SELECTION OF BROKERAGE FIRMS FOR E-SERVICES USING FUZZY DECISION MAKING PROCESS WITH AHP AND MARCOS APPROACHES

Subrata Jana[1,2,3] – Bibhas Chandra Giri[1] – Anirban Sarkar[4]– Shaziab Asharaf[5] – Chiranjibe Jana[6*]– Dragan Pamucar[7]– Dragan Marinkovic[8]

[1]Department of Mathematics, Jadavpur University, Kolkata, India
[2]Department of Department of Basic Science and Humanities, Techno International New Town, Kolkata, India
[3]Department of Department of Basic Science and Humanities, Seacom Engineering College, Howrah, India
[4]Department of Management and Marketing, West Bengal State University, Barasat, India
[5]Institute of Mathematics Khawaja Fareed University of Engineering and Information Technology, Rahim Yar Khan, Pakistan
[6]Saveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences, Chennai, India
[7]Department of Operations Research and Statistics, Faculty of Organizational Sciences, University of Belgrade, Belagrade, Serbia
[8]Faculty of Mechanical and Transport Systems, Technische Universitat Berlin, Germany

ARTICLE INFO

***Article history*:**
Received: 02.08.2024.
Received in revised form: 14.10.2024.
Accepted: 04.12.2024.

Keywords:
Financial e-Services
Brokerage firms
Ranking
Fuzzy AHP
Fuzzy MARCOS
Fuzzy VIKOR

DOI: 10.30765/er.2585

Abstract:

Financial e-services revolutionize brokerage firms in today's world, enabling clients to manage investments, conduct trades, and access real-time market data seamlessly online. With intuitive platforms and robust security measures, investors can monitor portfolios, execute transactions, and stay informed anytime, anywhere, fostering greater autonomy and efficiency in their financial endeavours. The main objectives of this study are to make a comparative analysis among the features of the e-services and find out the ranking of the brokerage firms from best to least good, for better decision making. The development of criteria and sub-criteria for ranking of brokerage firms according to their financial e-services was rooted in a thorough examination of existing literature and the insights of experts. Assigning weights to these criteria and sub-criteria was crucial in the assessment process. There are three decision makers and who have chosen factor and sub-factor ratings according to their choice and the values of the three decision makers have been averaged according to the rules of vague numbers. Analytic Hierarchy Process (AHP) was employed to organize the problem hierarchy and establish comparison matrices, enabling subjective evaluations of the pivotal factors. The components weights and sub-factors were then extracted using Fuzzy AHP, then calculation was done for the secondary weights that would help in the ranking and Fuzzy Measurement of Alternatives and Ranking according to Compromise Solution (MARCOS), a well-known method for ranking was used. The Fuzzy MARCOS approach indicates that Groww ranks highest, followed by Zerodha and Angel One in second and third place, respectively. According to the Fuzzy VIKOR method, Zerodha and Groww rank as the first- and second-best broking firms, respectively, while Angel One is the third favoured option.

*Corresponding author
E-mail address: jana.chiranjibe7@gmail.com

1 Introduction

Financial literacy has become critically necessary in the current context for effective financial management, establishing a robust basis for saves and investments [1]. Regardless of whether one is an investor, trader, or a newbie seeking familiarity with financial markets, it is essential to consistently monitor the stock market to make informed judgements. Acquiring all pertinent information about the financial market manually is a daunting endeavour, particularly for novices. In the digital age, several financial e-services offered by broking organisations are growing to enhance public comprehension of financial markets [2]. Mobile apps enable users to access all financial e-services of broking businesses, offering full real-time information on the stock market in a single touch [3].

1.1 Financial e-services of Brokerage Firms

Brokerage firms provide a range of financial e-services to help clients manage their investments, trade securities, and access market information. These electronic services have become increasingly sophisticated with advancements in technology. Here are some common financial e-services offered by brokerage firms [4]:

- Online Trading Platforms: Brokerage firms offer online trading platforms that allow clients to buy and sell financial instruments such as stocks, bonds, options, and mutual funds. These platforms often provide real-time market data, charts, and research tools to help investors make informed decisions.
- Mobile Trading Apps: Many brokerage firms offer mobile applications that enable clients to trade and manage their investments using smartphones and tablets. Mobile apps often include features like real-time quotes, market news, and account management tools for on-the-go access.
- Research and Analysis Tools: Brokerage firms provide research and analysis tools to help clients make informed investment decisions. These tools may include fundamental and technical analysis, market research reports, and financial news.
- Educational Resources: Brokerage firms often offer educational resources such as webinars, articles, and tutorials to help clients improve their understanding of financial markets and investment strategies.
- Automated Trading and Robo-Advisors: Some brokerage firms provide automated trading services or robo-advisors that use algorithms to manage and optimize clients' investment portfolios based on their financial goals and risk tolerance.
- Account Management: Clients can manage their accounts online, including activities such as fund transfers, account statements, tax reporting, and setting preferences for alerts and notifications.
- Customer Support and Chatbots: Brokerage firms use online customer support services and chatbots to assist clients with account-related inquiries, technical issues, and general information.
- Risk Management Tools: Some brokerage platforms offer risk management tools to help investors assess and manage the risk associated with their portfolios.
- Advanced Trading Features: Advanced traders may have access to features such as options trading, margin trading, and other advanced order types.
- Social Trading Platforms: Some brokerage firms integrate social trading platforms, allowing investors to follow and replicate the trading strategies of experienced traders.
- Security Features: Security is a paramount concern for financial e-services. Brokerage firms implement encryption, two-factor authentication, and other security measures to protect clients' accounts and sensitive information.

It's essential for investors to carefully evaluate the features and fees associated with a brokerage firm's e-services to ensure they align with their investment goals and preferences. Additionally, staying informed about market trends and advancements in financial technology can help investors make the most of available e-services. The availability and features of these apps may vary based on your location and the specific financial institutions or services they are associated with [5].

1.2 Motivation

The current proliferation of broking businesses has resulted in user confusion, complicating the selection of the most advantageous option. Appropriate e-services from broking businesses may serve as an efficient instrument for managing finances, facilitating future savings, and enabling educated financial decision-

making. It offers simplicity, security, and a transparent perspective on your financial status, so enhancing your overall financial well-being. Numerous broking businesses exist in the market, offering a variety of electronic services. Selecting e-services from credible sources is essential. It is our responsibility to pick the e-services that meet the specified criteria depending on needs. Moreover, many e-services include distinct characteristics that address diverse purposes, resulting in a multi-criteria decision-making dilemma among consumers.

1.3 Review of Literature

From a series of literature review this study has gone through to observe that, many researches have been taken place earlier in various fields of finance and other industries from different perspective by using different MCDM techniques for solving the multi-criteria decision-making problem. Different researchers have applied different MCDM methods or combination of MCDM methods according to the appropriateness of their study for the purpose of selecting the optimal alternative [6], [7]. Table 1 represents some existing literature on various financial e-services using different kinds of MCDM techniques.

Table 1. Review of Literature

Authors	Years	Methods Used	Application Areas
Mirfakhraddini, S. H., & Amiri, Y. [8]	2010	BSC, FANP & FUZZY TOPSIS	E-banking services
Tsai, W. H., Hsu, W., & Lin, T. W. [9]	2011	AHP & VIKOR	Banking Sector
Carrasco, R. A. et. al. [10]	2012	SERVQUAL scales under fuzzy linguistic modeling	e-financial services questionnaires
Zadeh, M. H. K., & Hasan Mehr Manesh, D. A. B. T. [11]	2013	Analytic Network Process (ANP)	Banking & Financial Institutions
Elbadrawy, R. et. al. [12]	2014	A Hybrid Model AHP & PROMETHEE	E-banking services
Komlan, G. [13]	2016	AHP-TOPSIS	financial institution (Togo)
Koushan, N. et. al. [14]	2016	Fuzzy TOPSIS	Capital Market
Hinduja, A., & Pandey, M. [15]	2017	Grey Relational Analysis (GRA)	Life Insurance
ARSLAN, H. M. [16]	2018	SMART & EDAS	Banking Sector
Gupta, K. P., & Manrai, R. [17]	2018	Fuzzy AHP	Mobile financial services in emerging markets
Hinduja, A., & Pandey, M. [18]	2018	An Intuitionistic Fuzzy AHP	Life Insurance
Mustafa, S. Z., & Kar, A. K. [19]	2019	Generalized Analytic network process (GANP)	Digital services for emerging economics
Agrawal, V. et. al. [20]	2020	AHP–TOPSIS–DEMATEL	E-service quality of Indian banking
Gbongli, K. et. al. [21]	2020	SEM, TOPSIS, AHP	mobile financial services
Kahraman, U. A. [22]	2020	AHP and ANP	Selection of suitable bank
Lam, W. S. et. al. [23]	2020	Analytic Hierarchy Process Model	E-Payment Systems
Singh, N. et. al. [24]	2020	Triangular neutrosophic arena using MCGDM technique	Impact of social media in banking sector
Ghosh, A. et.al. [25]	2021	DEA and SEM	Indian Life Insurance Companies
Gupta, K. P. et. al. [26]	2021	Analytic Hierarchy Process approach	Payments bank services
Kapoor, A. et. al. [27]	2021	Fuzzy TOPSIS	Mobile wallet service

