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A Model for Ranking the Usability Attributes of Mobile Health Applications in Nigeria (MCDM Approach)

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Abstract— In Nigeria, the mobile health trend is gradually improving and generally upgrading the way healthcare services are being rendered. Assessing the usability of these apps is still a major task as a result of the many attributes embedded in most usability models. In other to rank some of these attributes, a Multi-Criteria Decision Making technique (MCDM) was used. The attributes ranked were adopted from the Enhanced Usability Model (EUM) which was designed based on the People at the Center of Mobile Application Development (PACMAD) model and the Integrated Measurement Model (IMM). Attributes were ranked using their priority weights based on the Triangular Fuzzy Numbers (TFN) and Fuzzy Chang extent analysis model. Results of evaluation showed that effectiveness and efficiency had the highest priorities with 40% and 33% while satisfaction, user interface aesthetics and universality had the lowest ranks. Three mHealth apps were analyzed and results showed that Omomi had the highest ranking with a weight of 41%, Find-A-Med ranked second with a weight of 30% while Hudibia ranked lowest with a weight of 29%. In conclusion, it was established that the mathematical technique used is a powerful tool for analyzing human decision-making process. Future works would consider other MCDM models and comparisons done.

Keywords/Index Terms— FAHP, Fuzzy Chang Extent Analysis Model, Mhealth Applications, MCDM, Usability Models

1. Introduction

In Nigeria, the health sector is choked up and there currently exist a dearth of professionals in the health sector as a result of migration to more developed countries as a result of poor remuneration and low standard of living. Recent studies corroborated this assertion as it was recently reported that the doctor to patient ratio currently is four doctors per 10,000 patients as against global recommendations (Adegoke, 2019). According to Adebara, Adebara, Olaide, Emmanuel and Olanrewaju, 2017), other issues currently plaguing the Nigerian health sector include hitches in moving to and fro to access a medical center/clinic as a result of bad roads and high cost of transportation, long waiting period used to see an over-stressed medical personnel, overcrowding, high cost of health care amongst other issues. In order to reach out to more patients and increase the quality of health care, mobile health care is an emerging trend that continues to offer effective tools and prompt awareness which provide solutions for both the patients and other stakeholders in the health sector (Oguntimilehin, & Ademola, 2014).

The subscription for mobile broadband continues to increase at an astronomical level as the International Telecommunication Union assessed that the total number of internet subscribers increases from 43 million in 2007 to about 123 million in 2019. Portable, wireless and smart devices are now highly accessible on the internet (Adewumi, Omoregbe & Misra, 2016). The mobile health market is gradually becoming saturated with its own share of mHealth apps that continue to provide solutions in various health care domain. Some of such apps include Omomi, a child care app, Hudibia, an app that provides a connection to doctors' health care tips amongst others, MyPaddi, an app that allows youths talk to doctors pertaining to any life issues amongst other great apps. The issue with accessing most of these apps which are developed in Nigeria is that when searching for them on stores such as Google play store, these apps don't come up which is sad in a country with over 200 million people and lots of app developers. A high percentage of the mhealth apps developed in Nigeria are not even listed by SimilarWeb so if some of the most common mhealth apps in Nigeria are not known on a global basis then there is a serious problem.

In spite of the increased attention to mhealth in the country, the number of mhealth solutions that are currently being used and fully implemented is still low (Kenny, O'Connor, Eze, Ndibuagu & Heavin, 2017). This could be as a result of the high complexity involved in the design, implementation and evaluation of such systems (Santos, Misra & Soares, 2020). The first step in proffering a solution to the issues identified is to initially develop a solution providing mhealth and assess its usability even before it gets deployed as it has been shown in various researches that usability is an important quality evaluation construct (Ajayi, et al., 2017). Usability has been identified by numerous researchers as one of the factors for assessing the quality of mobile health applications (mHealth apps). Ascertaining the usability of a product before final implementation would help app developers to be able to design better and more marketable apps in an already congested market. Popular usability attributes include satisfaction, efficiency, and effectiveness amongst others. In trying to evaluate the usability of any app in general, it is observed that some attributes are objective while some are subjective in nature. The problem is on how to evaluate both constructs simultaneously and in other to do this, decision makers or usability experts are needed.

Most usability studies use techniques that are resource consuming in terms of time and cost. The problem is on how to evaluate numerous usability attributes of mHealth apps at once, saving resources and also getting better results. Hence, the focus of this paper is to rank and prioritize the usability attributes of mHealth apps developed in Nigeria using MCDM techniques. In this paper, section 1 talks about the Introduction, literature reviewed and related works were discussed in section 2, section 3 talks about the methodology, section 4 show the results of the analysis and conclusion was done in section 5.

2. Literature Review

Advancement in technology has rapidly improved all aspects of life (Khan, 2020) and the health sector is not an exception ranging from drugs, vaccines, prosthetics, research and even doctor-patient relationship (Mitchel & Khan, 2019). The use of mhealth apps continues to grow exponentially as a result of mobile technologies such as smart phones, wearable and other smart devices. Most developing countries have also embraced the use of mhealth apps to transform their health sector services delivery (Iheme et al., 2017; Iheme et al., 2018). Despite the proliferation of various mhealth solutions, the number of localized functional apps is still few according to Kallander et al., 2013. Kenny et al., 2017 identified usability as one of the reasons for these low statistics. Nielson (1993) defined usability as an important quality constructs with memorability, learnability, efficiency, errors and satisfaction as its components. The International Standard Organization (ISO) 9241-11 defined usability as having three components which include effectiveness, efficiency and satisfaction (Bevan, Carter, Earthy, Geis & Harker, 2016). Numerous researchers have also defined usability as having several components but one unifying component amongst them is ease of use.

How best to evaluate usability has always been a bone of contention amongst researchers and the challenge has always been on ways to measure both the subjective and objective components to get adequate and unbiased results (Hornbæk, 2006). One way that this issue is being handled currently is by applying Multi-Criteria Decision Making (MCDM) techniques that are developed based on mathematical and psychological principles. These techniques make it easier for domain experts to make decisions more accurately when faced situations where there exist conflicting criteria (Boutkhoum, Hanine1, Boukhriss, Agouti, & Tikniouine, 2016). Various MCDM methods have been proposed over the years and what they all have in common is that they judge various available alternatives in order to be able to choose a preferred alternative that will be efficient as well as acceptable by decision makers (Skinner, 2009). This technique has become popular as a result of its effectiveness when decisions need to be made especially in solving complex problems (Rekik, Kallel, Casillas & Alimi, 2016). It has been found to be of high theoretical value and has been applied in different research areas both in the academia and the industry (Mardani *et al*., 2015; Fu & Fan, 2016).

