Representations of Evaluated Apps**

### Visual Representations of Evaluated Apps

				
<b>Glimp</b>	<b>xDrip</b>	<b>Shuggah</b>	<b>Diabox</b>	<b>Libre</b>
Open-source design, emphasizes flexibility, requires user configuration	Highly customizable interface, supports data sharing and cloud sync	User-friendly interface, designed for simplicity and quick setup	Moderately-complex interface, designed for miltoptle CGM devices	Proprietary interface with polished design, offers advanced features but at higher cost

These visual representations, combined with descriptive summaries, help provide a clearer comparison of the strengths and limitations of each app

**Table-5 Linguistic variables of mHealth application assessment by first expert/healthcare specialist**

	Accuracy	User Friendliness	Customization	Data Sharing	Compatibility	Analytics	Cost Efficiency	Support	Battery Consumption	Data Privacy Risks
Xdrip	H	VH	A	H	VH	A	L	H	H	A
Diabox	VH	H	L	H	A	VH	H	L	L	H
Glimp	H	H	H	VH	VH	VH	H	A	H	VH
Shuggah	H	VH	H	H	L	H	L	H	H	H
Libre	H	VH	H	VH	H	H	L	H	VH	H

Table 5 presents the linguistic variables assessment of various CGM apps by a first healthcare expert. The assessment will be conducted using ten criteria, which include Accuracy, User Friendliness, Customization, Data Sharing, Compatibility, Analytics, Cost Efficiency, Support, Battery Consumption, and Data Privacy Risks. The tools were evaluated on Xdrip, Diabox, Glimp, Shuggah, and Libre and the parameters were rated on the basis of linguistic terms, where H (High), VH (Very High), L (Low), A (Average).

Precision: Diabox is rated with the highest score, and it is called Very High (VH); Xdrip and Glimp are called High (H), Shuggah and Libre are High (H). Easy to use: Tools more or less scored well, with Shuggah and Libre scoring a Very High, with Xdrip, Glimp and Diabox being High or Average. Individualization: Ratings are not uniform; the rating of Xdrip and Glimp are the same (average), and some products, Shuggah, Libre, Diabox, etc., have conflicted and contradictory results; certain parts of the products have Low rating and other parts have High rating. Data sharing: Xdrip, Glimp and Libre have a rating of High or Very High. Compatibility: Here Xdrip scores a very high (VH) compliance, and Glimp and Libre are rated very high (VH), but Diabox and Shuggah are rated very low (VL) or low (LL). Analytics: Diabox and Glimp have been rated as Very High (VH) and the remaining such as the Xdrip and Shuggah as Average or Low. Cost Efficiency: Xdrip has a rating of Average,

whereas Diabox and Libre have a low (Low) or average (Average) rating. Support: Most tools have Strong ratings ( Diabox and Glimp have High ratings); others have a mixed rating. Battery usage: The use of battery is widely varied, with Xdrip and Diabox having Higher usage, whereas Glimp and Libre are providing good battery usage. Privacy risk: They differ depending on the tool; Xdrip and Glimp are the most effective, and Diabox is the lowest.

To sum up, the present analysis revealed that Glimp and Diabox are the most successful in the categories of accuracy, usability, and analytics, whereas Shuggah and Libre experience issues with personalising and being financially efficient. For each mHealth application, the tools indicate different strengths and weaknesses for several criteria, thus offering a global view of the performance of each tool based on the first medical opinion.

**Table-6 Linguistic variables of mHealth application assessment by second expert/healthcare specialist**

	Accuracy	User Friendliness	Customization	Data Sharing	Compatibility	Analytics	Cost Efficiency	Support	Battery Consumption	Data Privacy Risks
Xdrip	H	VH	H	L	H	A	L	H	H	A
Diabox	VH	A	H	VH	A	VH	H	H	VH	A
Glimp	VH	H	VH	H	VH	A	L	A	H	A
Shuggah	H	A	H	VH	H	H	VH	H	H	H
Libre	H	A	H	VH	H	A	L	H	A	H

Table 6 provides a detailed evaluation of five CGM apps — Xdrip, Diabox, Glimp, Shuggah, and Libre — assessed by a second healthcare expert across ten linguistic variables: Accuracy, User Friendliness, Customization, Data Sharing, Compatibility, Analytics, Cost Efficiency, Support, Battery Consumption, and Data Privacy Risks. Xdrip was rated high in Accuracy, Customization, Compatibility, Support, and Battery Consumption, very high in User Friendliness, but showed low performance in Data Sharing and Cost Efficiency, while Analytics and Data Privacy Risks were considered average. Diabox received very high ratings in User Friendliness, Data Sharing, and Analytics, high in Customization, Cost Efficiency, Support, and Battery Consumption, but was considered average in Accuracy and Compatibility, and average in Data Privacy Risks. Glimp showed very high performance in Accuracy, Customization, and Compatibility, high in User Friendliness and Battery

Consumption, but had average ratings in Analytics, Support, and Data Privacy Risks, with low performance in Cost Efficiency. Shuggah demonstrated high ratings in Accuracy, Customization, Compatibility, Support, and Battery Consumption, very high in Cost Efficiency, average in User Friendliness and Analytics, and high in Data Privacy Risks. Libre showed high ratings in Accuracy, Customization, Compatibility, and Support, average in User Friendliness, Analytics, and Battery Consumption, low in Cost Efficiency, and high in Data Privacy Risks. In general, Diabox and Glimp were also distinguished in critical areas of usability and data-management, Xdrip provided a good technical support and compatibility, but was weak in cost-efficiency, whereas Shuggah and Libre provided a balanced and relatively good performances of most variables.

**Table-7 Linguistic variables of mHealth application assessment by third expert/healthcare specialist**

	Accuracy	User Friendliness	Customization	Data Sharing	Compatibility	Analytics	Cost Efficiency	Support	Battery Consumption	Data Privacy Risks
Xdrip	H	VH	VH	H	H	L	L	A	H	A
Diabox	VH	H	VH	H	L	H	VL	H	L	H
Glimp	VH	H	H	VH	H	VH	L	VH	L	A
Shuggah	H	VH	L	A	H	H	L	H	H	H
Libre	H	VH	L	A	H	A	L	H	VH	L

Table 7 presents the linguistic variables assessment of various CGM apps by a third expert in healthcare, evaluating them across ten different criteria: Accuracy, User Friendliness, Customization, Data Sharing, Compatibility, Analytics, Cost Efficiency, Support, Battery Consumption, and Data Privacy Risks. The evaluation uses linguistic terms such as "H" (High), "VH" (Very High), "L" (Low), "VL" (Very Low), and "A" (Average) to assess the performance of each application.