Kapoor, A. et. al. [28]	2022	Best Worst Method (BWM)	Mobile banking service
Amiri, M. et. al. [29]	2023	Best Worst Method (BWM)	Digital Banking
Aziz, K. A. et. al. [30]	2023	Analytical hierarchy process	Internet Banking
Sindwani, R. [31]	2023	Fuzzy TOPSIS	Banking Sector
Varshney, N., & Agrawal, R. (2023, April). [32]	2023	VIKOR Method	Finance Risk
Rezaei, A., & Hemati, M. [33]	2023	Delphi, Kano and AHP	Managers' mental paradigms
Shafi Salimi, P., & Edalatpanah, S. A. [34]	2020	fuzzy AHP method and D-Numbers	Supplier selection
Sheergojri, A. R., & Iqbal, P. [35]	2024	Fuzzy mathematical modelling approaches	Tumors treatment
Gu, Y. et. al. [36]	2024	Fuzzy Analytic Hierarchy Process	Financial Capacity of Farmers
Ghanadzadeh, M. et. al. [37]	2024	A Fuzzy Multiobjective Approach	Resource Allocation in Multicommodity Networks
Nafei, A. et. al. [38]	2023	Neutrosophic Multi-Choice Goal Programming (NMCGP)	Any real-life problems
Soltanifar, M. [39]	2024	COPRAS and MOORA	Multi attribute decision making problems
Nafei, A. H., & Nasseri, S. H. [40]	2019	Neutrosophic Integer Programming	Any real-life problems
Akram, M. et. al. [41]	2023	Extended DEA method with Fermatean fuzzy sets.	Multi-objective transportation problem
Farajpour Khanaposhtani, G. [42]	2023	SVM & TOPSIS	Constructing a date factory
Nafei, A., Gu, Y., & Yuan, W. [43]	2021	Extension of the TOPSIS & Fuzzy Neutrosophic sets	Car Companies
This Paper	2024	Fuzzy AHP & Fuzzy MARCOS	Brokerage Firms

1.4 Research Gap

Financial awareness, knowledge and assistance are the most important factors for trading in stock market whether any individual is an experienced investor or a novice learner [1]. While doing the literature review, any such research paper on financial e-services of brokerage firm [2,3] using Fuzzy AHP [50] and Fuzzy MARCOS [51] which help people in decision making purpose while selecting any brokerage firm according to their individual need has not been found. Hence this study aims to fill this gap by providing a detailed overview of some selected financial e-services of brokerage firms [4] considering various factors and criteria, their comparative analysis and based on it, a best to worst ranking of the e-services which will benefit the investors or other users of the e-services while making decision on which application to choose for the fulfilment of their need. This research will help in this assessment and will give a suitable decision-making problem-solving model.

1.5 Objectives

The purpose of this study is to:

- Identify important features and criteria of e-services of the selected brokerage firms.
- Make a comparative analysis among the features of the e-services using Fuzzy Analytical Hierarchy Process (F-AHP) MCDM technique.

- Make a ranking of the brokerage firms from best to least good, for better decision making.

1.6 Justification of F-AHP, F-MARCOS & F-VIKOR

Multi-criteria decision-making (MCDM) is a systematic approach used to make decisions when there are multiple criteria or factors that need to be considered simultaneously. In many real-world situations, decisions are not based on a single criterion, but rather involve a variety of factors that need to be balanced against each other. MCDM methods provide a structured framework to analyse, evaluate, and rank different alternatives based on their performance with respect to these multiple criteria [6]. MCDM methods are commonly used in various fields such as business, engineering, economics, environmental management, and public policy, among others. There are various MCDM methods available, each with its own advantages and limitations [7]. Some popular MCDM methods include Analytic Hierarchy Process (AHP) [44], Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) [45], Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) [46], ELECTRE (Elimination and Choice Expressing Reality) [47], MARCOS (Measurement of Alternatives and Ranking according to Compromise Solution) [48] and VIKOR (VlseKriterijumska Optimizacija I Kompromisno Resenje) [49] among others. Choosing the most appropriate MCDM method depends on the specific characteristics of the decision problem, the availability of data, the complexity of criteria interactions, and the preferences of the decision maker [6], [7].F-AHP (Fuzzy Analytic Hierarchy Process) [50], F-MARCOS (Fuzzy Measurement of Alternatives and Ranking according to Compromise Solution) [51], and F-VIKOR (Fuzzy VlseKriterijumska Optimizacija I Kompromisno Resenje) [52] are decision-making methods that extend traditional Analytic Hierarchy Process (AHP) [44], Measurement of Alternatives and Ranking according to Compromise Solution (MARCOS) [48], and VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) [49] to handle uncertainty and imprecision through the incorporation of fuzzy logic.

1.6.1. F-AHP (Fuzzy Analytic Hierarchy Process) [50]

- Handling Uncertainty: Traditional AHP [44] assumes crisp, precise inputs. However, in many real-world scenarios, the decision-making criteria or alternatives may not be clearly defined and may involve subjective judgments. F-AHP [50] extends AHP [44] by allowing for fuzzy linguistic variables to represent imprecise judgments and uncertainties.
- Fuzzy Pairwise Comparisons: In F-AHP [50], pairwise comparisons of criteria and alternatives are conducted using fuzzy numbers or linguistic terms. This enables decision-makers to express their judgments in a more flexible and intuitive manner.
- Aggregation of Fuzzy Judgments: F-AHP [50] uses fuzzy arithmetic to aggregate the fuzzy pairwise comparison judgments, which allows for the propagation of uncertainty throughout the decision-making process.
- Sensitivity to Decision-Maker Preferences: F-AHP [50] allows for the incorporation of decision-maker preferences using fuzzy membership functions. This means that decision-makers can express their level of confidence in their judgments.

1.6.2. F-MARCOS (Fuzzy Measurement of Alternatives and Ranking according to Compromise Solution) [51]

- Addressing Complex Decisions: F-MARCOS [51] is designed for situations where there are multiple criteria and alternatives, making the decision-making process complex. It extends MARCOS [48] by incorporating fuzzy logic to handle imprecise data and subjective judgments.
- Fuzzy Ratio Analysis: F-MARCOS [51] employs fuzzy ratio analysis to compare the performance of alternatives with respect to multiple criteria. This allows for the consideration of imprecision in both the criteria weights and the performance scores.
- Trade-off Analysis: F-MARCOS [51] helps in identifying the trade-offs between criteria and alternatives, which is crucial for complex decision-making.

1.6.3. F-VIKOR (Fuzzy VlseKriterijumska Optimizacija I Kompromisno Resenje) [52]

- Handling Multi-Criteria Decision Problems: F-VIKOR [52] is designed for multi-criteria decision-making problems where there is a need to identify a compromise solution among multiple alternatives.
- Fuzzy Sets in Decision-Making: F-VIKOR [52] employs fuzzy sets to represent imprecise information regarding criteria and alternatives. This is particularly useful in situations where the exact values are uncertain or not easily quantifiable.
- Consideration of Multiple Aspects: F-VIKOR [52] considers various aspects of decision-making, including the "maximax" and "maximin" principles, to provide a balanced compromise solution.
- Ranking and Selection of Alternatives: F-VIKOR [52] provides a ranking of alternatives based on a comprehensive evaluation that considers both optimistic and pessimistic scenarios, allowing for a robust decision.

F-AHP [50], F-MARCOS [51], and F-VIKOR [52] are valuable extensions of their respective classical decision-making methods, allowing for the incorporation of fuzzy logic to handle uncertainty, imprecision and subjective judgments in complex decision-making scenarios.

1.7 Novelties

There are three decision makers and who have chosen factor and sub-factor ratings according to their choice and the values of the three decision makers have been averaged according to the rules of vague numbers. The weights of the components and sub-factors were then extracted using Fuzzy AHP [50], then calculation was done for the secondary weights that would help in the ranking and Fuzzy MARCOS [51], a well-known method for ranking was used. It is evident from the previous research that the proposed methods of this study are certainly one of the most useful methods in taking challenging multi-criteria decisions for the decision-makers.

1.8 Beneficiaries

By reading this research paper can benefit various groups of people, like: consumers and individuals for improving financial management and risk mitigation, small business owners for streamlining financial operations, financial professionals to make recommendation for clients and staying informed, academics and researchers for academic enrichment, policy makers and regulators for policy formulation, apps developers and companies for product improvement, investors to find investment opportunities, educators and trainers for curriculum enhancement, media and journalists for reporting. So, this research paper on the selection of the best e-services of brokerage firms can provide valuable insights and guidance to a wide range of people [53].

1.9 Structure of the Paper

The rest part of the paper is composed in the following way: Section 2 describes Mathematical Preliminaries; Section 3 depicts the conceptual framework in detail; Numerical Application is calculated in Section 4; Section 5 deals with comparative analysis; Section 6 represents the Conclusions; Lastly, Limitations & Future Scopes are compiled in the Section 7 & Section 8 respectively.

2 Mathematical Preliminaries

2.1 Fuzzy Logic

Fuzzy set concept was introduced by the author Zadeh in 1965 to deal with the uncertainty and impreciseness of real-life problems [54].

Definition 1: A set $\hat{S}$, defined as $\hat{S} = \{(u, \mu_{\hat{S}}(u): u \in \hat{S}, \mu_S(u) \in (0,1)\}$, where $\mu_{\hat{S}}(u)$ signifies the degree of membership function of $\hat{S}$ which ranges from zero to one. In real life circumstances, where the vagueness and uncertainty might prevail in information's, fuzzy logic can be efficiently used to deal with these problems.