Velasquez & Hester (2013) gave a summarized report of some commonly used MCDM techniques and it was affirmed that the Analytic Hierarchy Process (AHP) technique is simple to use, can be expanded to accommodate future needs and the hierarchical structure specified in it can be easily modified to fit numerous sized problems. It has been widely applied in many domain areas such as to improve human performance (Albayrak & Erensal, 2004), resource allocation (Saaty, Reniwati & Shang, 2007), supplier selection (Hwang, Moon, Chung & Goan, 2004; Kubde, 2012), information management (Li & Yu, 2016), learning (Sinozic & Orehovacki, 2018), solving information systems usability problems (Delice & Gungor, 2009; Byun & Finnie, 2011), energy technology (Siksnelyte-Butkiene, Zavadskas, & Streimikiene, 2020), agriculture (Lin, 2020) amongst others.
AHP as a MCDM technique is a powerful tool for solving ranking, selection and comparison problems especially when it relates to decision making but it can only deal with crisp numbers while in reality, decisions take place in situations that cannot be precisely ascertained as a result of their complex nature. In other to solve this issue, fuzzy logic was proposed by Zadeh (1965) as a modelling technique for solving ill-structured problems and to describe a logical system that aims at formalization of approximate reasoning (Zadeh, 1994). It is a simple and highly applicable problem solving technique that provides an easy way of precise conclusions from ambiguous information (Omar, Waweru & Rimiru, 2015) and has also been widely used in solving MCDM problems (Kahraman, Onar & Oztaysi, 2015).

2.1 Fuzzy Analytic Hierarchy Process (FAHP)

The fuzzy AHP technique was introduced by van Laarhoven and Pedrycz (1983) who compared fuzzy ratios as depicted by triangular membership functions, to overcome the limitations of AHP that can only deal with crisp values in an ever increasing complex situations where important decisions have to be made. As a result of the incapacity of AHP to handle the imprecision, incompleteness and subjective nature of humans during decision making process, the pair-wise comparison procedure has been enhanced in fuzzy AHP. Instead of a crisp value, fuzzy AHP uses a range of value to incorporate the decision maker's uncertainty (Afolayan, Ojokoh & Adetunbi, 2020). FAHP presents a logical, scientific and systematic approach for comparing and weighting multiple criteria and alternatives to decision makers in situations where complete information is not available. As a result of the enormous ability involved in decision making, it has attracted the interest of numerous researchers who continually strive to improve on the technique.

There is simply no standard format for solving FAHP issue as a result of numerous techniques available but they still have to follow the general procedure as outlined by Lin (2020);

i. Define the unstructured problem stating the objectives and goals clearly
ii. Developing the AHP hierarchy indicating criteria and alternatives relating to the problem under study as

depicted in Figure 2.13 which shows a three level hierarchical decision structure with n criteria and m alternatives.

iii. Obtain the fuzzy pairwise comparison from expert(s) by ascribing weights to criteria and alternatives

iv. Approve the weights used and construct the fuzzy pairwise comparison matrix

v. After the judgement matrix has been constructed, defuzzify the fuzzy values

vi. Calculate the eigenvalue and the eigenvector

vii. Perform consistency check by obtaining the consistency ratio

viii. Rank the alternatives by calculating the relative weight of each element in the hierarchical structure

ix. For decision making, choose the alternative and criteria with the highest rank.

Related Works

Table 1 presents some of the related works reviewed focus of study, technique employed, result of analysis, their strengths and limitations.

Table 1: Review of Related Works

S/N	Source	Research Focus	Approach/ Technique	Result(s)	Strengths and Limitations
1	Lamichhane & Meesad, 2011	Evaluated the usability of government websites of Nepal	FAHP	Quantitative and Qualitative usability attributes were able to be quantified, most important usability attribute was identified through the ranking process.	Model can be used by both experts and novice users but it lacks a well-articulated and standardized usability model hierarchical structure.
2	Dubey, Gulati & Rana (2012)	Proposed a method for usability evaluation of software systems.	Fuzzy Multi-criteria weighted average (SAW).	Usability model used was said to integrate many usability attributes and the approach gave a crisp usability result after defuzzification.	SAW is very simple and easy to use although results of analysis may not portray the real situation of things and could also be illogical.
3	Nagpal, Mehrotra, Sharma & Bhatia, 2013	Identified the important factors that affect website usability and proposed usability evaluation method for an educational institute website	ANFIS, Fuzzy logic toolbox in MATLAB, Sugeno model	ANFIS gave a better usability evaluation result than just FIS and could also predict 97% usability evaluation accuracy result.	ANFIS is a powerful tool for solving membership function issues which is common in fuzzy logic systems and also for obtaining fuzzy if-then rules but the model could neither rank nor assign relative importance weight to each usability attributes identified
4	Ayag, 2014	Proposed an intelligent model to assist companies select most suitable CAM software among a set of existing alternatives	FAHP	Result of analysis showed that alternative A had the highest ranking using eigenvector method and system cost (hardware and software) criteria.	Fuzzy numbers allow decision makers to be able to give an estimate of their judgements regarding any selection issues in CAM but a well-structured framework to show the interrelationship between the goals, criteria and alternatives of the problem being solved was absent in this study.