Accuracy proves that Diabox and Glimp are significantly higher performance and achieve VH ratings, whereas Xdrip and Shuggah are High (H) ratings. The rating of Diabox, Shuggah, and Libre is Very High, whereas the rating of Xdrip and Glimp is High. Customization: The Xdrip and Diabox have a score of Very High (VH) with the other apps such as Shuggah and Libre having either Low (L) or Average (A). The study indicates that

Data Sharing functionality in Xdrip, Glimp and Libre is good with High or Very High rating. The compatibility was found to offer a stable good performance during the repertoire with most of the applications rated as High (H) and the remaining application namely Diabox being rated as Low. The scores of analytics are wide; Glimp scores are Very High, Xdrip and Libre score Low. Cost Efficiency: Xdrip and Glimp is rated as Low, Diabox and Libre as rated as Average and Shuggah as rated as Low. The overall support is high on all of the tools excepting Glimp and Libre that both score the Low and Average rating respectively. Battery Consumption: Glimp and Libre have the highest score (Very High (VH)) and other products such as Xdrip and Diabox have the lowest score (Average (A) and High (H)). Last but not the least, Data Privacy Risks is somewhat an average (A) with Glimp and the other tools scored Low (L) or High (H).

Overall, it can be seen that Glimp and Diabox are overall good in features of accuracy, ease of use, and data sharing, whereas Shuggah and Libre are not so good when it comes to customization and battery life. There are strengths and weaknesses of each mHealth application on the evaluation criteria, and the ratings are based on the different priorities of the healthcare expert in evaluating his or her performance.

**Table-8 Fuzzy decision matrix assessment by first expert/healthcare specialist**

	Accuracy	User Friendliness	Customization	Data Sharing	Compatibility	Analytics	Cost Efficiency	Support	Battery Consumption	Data Privacy Risks
Xdrip	5,7,9	7,9,9	3,5,7	5,7,9	7,9,9	3,5,7	1,3,5	5,7,9	5,7,9	3,5,7
Diabox	7,9,9	5,7,9	1,3,5	5,7,9	3,5,7	7,9,9	5,7,9	1,3,5	1,3,5	5,7,9
Glimp	5,7,9	5,7,9	5,7,9	7,9,9	7,9,9	7,9,9	5,7,9	3,5,7	5,7,9	7,9,9
Shuggah	5,7,9	7,9,9	5,7,9	5,7,9	1,3,5	5,7,9	1,3,5	5,7,9	5,7,9	5,7,9
Libre	5,7,9	7,9,9	5,7,9	7,9,9	5,7,9	5,7,9	1,3,5	5,7,9	7,9,9	5,7,9

Table 8 presents a fuzzy decision matrix assessment for various healthcare tools, evaluated by an expert on a range of parameters. The table offers a comparison of five various healthcare solutions and Xdrip, Diabox, Glimp, Shuggah and Libre on ten criteria, which include Accuracy, User Friendliness, Customization, Data Sharing, Compatibility, Analytics, Cost Efficiency, Support, Battery Consumption and Data Privacy Risks. The ratings of each tool are placed in a fuzzy scale of 1, 3, 5, 7 and 9 as a higher rating the better the performance of that tool.

According to Accuracy, Diabox is rated at 7, 9 and 9 that results in a more precise tool whereas Xdrip and Shuggah have 7, 9 and 9 which have a mixture of moderate ratings. User Friendliness-wise, the majority of solutions are well-done, as Glimp, Shuggah, Libre, and Xdrip have scores within 7 to 9. Customization has a large deviation with certain tools such as Glimp having better scores compared to others such as Diabox which always has lower scores. Most tools perform well in Data Sharing and Compatibility although Glimp and Libre are the best in these areas as their rating is quite high on these parameters. Analytics indicate that Diabox and Glimp have been doing well, whereas Cost Efficiency is a weakness of Xdrip and Shuggah. The most important ones are Support and Battery Consumption, in which the ratings varied dramatically, with Diabox and Xdrip having among the lowest ratings in these areas. Lastly, there are Data Privacy Risks that demonstrate certain variability with Glimp scoring higher than other applications such as Diabox, which has an inferior privacy rating. Altogether, Glimp and Libre appear to be the most consistent players in most categories, whereas Diabox and Shuggah have certain weaknesses in such areas as cost-effectiveness and battery life.

**Table-9 Fuzzy decision matrix assessment by second expert/healthcare specialist**

	Accuracy	User Friendliness	Customization	Data Sharing	Compatibility	Analytics	Cost Efficiency	Support	Battery Consumption	Data Privacy Risks
Xdrip	5,7,9	7,9,9	5,7,9	1,3,5	5,7,9	3,5,7	1,3,5	5,7,9	5,7,9	3,5,7
Diabox	7,9,9	3,5,7	5,7,9	7,9,9	3,5,7	7,9,9	5,7,9	5,7,9	7,9,9	3,5,7
Glimp	7,9,9	5,7,9	7,9,9	5,7,9	7,9,9	3,5,7	1,3,5	3,5,7	5,7,9	3,5,7
Shuggah	5,7,9	3,5,7	5,7,9	7,9,9	5,7,9	5,7,9	7,9,9	5,7,9	5,7,9	5,7,9
Libre	5,7,9	3,5,7	5,7,9	7,9,9	5,7,9	3,5,7	1,3,5	5,7,9	3,5,7	5,7,9

Table 9 shows the fuzzy decision matrix created by the second healthcare specialist to assess the usability of five CGM apps — Xdrip, Diabox, Glimp, Shuggah, and Libre — across ten important criteria: Accuracy, User Friendliness, Customization, Data Sharing, Compatibility, Analytics, Cost Efficiency, Support, Battery Consumption, and Data Privacy Risks, using fuzzy values (minimum, average, and maximum scores). Accuracy gave Diabox and Glimp the top score (7,9,9) and Xdrip, Shuggah, and Libre were next (5,7,9). On User Friendliness,