Definition 2: Triangular Fuzzy Number (TFN) A number $\hat{T} = \{(t_1, t_2, t_3), \mu_{\hat{T}}(x)\}$ on $\Re$ is defined as TFN if it satisfies the following properties:

a. $\mu_{\hat{T}}(x)$ is a continuous function [0,1].
b. $\mu_{\hat{T}}(x)$ is strictly increasing continuous function in $[t_1, t_2]$.
c. $\mu_{\hat{T}}(x)$ attains maximum value 1 at t_2.
d. $\mu_{\hat{T}}(x)$ is strictly decreasing continuous function in $[t_2, t_3]$.

The following equation represents the membership function of symmetric TFN.

$$\mu_{\hat{T}}(x) = \begin{cases} \dfrac{x - t_1}{t_2 - t_1}, & t_1 \le x \le t_2 \\ \dfrac{t_3 - x}{t_3 - t_2}, & t_2 \le x \le t_3 \\ 0 \quad Otherwise \end{cases} \tag{1}$$

Representation of the membership function of linear HFN.
Where $t_1, t_2, t_3$are real numbers such that $t_1 \le t_2 \le t_3$

2.2 Arithmetic Operations of Linear TFN

Let $L = (l_1, l_2, l_3)$ and $M = (m_1, m_2, m_3)$ be two TFN, then the generalized arithmetic operation between the two can be expressed in the following way:

(a) Addition: $(L + M) = (l_1 + m_1, l_2 + m_2, l_3 + m_3)$ (2)

(b) Subtraction: $(L - M) = (l_1 - m_3, l_2 - m_2, l_3 - m_1)$ (3)

(c) Multiplication: $(L \times M) = (l_1 m_1, l_2 m_2, l_3 m_3)$ (4)

(d) Scalar Multiplication: $kL = (kl_1, kl_2, kl_3)$ (5)

(e) Division: $\left(\frac{L}{M}\right) = (\frac{l_1}{m_3}, \frac{l_2}{m_2}, \frac{l_3}{m_1})$ (6)

(f) Inverse:$L^- = \left(\frac{1}{l_3}, \frac{1}{l_2}, \frac{1}{l_1}\right)$ (7)

2.3 Distance Measure of two TFN

Let $L = (l_1, l_2, l_3)$ and $M = (m_1, m_2, m_3)$ be two TFN's, then the distance between the two TFN can be expressed in vertex method as:

$$d(L, M) = \sqrt{1/3[(l_1 - m_1)^2 + (l_2 - m_2)^2 + (l_3 - m_3)^2]} \tag{8}$$

2.4 Fuzzy Analytic Hierarchy Process (F-AHP) [50]

The Analytic Hierarchy Process (AHP) MCDM tool was introduced by T. L. Satty. A systematic technique which helps the decision makers to solve the real-life problems with heuristic procedures. Evaluation of criteria and sub-criteria weights are important for the ranking of financial app of brokerage firms. AHP structures the problem hierarchy with the construction of comparison matrices to give subjective judgments about the factor's which are considered highly responsible in ranking the best. In this paper, FAHP is used rather than AHP as Fuzzy logic incorporates the hesitancy and uncertainty of the DMs. The steps for FAHP are described below.

Step 1: Construction of a comparison matrix in terms of TFN by a decision expert or a group of decision experts using table 2.

Table 2. Linguistic terms & Triangular Fuzzy Number (TFN)

Linguistic Terms	TFN
Very Less Important	$(1, 2, 2.5)$
Less Important	$(2, 2.8, 3)$
Fair Important	$(3, 3.5, 4)$
Important	$(4, 4.5, 5)$
High Important	$(5, 7, 7)$

Let a team of 'E' decision-makers associated in the pairwise comparison of criteria and sub-criteria weight. Thus, 'e' set of matrices are obtained, $M_e = \{M_{noe}\}$, Where $M_{noe} = (p_{noe}, q_{noe}, r_{noe})$ expresses the relative preference of n criteria to o criteria as decided by the $'e'$ decision maker.

$$\left.\begin{aligned} p_{no} &= \min_{e=1,2,\dots,E}(p_{noe}), \\ q_{no} &= \sqrt[e]{\prod_{e=1}^{E} q_{noe}}, \\ r_{no} &= \max_{e=1,2,\dots,E}(r_{noe}) \end{aligned}\right\} \tag{9}$$

Step 2: Defuzzification rule of TFN. A TFN $M_{noe} = (P_{noe}, q_{noe}, r_{noe})$can be defuzzified in the following way:

$$M_{noe}^{D} = \frac{(P_{noe} + 4q_{noe} + r_{noe})}{6} \tag{10}$$

Step 3: Formation of comparison matrix in terms of defuzzified values. Generalized demonstration of comparison matrix in crisp values:

$$(M_{no}) = \begin{pmatrix} 1 & (M_{12}) & . & . & (M_{1v}) \\ (M_{21}) & 1 & . & . & (M_{2v}) \\ . & . & 1 & . & . \\ . & . & . & 1 & . \\ (M_{u1}) & (M_{u2}) & . & . & 1 \end{pmatrix} \tag{11}$$

Step 4: Normalization of each element of the defuzzified matrix:

$$N_{no} = \frac{M_{no}}{\sum_{n=1}^{u} M_{no}}, \quad \text{where } n = 1,2,\dots.,u; o = 1,2,\dots.,v \tag{12}$$

Step 5: Assessment of criteria priority weight (P.W):

$$P.W = \frac{P^{th} rootvalue}{\sum P^{th}\, root} \tag{13}$$

Step 6: Determine the Consistency Index$(C.I)$ of the matrix, where v is the size of the matrix:

$$(C.I) = \frac{\delta_{max} - v}{v - 1} \tag{14}$$

Step 7: Calculate Consistency ratio (C.R), where the value of Random Index (R.I) fluctuates with the size of the matrix 'v'. The value of C.R ≤ 0.1 signifies the matrix to be a consistent matrix:

$$(C.R) = \frac{C.I}{R.I} \tag{15}$$

2.5 Fuzzy MARCOS Method [51]

The MCDM tool MARCOS method was developed by Stevic et al (2020). The steps involved in fuzzy MARCOS method are explained below.

Step 1: Formation of decision matrix with the help of DMs in linguistic terms. The linguistic variables are transformed to TFN.

Step 2: The fuzzy decision matrix is extended by the evaluation of fuzzy ideal $F(\tilde{I})$ and anti-ideal $F(\widetilde{AI})$solution. Here the fuzzy ideal $F(\tilde{I})$ depicts the alternative having the best performance whereas the fuzzy anti- ideal $F(\widetilde{AI})$ symbolises the worst alternative. The $F(\tilde{I})$ and $F(\widetilde{AI})$ can be calculated using the following equations (16) and (17). B belongs to the Benefit Criteria while C belongs to the Non-Benefit Criteria.

$$F(\tilde{I}) = \max_n x_{no} ifo \in Band \min_n x_{no}\, ifo \in C \tag{16}$$

$$F(\widetilde{AI}) = \min_n x_{no}\, ifo \in Band \max_n x_{no}\, ifo \in C \tag{17}$$

Step 3: Construction of Normalized fuzzy matrix $\widetilde{NF}= [n_{no}]_{u\times v}$ by using equations (18) and (19), where the variables $x_{no}^p, x_{no}^q, x_{no}^r$ and x_i^p, x_i^q, x_i^r denotes the element of the matrix X.

$$n_{no} = \left(n_{no}^p, n_{no}^q, n_{no}^r\right) = \left(\frac{x_i^p}{x_{no}^r}, \frac{x_i^p}{x_{no}^q}, \frac{x_i^p}{x_{no}^p}\right) ifo \in C \tag{18}$$

$$n_{no} = \left(n_{no}^p, n_{no}^q, n_{no}^r\right) = \left(\frac{x_{no}^p}{x_i^r}, \frac{x_{no}^q}{x_i^q}, \frac{x_{no}^r}{x_i^p}\right) ifo \in B \tag{19}$$

Step 4: Calculation of the weighted fuzzy normalized matrix $WN = [w_{no}]_{u\times v}$ which is calculated by the product of normalized fuzzy matrix with the weights of the criteria wc_o:

$$w_{no} = \left(w_{no}^p, w_{no}^q, w_{no}^r\right) = N_{no} \otimes wc_o = (N_{no}^p \times wc_o^p, N_{no}^q \times wc_o^q, N_{no}^r \times wc_o^r) \tag{20}$$

Step 5: Computation of fuzzy matrix T_n using the equation (21), here $T_n(t_n^p, t_n^q, t_n^r)$ denotes the summation of the elements of the weighted fuzzy matrix WN:

$$T_n = \sum_{n=1}^{u} w_{no} \tag{21}$$

Step 6: Determination of the utility degree of the alternatives G_n using the equations (22) and (23):

$$G_n^+ = \frac{G_n}{G_i} = \left(\frac{g_n^p}{g_i^r}, \frac{g_n^q}{g_i^q}, \frac{g_n^r}{g_i^p}\right) \tag{22}$$

$$G_n^- = \frac{G_n}{G_{ai}} = \left(\frac{g_n^p}{g_{ai}^r}, \frac{g_n^q}{g_{ai}^q}, \frac{g_n^r}{g_{ai}^p}\right) \tag{23}$$

