Integrating Cutting-Edge Mathematics Teaching Methods and Neutrosophic Logic Based Evaluation for Technological Innovation Initiatives for Indian MSMEs

By

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(23PMA025)

Supervisor

Dr. C. Antony Crispin Sweety

Thesis submitted to

Avinashilingam Institute for Home Science and Higher Education for Women

Coimbatore – 641 043

In Partial Fulfillment of the Requirements for the Degree of Master of science in Mathematics

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Signature of the Director | **Signature of the Supervisor** 28/04/25

DECLARATION

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I declare that the thesis **"Integrating Cutting-Edge Mathematics Teaching Methods and Neutrosophic logic based Evaluation for Technological Innovation Initiatives for Indian MSMEs"** submitted by me for the degree of **Master of Science (M.Sc.)** is the record of work carried out during the period from December 2024 to April 2025 under the guidance of **Dr. C. Antony Crispin Sweety, M.Sc., B.Ed., M.Phil., Ph.D.**, Assistant Professor. Department of Mathematics, Avinashilingam Institute for Home Science and Higher Education for women, Coimbatore, and has not formed the basis for the award of any Degree. Diploma, Associateship, Fellowship, Titles in this institute or any other University or other similar institution of Higher Learning.

R. Yazhini
28/04/2025

Signature of the Candidate

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CONTENT

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ABSTRACT

Micro, Small, and Medium Enterprises (MSMEs) play a vital role in economic growth, innovation, and employment generation. Strengthening MSME sustainability through strategic decision-making and mathematical models is essential for fostering long-term development and competitiveness. This thesis presents an integrated approach that combines advanced mathematical education with decision-making models to equip students with the skills needed to drive innovation and entrepreneurship within Indian Micro, Small, and Medium Enterprises. Recognizing the gap between abstract mathematical education and real-world entrepreneurial applications, the study introduces a reformed pedagogy that incorporates innovation, problem-solving, and data-driven techniques into the teaching of higher mathematics. The framework proposed empowers students with both analytical and entrepreneurial skills, preparing them for impactful roles in MSME development. It applies Fermatean Neutrosophic Combinative Distance-Based Assessment method - a robust Multi-Criteria Decision-Making (MCDM) model to evaluate sustainable Technology innovation in MSMEs under uncertainty. By incorporating Fermatean Neutrosophic Sets, the model effectively captures uncertainty, imprecision, and conflicting expert opinions, making it highly suitable for complex evaluations in MSMEs, such as technology adoption, project planning, and policy impact. Through curriculum innovations, case studies, and mathematical modeling, this thesis demonstrates how integrating higher mathematics with entrepreneurship education enhances students problem-solving capabilities, employability, and ability to contribute meaningfully to India's innovation-driven MSME sector. The study concludes that a mathematics-entrepreneurship collaboration is essential for producing skilled graduates capable of navigating and contributing to today's dynamic economic landscape.

CHAPTER 1

Chapter 1

INTRODUCTION

Micro, Small, and Medium Enterprises (MSMEs) form the backbone of many economies, especially in developing nations. In the context of MSMEs (Micro, Small, and Medium Enterprises), a **micro enterprise** refers to the smallest category of business, defined by limited investment and low turnover. These businesses typically operate on a very small scale, often run by individuals, families, or small groups with limited capital and a small workforce. They are usually focused on local markets and include examples such as street vendors, tailoring shops, home-based food producers, and artisans. Micro enterprises play a crucial role in employment generation, entrepreneurship promotion, and poverty alleviation, especially in rural and semi-urban areas. To support their growth, governments often provide benefits such as subsidies, collateral-free loans, skill development programs, and simplified compliance procedures. MSMEs are characterized by their limited scale of operations but have a significant impact on employment, innovation, industrial output, and equitable distribution of income. MSMEs are often more adaptable and flexible than larger corporations, which allows them to respond quickly to changes in the market. They are active in various sectors, including manufacturing, services, retail, and export, and contribute to both urban and rural development. Governments worldwide acknowledge their importance and provide various forms of support, such as easy access to credit, subsidies, marketing assistance, training, and infrastructure development. Over the years, MSMEs have played a key role in promoting entrepreneurship and innovation, particularly in developing economies like India.