Xdrip was rated the best (7,9,9), at the expense of Diabox (3,5,7), Shuggah (3,5,7), and Libre (3,5,7) with Glimp at the middle ground (5,7,9). With respect to Customization, Glimp ranked highly (7,9,9) and the other applications such as Xdrip, Diabox, Shuggah, and Libre had a comparatively weak but good rating (5,7,9). Diabox and Shuggah were the most competent (7,9,9) followed by Xdrip (1,3,5), then Glimp and Libre had averaged scores (5,7,9). The best compatibility was with Glimp (7,9,9) which meant that it was very compatible with the system whilst Diabox scored lower (3,5,7) and rest had medium compatibility levels (5,7,9). Diabox topped in Analytics with a very high evaluation (7,9,9), was followed by Shuggah (5,7,9), and Xdrip, Glimp as well as Libre were slightly down the list with (3,5,7). Diabox and Shuggah ranked the highest in Cost Efficiency (5,7,9) indicating that they are more economical, and the rest of the units including Xdrip, Glimp, and Libre ranked lower (1,3,5). In the case of Support, Glimp was the only application that scored less (5,7,9); all other applications scored higher (3,5,7), which means that there is a minor gap in user support services. Diabox worked the best in Battery Consumption (7,9,9), and Xdrip, Glimp, and Shuggah were regular in evaluation (5,7,9), and Libre was not rated comparatively (3,5,7). Finally, under Data Privacy Risks, Shuggah and Libre scored the highest (5,7,9) with enhanced privacy protection as compared to the rest, namely, Xdrip, Diabox, and Glimp with an average score (3,5,7). All in all, Diabox was the best in most parameters, particularly in Accuracy, Data Sharing, Analytics, Cost Efficiency and Battery Consumption compared to Glimp that is strong in Accuracy, Customization and Compatibility but rather weak in Data Sharing and Cost Efficiency; Shuggah and Libre demonstrate stable but low performances in most of the categories.

**Table-10 Fuzzy decision matrix assessment by third expert/healthcare specialist**

	Accuracy	User Friendliness	Customization	Data Sharing	Compatibility	Analytics	Cost Efficiency	Support	Battery Consumption	Data Privacy Risks
Xdrip	5,7,9	7,9,9	7,9,9	5,7,9	5,7,9	1,3,5	1,3,5	3,5,7	5,7,9	3,5,7
Diabox	7,9,9	5,7,9	7,9,9	5,7,9	1,3,5	5,7,9	1,1,3	5,7,9	1,3,5	5,7,9
Glimp	7,9,9	5,7,9	5,7,9	7,9,9	5,7,9	7,9,9	1,3,5	7,9,9	1,3,5	3,5,7
Shuggah	5,7,9	7,9,9	1,3,5	3,5,7	5,7,9	5,7,9	1,3,5	5,7,9	5,7,9	5,7,9
Libre	5,7,9	7,9,9	1,3,5	3,5,7	5,7,9	3,5,7	1,3,5	5,7,9	7,9,9	1,3,5

Table 10 presents the fuzzy decision matrix based on the assessment by the third healthcare expert, evaluating five CGM apps — Xdrip, Diabox, Glimp, Shuggah, and Libre — across ten key criteria: Accuracy, User Friendliness, Customization, Data Sharing, Compatibility, Analytics, Cost Efficiency, Support, Battery Consumption, and Data Privacy Risks, using fuzzy numbers (minimum, average, and maximum values). In the Accuracy, both Glimp and Diabox were doing well with (7,9,9) whereas Xdrip, Shuggah and Libre were performing at a high level (5,7,9). User Friendliness, Xdrip, Shuggah, and Libre scored highest (7,9,9) and Diabox and Glimp had lower scores, but still good (5,7,9). Xdrip and Diabox (7,9,9) had the highest customization, Glimp scored lower (5,7,9), and Shuggah and Libre scored very low (1,3,5), indicating that the products lacked many options to be customised. Glimp had the highest score of (7,9,9), Diabox and Xdrip scored higher (5,7,9), and Shuggah and Libre scored lower (3,5,7). In terms of Compatibility, Glimp and Xdrip had more favourable ratings (5,7,9), Diabox had low compatibility (1,3,5) and Shuggah and Libre had moderate ratings. Glimp again performed best in Analytics (7,9,9) and then Diabox and Shuggah (5,7,9) and the lowest performance was scored by Xdrip (1,3,5). In terms of Cost Efficiency, all the apps with the exception of Diabox were rated low with the apps being Xdrip, Glimp, Shuggah, and Libre with a rating of (1,3,5) and Diabox registering (1,1,3) which is relatively low. Supportwise, Glimp received the best scores (7,9,9), and the rest scored moderately (5,7,9), with the exception of Xdrip having a shorter range (3,5,7). Libre was the best in the Battery Consumption with the highest score (7,9,9), others, especially Glimp performed poor with low scores (1,3,5). In the case of Data Privacy Risks, Diabox, Shuggah, and Glimp scored relatively high (5,7,9) and Xdrip and Libre scored lower on privacy. In general, Glimp displayed the best consistent and high performance on such vital criteria as Accuracy, Data Sharing, Analytics and Support, whereas Diabox was strong in such aspects as Accuracy and Analytics but weak in such as Compatibility and Cost Effectiveness; Xdrip was strong in such aspects like User Friendliness but weak in such aspects as Analytics and Cost Effectiveness and Shuggah and Libre had highly variable scores, soaring in areas like Battery Consumption and Support and crashing in areas like Customization and Cost Effectiveness.

**Table-11 Combined Fuzzy decision matrix assessed by all the experts/healthcare specialist**

	Accuracy	User Friendliness	Customization	Data Sharing	Compatibility	Analytics	Cost Efficiency	Support	Battery Consumption	Data Privacy Risks
Xdrip	5,7,9	7,9,9	5,7,8.3	3.6,5.3,7.6	5.6,7.6,9	2.3,4.3,6.3	1,3,5	4.3,6.3,8.3	5,7,9	3,5,7
Diabox	7,9,9	4.3,6.3,8.3	4.3,6.3,7.6	5.6,7.6,9	2.3,4.3,6.3	6.3,8.3,9	3.6,5,7	3.6,5.6,7.6	3,5,6.3	4.3,6.3,8.3
Glimp	6.3,8.3,9	5,7,9	5.6,7.6,9	6.3,8.3,9	6.3,8.3,9	5.6,7.6,8.3	2.3,4.3,6.3	4.3,5.6,7.6	3.6,5.6,7.6	4.3,6.3,7.6
Shuggah	5,7,9	5.6,7.6,8.3	5.6,7.6,9	5,7,8.3	3.6,5.6,7.6	5,7,9	3,5,6.3	5,7,9	5,7,9	5,7,9
Libre	5,7,9	5.6,7.6,8.3	5.6,7.6,9	5.6,7.6,8.3	5,7,9	3.6,5.6,7.6	1,3,5	5,7,9	5.6,7.6,8.3	3.6,5,7.6