Step 7: Computation of fuzzy matrix S_n using equation (24):

$$S_n = s_n = \left(s_n^p, s_n^q, s_n^r\right) = G_n^+ + G_n^- = (G_n^{+p} + G_n^{-p}, G_n^{+q} + G_n^{-q}, G_n^{+r} + G_n^{-r}) \tag{24}$$

3 Conceptual Framework

The Structure of the conceptual framework of the study is represented in the following Figure 1:

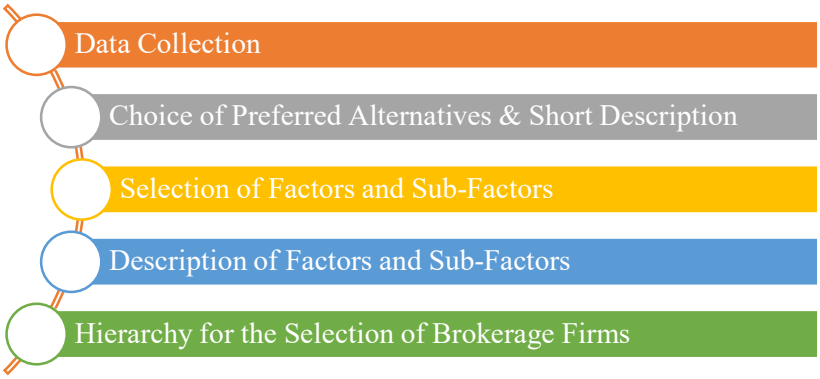

Figure 1. Structure of the Conceptual Framework

3.1 Data Collection

Secondary data has been used for this research. Data has been fetched from the website of National Stock Exchange (NSE), India.

3.2 Choice of Preferred Alternatives & Short Description

Six alternatives that is brokerage firms are selected for the preference assessment. The selected alternatives with its respective explanation are represented in Table 3. Selection Parameter: 10L plus users (on 14 January 2024).

Table 3. Alternatives and its respective description for the present study

Alternatives	Short Description
Angel One (A1)	Angel One Limited, previously recognized as Angel Broking Limited, is an Indian brokerage firm that was founded in 1996. The company holds membership in prominent Indian financial exchanges such as the Bombay Stock Exchange, National Stock Exchange of India, National Commodity & Derivatives Exchange Limited, and Multi Commodity Exchange of India Limited.
Groww (A2)	Groww, a Bangalore-based investment platform, was established in May 2017 by Lalit Keshre, Harsh Jain, Neeraj Singh, and Ishan Bansal, former Flipkart employees. Recognizing the demand for a user-friendly investment platform in India, they founded Groww. Initially focusing on direct mutual fund distribution, the company expanded its offerings in 2020 to include access to stocks, digital gold, exchange-traded funds (ETFs), Intraday trading, and initial public offerings (IPOs).
HDFC Securities (A3)	HDFC Securities Limited, a subsidiary of HDFC Bank, operates as a financial services intermediary in India. Established in 2000 and headquartered in Mumbai, it has a widespread presence with branches in key cities and towns. Originally formed through a collaboration between HDFC Bank Limited, HDFC Limited, and Indocean e-Securities Holdings Limited, HDFC Securities offers stock broking services and serves as a distributor for various financial products.
ICICI Direct (A4)	ICICI Direct, a part of the ICICI Group of companies, operates as a full-service stockbroker under the subsidiary ICICI Securities. Specializing in online trading and investment services, ICICI Direct provides its customers with the opportunity to engage in various investment avenues such as stocks, IPOs, Mutual Funds, Bonds, NCDs, ETFs, and NPS through its online platform.

Alternatives	Short Description
Upstox (A5)	Upstox, initially founded as RKSV Securities in 2009, is an Indian investment platform offering a range of financial products, including stocks, IPOs, mutual funds, derivatives, ETFs, digital gold, currencies, commodities and futures/options. Started in a Delhi apartment, Upstox grew through word-of-mouth recommendations and relocated to Mumbai. Pioneering unlimited trading plans in 2012, the company rebranded to Upstox in 2016. It introduced the Upstox Pro suite and pioneered Aadhaar-enabled online account opening, becoming the first in the industry to offer a fully digital trading process.
Zerodha (A6)	Zerodha Broking Ltd., an Indian financial services firm, was founded in 2010 by brothers Nithin and Nikhil Kamath. Headquartered in Bengaluru, it provides institutional and retail brokerage, currency and commodity trading, mutual funds, and bonds. Zerodha gained unicorn status in June 2020, achieving a self-valuation of approximately $1 billion through an ESOP buyback, valuing each share at over four times the book value of ₹700 per share. The name Zerodha reflects the company's commitment to breaking barriers in the financial industry.

3.3 Selection of Factors and Sub-Factors

Eight factors along with thirty-five sub factors represented in Table 4 are identified for assessment based on general functions and availability of information.

Table 4. Classification of factors and sub- factors considered in this research

Factors	Sub-Factors
Functional Attributes (F)	
1. Market Data ($F1$)	a) Indian Indices ($F11$) b) Global Indices ($F12$) c) Commodities ($F13$) d) Currencies ($F14$) e) Mutual Funds ($F15$) f) Future & options ($F16$) g) Bonds ($F17$) h) Exchange Traded Funds (ETFs) ($F18$) i) Unit Linked Insurance Plan (ULIPs) ($F19$) j) Crypto currency ($F110$)
2. Stock Actions ($F2$)	a) Industry – wise performance ($F21$) b) Company- wise performance ($F22$)
3. Customizable Factors ($F3$)	a) Portfolio Creation ($F31$) b) Watch list Creation ($F32$)
4. Trending News ($F4$)	a) Indian news ($F41$) b) International news ($F42$) c) IPO news ($F43$)
5. Tools for analysis ($F5$)	a) Price alerts ($F51$) b) Stock screener ($F52$) c) Comparison Chart ($F53$) d) Candlestick Chart ($F54$) e) Calculators ($F55$)
6. Expert Analysis ($F6$)	a) Financial markets/ Stocks advisor ($F61$) b) Personal Finance advisor ($F62$) c) Knowledge Portal ($F63$)
7. Multimedia ($F7$)	a) Live TV ($F71$) b) Podcast ($F72$)

Factors	Sub-Factors
Functional Attributes (F)	
8. General Attributes $(G8)$	
a) User Friendly $(G81)$	
b) Presentation $(G82)$	
c) Content Quality $(G83)$	
d) Relevance of information $(G84)$	
e) Problem solving ability $(G85)$	
f) Customization $(G86)$	
g) Security $(G87)$	
h) Decision- making support / Satisfactory $(G88)$	

3.4 Description of Factors and Sub-Factors

Detailed explanation of factors and sub-factors are depicted:

Functional Attributes (F):

1. Market Data$(F1)$: Market data encompasses price and trade information for various financial instruments, made available by trading venues like stock exchanges. It enables traders and investors to access current prices and historical patterns for assets like stocks, bonds, derivatives, and currencies. These apps offer comprehensive market insights.

Indian Indices$(F11)$: BSE Sensex and NSE Nifty are considered as the benchmark indices in India. They represent the overall market performance in India.

Global Indices$(F12)$: Global indices represent the performance of the global stock market. Major global indices are – S&P 500, Dow Jones Industrial Average, NASDAQ, NYSE, Wall Street etc.

Commodities$(F13)$: Commodity market involves buying, selling or trading a raw product such as food, energy or metals (i.e., oil, gold, silver, copper, and coffee) through commodity trading exchanges such as MCX, NCDEX, and NMCE etc. These applications provide data on everyday commodity prices and price changes.

Currency$(F14)$: The currency market is a worldwide decentralized platform where currencies are traded, setting foreign exchange rates. Apps display real-time currency exchange rates for various currencies.

Mutual Funds $(F15)$: Mutual funds are pooled investments wherein investor's money is invested in selective shares or bonds after careful research by fund managers. These apps show the popular mutual funds and their individual returns if invested for a given time period.

Futures & Options $(F16)$: Futures and options are key stock derivatives in the market. They are contracts between two parties to trade a stock at a set price on a future date, offering a way to manage investment risk through predetermined prices.

Bonds $(F17)$: The bond market is where investors buy and sell debt securities, primarily bonds issued by companies or governments.

Exchange Traded Funds$(F18)$: ETFs are uncomplicated investments that blend stock flexibility with mutual fund ease. They're traded on the stock market and can be bought or sold like stocks at any time.

Unit-Linked Insurance Plan$(F19)$: ULIPs are a blend of insurance and investment, offering policyholders both life coverage and the chance to earn returns on their premiums.

Crypto currency$(F110)$: Crypto currencies are digital investments and online payment methods. People trade traditional currency for digital coins or tokens when buying them.

2. Stock Action$(F2)$**:** Stock action refers to the change and ups & downs in everyday prices of shares of the industries and companies listed in the stock exchanges.

Industry-wise performance$(F21)$: It shows the overall performance and changes in price of shares in each sector for e.g., IT, Defence, Retail, Telecommunications and Construction etc. In each sector the homogeneous companies are grouped together and each of their performance are shown individually.

Company-wise performance$(F22)$: Company wise performances are shown based on some categories such as Equity gainers, Equity losers, Equity movers etc. In each category the best to worst companies is presented accordingly. The overview, technical analysis, company financials and other important information of the companies is shown under each company.

3. Customizable Factors$(F3)$**:** These are the features that the user can create, alter or remove according to his will and need.