However, MSMEs also face several challenges, including financial constraints, lack of access to technology, competition from larger enterprises, limited market exposure, and inadequate infrastructure. These issues make effective decision-making a necessity for MSME owners and managers. Given the need to optimize limited resources, decision-making in MSMEs involves selecting the best possible course of action from multiple alternatives based on several criteria—such as cost, quality, efficiency, risk, and customer satisfaction.

Multi-Criteria Decision-Making (MCDM) refers to a set of methods used to evaluate and rank multiple alternatives based on several conflicting criteria, commonly applied in areas like engineering, business, and environmental management. Popular MCDM methods include AHP, TOPSIS, COPRAS, MOORA, and CODAS, each with unique techniques for comparing and ranking alternatives.

Among them, the **CODAS (Combinative Distance-based Assessment)** method is known for using both Euclidean and Taxicab distances to assess alternatives relative to the negative ideal solution.

The integration of Fermatean Neutrosophic logic with CODAS, known as Fermatean Neutrosophic CODAS, provides a powerful tool for accurate and robust decision-making, offering better discrimination among alternatives and improved reliability in uncertain environments.

ABBREVIATION

MSME – Micro, Small and Medium Enterprises

MCDM – Multi-Criteria Decision–Making

CODAS – Combinative Distance - based Assessment

AHP – Analytic Hierarchy Process

TOPSIS – Technique for Order Preference by Similarity to Ideal Solution

COPRAS – Complex Proportional Assessment

MOORA – Multi-Objective Optimization on the Basis of Ratio Analysis

1.1LITERATURE REVIEW

Schumpeter (1947, 1959) – Defined entrepreneurs as agents of innovation and change in economic activities.

Jamieson (1984), Winterton (2002) – Discussed categories and impact of entrepreneurial training.

Ronstadt (1989), Cooper et al. (1994) – Prior experience and occupational background as innovation drivers.

OECD (1997) – Provided foundational definitions and views on technological innovation and MSME challenges.

Cummings & Oldham (1997) – Viewed technological innovation as integration of new tech and processes.

Tidd et al. (2001) – Linked technological innovation to converting ideas into organizational improvements.

Subrahmanya (2005, 2010) – Showed the role of entrepreneur-led innovation and academic linkages.

Slotte-Kock & Coviello (2010), Davidsson & Honig (2003) – Importance of entrepreneur networks.

Hayashi (2002) – Emphasized subcontracting and inter-firm cooperation in Indonesian MSMEs.

Masakure et al. (2009), Zeng et al. (2010) – Governmental support for MSME innovation.

Meng & Liang (1996), Zaridis & Mousiolis (2014) – Correlated education with successful innovation decisions.

Jagersma (2008) – Emphasized managerial decision-making influenced by education and training.

Decision-making is the process of choosing the best option among several alternatives to achieve a specific goal or solve a problem. Fuzzy and neutrosophic methods refine decision-making under uncertainty. Peng & Ma (2019) [50] enhanced CODAS with a new score function, improving multi-criteria analysis.

This involves assessing options based on criteria such as risks, benefits, and potential outcomes.

In Multi-Criteria Decision Making (MCDM), various methods are employed to evaluate alternatives based on multiple criteria [26], including CODAS (Combinative Distance-based Assessment)[35,50,53,69,79], which assesses alternatives by their distance from ideal solutions while considering both qualitative and quantitative criteria. The choice of method depends on the specific requirements of the decision-making problem and the nature of the data.

Fermatean Neutrosophic Set (FNS) is a flexible framework and generalized theory introduced by Antony Crispin Sweety et al. (2021) [3] that includes fuzzy, intuitionistic fuzzy, Pythagorean fuzzy, spherical fuzzy, Fermatean fuzzy sets, and neutrosophic set theory.