Table 11 presents the combined fuzzy decision matrix for the assessment of five CGM apps — Xdrip, Diabox, Glimp, Shuggah, and Libre — as evaluated by healthcare specialists across ten critical criteria: Accuracy, User Friendliness, Customization, Data Sharing, Compatibility, Analytics, Cost Efficiency, Support, Battery Consumption, and Data Privacy Risks. All the evaluations have the form of a fuzzy number (minimum, average, and maximum values). Diabox scored the best in Accuracy with values (7,9,9), then closely Glimp (6.3,8.3,9) followed with similar moderate scores of Xdrip, Shuggah, and Libre (5,7,9). On User Friendliness, Xdrip scored best (7,9,9) compared to Diabox (4.3,6.3,8.3) of the applications. Under Customization, Glimp, Shuggah, and Libre were all highly rated (5.6,7.6,9), with a lower score of Diabox and Xdrip. Data Sharing Glimp disclosed the best result (6.3,8.3,9), Diabox demonstrated a rather good result (5.6,7.6,9), and Xdrip demonstrated a worse result (3.6,5.3,7.6). Glimp (6.3,8.3,9) had the highest score in compatibility; this means it was very adaptive whereas Diabox had the lowest score (2.3,4.3,6.3). Analytics, Diabox was the best assessed (6.3,8.3,9), Glimp and Shuggah had strong ratings (5.6,7.6,8.3) and (5,7,9) respectively, and Xdrip has poor analytics scores (2.3,4.3,6.3). In what concerns Cost Efficiency, Diabox scored superior (3.6,5,7), and Xdrip and Libre scored lowest (1,3,5), implying that they are comparatively less cost-effective. Shuggah and Libre made the best assessments (5,7,9) in the Support criterion with Diabox and Glimp making lower yet acceptable scores. In the case of Battery Consumption, Shuggah and Libre once again scored highly with (5,7,9) and (5.6,7.6,8.3) respectively and Diabox was rated lower (3,5,6.3). Finally, regarding the Data Privacy Risks, Shuggah scored the highest (5,7,9) and Xdrip had a relatively lower range (3,5,7). All in all, Glimp had the highest evaluations throughout all parameters with Diabox having good results in parameters such as Accuracy, Analytics and Cost Efficiency but with lower scores in parameters such as Compatibility and Battery Consumption, Xdrip had good User Friendliness but lower scores in parameters such as Cost Efficiency and Analytics and Shuggah and Libre had highly balanced and stable results

across nearly all the evaluation parameters.

**Table-12 Combined crisp decision matrix**

	Acc	User Friendliness	Customization	Data Sharing	Compatibility	Analytics	Cost Efficiency	Support	Battery Consumption	Data Privacy Risks
Xdrip	7.00	8.50	6.83	5.45	7.45	4.30	3.00	6.30	7.00	5.00
Diabox	8.50	6.30	6.13	7.45	4.30	7.98	5.15	5.60	4.83	6.30
Glimp	7.90	7.00	7.45	7.98	7.98	7.28	4.30	5.78	5.60	6.13
Shuggah	7.00	7.28	7.45	6.83	5.60	7.00	4.83	7.00	7.00	7.00
Libre	7.00	7.28	7.45	7.28	7.00	5.60	3.00	7.00	7.27	5.30

Table 12 shows the combined crisp decision matrix for five CGM apps — Xdrip, Diabox, Glimp, Shuggah, and Libre — evaluated across ten important factors: Accuracy, User Friendliness, Customization, Data Sharing, Compatibility, Analytics, Cost Efficiency, Support, Battery Consumption, and Data Privacy Risks. Diabox was the top in terms of Accuracy with 8.5, Xdrip and Shuggah scored lower with 7, and Glimp scored a little better with 7.995. Xdrip scored highest in terms of User Friendliness at 8.5 as Diabox scored lowest at 6.3, and Glimp, Shuggah, and Libre had moderate scores of 7 to 7.275. In Customization, Glimp, Shuggah and Libre got the highest of 7.45 which means that they have strong personalization capabilities when compared to Diabox and Xdrip which is a bit lower. On the criterion of Data Sharing, Glimp scored the highest of 7.975 and Diabox ranked just below with a score of 7.45, Libre with 7.275, Shuggah with 6.825 and Xdrip was much lower with a score of 5.45. On Compatibility, Glimp again did the best with 7.975 with Diabox again trailing at 4.3, and the rest between 5.6 and 7.45. The dominance of analytics was at Diabox with 7.975, Glimp with 7.275, Shuggah with 7, Libre with 5.6, and Xdrip with a big number 4.3. Diabox achieved a 5.15 in Cost Efficiency, Glimp 4.3 and Xdrip and Libre were the lowest with 3 each. The highest score was 7 on Shuggah and Libre as there is a strong user support and lower scores were recorded on Xdrip and Diabox as 6.3 and 5.6 respectively. In the case of Battery Consumption, Libre scored best at 7.27 with the others Libre, Shuggah,

and Glimp around 7, and Glimp, 5.6 respectively. In Data Privacy Risks, Shuggah scored the best with 7 in terms of being superior in terms of privacy, whereas Xdrip had the lowest score with 5. Altogether, Glimp has performed fairly well and consistently on the majority of aspects, specifically, Data Sharing, Compatibility, and Customization, but Diabox did well in Accuracy, Analytics, and Cost Efficiency, but poorly in Compatibility and Battery Consumption, Xdrip was fairly well-balanced in terms of usability in most of the assessed factors, whereas Shuggah and Libre were fairly well balanced with each other.