5	Isik, Ince & Yigit, 2015	Proposed a MCDM technique to select the most LMS based on users' needs from a group of 10 LMS	FAHP	Joomla LMS was chosen as the best LMS based from the result of their analysis.	A more reliable and faster result was gotten using this approach as against traditional forms of usability evaluation but the number of criteria proposed was too much for FAHP technique to yield a reliable and valid result with 9 criteria, 16 sub criteria and 10 alternatives.
6	Al-Soub, 2015	Proposed a multi stage fuzzy framework for open source software (OSS) usability	Fuzzy Logic	It was concluded that the stage-wise fuzzy reasoning approach yields a more logical approach to usability evaluation	The stage wise reasoning approach is a good approach for reducing number of rules in fuzzy systems but the model was not validated and it can neither be used to rank nor weigh the relative priority of usability attributes used.
7	Nagpal, Mehrotra, Bhatia & Sharma, 2015	Proposed a hybrid fuzzy MCDM model to rank university website usability	Fuzzy AHP and Fuzzy TOPSIS	It was concluded that there should be a balance between information and response time as w4 had the highest rank.	FAHP approach to usability provides a faster and better results using domain experts. Sensitivity analysis was not done to validate the efficacy of the approach employed.
8	Sanga & Venter, 2015	Proposed an algorithm for assessing the quality of free and open source software (FOSS) in an uncertain situation before such software is adopted	FAHP	From the attributes ranked, operability gave the highest priority value	The algorithm proposed adds more knowledge to the field of computational intelligence and software metrics. Data used for this study was collected between 2007 and 2009 while study was done in 2015. This could have an effect on the final outcome of the analysis considering the relevance of information used.
9	Gupta & Ahlawat, 2016	Tried to solve the complex usability evaluation issue by proposing the Generalized Usability Model and evaluating it.	Fuzzy Logic toolbox in MATLAB, Mamdani fuzzy system and FIS.	The model was just proposed and its applicability tested with a fuzzy based expert system.	The work proposed how to evaluate usability with a fuzzy based system but no validation was done and the model cannot rank usability attributes proposed based on their relative priority.
10	Zhou & Chan, 2017	Proposed a theoretical framework to determine product usability evaluation with the ISO 9241 usability model	FAHP	Compared to AHP, FAHP could capture the uncertainty involved in human decision making process.	The study was able to demonstrate how the uncertainty inherent in human decision making process can be extracted and used for analytical purposes. The approach is still highly theoretical and yet to be tested or Validated
12	Oh, Lee, & Lee (2019)	Proposed a new model for biometric systems usability assessment	Analytic Network Process (ANP) and Decision Making Trial and Evaluation Laboratory Model (DEMATEL)	The approach made it possible for them to be able to show the relationship between identified usability factors and their corresponding weights with privacy concerns ranking the highest.	The work emphasized more on the security aspect of information systems.

In lieu of the related works reviewed, it is evidently observed that evaluating the subjective and objective usability attributes of mobile health apps developed in Nigeria using MCDM techniques for efficient decision making is an area that is yet to be explored.

2.2 Basic Concepts and Definitions on Fuzzy Sets

Definition 1: If X is a collection of objects denoted by x, then a fuzzy set Ã in X is a set of ordered pairs:

$$\tilde{A} = \{(x, \mu_{\tilde{A}}(x)) \mid x \in X\}$$

where $\mu_{\tilde{A}}(x)$ is the membership function.

The range of the membership function is a subset of the non-negative real numbers whose suprenum is finite (Zimmermann, 2001).

Definition 2: A membership function (MF) is a curve that defines how each point in the input space is mapped to a membership value between 0 and 1 (Mandal, Choudhury & Chaudhuri, 2014).

Fuzzy membership functions are the building blocks of fuzzy sets. They were introduced to deal with the uncertainties inherent in making real life decisions and it is said to be subjective in nature (Singpurwalla & Booker, 2004). There presently exists different kinds of membership functions with various shapes and based on this, different types of fuzzy sets can be obtained. They enable linguistic terms to be quantified and for fuzzy sets to be represented graphically.

Definition 3: A normalized fuzzy set is one such that $\mu_{\tilde{A}}(x) = 1$ i.e. the maximum membership value is 1.

There exist different types of membership functions which include simple triangular and trapezoidal which are linear alongside Gaussian, bell shaped, pi-shaped, and sigmoidal shaped which are non-linear. The only rule is that they must be between 0 and 1. Zadeh categorized those with straight lines as being linear and curved ones as being non-linear. Various researches has shown that the linear shaped membership functions are simple to use, easy to implement, do not add unnecessary complexity to systems and are widely used (Nadaban, Dzitac & Dzitac, 2016; Nagpal, Mehrotra, Bhatia, & Sharma, (2015).

Definition 4: A triangular membership function A is defined by a lower limit a_1, upper limit a_3 and a value a_2, where $a_1 < a_2 < a_3$ where x is the mean value of A and a_1, a_2 and a_3 are real numbers as depicted in Figure 1 and given by equation (1):

$$\mu_{(A)}(x) = \begin{cases} 0, & x < a_1 \\ \dfrac{x - a_1}{a_2 - a_1}, & a_1 \le x \le a_2 \\ \dfrac{a_3 - x}{a_3 - a_2}, & a_2 \le x \le a_3 \\ 0, & x > a_3 \end{cases} \quad (1)$$

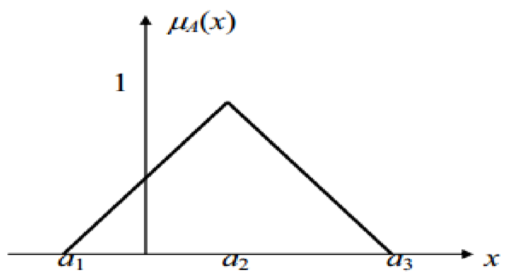

Figure 1: Triangular Fuzzy Number (TFN) (a_1, a_2, a_3)

Properties of TFN as identified by Lee, 2005 include:

i. Addition or subtraction between TFNs yields a TFN result.
ii. Multiplication and division of TFNs does not yield a TFN result.

iii. Maximum or minimum operation does not give TFN but can be approximated by TFNs.

Operations of Triangular Fuzzy Number (TFN)

The operations on TFNs include addition, multiplication and inverse operations according to the extension principles. Suppose M_1 and M_2 are two non-negative TFNs where $M_1 = (a_1, a_2, a_3)$ and $M_2 = (b_1, b_2, b_3)$, and $\alpha \in \mathbf{R}^+$ then the following holds:

i. $M_1 (+) M_2 = (a_1 + b_1, a_2 + b_2, a_3 + b_3)$
ii. $M_1 (-) M_2 = (a_1 - b_3, a_2 - b_2, a_3 - b_1)$
iii. $\alpha M_1 = (\alpha a_1, \alpha a_2, \alpha a_3)$
iv. $M_1 (x) M_2 \approx (a_1 \cdot b_1, a_2 \cdot b_2, a_3 \cdot b_3)$
v. $M_1^{-1} \approx (a_1, a_2, a_3)^{-1} \approx (1/a_3, 1/a_2, 1/a_1)$
vi. $M_1/M_2 \approx (a_1/b_3, a_2/b_2, a_3/b_1)$