1.2 OUTLINE OF THE THESIS

This thesis presents an innovative framework combining mathematical logic and entrepreneurship education to support Micro, Small, and Medium Enterprises (MSMEs).

Chapter 1 Introduces the theoretical foundation of Neutrosophic Sets, which extend classical and fuzzy set theories by incorporating the concepts of truth, indeterminacy, and falsity. This approach provides a powerful tool for modeling uncertainty and imprecision in complex decision-making environments, particularly relevant in entrepreneurship and educational contexts.

Chapter 2 Explores an innovation-driven approach to teaching higher mathematics within MSME-focused entrepreneurship education. It emphasizes how mathematical thinking-combined with creativity, problem-solving, and digital learning tools-can foster entrepreneurial mindsets among learners. The chapter proposes curriculum reforms and pedagogical strategies that integrate real-world MSME challenges into higher mathematics instruction, preparing students for entrepreneurial ventures.

Chapter 3 Introduces the Fermatean Neutrosophic CODAS (Combinative Distance-based Assessment) method as an advanced Multi-Criteria Decision-Making (MCDM) tool. This chapter applies the method to evaluate and rank various innovation in MSMEs. By handling high degrees of uncertainty and vagueness, Fermatean Neutrosophic CODAS enables more reliable strategy selection in MSMEs.

1.3 BASIC CONCEPTS

This chapter provides a preliminary overview of our research, emphasizing the importance of adaptable sets that are crucial in the subsequent parts of the thesis.

Definition 1.3.1

Let X be a nonempty set. A fuzzy set A drawn from X is defined as

$$A = \{\langle x, \mu_A(x)\rangle | x \in X\}$$

Where $\mu_A: X \to [0,1]$ is the membership function of the fuzzy set A.

Definition 1.3.2

Let X be a universe. An intuitionistic fuzzy set A on X can be defined as follows:

$$A = \{\langle x, \mu_A(x), \nu_A(x)\rangle | x \in X\}$$

Where $\mu: X \to [0,1]$ and $\nu_A: X \to [0,1]$ such that $0 \leq \mu_A(x) + \nu_A(x) \leq 1$ for any $x \in X$Where, $\mu_A(x)$ and $\nu_A(x)$ is the degree of membership and degree of non-membership of the element x respectively.

Definition 1.3.3

Let U be a universe set. A Neutrosophic Set (NS) A in U is characterized by a truth membership functionT_A, an indeterminacy membership function I_A and a falsity membership function $F_A$where T_A , I_A and F_A are real standard elements of [0,1]. It can be written as

$$A = \{\langle X, (T_A(x)) + (I_A(x)) + (F_A(x))\rangle : x \in E, T_A, I_A, F_A \in]^{-}0, 1^{+}[\}$$

There is no restriction on the sum of $(T_A(x)), (I_A(x))$and$(F_A(x))$ and so

$$0^{-} \leq (T_A(x)) + (I_A(x)) + (F_A(x)) \leq 3^{+}$$

Definition 1.3.4

Let X is a space of points (objects) with generic elements in X denoted by x. A neutrosophic set A in X is characterized by a truth-membership function $T_A(x)$, an indeterminacy membership function $I_A(x)$, and a falsity membership function $F_A(x)$ if the functions $T_A(x), I_A(x), F_A(x)$ are singletons subintervals/subsets in the real standard [0,1], i.e. $T_A(x)$: X → [0, 1], $I_A(x)$: X → [0,1], $F_A(x)$: X → [0,1]. Then a simplification of the neutrosophic set A is denoted by

$$\mathrm{A} = \{< \mathrm{x}, T_A(x), I_A(x), F_A(x) >, x \in X\}.$$

Definition 1.3.5

Let X is a space of points (objects) with generic elements in X denoted by x. An SVNS A in X is characterized by a truth-membership function $T_A(x)$, an indeterminacy membership function $\mathrm{I}_A(x)$ and a falsity-membership function $F_A(x)$, for each point $x \in X$, $T_A(x), I_A(x), F_A(x) \in [0,1]$. Therefore, a SVNS A can be written as $A_{\mathrm{SVNS}} = \{< x: T_A(x), I_A(x), F_A(x) >, x \in X\}$.