**Table-13 Normalized decision matrix**

	Accuracy	User Friendliness	Customization	Data Sharing	Compatibility	Analytics	Cost Efficiency	Support	Battery Consumption	Data Privacy Risks
Xdrip	0.18	0.23	0.19	0.15	0.23	0.12	0.14	0.19	0.22	0.16
Diabox	0.22	0.17	0.17	0.21	0.13	0.24	0.25	0.17	0.15	0.21
Glimp	0.21	0.19	0.21	0.22	0.24	0.22	0.21	0.18	0.17	0.20
Shuggah	0.18	0.20	0.21	0.19	0.17	0.21	0.23	0.22	0.22	0.23
Libre	0.18	0.20	0.21	0.20	0.21	0.17	0.14	0.22	0.22	0.17

Table 13 presents the normalized decision matrix for five CGM apps — Xdrip, Diabox, Glimp, Shuggah, and Libre — evaluated across ten essential usability factors: Accuracy, User Friendliness, Customization, Data Sharing, Compatibility, Analytics, Cost Efficiency, Support, Battery Consumption, and Data Privacy Risks. Diabox has the highest normalised score of 0.22 in terms of the Accuracy criterion and Glimp has the second highest score of 0.21 with a lower score shared by Xdrip, Shuggah and Libre at 0.18. In terms of User Friendliness, Xdrip scored the highest of 0.23, Glimp and Shuggah came in second and third with 0.19 and 0.20 respectively whereas Diabox recorded the lowest of 0.17. In the case of Customization, Glimp, Shuggah, Libre all performed quite well with the same result of 0.21, whereas Xdrip and Diabox are slightly lower. Glimp was also on the top spot in Data Sharing, with a normalised value of 0.22, followed by Diabox, Libre, Shuggah with 0.21, 0.20, and 0.19 respectively. The compatibility was greatest with Glimp at 0.24, meaning that it has better adaptability across platforms as compared

to Diabox which recorded the lowest compatibility score of 0.13. It was analytics that Diabox ranked top with 0.24, Glimp, with 0.22, and Xdrip, with 0.12. Diabox scored the highest of 0.25 in Cost Efficiency which supports its monetary strength, with the lowest score of 0.14 in Xdrip and Libre. In the case of Support, Shuggah and Libre, the normalised values of 0.22 and 0.22, respectively, were performed well whereas Xdrip and Diabox yielded slightly lower values. In Battery Consumption, Xdrip, Shuggah and Libre encountered the highest rating of 0.22 in battery management with Diabox recording the lowest rating of 0.15. Lastly, regarding Data Privacy Risks, Shuggah had the highest score of 0.23, which implies enhanced security, whereas Xdrip and Libre receive lower marks of 0.16 and 0.17 respectively. On the whole, Glimp showed a very stable and good level of performance in most of the usability variables, Diabox was very strong in cost and analytics, though worse in compatibility and battery-related variables, Xdrip was performing well in user-friendliness, whereas Shuggah and Libre were fairly balanced and stable in terms of their performance on the majority of variables.

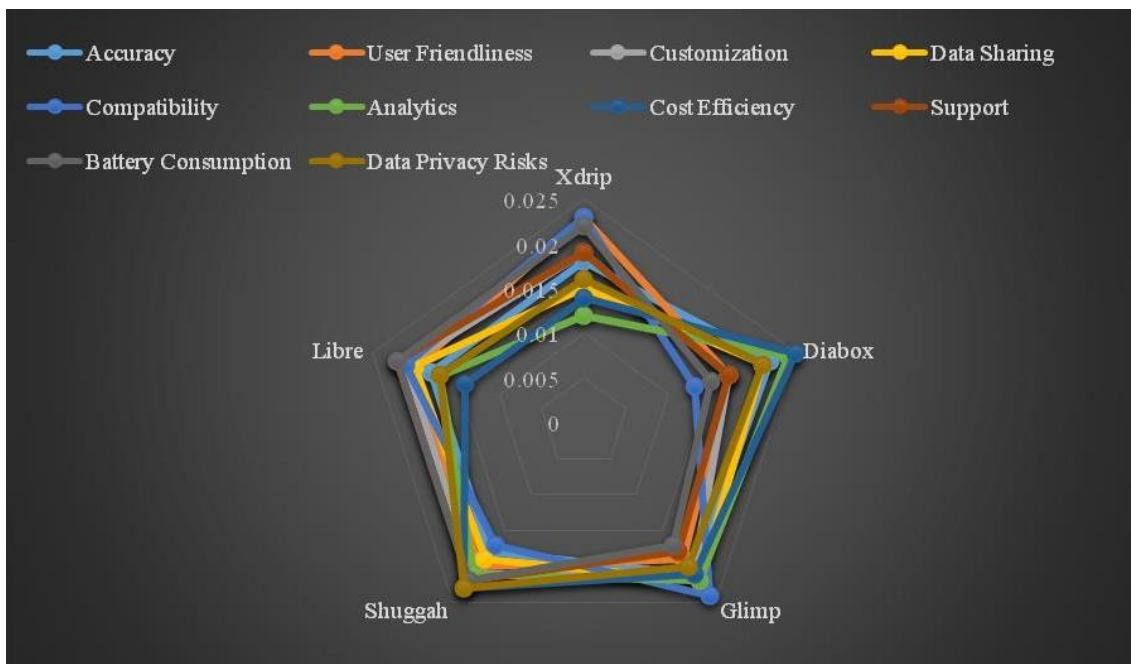
**Table-14 Weighted- Normalized decision matrix**

	Accuracy	User Friendliness	Customization	Data Sharing	Compatibility	Analytics	Cost Efficiency	Support	Battery Consumption	Data Privacy Risks
Xdrip	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.02	0.02	0.02
Diabox	0.02	0.02	0.02	0.02	0.01	0.02	0.03	0.02	0.02	0.02
Glimp	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Shuggah	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Libre	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.02	0.02

Table 14 presents the weighted-normalized decision matrix for five CGM apps — Xdrip, Diabox, Glimp, Shuggah, and Libre — evaluated across ten critical usability factors: Accuracy, User Friendliness, Customization, Data Sharing, Compatibility, Analytics, Cost Efficiency, Support, Battery Consumption, and Data Privacy Risks. Accuracy wise, Diabox got the highest mark of 0.02, then Glimp with a close 0.02 score, with Xdrip, Shuggah, and Libre, having a low score of 0.02. On User Friendliness, Xdrip scored the highest at 0.02, Glimp (0.02), Shuggah (0.02), and Libre (0.02) were not far behind at 0.017. The score of Glimp, Shuggah, and Libre was 0.02, as well as Customization, and Xdrip and Diabox were a

bit lower. Glimp has recorded the highest score (0.02) in the Data Sharing criterion, which is then followed by Diabox (0.02), Libre (0.02), Shuggah (0.02), and Xdrip (0.01), showing that Xdrip had a lower score in this aspect. On Compatibility, Glimp scored the highest (0.02) which indicates high platform adaptability whereas Diabox scored much lower at 0.01. Analytics wise Diabox was the best with 0.02 points with Xdrip as the worst with 0.01. On the aspect of Cost Efficiency, Diabox had the highest value (0.03) which shows its financial sustainability, but on the other hand, Xdrip and Libre recorded the lowest (0.01). Shuggah and Libre were the most successful with 0.02 in Support, and Xdrip barely ahead of Diabox. Battery Consumption had better normalised scores with Xdrip, Shuggah, and Libre (all 0.02), with Diabox the lowest score of 0.01. Lastly, in the case of Data Privacy Risks, Shuggah got the highest weighted score (0.02), followed by Xdrip and Libre (0.02 and 0.02 respectively). All in all, Glimp had good performance in most variables with consistent performance, but Diabox was stronger in cost-related variables and lower in compatibility and battery related variables, Xdrip was moderate but marginally lower in critical parameters related to the user compared to others, and Shuggah and Libre offered a more equal performance on the parameters of usability.