Definition 5: A trapezoidal membership function is defined by a lower limit a_1, an upper limit a_4, a lower support limit a_2 and an upper support limit a_3 as shown in Figure 2 and given by equation 2:

$$\mu_{(A)}(x) = \begin{cases} 0, & x < a_1 \\ \dfrac{x - a_1}{a_2 - a_1}, & a_1 \le x \le a_2 \\ 1, & a_2 \le x \le a_3 \\ \dfrac{a_4 - x}{a_4 - a_3}, & a_3 \le x \le a_4 \\ 0, & x > a_4 \end{cases} \quad (2)$$

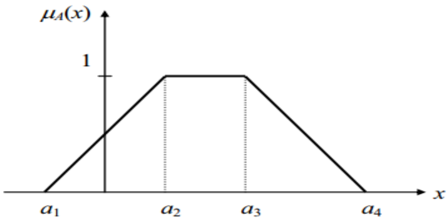

Figure 2: Trapezoidal Fuzzy Number (TrFN) (a_1, a_2, a_3, a_4)

Operations on Trapezoidal Fuzzy Number (TrFN)

Suppose M_1 and M_2 are two non-negative TFNs where $M_1 = (a_1, a_2, a_3, a_4)$ and $M_2 = (b_1, b_2, b_3, b_4)$, and $\alpha \in \mathbf{R}^+$ then the following holds:

i. $M_1 (+) M_2 = (a_1 + b_1, a_2 + b_2, a_3 + b_3, a_4 + b_4)$
ii. $M_1 (-) M_2 = (a_1 - b_4, a_2 - b_3, a_3 - b_2, a_4 - b_1)$
iii. $\alpha M_1 = (\alpha a_1, \alpha a_2, \alpha a_3, \alpha a_4)$
iv. $M_1 (x) M_2 \approx (a_1 \cdot b_1, a_2 \cdot b_2, a_3 \cdot b_3, a_4 . b_4)$
v. $M_1^{-1} \approx (a_1, a_2, a_3, a_4)^{-1} \approx (1/a_4, 1/a_3, 1/a_2, 1/a_1)$
vi. $M_1/M_2 \approx (a_1/b_4, a_2/b_3, a_3/b_2, a_4/b_1)$

Definition 6: According to Zadeh (1975), a linguistic variable in fuzzy logic is defined as a variable whose values are words or sentences in a natural or artificial language. For example, height is a linguistic variable if its values are verbal rather than numerical, such values includes: tall, not tall, very tall, extremely tall and quite tall instead of the use of crisp numbers.

3. Methodology

In this paper, a MCDM optimization model used to rank usability attributes of three mHealth apps developed in Nigeria based on their weights. This was needed for improving decision-making by developers in order to optimally minimize resources used during mHealth app development. It was also needed for increasing the level of usability and integration of mHealth apps by users and on different platforms' application store. Fuzzy logic was integrated with Analytic Hierarchy Process (AHP) in order to make better judgement when decision makers are faced with uncertainty or incomplete decisions.

3.1 Enhanced Usability Model (EUM)

The EUM was proposed by Kasali *et al.* (2019) for specifically assessing the usability of mobile applications during and after development to optimize resources and for increased usability (see Figure 3). The model was designed based on the usability factors specified in the People at the Center of Mobile Application Development (PACMAD) proposed by Harrison Flood & Duce (2013) and the Integrated Measurement Model (IMM) proposed by Hasan & Al-Sarayreh (2015) respectively.

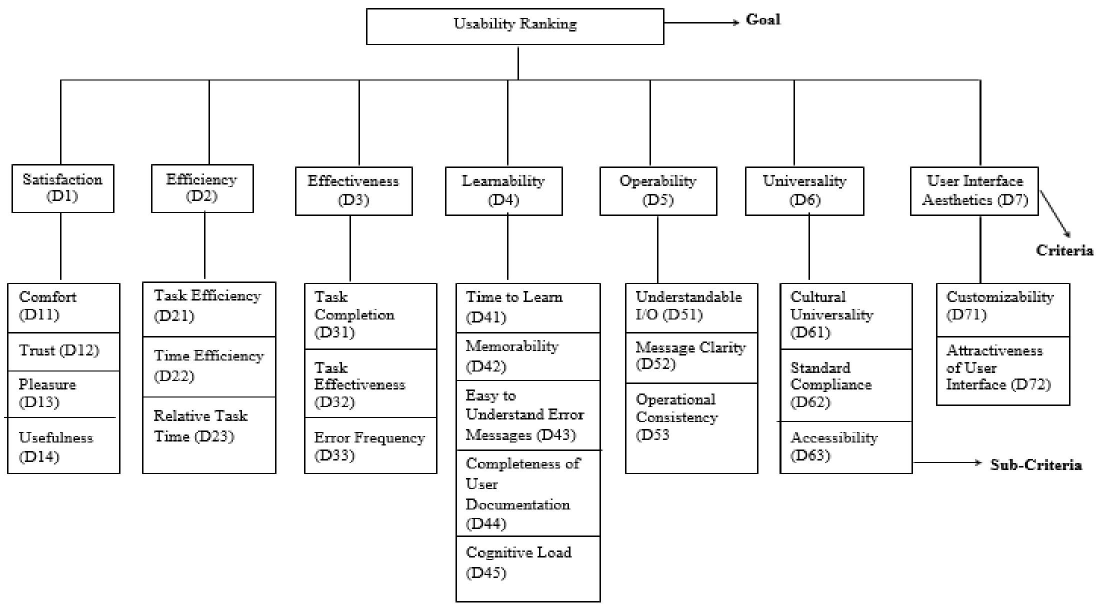

Figure 3: The Enhanced Usability Model (Kasali *et al.*, 2019)

For the purpose of this study, potential users and application developers were chosen purposively and randomly. Participants' commitment was totally ensured, measuring tool was standardized and data collected was anonymized. It was necessary that respondents understand some basic computer science principles, app design and the meaning of each criteria and sub-criteria specified in the usability model. For the evaluation and comparison of selected mHealth apps, a group of five decision makers performed cognitive walkthrough using the attributes specified in the EUM.

Pairwise comparisons were obtained from decision makers by allocating weights to criteria and sub-criteria.This was achieved by using Saaty's 1-9 numerical scale (Saaty, 2008) and by the fuzzification of the linguistic variables using triangular fuzzy numbers which has been justified from literature reviewed to be easy, simple to implement and has been widely used in solving fuzzy MCDM problems. Linguistic variables used correlate with the ones proposed by Tan, Lu and Zhang (2016) while the membership values used was adopted from Nuhodzic, Macura, Bojovic,

& Milenkovic (2010) as depicted in table 2.