For two SVNS, $A_{\mathrm{SVNS}} = \{< x: T_A(x), I_A(x), F_A(x) >, x \in X\}$ and $B_{\mathrm{SVNS}} = \{< x: T_B(x), I_B(x), F_B(x) >, x \in X\}$, the following expressions are defined in as follows: $A_{\mathrm{NS}} \subseteq B_{\mathrm{NS}}$ if and only if $T_A(x) \leq T_B(x)$, $I_A(x) \geq I_B(x)$, $F_A(x) \geq F_B(x)$. $A_{\mathrm{NS}} = B_{\mathrm{NS}}$ if and only if $T_A(x) = T_B(x)$, $I_A(x) = I_B(x)$, $F_A(x) = F_B(x)$. $A^c = < x, F_A(x), 1 - I_A(x), T_A(x) >$

For convenience, a SVNS A is denoted by $A = < T_A(x), I_A(x), F_A(x) >$ for any x$\in X$; for two SVNSs A and B. Then,

(1) $A \cup B = < \max(T_A(x), T_B(x)), \min(I_A(x), I_B(x)), \min(T_A(x), T_B(x)) >$
(2) $A \cap B = < \min(T_A(x), T_B(x)), \max(I_A(x), I_B(x)), \max(T_A(x), T_B(x)) >$

Definition 1.3.6

A single-valued neutrosophic set (SVNS) A in X is a neutrosophic set which is of the form

$$A = \{\langle x: (T_A(x)) + (I_A(x)) + (F_A(x))\rangle, x \in X\}$$

that is characterized by the degree of membership (namely $(T_A(x))$, the degree of indeterminacy (namely $(I_A(x))$ and the degree of non-membership (namely $(F_A(x))$, where $T_A(x), I_A(x), F_A(x) \in [0,1]$ such that $0 \leq (T_A(x)) + (I_A(x)) + (F_A(x)) \leq 3$, for all $x \in X$, respectively. For X, $SVNS(X)$ denotes the collection of all single valued neutrosophic sets of X.

Definition 1.3.7

A spherical fuzzy set $\tilde{A}$ of the universe of discourse U is given by

$$\tilde{A} = \{< x, (T_{\tilde{A}}(x), I_{\tilde{A}}(x), F_{\tilde{A}}(x)) > | x \in U\}$$

where $T_{\tilde{A}}(x): U \to [0,1], I_{\tilde{A}}(x): U \to [0,1], F_{\tilde{A}}(x): U \to [0,1]$ and

$0 \leq T_{\tilde{A}}{}^2(x) + I_{\tilde{A}}{}^2(x) + F_{\tilde{A}}{}^2(x) \leq 1 \forall x \in U.$

The numbers $T_{\tilde{A}}(x), I_{\tilde{A}}(x)$ and $F_{\tilde{A}}(x)$ are the degree of membership, non-membership and hesitancy of x to$\tilde{A}$, respectively.

Definition 1.3.8

Consider X be a set that is not empty, and I be the unit interval $[0,1]$. A Pythagorean fuzzy set A is an object that has the form

$$A = \{\langle x, \mu_A(x), \nu_A(x)\rangle | x \in X\}$$

where the degree of membership function is $\mu_A: X \to [0,1]$ and the degree of non-membership function is $\nu_A: X \to [0,1]$ for each element $x \in X$to the set A, and $(\mu_A(x))^2 + (\nu_A(x))^2 \leq 1$ for each $x \in X$.

Definition 1.3.9

Consider X be a set that is not empty (universe). $(\not{P}\not{N}\not{S})$is a Pythagorean neutrosophic set with T and F are dependent neutrosophic components A on X is an object of the form

$$A = \{\langle x, T_A(x), I_A(x), F_A(x)\rangle | x \in X\}$$

Where $T_A(x), I_A(x), F_A(x) \in [0,1]$, $0 \leq (T_A(x))^2 + (I_A(x))^2 + (F_A(x))^2 \leq 2$, for every$x \in X$. The degree of membership is $T_A(x)$, the degree of indeterminacy is $I_A(x)$ and the degree of non- membership is$F_A(x)$. Here $T_A(x)$ and $F_A(x)$ are dependent components and $I_A(x)$ is an independent.