Figure-4 Radar Chart: Weighted-Normalized Decision Matrix

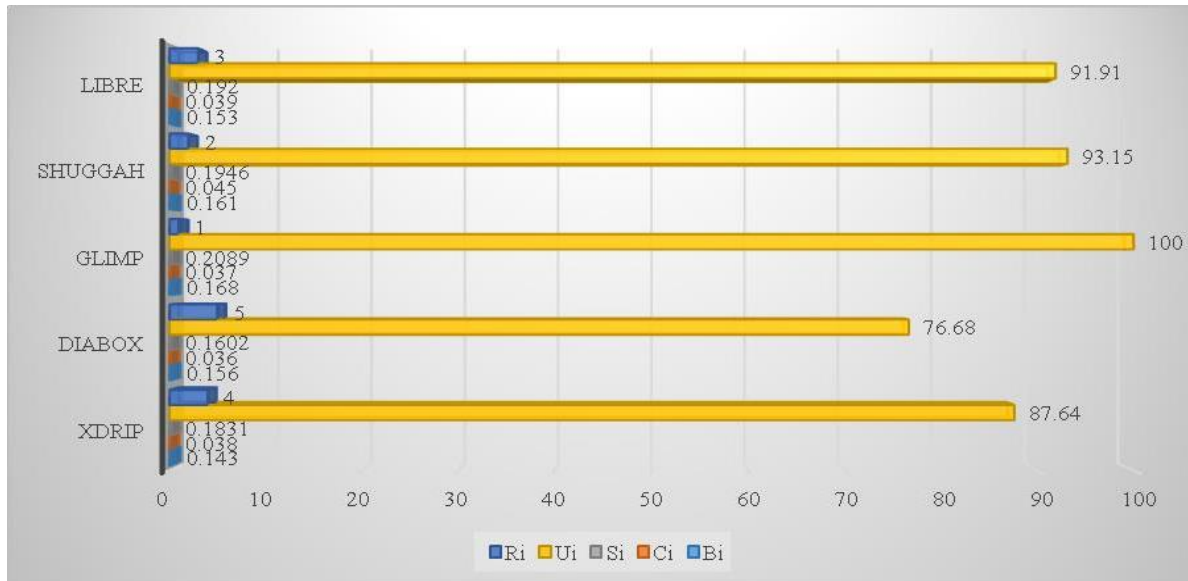


**Table-15 Ranking of mHealth application usability:**

	$B_i$	$C_i$	$S_i$	$U_i$	$R_i$
Xdrip	0.143	0.038	0.1831	87.64	4
Diabox	0.156	0.036	0.1602	76.68	5
Glimp	0.168	0.037	0.2089	100	1
Shuggah	0.161	0.045	0.1946	93.15	2
Libre	0.153	0.039	0.192	91.91	3

Table 15 shows the ranking of mHealth applications usability on the basis of five parameters i.e.  $B_i$  (Benefit Index),  $C_i$  (Cost Index),  $S_i$  (Suitability Index),  $U_i$  (Usability Score) and  $R_i$  (Overall Rank). The highest performance was found in application Glimp with the benefit Index of 0.168, their cost Index of 0.037, and their highest Suitability Index of 0.2089 resulting in the highest Usability Score of 100 and 1st position. Shuggah was placed at position two with the highest Benefit Index of 0.161, the lowest Cost Index of 0.045 in all the apps, and the best Suitability Index of 0.1946 leading to Usability Score of 93.15. Libre got the third position with a Benefit Index of 0.153, Cost Index of 0.039 and Suitability Index of 0.192 resulting in a Usability Score of 91.91. Xdrip was placed at position four, the Benefit Index of the product was 0.143, the Cost Index was 0.038, the Suitability Index was 0.1831 and Usability Score was 87.64. Although Diabox has a good Benefit Index of 0.156 and the lowest Cost Index of 0.036, it had the lowest Suitability Index of 0.1602 and Usability Score of 76.68, which ranked it fifth. By and large, Glimp proved to be the most beneficial, least costly, and most appropriate, with the next two according to usability being Shuggah and Libre but in that order in terms of overall usability. Diabox was the least practical, although relatively cheaper.

Figure-5 Bar Chart of Utility Scores (U<sub>i</sub>)



### Interpretation of Ui Scores

The application that has the largest utility level (Ui) in this study was scaled to 100 and was used as the reference point (Glimp = 100). Other apps were measured against this standard; a Ui of 85 instead of meaning that the reference app was found to be 100% better than the other apps. Therefore, the Ui values are to be considered as comparative standards, rather than the ones of effective superiority.

### Discussion:

The AI can be used to optimise the framework through adaptive weighting, predictive modelling, and feedback clustering. Generalizability and procurement decisions will be enhanced through the use of broader expert panels, sensitivity analysis and association with clinical outcomes (e.g., time-in-range). The paper adopted TFNs instead of the trapezoidal or other fuzzy sets. This was done in order to simplify the process and make expert ratings easy to use. Even though trapezoidal fuzzy numbers are more flexible to represent uncertainty, the past literature demonstrates that TFNs are adequate and are widely used in MCDM involving healthcare scenarios. Future research can explore the hypothesis of whether different fuzzy sets (e.g., trapezoidal, Gaussian) can lead to a material change in the app rankings.

Even though not used specifically in this study, the standardised usability tools (e.g., the System Usability Scale (SUS) (Brooke, 1996) and the Mobile App Rating Scale (MARS)) (Stoyanov et al., 2015) are conceptually consistent with domains represented by each of these tools. MARS still finds application in diabetes app appraisals (Saliassi et al., 2024) and more widespread digital health interventions (Veluvali et al., 2025) which are still relevant today in

benchmarking the usability of mobile health applications. Future studies must include direct SUS/MARS testing and fuzzy MCDM models in the study to give good external validation and complement other available app evaluation studies.