Table 2: Linguistic Scale

Saaty's scale	Linguistic Variable for criteria	Linguistic Variable for alternatives	Corresponding TFN membership values (l,m,u)	Reciprocal of TFN (1/u,1/m,1/l)
1	Same level of significance	equally favored	(1,1,1)	(1,1,1)
2	between equal and moderately significant	between equal and moderately favored	(1,2,3)	(1/3,1/2,1)
3	moderately significant	moderately favored	(1,3,5)	(1/5,1/3,1)
4	between moderately and more significant	between moderately and more favored	(2,4,6)	(1/6,1/4,1/2)
5	more important	more favored	(3,5,7)	(1/7,1/5,1/3)
6	between more and strongly significant	between more and strongly favored	(4,6,8)	(1/8,1/6,1/4)
7	strongly significant	strongly favored	(5,7,9)	(1/9,1/7,1/5)
8	between strongly and extremely significant	between strongly and extremely favored	(6,8,9)	(1/9,1/8,1/6)
9	extremely significant	extremely favored	(7,9,9)	(1/9,1/9,1/7)

In order to get the fuzzy weights, extent analysis method was used and this was introduced by Chang (1996) for handling fuzzy AHP by using TFN for pair-wise comparison scale and the extent analysis method for analyzing the synthetic extent values of pair-wise comparisons.

3.3 Steps in Chang's Extent Analysis Method

Step 1: The value of fuzzy synthetic extent with respect to the *ith* object is defined as:

$$S_i = \sum_{j=1}^{m} \widetilde{M}_{g_i}^{j} \otimes \left[\sum_{i=1}^{n}\sum_{j=1}^{m} \widetilde{M}_{g_i}^{j}\right]^{-1} \quad (3)$$

where: $\otimes$ signifies the extended multiplication of two fuzzy numbers.

In order to obtain $\sum_{j=1}^{m} \widetilde{M}_{g_i}^{j}$, an addition of m extent analysis values was performed for a particular matrix such that:

$$\sum_{j=1}^{m} \widetilde{M}_{g_i}^{j} = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j\right) \quad (4)$$

And to obtain $[\sum_{i=1}^{n}\sum_{j=1}^{m} \widetilde{M}_{g_i}^{j}]^{-1}$ a fuzzy addition operation of $\widetilde{M}_{g_i}^{j}$ (j =1,2,…,m) values was performed, such that:

$$\sum_{i=1}^{n}\sum_{j=1}^{m} \widetilde{M}_{g_i}^{j} = \left(\sum_{i=1}^{n} l_i, \sum_{i=1}^{n} m_i, \sum_{i=1}^{n} u_i\right) \quad (5)$$

Then, the inverse of the vector is computed as:

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m}\widetilde{M}_{g_i}^{j}\right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n}u_i}, \frac{1}{\sum_{i=1}^{n}m_i}, \frac{1}{\sum_{i=1}^{n}l_i}\right) \quad (6)$$

Where u_i , m_i , $l_i > 0$

Finally, to obtain the S_j, the following multiplication was performed:

$$\mathbf{S_i} = \sum_{j=1}^{m}\widetilde{M}_{g_i}^{j} \otimes \left[\sum_{i=1}^{n}\sum_{j=1}^{m}\widetilde{M}_{g_i}^{j}\right]^{-1} = \left(\sum_{j=1}^{m} l_j \otimes \sum_{i=1}^{n} l_i, \sum_{j=1}^{m} m_j \otimes \sum_{i=1}^{n} m_i, \sum_{j=1}^{m} u_j \otimes \sum_{i=1}^{n} u_i\right) \quad (7)$$

Step 2: The degree of possibility of $\widetilde{M}_2 = (l_2, m_2, u_2) \geq \widetilde{M}_1 = (l_1, m_1, u_1)$ is defined as

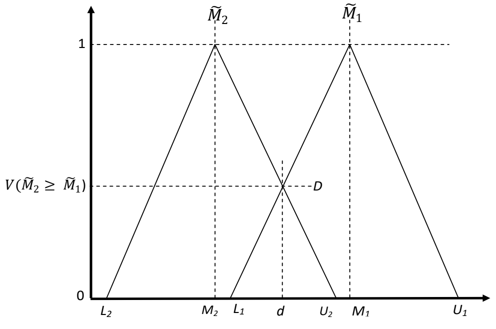

Figure 4: The Degree Of Possibility Of $\widetilde{\boldsymbol{M}}_1 \geq \widetilde{\boldsymbol{M}}_2$

$$V(\breve{M}_2 \geq \breve{M}_1) = \sup\left[min\left(\breve{M}_1(x), \breve{M}_2(y)\right)\right] \quad (8)$$

This can be equivalently expressed as:

$$V(\breve{M}_2 \geq \breve{M}_1) = hgt(V(\breve{M}_2 \cap \breve{M}_1) = \breve{M}_2(d) = \begin{cases} 1, & if \quad m_2 \geq m_1 \\ 0, & if \quad l_1 \geq u_2 \\ \dfrac{l_1 \geq u_2}{(m_2 - u_2) - (m_1 - l_1)}, & otherwise \end{cases} \quad (9)$$

Figure 3 illustrates V ($\widetilde{M}_2 \geq \widetilde{M}_1$) for the case d for the case $m_1 < l_1 < u_2 < m_1$, where d is the abscissa value corresponding to the highest crossover point D between $\widetilde{M}_1$ and $\widetilde{M}_2$,To compare $\widetilde{M}_1$ and $\widetilde{M}_2$, we need both of the values V($\widetilde{M}_1 \geq \widetilde{M}_2$) and V($\widetilde{M}_2 \geq \widetilde{M}_1$).

Step 3: The degree of possibility for a convex fuzzy number to be greater than k convex fuzzy numbers M_i(i=1, 2… K) defined as:

$$V(\breve{M} \geq \breve{M}_1, \breve{M}_2, \dots, \breve{M}_K) = \min\left(V(\breve{M}_2 \geq \breve{M}_1)\right), i = 1,2, \dots, k$$

Step 4:

Finally, $W = (\min(V(s_1 \geq s_k)), \min(V(s_2 \geq s_k)), \dots, \min(V(s_1 \geq s_k)))^T$ is the weight vector for *k=1, 2. . . n.* Finally, for the purpose of decision making, the criteria with the highest rank was chosen.