Definition 1.3.10

Let X be a non-empty set (universe). A Fermatean neutrosophic set (FNS) A_F on X is an object of the form:

$$A_F = \{< s, T_{A_F}(s), I_{A_F}(s), F_{A_F}(s)) > | s \in X\}$$

Where, $T_{A_F}(s), I_{A_F}(s), F_{A_F}(s) \in [0,1]$, $0 \leq T^3{}_{A_F}(s), F^3{}_{A_F}(s) \leq 1, F^3{}_{A_F}(s) \leq 1, I^3{}_{A_F}(s) \leq 1$ then $0 \leq T^3{}_{A_F}(s), I^3{}_{A_F}(s), F^3{}_{A_F}(s) \leq 2, \forall s \in X$

$T_{A_F}(s)$ is the degree of membership, $I_{A_F}(s)$ is the degree of indeterminacy and $F_{A_F}(s)$ is the degree of non-membership. Here $T_{A_F}(s)$ and $I_{A_F}(s)$are independent components and $F_{A_F}(s)$ is a dependent component on $T_{A_F}(s)$.

Definition 1.3.11

Let $X = \{x_1, x_2, \ldots, x_n\}$ be a discrete confined set. A mapping $d: NS(X) \times NS(X) \to [0,1]$ is said to be a distance measure between two neutrosophic sets if it satisfies the following axioms:

i. $d(A,B) \geq 0$ for all $A,B \in NS(X)$.

ii. $d(A,B) = 0$ if and only if $A = B$ for all $A,B \in NS(X)$.

iii. $d(A,B) = d(B,A)$ for all $A,B \in NS(X)$.

iv. If $A \subseteq B \subseteq C$ for all $A,B,C \in NS(X)$, then $d(A,C) \geq d(A,B)$and $d(A,C) \geq d(B,C)$

Definition 1.3.12

The Hamming distance between two single-valued neutrosophic sets A and B is defined as

$$\mathrm{d_H}(\mathrm{A},\mathrm{B}) = \frac{1}{3}\sum_{\mathrm{j}=1}^{\mathrm{n}}\left(\left|\mathrm{T_A}(x_j)^2 - T_B(x_j)^2\right| + \left|\mathrm{I_A}(x_j)^2 - I_B(x_j)^2\right| + \left|\mathrm{F_A}(x_j)^2 - F_B(x_j)^2\right|\right)$$

Definition 1.3.13

The Euclidean distance between two single-valued neutrosophic sets A and B is defined as

$$d_E(\mathrm{A},\mathrm{B}) = \left\{\frac{1}{3}\sum_{\mathrm{j}=1}^{\mathrm{n}}\left(\left(\mathrm{T_A}(\mathrm{x_j}) - \mathrm{T_B}(\mathrm{x_j})\right)^2 + \left(\mathrm{I_A}(\mathrm{x_j}) - \mathrm{I_B}(\mathrm{x_j})\right)^2 + \left(\mathrm{F_A}(\mathrm{x_j}) - \mathrm{F_B}(\mathrm{x_j})\right)^2\right)\right\}^{\frac{1}{2}}$$

Definition 1.3.14

A pythagorean fuzzy number P in fixed set X can be defined as given in Equations (1) - (3). Let X be fixed and $T_P(x) : X \to [0, 1]$ represents the degree of membership of the element $x \in X$. $F_P(x) : X \to [0, 1]$ represents the degree of non membership of the element $x \in X$ to P.