Portfolio Creation$(F31)$: Creating a portfolio helps a user to estimate and analysis the risk and return they are going to obtain by investing in a diversified pool of stocks/ mutual funds/ bonds/ ULIPs etc. in each period of time. These apps provide this opportunity to create and give insights before investing, on the risk and return the investor must come across if he invests in his choice of stocks.

Watch list Creation$(F32)$: Creating a watchlist helps the user to stay abreast with the changes in the stock price of his choice of companies or changes in the points of the indices that matters most to the user. The user can create a list of those companies or indices the user is interested into, so that he need not to search every time for those particular company or indices. They can also add foreign currencies to check upon the daily appreciation or depreciation with the home currency.

4. Trending News$(F4)$**:** The apps provide all the necessary news and trending topics of national and international importance that might affect the decisions of the investors.

National News$(F41)$: News on only of national importance i.e., Indian financial market news.

International News$(F42)$: Covers national as well as news of global importance.

IPO News$(F43)$: Details published by the companies that are going public for the first time to raise fund from public through Initial Public Offering (IPO).

5. Tools for analysis$(F5)$**:** Tools that helps to analyse the performance of stocks of companies and for decision making.

Price alert$(F51)$: This feature gives alert every time there is a rise or fall in the price of the stocks selected by the investor so that he can take decision based on that price change accordingly.

Stock screener$(F52)$: This feature enables the user to filter and create a list of the stocks with the criteria they are looking for. For e.g., if a person wants a list of mid cap equity stocks with a price between Rs. 10-100 with a return of 10% -15%, it will present a list of stocks with these criteria only.

Comparison Chart$(F53)$: This feature enables the user to compare the stock performance of two different companies with the help of graphical charts.

Candlestick Chart$(F54)$: This is a financial chart/tool for determining possible short-term price movements based on past patterns.

Calculators$(F55)$: Different calculators to calculate House Property Income, HRA, education loan, car loan, home loan, Tax impact, EMI, gratuity etc.

6. Expert Analysis$(F6)$**:** Expert analysis refers to the opinions and advice by the financial analysts to help the users/ investors in investing that will be beneficial.

Stock advisor$(F61)$: Opinions of experts on the stocks, mutual funds, derivatives etc in which investors should invest or not to invest with detailed explanation to stay in a beneficial position in the trading market.

Personal Finance advisor$(F62)$: Opinions of experts on car loan, home loan, insurance policies, tax benefits, retirement schemes etc.

Knowledge portal$(F63)$: Provides definitions regarding various financial market terms that is essential to know before entering in the market.

7. Multimedia$(F7)$**:** News articles other than in written form.

Live TV$(F71)$: Live news channel streaming.

Podcasts$(F72)$: Audio lectures/ analysis on multiple topics related to financial market.

General Attributes (G):

1. User friendly$(G81)$**:** The extent of user-friendliness refers to the ease of use and easy to understand attribute for operating the apps.

2. Presentation$(G82)$**:** How well articulately all the data are presented.

3. Content Quality$(G83)$**:** It refers to the quality of writing and understand ability of the articles or information that are presented in the apps.

4. Relevance of information$(G84)$**:** The information that are provided too much extent they are relevant with the financial markets or to what extent those effect the financial markets nationally and globally.

5. Problem-solving ability$(G85)$**:** The ability to guide and offer solution to the problems of the users relating to financial markets.

6. Customization$(G86)$**:** This useful feature offers the user to create, alter or delete list of information within the app according to his need whenever needed.

7. Security$(G87)$**:** To what extent the apps provide security while using the apps, for e.g., not accessing or share personal data of the user from phone, provide firewall to protect from hackers etc.

8. Decision-making support / Satisfactory$(G88)$**:** The satisfaction level of using the apps and to what extent it can assist the users for decision-making.

3.5 Hierarchy for the Selection of Brokerage Firms

The hierarchical categorisation of the eight primary factors and their 35 sub-factors provides a systematic framework for organising financial data, enhancing analysis and decision-making. Each primary factor, namely Market Data, Stock Actions, and Customisable Factors, constitutes a significant category essential for comprehending financial markets. Specific sub-factors provide deeper information; for example, Market Data include multiple asset classes such as Indian Indices and Commodities, whilst Stock Actions contains performance data at both the sector and company levels. This organisation enables users to effectively explore intricate data, customise their analytical tools and resources, and remain informed with pertinent news and expert analysis. The hierarchy improves clarity and use, facilitating educated investment choices and efficient financial planning. The Figure 2 represents the hierarchical framework of the study.

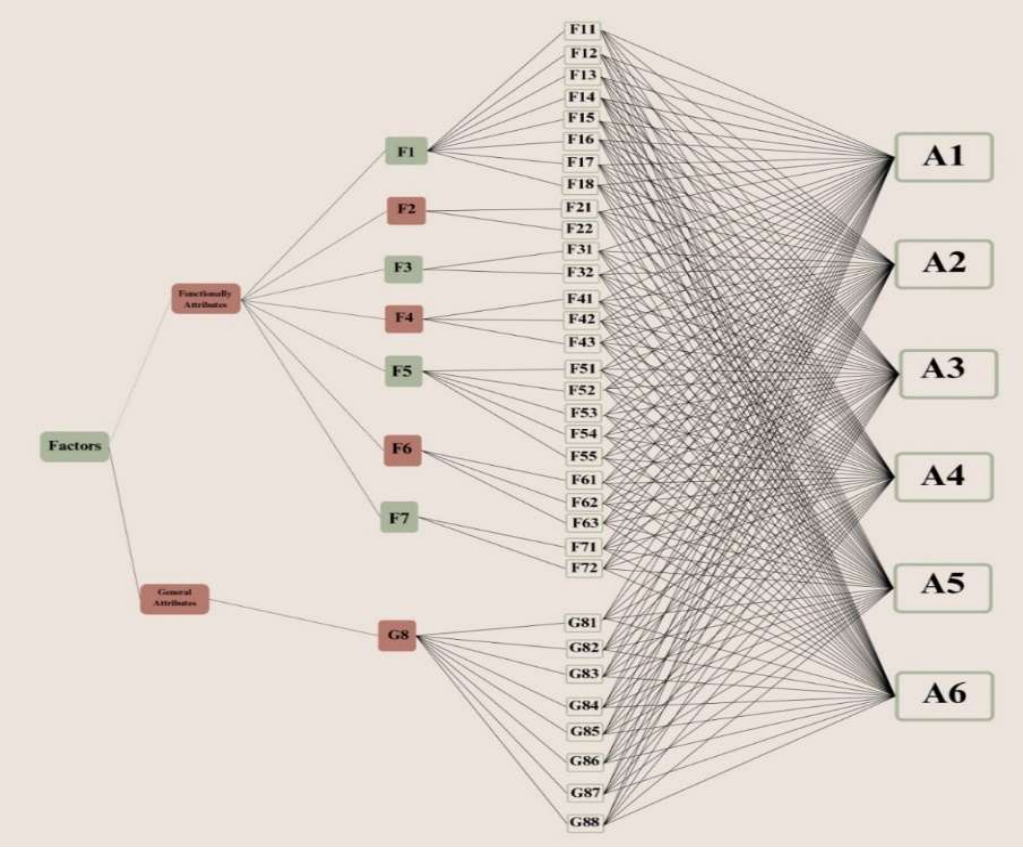

Figure 2. Hierarchical Structure of the problem

4 Numerical Application

This section is presenting the numerical application of Triangular Fuzzy MARCOS Methodology for Selection of Financial e-services of brokerage firms. Linguistic terms in Triangular Fuzzy Number (TFN) [55] for the comparative analysis of factors and sub-factors are represented in Table 5. Here we choose three decision makers for factors and each sub-factors, and first we average factors and sub-factors weights. Table 6 contains factors, sub-factors and global weights.

Table 5. Linguistic variables expressed in form of TFN

Liguistic Terms	TFN	Inverse TFN
Equally Important (EI)	(1, 1, 1)	(1, 1, 1)
Very Low (VL)	(1, 1, 1.1)	(0.9, 1, 1)
Low (L)	(1, 1.1 , 1.3)	(0.77, 0.91, 1)
Medium Low (ML)	(1.1, 1.3, 1.5)	(0.67, 0.77, 0.91)
Medium (M)	(1.3, 1.5, 1.7)	(0.59, 0.67, 0.77)
Medium High (MH)	(1.5, 1.7, 1.9)	(0.53, 0.59, 0.67)
High (H)	(1.7, 1.9, 2)	(0.50, 0.53, 0.59)
Very High (VH)	(1.9, 2, 2)	(0.50, 0.50, 0.53)