3.4 Mobile Health Applications Evaluated

Three popular mhealth apps that were developed in Nigeria were selected based on widespread and general review of their objectives, functionalities and based on their number of downloads. The apps evaluated include *Omomi*; an app designed for nursing mothers, *Hudibia*, a telemedicine mobile app that helps users connect to health care professionals, book clinic appointments amongst other numerous functions and *Find-A-Med*, which is a mobile directory that helps users locate health facilities by using GPS. The usability constructs ranked by the respondents include Satisfaction, Efficiency, Effectiveness, Learnability, Operability, Universality and User Interface Aesthetics. All these were done according to the guidelines provided for each construct in the EUM.

4. Results and Discussions

Table 3 shows the result of the Fuzzy pairwise obtained alongside the resulting weight with respect to the criteria

Table 3: The Fuzzy comparison matrix of main decision criteria with respect to the goal

	D_1	D_2	D_3	D_4	D_5	D_6	D_7	W_c
Satisfaction (D_1)	1	0.20	0.14	0.25	0.12	2.00	2.00	0
Efficiency (D_2)	5.00	1	0.50	6.00	4.00	7.00	9.00	0.333
Effectiveness (D_3)	7.00	2.00	1	3.00	6.00	9.00	8.00	0.3999
Learnability (D_4)	4.00	0.17	0.33	1	0.50	7.00	8.00	0.065
Operability (D_5)	8.00	0.25	0.17	2.00	1	8.00	7.00	0.202
Universality (D_6)	0.50	0.14	0.11	0.14	0.12	1	0.50	0
User Interface Aesthetics (D_7)	0.50	0.11	0.12	0.12	0.14	2.00	1	0

W_c – Weight of criteria

According to equation (7), the following are the results of the fuzzy synthetic extent values:

$S_1 = (3.60, 5.72, 7.89)\ (^1/_{150.28}, ^1/_{128.16}, ^1/_{107.94}) = (0.02, 0.04, 0.07)$

$S_2 = (28.33, 32.50, 37.00)\ (^1/_{150.28}, ^1/_{128.16}, ^1/_{107.94}) = (0.19, 0.25, 0.34)$

$S_3 = (31.00, 36.00, 41.00)\ (^1/_{150.28}, ^1/_{128.16}, ^1/_{107.94}) = (0.21, 0.28, 0.38)$

$S_4 = (17.73, 21.00, 24.70)\ (^1/_{150.28}, ^1/_{128.16}, ^1/_{107.94}) = (0.12, 0.16, 0.23)$

$S_5 = (22.34, 26.42, 30.53)\ (^1/_{150.28}, ^1/_{128.16}, ^1/_{107.94}) = (0.15, 0.21, 0.28)$

$S_6 = (2.14, 2.52, 3.59)\ (^1/_{150.28}, ^1/_{128.16}, ^1/_{107.94}) = (0.014, 0.019, 0.033)$

$S_7 = (2.79, 4.00, 5.56)\ (^1/_{150.28}, ^1/_{128.16}, ^1/_{107.94}) = (0.019, 0.031, 0.061)$

According to equation (9), the following are the results of the degree of possibility for comparison of any two fuzzy synthetic extent values:

$V(S_1 \geq S_2) = 0$, $V(S_1 \geq S_3) = 0$, $V(S_1 \geq S_4) = 0$, $V(S_1 \geq S_5) = 0$, $V(S_1 \geq S_6) = 1$, $V(S_1 \geq S_7) = 1$

$V(S_2 \geq S_1) = 1$

$V(S_2 \geq S_3) = 0.83$

$V(S_2 \geq S_4) = 1$, $V(S_2 \geq S_5) = 1$, $V(S_2 \geq S_6) = 1$, $V(S_2 \geq S_7) = 1$

$V(S_3 \geq S_1) = 1$, $V(S_3 \geq S_2) = 1$, $V(S_3 \geq S_4) = 1$, $V(S_3 \geq S_5) = 1$, $V(S_3 \geq S_6) = 1$, $V(S_3 \geq S_7) = 1$

$V(S_4 \geq S_1) = 1$

$V(S_4 \geq S_2) = 0.31$

$V(S_4 \geq S_3) = 0.16$

$V(S_4 \geq S_5) = 0.65$

$V(S_4 \geq S_6) = 1$, $V(S_4 \geq S_7) = 1$

$V(S_5 \geq S_1) = 1$

$V(S_5 \geq S_2) = 0.67$

$V(S_5 \geq S_3) = 0.51$

$V(S_5 \geq S_3) = 1$, $V(S_5 \geq S_6) = 1$, $V(S_5 \geq S_7) = 1$

$V(S_6 \geq S_1) = 0.27$

$V(S_6 \geq S_2) = 0$, $V(S_6 \geq S_3) = 0$, $V(S_6 \geq S_4) = 0$, $V(S_6 \geq S_5) = 0$, $V(S_6 \geq S_7) = 0.56$

$V(S_7 \geq S_1) = 0.67$

$V(S_7 \geq S_2) = 0$, $V(S_7 \geq S_3) = 0$, $V(S_7 \geq S_4) = 0$, $V(S_7 \geq S_5) = 0$, $V(S_7 \geq S_6) = 1$

Using these values the minimum degree of possibilities are calculated as follows:

$d'(C_1) = V(S_1 \geq S_2, S_3, S_4, S_5, S_6, S_7) = min\,(0, 0, 0, 0, 1, 1)$

$d'(C_2) = V(S_2 \geq S_1, S_3, S_4, S_5, S_6, S_7) = min\,(1, 0.83, 1, 1, 1, 1)$

$d'(C_3) = V(S_3 \geq S_1, S_2, S_4, S_5, S_6, S_7) = min\,(1, 1, 1, 1, 1, 1, 1)$

$d'(C_4) = V(S_4 \geq S_1, S_2, S_3, S_5, S_6, S_7) = min\,(1, 0.31, 0.16, 0.65, 1, 1)$

$d'(C_5) = V(S_5 \geq S_1, S_2, S_3, S_4, S_6, S_7) = min\,(1, 0.67, 0.51, 1, 1, 1)$

$d'(C_6) = V(S_6 \geq S_1, S_2, S_3, S_4, S_5, S_7) = min\,(0.27, 0, 0, 0, 0, 0.56)$

$d'(C_7) = V(S_7 \geq S_1, S_2, S_3, S_4, S_5, S_6) = min\,(0.67, 0, 0, 0, 0, 1)$

Therefore, the weight vectors is generated as:

$W' = (d'(C1), d'(C2), d'(C3), d'(C4), d'(C5), d'(C6), d'(C7))^T = (0, 0.83, 1, 0.16, 0.51, 0, 0)^T$

The normalized weight vectors for the decision criteria are calculated as follows:

$$W = \frac{W'}{\sum_{i=1}^{n} d'(Ci)} = (0.000, 0.333, 0.3999, 0.065, 0.202, 0.000, 0.000)$$

Table 4: Fuzzy pairwise comparison matrix of the sub-criteria with respect to Satisfaction

	D_{11}	D_{12}	D_{13}	D_{14}	Wc
Comfort (D_{11})	1	0.50	6.00	0.50	0.310
Trust (D_{12})	2.00	1	6.00	2.00	0.443
Pleasure (D_{13})	0.17	0.17	1	0.33	0.000
Usefulness (D_{14})	2.00	0.50	3.00	1	0.247

Table 5: Fuzzy pairwise comparison matrix of the sub-criteria with respect to efficiency

	D_{21}	D_{22}	D_{23}	Wc
Task efficiency (D_{21})	1	0.20	0.33	0.000
Time efficiency (D_{22})	5.00	1	2.00	0.681
Relative task time (D_{23})	3.00	0.50	1	0.320

Table 6: Fuzzy pairwise comparison matrix of the sub-criteria with respect to effectiveness

	D_{31}	D_{32}	D_{33}	WC
Task completion (D_{31})	1	1.00	3.00	0.429
Task effectiveness (D_{32})	1.00	1	4.00	0.572
Error frequency (D_{33})	0.33	0.25	1	0.000

Table 7: Fuzzy pairwise comparison matrix of the sub-criteria with respect to learnability

	D_{41}	D_{42}	D_{43}	D_{45}	D_{45}	Wc
Time to learn (D_{41})	1	0.50	1.00	2.00	1.00	0.062
Memorability (D_{42})	2.00	1	2.00	3.00	6.00	0.419
Easy to understand error messages (D_{43})	1.00	0.50	1	2.00	2.00	0.149
Completeness of user	0.50	0.33	0.50	1	1.00	0.188

documentation (D_{44})						
Cognitive load (D_{45})	1.00	0.17	0.50	1.00	1	0.182

Table 8: Fuzzy pairwise comparison matrix of the sub-criteria with respect to operability

	D_{51}	D_{52}	D_{53}	Wc
Understandable I/O (D_{51})	1	1.00	4.00	0.572
Message clarity (D_{52})	1.00	1	3.00	0.429
Operational consistency (D_{53})	0.25	0.33	1	0.000

Table 9: Fuzzy pairwise comparison matrix of the sub-criteria with respect to universality

	D_{61}	D_{62}	D_{63}	Wc
Cultural universality (D_{61})	1	3.00	4.00	0.816
Standard compliance (D_{62})	0.33	1	2.00	0.184
Accessibility (D_{63})	0.25	0.50	1	0.000

Table 10: Fuzzy pairwise comparison matrix of the sub-criteria with respect to user interface aesthetics

	D_{71}	D_{72}	Wc
Customizability (D_{71})	1	0.25	0
Attractive user interface (D_{72})	4.00	1	1

Table 11 shows the determination of the local and global weight for criteria and sub-criteria

Table 11: Local weight and global weight for criteria and sub-criteria

Criterion (C)	**Local weight (CL)**	**Sub-criterion (SC)**	**Local weight (SCL)**	**Global weight (CL * SCL)**
Satisfaction		Comfort	0.310	0
		Trust	0.443	0
		Pleasure	0.000	0
	0	Usefulness	0.247	0

Efficiency	0.333	Task efficiency	0.000	0
		Time efficiency	0.681	0.2268
		Relative task time	0.320	0.1062
Effectiveness	0.399	Task completion	0.429	0.1712
		Task effectiveness	0.572	0.2287
		Error frequency	0.000	0
Learnability	0.065	Time to learn	0.062	0.0041
		Memorability	0.419	0.0272
		Easy to understand error messages	0.149	0.0097
		Completeness of user documentation	0.188	0.0122
		Cognitive load	0.182	0.0118
Operability	0.202	Understandable I/O	0.572	0.1155
		Message clarity	0.429	0.0865
		Operational consistency	0.000	0
Universality	0	Cultural universality	0.816	0
		Standard compliance	0.184	0
		Accessibility	0.000	0
User interface aesthetics	0	Customizability	0	0
		Attractive user interface	1	0

From usability criteria, based on the opinions of the participants and extent analysis method as shown in Table 10, Effectiveness was ranked highest with 40%, followed by Efficiency with 33%, Operability with 20%, Learnability with 6% while User Interface Aesthetics, Universality and Satisfaction had the same weight of 0% which implies that users do not really care much about the last three usability attributes in an mHealth app but they should never be ignored. Based on sub-criteria results, for Satisfaction criteria, Trust ranked the highest with 44% followed by Comfort with 31%, Usefulness with 25% while Pleasure ranked the lowest with 0%.

For Efficiency, Time efficiency ranked the highest with 68%, followed by Relative task time with 32% while Task efficiency ranked the lowest with 0%.
For Effectiveness, Task effectiveness ranked the highest with 57%, Task completion with 43% and Error frequency with 0%. For Learnability, Memorability ranked the highest with 42%, Completeness of user documentation with 19%, Cognitive load with 18%, Easy to understand error messages with 15% and Time to learn ranked the lowest with 6%

For Operability, Understandable I/O ranked the highest with 57%, Message clarity with 43% and lastly Operational Consistency with 0%.

For Universality, Cultural universality ranked the highest with 82%, Standard compliance with 18% and Accessibility with 0%.