$P \approx \{x, T_P(x), F_P(x); x \in X\}$

$T_P(x) : X \to [0, 1]$ and $F_P(x) : X \to [0, 1]$

$0 \leq T_P(x)^2 + F_P(x)^2 \leq 1.$

The Hesitancy degree can be determined by:

$\pi P(x) = \sqrt{1 + T_P(x)^2 - F_P(x)^2}$

Definition 1.3.18

The Normalized Euclidean distance between two single-valued neutrosophic sets A and B is defined as

$$d_{n-E}(A,B) = \left\{\frac{1}{3}\sum_{j=1}^{n}\left(\left(T_A(x_j) - T_B(x_j)\right)^2 + \left(I_A(x_j) - I_B(x_j)\right)^2 + \left(F_A(x_j) - F_B(x_j)\right)^2\right)\right\}^{\frac{1}{2}}$$

Definition 1.3.19

The distance measures between two single-valued neutrosophic sets A and B are defined as

$$D_1(A,B) = \frac{1}{3n}\sum_{j=1}^{n}\left(|T_A(x_j)^2 - T_B(x_j)^2| + |I_A(x_j)^2 - I_B(x_j)^2| + |F_A(x_j)^2 - F_B(x_j)^2|\right)$$

And

$$D_2(A,B) = \frac{1}{3n}\sum_{j=1}^{n}\left|\left(T_A(x_j)^2 - T_B(x_j)^2\right) - \left(I_A(x_j)^2 - I_B(x_j)^2\right) - \left(F_A(x_j)^2 - F_B(x_j)^2\right)\right|$$

Definition 1.3.20

A mapping $S: NS(X) \times NS(X) \to [0,1]$ is said to be a similarity measure between two neutrosophic sets if it satisfies the properties of axioms:

i. $S(A,B) \geq 0$ for all $A, B \in NS(X)$.

ii. $S(A,B) = 0$ if and only if $A = B$ for all $A, B \in NS(X)$.

iii. $S(A,B) = S(B,A)$ for all $A, B \in NS(X)$.

If $A \subseteq B \subseteq C$ for all $A, B, C \in NS(X)$, then $S(A,C) \geq S(A,B)$ and $S(A,C) \geq S(B,C)$.

Definition 1.3.21

Let $A_F = \{(x, T_{A_F}(x), I_{A_F}(x), F_{A_F}(x)) \mid x \in X\}$, $B_F = \{(x, T_{A_F}(x), I_{A_F}(x), F_{A_F}(x)) \mid x \in X\}$ be any two Fermatean neutrosophic sets (FNSs). For comparing any two FNSs, a comparison method is developed as follows:

If Score (A_F) < Score (B_F) then $A_F < B_F$

If Score (A_F) > Score (B_F) then $A_F > B_F$

If Score (A_F) = Score (B_F) then check Accuracy (A_F) in the next step

If Accuracy (A_F) > Accuracy (B_F) Then $A_F > B_F$

If Accuracy (A_F) < Accuracy (B_F) Then $A_F < B_F$

If Accuracy (A_F) = Accuracy (B_F) Then $A_F = B_F$

CHAPTER 2

Chapter 2

In higher mathematics education, while theoretical knowledge and analytical skills are emphasized, there is often a noticeable gap in practical application and entrepreneurial thinking. Most curricula focus on proofs, abstract concepts, and academic performance, with limited exposure to real-world problem solving, innovation, or business-oriented applications. As a result, many students with strong mathematical backgrounds are not guided or encouraged to explore entrepreneurship as a viable path, leading to a lack of startups or innovative ventures in math-heavy domains. This disconnect between academic training and market-driven opportunities has become a major challenge in nurturing job creators rather than job seekers.

Entrepreneurship is increasingly essential in today's fast-evolving world. It promotes innovation, creates employment, addresses societal needs through technology and services, and drives economic growth. Mathematics to higher education students , entrepreneurship offers a way to apply complex models, algorithms, data analysis, and optimization techniques to solve real-life problems in sectors such as fintech, logistics, data science, AI, and even in educational technology. However, without practical exposure and mentorship, students often fail to see how their skills can translate into business solutions.