Table 6. Factor, sub-factor and global weights

Factor Weights	Sub − Factor Weights	Global Weights
F1=(0.100, 0.121, 0.144)	F11=(0.136, 0.164, 0.190) F12=(0.083, 0.098, 0.119) F13=(0.082, 0.096, 0.116) F14=(0.091, 0.113, 0.133) F15=(0.118, 0.141, 0.168) F16=(0.094, 0.115, 0.136) F17=(0.060, 0.070, 0.085) F18=(0.057, 0.066, 0.081) F19=(0.066, 0.080, 0.098) F110=(0.046, 0.052, 0.063)	F11=(0.013, 0.019, 0.027) F12=(0.008, 0.012, 0.017) F13=(0.008, 0.011, 0.016) F14=(0.009, 0.013, 0.019) F15=(0.011, 0.017, 0.024) F16=(0.009, 0.013, 0.019) F17=(0.006, 0.008, 0.012) F18=(0.005, 0.008, 0.011) F19=(0.006, 0.009, 0.014) F110=(0.004, 0.006, 0.009)
F2=(0.107, 0.132, 0.163)	F21=(0.316, 0.349, 0.422) F22=(0.549, 0.650, 0.732)	F21=(0.034, 0.046, 0.069) F22=(0.058, 0.086, 0.119)
F3=(0.068, 0.082, 0.103)	F31=(0.497, 0.628, 0.765) F32=(0.308, 0.371, 0.474)	F31=(0.034, 0.052, 0.079) F32=(0.021, 0.030, 0.049)
F4=(0.080, 0.101, 0.127)	F41=(0.285, 0.312, 0.346) F42=(0.189, 0.199, 0.221) F43=(0.445, 0.489, 0.519)	F41=(0.023, 0.032, 0.044) F42=(0.015, 0.021, 0.028) F43=(0.035, 0.049, 0.066)
F5=(0.161, 0.198, 0.242)	F51=(0.101, 0.111, 0.135) F52=(0.129, 0.142, 0.164) F53=(0.206, 0.241, 0.274) F54=(0.276, 0.319, 0.349) F55=(0.166, 0.185, 0.214)	F51=(0.016, 0.022, 0.033) F52=(0.021, 0.028, 0.039) F53=(0.033, 0.048, 0.066) F54=(0.044, 0.063, 0.085) F55=(0.027, 0.037, 0.052)
F6=(0.108, 0.137, 0.176)	F61=(0.292, 0.339, 0.401) F62=(0.184, 0.208, 0.245) F63=(0.365, 0.452, 0.542)	F61=(0.032, 0.047, 0.071) F62=(0.021, 0.028, 0.043) F63=(0.039, 0.062, 0.096)
F7=(0.115, 0.147, 0.182)	F71=(0.549, 0.651, 0.732) F72=(0.317, 0.349, 0.423)	F71=(0.064, 0.096, 0.134) F72=(0.037, 0.051, 0.077)
G8=(0.062, 0.078, 0.100)	G81=(0.062, 0.076, 0.098) G82=(0.078, 0.106, 0.136) G83=(0.069, 0.082, 0.101) G84=(0.082, 0.106, 0.141) G85=(0.128, 0.158, 0.186) G86=(0.087, 0.105, 0.136) G87=(0.177, 0.211, 0.241) G88=(0.128, 0.155 0.191)	G81=(0.004, 0.006, 0.009) G82=(0.005, 0.008, 0.014) G83=(0.004, 0.006, 0.011) G84=(0.005, 0.008, 0.014) G85=(0.008, 0.012, 0.019) G86=(0.005, 0.008, 0.014) G87=(0.011, 0.016, 0.016) G88=(0.008, 0.012, 0.019)

Table 7. Calculated sum of all sub-factors w.r.t. each alternative from weighted normalized matrix

Brokerage Firms	V_i
AAI	(0.4029, 0.6464, 1.0886)
Angel One	(0.4962, 0.7957, 1.2786)
Groww	(0.6172, 0.999, 1.5345)
HDFC Securities	(0.4775, 0.7661, 1.2391)
ICICI Direct	(0.4818, 0.7772, 1.2529)
Upstox	(0.4837, 0.7798, 1.2596)
Zerodha	(0.5315, 0.8539, 1.3489)
AI	(0.6402, 1.0332, 1.5728)

Table 8. Calculation of (Ki-), (Ki+), (Ti), F(Ki+), F(Ki-)

Brokerage Firms	$K_i -$	$K_i +$	T_i	$F(K_i+)$	$F(K_i-)$
Angel One	(0.4558,1.2309 ,3.1730)	(0.3155,0.7701 ,1.997)	(0.7713,2.0011 ,5.1701)	(0.1588,0.4288 ,1.1054)	(0.1099,0.2683, 0.6957)
Groww	(0.5669,1.5468 ,3.8082)	(0.3924,0.9678 ,2.3968)	(0.9594,2.5147 ,6.2051)	(0.1975,0.5389 ,1.3267)	(0.1367,0.3372, 0.8349)
HDFC Securities	(0.4387,1.1851 ,3.0749)	(0.3036,0.7415 ,1.9354)	(0.7423,1.9266 ,5.0104)	(0.1528,0.4128 ,1.0712)	(0.1058,0.2583, 0.6742)
ICICI Direct	(0.4426,1.2023 ,3.1093)	(0.3063,0.7523 ,1.9569)	(0.7489,1.9546 ,5.0662)	(0.1542,0.4188 ,1.0832)	(0.1067,0.2621, 0.6817)
Upstox	(0.4444,1.2064 ,3.1259)	(0.3076,0.7548 ,1.9674)	(0.7519,1.9612 ,5.0933)	(0.1548,0.4203 ,1.0889)	(0.1071,0.2629, 0.6854)
Zerodha	(0.4882,1.3210 ,3.3477)	(0.3379,0.8265 ,2.1069)	(0.8262,2.1476 ,5.4546)	(0.1701,0.4602 ,1.1662)	(0.1177,0.2879, 0.7341)

Table 9. Defuzzyfication, Calculation of f(ki) & Ranking

Brokerage Firms	$K_i -$	$K_i +$	$f(K_i+)$	$f(K_i-)$	$f(K_i)$	**Ranking (Fuzzy MARCOS)**
Angel One	1.425429	0.898868	0.496577	0.313139	0.552449	**3**
Groww	1.760422	1.110089	0.613278	0.386722	0.892456	**1**
HDFC Securities	1.375661	0.867479	0.479239	0.302203	0.510306	**6**
ICICI Direct	1.393531	0.878727	0.485466	0.306122	0.525191	**5**
Upstox	1.399314	0.882372	0.487479	0.307392	0.530064	**4**
Zerodha	1.520017	0.958517	0.529528	0.333918	0.638268	**2**

Results shows that the Groww has the best ranking while Zerodha is the second best according to the Fuzzy MARCOS technique.

5 Comparative Analysis

Two different MCDM techniques, fuzzy MARCOS and fuzzy VIKOR were employed for the selection of the best to worst financial e-services of brokerage firms in India.

From the Table 10,11 & Figure 3, Groww has the best ranking, Zerodha is the second best and Angel One positioning third according to the Fuzzy MARCOS technique. Considering the Fuzzy VIKOR technique Zerodha is the top ranking, Groww is the second-best choice but Angel One is the third preferred choice. Overall, the e-services of brokerage firm which looked up upon are Groww, Zerodha and Angel One.

Table 10. Ranking Using FUZZY-VIKOR Method

Brokerage Firms	S_i	R_i	Q_i	**Ranking (Fuzzy VIKOR)**
Angel One	0.4327159	0.074178	0.639442	**3**
Groww	0.2849787	0.074178	0.499249	**2**
HDFC Securities	0.4605589	0.082707	0.70976	**6**
ICICI Direct	0.4407849	0.074178	0.647099	**4**
Upstox	0.3995366	0.082707	0.651854	**5**
Zerodha	0.0649298	0.020085	0	**1**

Table 11 denotes the comparative ranking obtained under the two methodologies, fuzzy MARCOS and fuzzy VIKOR.

Table 11. Ranking table for comparative analysis

Brokerage Firms	Ranking (Fuzzy MARCOS)	Ranking (Fuzzy VIKOR)
Angel One	3	3
Groww	1	2
HDFC Securities	6	6
ICICI Direct	5	4
Upstox	4	5
Zerodha	2	1

Figure 3 shows the graphical represents of comparative ranking.

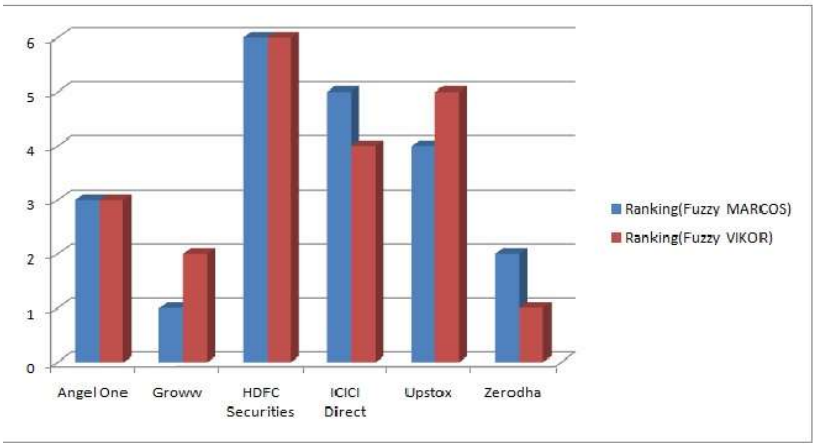

Figure 3. Comparative Ranking

6 Conclusions

Groww has the highest rating, according to the Fuzzy MARCOS approach, followed by Zerodha and Angel One in that order. Additionally, the Fuzzy VIKOR approach places Zerodha at the top of the list of favoured possibilities, with Groww and Angel One coming in as the second and third favourite choices, respectively. When both approaches are taken into consideration, Groww, Zrodha, and Angel One are constantly shown to be the most highly prestigious broking businesses. It is important for readers to bear in mind that these rankings are derived from certain methods, and it is possible that they may not accurately

reflect the ideas or preferences of every single person. It's possible that various individuals will have varied choices, depending on the demands and preferences that they have.