In order to further validate our rankings that were based on the professional opinions, we cross-tested our results with the results of published user-trial studies of diabetes mobile health applications. As an example, Stephen et al. (2022) discovered that mHealth applications in type 1 diabetes helped to increase treatment satisfaction but emphasised the usability issues, which align with our described criteria. The results of the clinical trial conducted by Herrero et al. (2024) on the Accu-Chek Smart Guide Predict app demonstrate a high level of accuracy in predicting glucose, which confirms our underlining of accuracy and reliability as being very important as usability factors. In the same manner, Sherazi et al. (2024) evaluated Diabetes:M in rural Bosnia-Herzegovina and found that bolus calculators and reporting tools were more satisfactory to the users, which corresponds with our findings regarding the significance of analytics and functionality. These agreements with empirical user-trial results give secondary validation of the Fuzzy-COPRAS results in this paper.

### **Clinical Relevance of $U_i$ Values**

The  $U_i$  scores generated by Fuzzy-COPRAS offer a structured, quantitative means of ranking CGM applications, but they should be interpreted as relative indices of usability. While Glimp was ranked highest, this reflects performance across the selected criteria and weights, rather than an absolute claim of clinical superiority. Future studies should link these mathematical rankings to empirical usability outcomes (e.g., patient satisfaction, adherence rates, or error reduction) to strengthen the clinical interpretation of  $U_i$  scores.

### **Conclusion**

This study looked at five Continuous Glucose Monitoring (CGM) applications using ten usability and performance criteria with the Fuzzy COPRAS technique. Due to its strengths in analytics, data sharing, and compatibility, which are clinically beneficial for people with Type 1 Diabetes, Glimp was chosen as the top app. These features help with long-term glycemic management, enhance communication between clinicians and patients, and aid real-time decision-making. All of this supports Glimp's leading position.

### **Limitations**

Despite its contributions, the current study has a number of constraints. Firstly, without direct input of the end-user, they based the assessment on expert input thus limiting the possibility

of capturing the patient-centred views and we explicitly acknowledge the small and homogeneous expert panel from Delhi/NCR limits external validity. Second, the investigation did not include real-world performance data like longitudinal clinical performance, app-store ratings and downloaded numbers. Lastly, only five applications were involved in the sample, which may limit the applicability of the results.

### **Future Scope**

To address the limitations identified, the future research should use a more structured approach to weighting the evaluation criteria, including the Delphi method or the Analytic Hierarchy Process (AHP), to narrow down on the prioritisation of the evaluation criteria identified in the previous study. Moreover, these researches ought to recruit greater and more diverse expert groups and carry out patient-focused usability tests. The future assessments of the continuous glucose monitoring (CGM) apps should reflect empirical usage data and explore new facets, such as medical device interoperability, personalised artificial intelligence (AI) event notifications and analytics, integration with electronic health records (EHR), and effective data governance mechanisms that would protect privacy and guarantee regulatory adherence.

future work should include a larger, geographically diverse panel of clinicians, patients, and informatics specialists. The anecdotal experiments with end users indicate that user satisfaction and enhanced effectiveness of the therapy increase with streamlined interfaces, wide device compatibility, and affordability. In order to foster the usability, the credibility, and adoption of CGM applications, one will have to utilise the most up-to-date technologies, including artificial intelligence (Veluvali et al., 2025; Ying et al., 2025), integrate with the EHR systems smoothly (Lin et al., 2025), and meet the requirements of interoperability (Ndlovu et al., 2021), as well as reinforce the governance mechanisms. this study is based on expert judgments, future work should triangulate the F-COPRAS rankings with empirical usability metrics from actual T1D users. Validated tools such as the System Usability Scale (SUS), Mobile App Rating Scale (MARS), and User Experience Questionnaire (UEQ) can be used to collect end-user data on usability, engagement, and satisfaction. A mixed- methods follow-up study combining F-COPRAS with SUS/MARS scores would strengthen the ecological validity and clinical relevance of the model.

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### **Conflict of Interest**

In this regard, the authors have no conflicts of interest to report regarding the publication of this paper. The study was performed in a blinded manner and the authors of this research declare they have no conflicts of interest. The results were analyzed and all assessments and data analysis were done objectively so as to maintain scientific neutrality during the conduct of the study.

### **Conflict of interest disclosures for experts**

All three experts confirmed that they had no financial or professional conflicts of interest with any of the CGM apps (Glimp, xDrip, Shuggah, Diabox, Libre) evaluated in this study. Their participation was voluntary, and they did not receive any monetary or institutional benefit for their contributions. The results were analyzed and all assessments and data analysis were done objectively so as to maintain scientific neutrality during the conduct of the study.

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### **Ethical Considerations and Consent**

Since the study did not involve patients or identifiable medical data, formal Institutional Review Board (IRB)/Ethics Committee approval was not sought. However, writing informed consent was done beforehand by all three experts. The author has signed consent forms that are stored safely and can be provided to the Editor upon request though these are not publicly disclosed to ensure confidentiality to participants.

### **Reference**

Brooke, J. (1996). SUS: A quick and dirty usability scale. In P. W. Jordan, B. Thomas, B. A. Weerdmeester, & I. L. McClelland (Eds.), *Usability Evaluation in Industry* (pp. 189–

- 194). London: Taylor & Francis.
- Önüt, S., Kara, S. S., & Isik, E. (2009). Long term supplier selection using a combined fuzzy MCDM approach: A case study for a telecommunication company. *Expert Systems with Applications*, 36(2), 3887–3895.
- Stoyanov, S. R., Hides, L., Kavanagh, D. J., Zelenko, O., Tjondronegoro, D., & Mani, M. (2015). Mobile app rating scale (MARS): A new tool for assessing the quality of health mobile apps. *JMIR mHealth and uHealth*, 3(1), e27. <https://doi.org/10.2196/mhealth.3422>
- Nguyen, H.-T., Dawal, S. Z. M., Nukman, Y., Aoyama, H., & Case, K. (2015). An integrated approach of fuzzy linguistic preference based AHP and fuzzy COPRAS for machine tool evaluation. *PLoS ONE*, 10(9), e0133599. <https://doi.org/10.1371/journal.pone.0133599>
- Lanzola, G., Losiouk, E., Del Favero, S., Facchinetti, A., Galderisi, A., Quaglini, S., Magni, L., & Cobelli, C. (2016). Remote blood glucose monitoring in mHealth scenarios: A review. *Sensors*, 16(12), 1983. <https://doi.org/10.3390/s16121983>
- Knight, B. A., McIntyre, H. D., Hickman, I. J., & Noud, M. (2016). Qualitative assessment of user experiences of a novel smartphone application designed to support flexible intensive insulin therapy in type 1 diabetes. *BMC Medical Informatics and Decision Making*, 16, 119. <https://doi.org/10.1186/s12911-016-0356-6>
- Zhou, R., & Chan, A. H. S. (2017). Using a fuzzy comprehensive evaluation method to determine product usability: A proposed theoretical framework. *Work*, 56(1), 9–19. <https://doi.org/10.3233/WOR-162474>
- Vettoretti, M., Cappon, G., Acciaroli, G., Facchinetti, A., & Sparacino, G. (2018). Continuous glucose monitoring: Current use in diabetes management and possible future applications. *Journal of Diabetes Science and Technology*, 12(5), 1064–1071. <https://doi.org/10.1177/1932296818774078>
- Fernández-Caramés, T. M., & Fraga-Lamas, P. (2018). Design of a fog computing, blockchain and IoT-based continuous glucose monitoring system for crowdsourcing mHealth. *Proceedings*, 4(37). <https://doi.org/10.3390/ecsa-5-05757>
- Barata, J. J. R., Munoz, R., de Carvalho Silva, R. D., Rodrigues, J. J. P. C., & de