For User Interface Aesthetics, Attractiveness of user interface ranked the highest with 100% while Customizability had the lowest rank with 0%. Table 12 depicts the determination of the fuzzy pairwise comparison matrix for the alternatives with respect to their corresponding sub-criteria

Table 12: Fuzzy pairwise comparison matrix for the alternatives with respect to sub-criteria

Trust				
	OM1	Hu1	FAM1	**Weight**
OM1	1	1/6	5	0.254
Hu1	6	1	3	0.746
FAM1	1/5	1/3	1	0
Usefulness				
	OM1	Hu1	FAM1	
OM1	1	4	3	0.82
Hu1	¼	1	½	0
FAM1	1/3	2	1	0.18

Comfort				
	OM1	Hu1	FAM1	
OM1	1	3	1/3	0.356
Hu1	1/3	1	2	0.278
FAM1	3	½	1	0.367
Pleasure				
	OM1	Hu1	FAM1	
OM1	1	1/5	2	0.038
Hu1	5	1	1	0.962
FAM1	½	1	1	0
Task Efficiency				
	OM1	Hu1	FAM1	
OM1	1	2	1/7	0
Hu1	½	1	3	0.231
FAM1	7	1/3	1	0.769
Relative Task Time				
	OM1	Hu1	FAM1	
OM1	1	¼	1/3	0
Hu1	4	1	1/5	0.231
FAM1	3	5	1	0.742
Time Efficiency				
	OM1	Hu1	FAM1	
OM1	1	9	3	1
Hu1	1/9	1	1/5	0
FAM1	1/3	5	1	0

Task Effectiveness				
	OM1	Hu1	FAM1	
OM1	1	8	1/8	0.492
Hu1	1/8	1	4	0
FAM1	8	¼	1	0.508
Task Completion				
	OM1	Hu1	FAM1	
OM1	1	1/7	6	0.342
Hu1	7	1	2	0.658
FAM1	1/6	½	1	0
Error Frequency				
	OM1	Hu1	FAM1	
OM1	1	5	1	0.651
Hu1	1/5	1	4	0.349
FAM1	1	¼	1	0
Cognitive Load				
	OM1	Hu1	FAM1	
OM1	1	1/5	1	0
Hu1	5	1	¼	0.515
FAM1	1	4	1	0.485
Memorability				
OM1	OM1	Hu1	FAM1	
	1	3	1/9	0
Hu1	1/3	1	5	0
FAM1	9	1/5	1	1

Time to Learn				
	OM1	Hu1	FAM1	
OM1	1	8	1/5	0.662
Hu1	1/8	1	2	0
FAM1	5	½	1	0.338
Completeness of documentation				
	OM1	Hu1	FAM1	
OM1	1	2	½	0.32
Hu1	½	1	¼	0
FAM1	2	4	1	0.68
Easy to understand				
	OM1	Hu1	FAM1	
OM1	1	1/7	2	0
Hu1	7	1	6	1
FAM1	½	1/6	1	0
Operations consistency				
	OM1	Hu1	FAM1	
OM1	1	1/5	6	0.525
Hu1	5	1	½	0.459
FAM1	1/6	2	1	0.016
Understandable I/O				
	OM1	Hu1	FAM1	
OM1	1	1/3	7	0.815
Hu1	3	1	1/3	0.128
FAM1	1/7	3	1	0.057

Message Clarity				
	OM1	Hu1	FAM1	
OM1	1	7	2	0.518
Hu1	1/7	1	1/8	0
FAM1	½	8	1	0.482
Standard Compliance				
	OM1	Hu1	FAM1	
OM1	1	4	7	1
Hu1	¼	1	3	0
FAM1	1/7	1/3	1	0
Accessibility				
	OM1	Hu1	FAM1	
OM1	1	3	½	0.231
Hu1	1/3	1	7	0.769
FAM1	2	1/7	1	0
Cultural Universality				
	OM1	Hu1	FAM1	
OM1	1	9	4	1
Hu1	1/9	1	1/6	0
FAM1	¼	6	1	0
Attractiveness of User Interface				
	OM1	Hu1	FAM1	
OM1	1	6	7	1
Hu1	1/6	1	1/3	0
FAM1	1/7	3	1	0

Customizability				
	OM1	Hu1	FAM1	
OM1	1	1/5	2	0
Hu1	5	1	7	1
FAM1	½	1/7	1	0

Key: OM1=*Omomi* Hu1= *Hudibia* FAM1= *Find-A-Med*

Table 13 shows the determination of the final weights of the alternatives. According to the final scores obtained from the FAHP analysis, it indicated that Omomi had the highest ranking with a weight of 41%, Find-A-Med ranked second with a weight of 30% while Hudibia ranked lowest with a weight of 29%.

Table 13: Final weights of alternatives

Overall Weight	**OM1**	**Hu1**	**FAM1**
Trust **(0)**	0.254	0.746	0
Usefulness **(0)**	0.82	0	0.18
Comfort **(0)**	0.356	0.278	0.367
Pleasure **(0)**	0.038	0.962	0
Task Efficiency **(0)**	0	0.231	0.769
Relative task Time **(0.2268)**	0	0.258	0.742
Time Efficiency **(0.10623)**	1	0	0
Task Effectiveness	0.492	0	0.508

(0.1712)			
Task Completion (0.2287)	0.342	0.658	0
Error Frequency (0)	0.651	0.349	0
Cognitive Load (0.0041)	0	0.515	0.485
Memorability (0.0272)	0	0	1
Time to learn (0.0097)	0.662	0	0.338
Completeness of documentation (0.0122)	0.32	0	0.68
Easy to understand (0.00118)	0	1	0
Operations consistency (0.1155)	0.525	0.459	0.016
Understandable I/O (0.0865)	0.815	0.128	0.057
Message clarity (0)	0.518	0	0.482
Standard compliance (0)	1	0	0
Accessibility (0)	1	0	0

Cultural universality (0)	0.231	0.769	0
Attractiveness of UI (0)	1	0	0
Customizability (0)	0	1	0
Overall	**0.41005**	**0.287**	**0.303**

5. Conclusion

This study ranked the criteria and sub-criteria in the Enhanced Usability Model (EUM) using the AHP model, a technique based on mathematical and psychological principles. The inability of human beings to make reliable and consistent decisions when faced with uncertainty makes the AHP a limited tool to use and as a result, Fuzzy AHP (FAHP) was used to overcome this short coming. The subjective nature of human decision making was depicted and analysed using TFN and Chang's extent analysis method to determine the weight of each criteria and sub-criteria identified in usability model. Opinions were elicited from decision makers which comprised of mHealth developers and mHealth apps users.

In developing a mHealth app, based on the findings of this work, usability attributes like efficiency, effectiveness, operability and learnability should be more focused on, while attributes like satisfaction, universality and user interface aesthetics should also be considered but given less priorities. This result also correlates with the findings in Kasali et al (2019) where the same usability attributes were evaluated using the AHP model. The FAHP used for evaluation purpose in this paper presented a well-structured and critical approach at analyzing difficult usability evaluation problems. In future, more usability factors can be considered and comparisons can be made with other widely used MCDM techniques to get more accurate rankings and to also understand the relationship between other MCDM techniques on usability models.

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