7 Limitations

This study is limited to

I. Financial e-services of six brokerage firms only.
II. Fifteen factors and twenty-seven sub factors only.
III. The MCDM techniques AHP & MARCOS.
IV. The financial e-services of brokerage firms which have been chosen for this study in the context of Indian financial market only.

8 Future Scopes

This study can be extended in future by

I. Considering more brokerage firms.
II. Choosing more factors and sub factors.
III. Applying other MCDM methods such as TOPSIS [45], PROMETHEE [46], ELECTRE [47], SAW [56], WASPAS [57], MACBETH [58], GTMA [59] and DEMATEL [60] , Fuzzy Hypersoft Sets approach[61], Circular Economy with uncertain MCDM [62], fuzzy SWARA and fuzzy MOORA integrated approach [63], etc. can be used to give a new shape to the results.
IV. Picking other Nation's brokerage firms of financial markets.

References

[1] A. Lusardi, and O.S. Mitchell, "Financial literacy around the world: an overview", *Journal of pension economics & finance*, vol. *10*, no. 4, pp. 497-508, 2011, doi:10.1017/S1474747211000448.

[2] R. Verma, Z. Iqbal, and G. Plaschka, "Understanding customer choices in e-financial services", *California Management Review*, vol. *46*, no. 4, pp. 43-67, 2004.

[3] H. Aygören, and M.E. Yeşilyurt, "Impact of firm attributes on the efficiency of brokerage houses", *BDDK Bankacılık ve Finansal Piyasalar Dergisi*, *5*(2), 159-181, 2011.

[4] T. Kvasnicova, I. Kremenova, and J. Fabus, "From an analysis of e-services definitions and classifications to the proposal of new e-service classification", *Procedia Economics and Finance*, vol. *39*, pp. 192-196, 2016, doi:10.1016/S2212-5671(16)30282-9.

[5] C. Francq, and J.M. Zakoian, "*GARCH models: structure, statistical inference and financial applications*", John Wiley & Sons, 2019, doi:10.1002/9781119313472.

[6] A. Toloie-Eshlaghy, and M. Homayonfar, "MCDM methodologies and applications: a literature review from 1999 to 2009", *Research Journal of International Studies*, vol. *21*, pp. 86-137, 2011.

[7] M. Stojčić, E.K. Zavadskas, D. Pamučar, Z. Stević, and A. Mardani, "Application of MCDM methods in sustainability engineering: A literature review 2008–2018", *Symmetry*, vol. *11*, no. 3, pp. 350, 2019, doi:10.3390/sym11030350.

[8] S.H. Mirfakhraddini, Y. Amiri, "Proposing solutions to improve E-banking services using BSC, FANP & FUZZY TOPSIS (Case study: Selected banks in Fars province)", *Industrial Management Journal*, vol. *2*, no. 2, pp. 141-298, 2010, https://imj.ut.ac.ir/article_22417.html?lang=en.

[9] W.H. Tsai, W. Hsu, and T.W. Lin, "New financial service development for banks in Taiwan based on customer needs and expectations", *The Service Industries Journal*, vol. *31*, no. 2, pp. 215-236, 2011, doi:10.1080/02642060903295636.

[10] R.A. Carrasco, F. Muñoz-Leiva, J. Sánchez-Fernández, and F.J. Liébana-Cabanillas, "A model for the integration of e-financial services questionnaires with SERVQUAL scales under fuzzy linguistic modelling", *Expert Systems with Applications*, vol. *39*, no. 14, pp. 11535-11547, 2012, doi:10.1016/j.eswa.2012.03.055.

[11] M.H. K. Zadeh, D.A.B.T. Hasan Mehr Manesh, "Electronic Services (IT) in the Banking and Financial Institutions (Case Study of Melli Bank Branches in Mashhad Province)", *FAUNA ROSSII I SOPREDEL NYKH STRAN*, vol. *9* no. 8., 2013.

[12] R. Elbadrawy, A.F.A. Moneim, and M.N. Fors, "A hybrid model AHP and PROMETHEE for evaluation of E-banking services", In *IIE Annual Conference. Proceedings* (p. 1462), 2014. Institute of Industrial and Systems Engineers (IISE).

[13] G. Komlan, "Integrating AHP-TOPSIS approach on prioritizing self-service technology (SST) decision making in financial institution (Togo)", *British Journal of Mathematics & Computer Science*, vol. *16*, no. 3, pp. 1-22, 2016, doi:10.9734/BJMCS/2016/25359.

[14] N. Koushan, C.J. RONDAN, and A.P. Verdet, "Ranking of ES-QUAL Factors from E-investors' Perceptions in Capital Market", INTERNATIONAL CONFERENCE ON NEW IDEAS IN MANAGEMENT ECONOMICS AND ACCOUNTING, 2016, https://sid.ir/paper/928134/en.

[15] A. Hinduja, and M. Pandey, " Multicriteria recommender system for life insurance plans based on utility theory", *Indian Journal of Science and Technology*, vol. *10*, no. 14, pp. 1-8, 2016, doi: 10.17485/ijst/2017/v10i14/111376.

[16] H.M. ARSLAN, "Determination of the Most Suitable Credit Provider in Banking Services with Multi Criteria Decision Making Methods", *International Journal of Engineering Science Invention*, vol. *7*, no. 3, pp. 14-21, 2018, http://www.ijesi.org/papers/Vol(7)i3/Version-5/D0703051421.pdf.

[17] K.P. Gupta, R. Manrai, "Prioritizing Factors Affecting the Adoption of Mobile Financial Services in Emerging Markets—A Fuzzy AHP Approach", In: Deep, K., Jain, M., Salhi, S. (eds) Performance Prediction and Analytics of Fuzzy, Reliability and Queuing Models. Asset Analytics. Springer, Singapore, 2019, doi:10.1007/978-981-13-0857-4_4.

[18] A. Hinduja, M. Pandey, "An intuitionistic fuzzy AHP based multi criteria recommender system for life insurance products", *International Journal of Advanced Studies in Computers, Science and Engineering*, vol. *7*, no. 1, pp. 1-8, 2018.

[19] S.Z. Mustafa, and A.K. Kar, "Prioritization of multi-dimensional risk for digital services using the generalized analytic network process", *Digital Policy, Regulation and Governance*, vol. *21*, no. 2, pp. 146-163, doi:10.1108/DPRG-06-2018-0031.

[20] V. Agrawal, N. Seth, and J.K. Dixit, "A combined AHP–TOPSIS–DEMATEL approach for evaluating success factors of e-service quality: an experience from Indian banking industry", *Electronic Commerce Research*, vol22, pp. 715-747, 2022, doi:10.1007/s10660-020-09430-3.

[21] K. Gbongli, Y. Xu, K.M. Amedjonekou, and L. Kovács, "Evaluation and classification of mobile financial services sustainability using structural equation modeling and multiple criteria decision-making methods", *Sustainability*, vol. *12*, no. 4, pp. 1288, 2020, doi:10.3390/su12041288.

[22] U.A. Kahraman, "Selection of suitable bank based on quality of providing systems for internet banking services using AHP and ANP methods", *Journal of Management and Accounting Studies*, vol. *8*, no. 4, pp. 50-60, 2020, doi:10.24200/jmas.vol8iss4pp50-60.

[23] W.S. Lam,W.H. Lam, and P.F. Lee, "The Impact of E-Payment Systems in the Selection of Cinema among the Undergraduate Students using Analytic Hierarchy Process Model." In *2020 IEEE Conference on e-Learning, e-Management and e-Services (IC3e)* (pp. 49-54), 2020, doi:10.1109/IC3e50159.2020.9288404.

[24] N. Singh, A. Chakraborty, S.B. Biswas, and M. Majumdar, "Impact of social media in banking sector under triangular neutrosophic arena using MCGDM technique", *Neutrosophic sets and systems*, vol. *35*, pp. 153-176, 2020, doi:10.5281/zenodo.3951653.

[25] A. Ghosh, "Analyzing Efficiency of Indian Life Insurance Companies using DEA and SEM", *Turkish Journal of Computer and Mathematics Education (TURCOMAT)*, vol. *12*, no. 12, pp. 3897-3919, 2021, doi:10.17762/turcomat.v12i12.8178.

[26] K.P. Gupta, R. Manrai, and U. Goel, "Analysing the factors that affect the adoption of payments bank services in India: An analytic hierarchy process approach", *International Journal of Business Information Systems*, vol. *37,* no. 4, pp. 522-543, 2021, doi:10.1504/IJBIS.2021.117003.

[27] A. Kapoor, R. Sindwani, and M. Goel, "Ranking mobile wallet service providers using fuzzy multi-criteria decision-making approach", *International Journal of E-Business Research (IJEBR)*, vol. *17*, no. 4, pp. 19-39, 2021, doi: 10.4018/IJEBR.2021100102.

[28] A. Kapoor, R. Sindwani, and M. Goel, "Assessing Mobile Banking Service Quality Dimensions Using Multi-Criteria Decision Making", In: Subudhi, R.N., Mishra, S., Saleh, A., Khezrimotlagh, D. (eds) Future of Work and Business in Covid-19 Era. Springer Proceedings in Business and Economics. Springer, Singapore, 2022, doi:10.1007/978-981-19-0357-1_12.

[29] M. Amiri, M. Hashemi-Tabatabaei, M. Keshavarz-Ghorabaee, J. Antucheviciene, J. Šaparauskas, and M. Keramatpanah, "Evaluation of Digital Banking Implementation Indicators and Models in the Context of Industry 4.0: A Fuzzy Group MCDM Approach", *Axioms*, vol. *12, no.* 6, pp. 516, 2023, doi:10.3390/axioms12060516.