- Albuquerque, V. H. C. (2019). Internet of Things based on electronic and mobile health systems for blood glucose continuous monitoring and management. *IEEE Access*, 7, 175116-175125. <https://doi.org/10.1109/ACCESS.2019.2956745>
- Wang, S., Li, B., & Zhu, Y. (2019). Comprehensive evaluation of usability at the mobile end interface. *IOP Conference Series: Materials Science and Engineering*, 573(1), 012037. <https://doi.org/10.1088/1757-899X/573/1/012037>
- Georgsson, M., Stagers, N., Årsand, E., & Kushniruk, A. (2019). Employing a user-centered cognitive walkthrough to evaluate a mHealth diabetes self-management application: A case study and beginning method validation. *Journal of Biomedical Informatics*, 91, 103110. <https://doi.org/10.1016/j.jbi.2019.103110>
- Ndlovu, K., Mars, M., & Scott, R. E. (2021). Interoperability frameworks linking mHealth applications to electronic record systems. *BMC Health Services Research*, 21, 6473.
- Stephen, D. A., Nordin, A., Nilsson, J., & Persenius, M. (2022). Using mHealth applications for self-care: An integrative review on perceptions among adults with type 1 diabetes. *BMC Endocrine Disorders*, 22, 138. <https://doi.org/10.1186/s12902-022-01039-x>
- Eghbali-Zarch, M., Tavakkoli-Moghaddam, R., Esfahanian, F., & Masoud, S. (2022). 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. <https://doi.org/10.1007/s11517-022-02602-3>
- Schubert-Olesen, O., Kröger, J., Siegmund, T., Thurm, U., & Halle, M. (2022). Continuous Glucose Monitoring and Physical Activity. *International Journal of Environmental Research and Public Health*, 19(19), 12296. <https://doi.org/10.3390/ijerph191912296>
- Gupta, K., Roy, S., Poonia, R. C., Nayak, S. R., Kumar, R., Alzahrani, K. J., Alnfai, M. M., & Al-Wesabi, F. N. (2022). Evaluating the usability of mHealth applications on type 2 diabetes mellitus using various MCDM methods. *Healthcare*, 10(1), 4. <https://doi.org/10.3390/healthcare10010004>
- Gupta, K., Roy, S., Poonia, R. C., Kumar, R., Nayak, S. R., Altameem, A., & Saudagar, A. K. J. (2022). 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. <https://doi.org/10.3390/app12094156>

- Yilmaz, I. (2023). A hybrid DEA–Fuzzy COPRAS approach to the evaluation of renewable energy: A case of wind farms in Turkey. *Sustainability*, 15(14), 11267. <https://doi.org/10.3390/su151411267>
- Ma, J., Wang, W., Li, J., & Xu, W. (2023). Usability evaluation of co-pilot screen based on fuzzy comprehensive evaluation method. *World Electric Vehicle Journal*, 14(8), 219. <https://doi.org/10.3390/wevj14080219>
- Sherazi, B. A., Laeer, S., Krutisch, S., Dabidian, A., Schlottau, S., & Obarcanin, E. (2023). Functions of mHealth diabetes apps that enable the provision of pharmaceutical care: Criteria development and evaluation of popular apps. *International Journal of Environmental Research and Public Health*, 20(1), 64. <https://doi.org/10.3390/ijerph20010064>
- Zivkovic, J., Mitter, M., Theodorou, D., Kober, J., Mueller-Hoffmann, W., & Mikulski, H. (2024). Transitioning from self-monitoring of blood glucose to continuous glucose monitoring in combination with a mHealth app improves glycemic control in people with type 1 and type 2 diabetes. *Diabetes Technology & Therapeutics*. <https://doi.org/10.1089/dia.2024.0169>
- Farrahi, R., Nabovati, E., Bigham, R., & Jeddi, F. R. (2024). Evaluating the usability of Iran’s national comprehensive health information system: A think-aloud study to uncover usability problems in the recording of childcare data. *BMC Medical Informatics and Decision Making*, 24, 341. <https://doi.org/10.1186/s12911-024-02746-2>
- Sherazi, B. A., Læer, S., Hasanbegovic, S., & Obarcanin, E. (2024). Evaluating usability of and satisfaction with mHealth app in rural and remote areas—Germany GIZ collaboration in Bosnia-Herzegovina to optimize type 1 diabetes care. *Frontiers in Digital Health*, 6, Article 1338857. <https://doi.org/10.3389/fdgth.2024.1338857>
- Herrero, P., et al. (2024). Clinical validation of the Accu-Chek Smart Guide Predict app for glucose prediction in type 1 diabetes. *Diabetes Technology & Therapeutics*, 26(2), 123–132.
- Saliasi, A., et al. (2024). Evaluating the usability of mHealth apps: Adaptation of the MARS scale for diabetes applications. *BMC Medical Informatics and Decision Making*, 24(1), 112.
- Lin, J., et al. (2025). Integrating mobile health app data into electronic health record systems:

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Scoping review. JMIR Medical Informatics, 13(1), e40549960.

Veluvali, V., et al. (2025). Impact of digital health interventions on glycemic control and weight management: Evidence from a large cohort. *npj Digital Medicine*, 8(1), 25.

Ying, X., et al. (2025). Artificial intelligence in glycemic management for diabetes. *Frontiers in Endocrinology*, 16, 12371392.

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