[30] K.A. Aziz, S. Abdullah, M.A. Jabar, R.N.H. No, and N.I.I. Tajuddin, "How analytical hierarchy process prioritizing internet banking influencing factors? a research study", *International Journal of Electrical and Computer Engineering*, vol. 13, no. 6, pp. 6646-6653, 2023, doi:10.11591/ijece.v13i6.pp6646-6653.

[31] R. Sindwani, "Assessing technology banking service providers using fuzzy MCDM approach", *International Journal of Productivity and Quality Management*, vol. *38*, no. 3, pp. 312-331, 2023, doi:10.1504/IJPQM.2023.129618.

[32] N. Varshney, and R. Agrawal, "Analysis of Finance Risk with Clustering Algorithm Using VIKOR Method", In *2023 1st International Conference on Cognitive Computing and Engineering Education (ICCCEE),* (pp. 1-6), 2023, doi: 10.1109/ICCCEE55951.2023.10424456.

[33] A. Rezaei, and M. Hemati, "Providing a hybrid fuzzy approach to explain managers' mental paradigms to prioritize employee needs", *Journal of fuzzy extension and applications*, vol. *4*, no. 3, pp. 155-172, 2023, doi:10.22105/jfea.2022.335662.1212.

[34] P. Shafi Salimi, and S.A. Edalatpanah, "Supplier selection using fuzzy AHP method and D-Numbers", *Journal of fuzzy extension and applications*, vol. *1*, no. 1, pp. 1-14, 2020, doi: 10.22105/jfea.2020.248437.1007.

[35] A.R. Sheergojri, and P. Iqbal, "Mathematical modeling and treating tumors in a fuzzy environment", *Computational Algorithms and Numerical Dimensions*, vol. *3*, no. 1, pp. 45-57, 2024, doi:10.22105/cand.2024.450759.1093.

[36] Y. Gu, K. Xu, X. Hu, and M. Chen, "Research on Improving the Financial Capacity of Farmers Based on Fuzzy Analytic Hierarchy Process", Management Analytics and Social Insights, vol. 1, no. 1, pp. 88-102, 2024, doi:https://doi.org/10.22105/6f2des36.

[37] M. Ghanadzadeh, B. Khabiri, and V. Imani, "Efficient Resource Allocation Management in Multicommodity Networks: A Fuzzy Multiobjective Approach", Management Analytics and Social Insights, vol. 1, no. 1, pp. 103-115, 2024, doi: https://doi.org/10.22105/zev39s65.

[38] A. Nafei, C.Y. Huang, S.M. Azimi, and A. Javadpour, "An optimized model for neutrosophic multi-choice goal programming", *Miskolc Mathematical Notes*, vol. *24*, no. 2, pp. 915-931, 2023, doi: 10.18514/MMN.2023.4020.

[39] M. Soltanifar, "A new interval for ranking alternatives in multi attribute decision making problems", *Journal of applied research on industrial engineering*, vol. *11*, no. 1, pp. 37-56, 2024, doi:10.22105/jarie.2022.339957.1467.

[40] A. H. Nafei, and S. H. Nasseri, "*A new approach for solving neutrosophic integer programming problems*", International Journal of Applied Operational Research, vol. 9, no. 1, pp. Winter 1-9, 2019.

[41] M. Akram, S.M. U. Shah, M.M.A. Al-Shamiri, and S.A. Edalatpanah, "Extended DEA method for solving multi-objective transportation problem with Fermatean fuzzy sets", *Aims Mathematics*, vol. *8*, no. 1, pp. 924-961, 2023, doi:10.3934/math.2023045.

[42] G. Farajpour Khanaposhtani, "A new multi-attribute decision-making method for interval data using support vector machine", *Big Data and Computing Visions*, vol. *3*, no. 4, pp. 137-145, 2023, doi.org/10.22105/bdcv.2023.190406.

[43] A. Nafei, Y. Gu, and W. Yuan, "*An extension of the TOPSIS for multi-attribute group decision making under neutrosophic environment*", Miskolc Mathematical Notes, 2021, doi:10.18514/MMN.2021.3332.

[44] T.L. Saaty, "Decision making with the analytic hierarchy process", *International journal of services sciences*, vol. *1*, no. 1, pp. 83-98, 2008, doi: 10.1504/IJSSCI.2008.017590.

[45] C.L. Hwang, and K. Yoon, "Multiple Attribute Decision Making: Methods and Applications", vol. 186, 1981, doi.org/10.1007/978-3-642-48318-9.

[46] J.P. Brans, and Vincke, "Note—A Preference Ranking Organisation Method: (The PROMETHEE Method for Multiple Criteria Decision-Making)", *Management science*, vol. *31*, no. 6, pp. 647-656, 1985, doi.org/10.1287/mnsc.31.6.647.

[47] B. Roy, "Classement et choix en présence de points de vue multiples", *Revue française d'informatique et de recherche opérationnelle*, vol.*2*, no. 8, pp. 57-75, 1968, doi.org/10.1051/ro/196802V100571.

[48] Z. Stević, D. Pamučar, A. Puška, and P. Chatterjee, "Sustainable supplier selection in healthcare industries using a new MCDM method: Measurement of alternatives and ranking according to COmpromise solution (MARCOS)" *Computers & Industrial Engineering*, vol. *140*, pp. 106231, 2020, doi.org/10.1016/j.cie.2019.106231.

[49] L. Duckstein, and S. Opricovic, "Multiobjective optimization in river basin development", *Water resources research*, vol. *16*, no. 1, pp. 14-20, 1980, doi.org/10.1029/WR016i001p00014.

[50] L. Mikhailov, and P. Tsvetinov, "Evaluation of services using a fuzzy analytic hierarchy process", *Applied Soft Computing*, vol. *5*, no. 1, pp. 23-33, 2004, doi.org/10.1016/j.asoc.2004.04.001.

[51] M. Stanković, Z. Stević, D.K. Das, M. Subotić, and D. Pamučar, "A new fuzzy MARCOS method for road traffic risk analysis", *Mathematics*, vol. *8*, no. 3, pp. 457, 2020, doi.org/10.3390/math8030457.

[52] S. Opricovic, "Fuzzy VIKOR with an application to water resources planning", *Expert Systems with Applications*, vol. *38*, no. 10, pp. 12983-12990, 2011, doi.org/10.1016/j.eswa.2011.04.097.

[53] C.A. Robb, P. Babiarz, and A. Woodyard, "The demand for financial professionals' advice: The role of financial knowledge, satisfaction, and confidence", *Financial Services Review*, vol. *21*, no. 4, pp. 291-306, 2012, https://users.ssc.wisc.edu/~carobb/wp-content/uploads/2016/08/FSR-2012.pdf

[54] L.A. Zadeh, "Fuzzy sets", *Information and control*, vol.*8*, no. 3, pp. 338-353, 1965, doi.org/10.1016/S0019-9958(65)90241-X.

[55] D. Dubois, and H. Prade, "Operations on fuzzy numbers", *International Journal of systems science*, vol. *9*, no. 6, pp. 613-626, 1978, doi.org/10.1080/00207727808941724.

[56] S.Y. Chou, Y.H. Chang, and C.Y. Shen, "A fuzzy simple additive weighting system under group decision-making for facility location selection with objective/subjective attributes", *European Journal of Operational Research*, vol. *189*, no. 1, pp. 132-145, 2008, doi.org/10.1016/j.ejor.2007.05.006.

[57] E.K. Zavadskas, Z. Turskis, J. Antucheviciene, and A. Zakarevicius, Optimization of weighted aggregated sum product assessment*", Elektronika ir elektrotechnika*, vo*l.122, no.* 6, pp. 3-6, doi: 10.5755/j01.eee.122.6.1810.

[58] C.A.Bana E Costa, J.C. Vansnick, "The MACBETH Approach: Basic Ideas, Software, and an Application In: Meskens, N., Roubens, M. (eds) Advances in Decision Analysis. Mathematical Modelling: Theory and Applications", vol 4, 1999, doi.org/10.1007/978-94-017-0647-6_9.

[59] V.R. Rao, "*Decision making in the manufacturing environment: using graph theory and fuzzy multiple attribute decision making methods*", vol. 2, p. 294, 2012, doi.org/10.1007/978-1-4471-4375-8.

[60] A. Gabus, and E. Fontela, "Perceptions of the world problematique: Communication procedure, communicating with those bearing collective responsibility".https://api.semanticscholar.org/CorpusID:157271447.

[61] H. Naveed and S. Ali, "Addressing Decision-Making Challenges: Similarity Measures for Interval-Valued Intuitionistic Fuzzy Hypersoft Sets", Decision Making Advances, vol. 3, no. 1, pp. 175–184, Dec. 2024.

[62] A. Biswas, K. H. Gazi, and S. P. Mondal, "Finding Effective Factor for Circular Economy Using Uncertain MCDM Approach", Manag. Sci. Adv., vol. 1, no. 1, pp. 31–52, Dec. 2024, doi: 10.31181/msa1120245.

[63] A. Özdağoğlu, M. K. Keleş, and M. Şenefe, "Evaluation of banks in terms of customer preferences with fuzzy SWARA and fuzzy MOORA integrated approach", J. Decis. Anal. Int. Comp., vol. 4, no. 1, pp. 216–232, Dec. 2024.