Higher education is facing several challenges, such as outdated syllabi, limited industry interaction, lack of interdisciplinary learning, and insufficient funding or support for startups. To bridge this gap, one promising avenue is to introduce students to MSME (Micro, Small, and Medium Enterprises). By starting a small-scale enterprise, students and graduates can test their mathematical skills in market scenarios—whether it's through developing analytical tools, statistical consulting, modeling services, or tech-based solutions.

If students from higher mathematics backgrounds engage with MSMEs, the future scope is vast. They can build niche businesses in areas like data analytics, operations research, mathematical software development, or education platforms tailored to competitive and advanced math learning. These ventures can grow over time into medium-scale enterprises, attract investments, and even collaborate with academic institutions or industries. This not only enhances their own career prospects but also contributes to national development through innovation-driven entrepreneurship.

2.1 INTEGRATING MATHEMATICS EDUCATION TO CULTIVATE ENTREPRENEURS IN THE MSME SECTOR

Integrating the application of higher mathematics into I&E (Innovation and Entrepreneurship) education provides a transformative path for students to acquire entrepreneurial skills grounded in analytical thinking and real-world relevance. This educational innovation not only enhances mathematical understanding but also serves as a catalyst for cultivating entrepreneurial mindsets among students-ultimately preparing them to start, manage, and grow MSMEs. Innovative teaching methods and structured decision-making tools can effectively support this integration, offering a framework for curriculum reform that aligns with the needs of the modern entrepreneurial economy.

In today’s innovation-driven and entrepreneurship-focused economy, universities should play a vital role in equipping students not only with strong technical knowledge but also with the entrepreneurial mindset needed to create and manage successful ventures. This is particularly relevant in the context of Micro, Small and Medium Enterprises (MSMEs), which are crucial to economic growth and job creation. To meet this need, traditional curricula-especially in foundational subjects like higher mathematics-must evolve to incorporate innovation and entrepreneurship (I&E) education that develops students’ ability to apply mathematical knowledge in practical, business-oriented contexts.

Higher Mathematics, while essential to engineering, science and technology, is often perceived by students as abstract and disconnected from the real-world challenges. By integrating I&E principles into the teaching of higher mathematics, educators can make the subject more application-oriented, fostering creativity, strategic thinking, and problem-solving skills that are directly transferable to entrepreneurial activities-especially within MSMEs.

This approach requires a thoughtful reimaging of teaching methods, where mathematical concepts are taught not only for their theoretical value but also for their relevance in business modeling, financial forecasting, operations research, and decision-making processes in small enterprises. Students can be encouraged to use mathematical tools to develop business plans, optimize resource allocation, assess market risks, and solve logistical problems typical in MSME operations.

To effectively teach the application of higher mathematics within the I&E framework, educators must shift from conventional lecture-based delivery to more dynamic, context-driven teaching methods. This includes Problem-Based Learning (PBL), Project-Oriented Learning, Interdisciplinary Integration, Simulation and Technology Use.

Students who understand the application of mathematics is entrepreneurial contexts are better equipped to identify opportunities, evaluate feasibility, and manage resources effectively.

However, when Higher Mathematics is taught with a focus on Innovation and Entrepreneurship(I&E), it becomes a powerful tool for developing critical thinking, business modeling, analytical reasoning, and data-driven decision-making skills-capabilities essential for starting and sustain MSMEs.

Integrating higher mathematics with entrepreneurship helps students create practical solutions, like optimizing delivery systems for startups, developing financial forecasting tools, or designing apps to predict crop yields. These examples show how math can drive innovation in business.

2.2 Innovation and Entrepreneurship Education

Innovative entrepreneurship education involves equipping individuals with fundamental entrepreneurial skills and creative thinking abilities. It goes beyond relying solely on students own entrepreneurial awareness, mindset, and capabilities. This form of education is open to the broader society and is specially designed for individuals at various stages of their entrepreneurial journey-whether they are planning to start a business, have already started one, or have achieved entrepreneurial success. These individuals are categorized based on their progress and level of development.

Focusing on the development of innovative thinking and practical skills, this type of education is inherently hands-on and application-oriented. However, for innovation and entrepreneurship education to be truly effective, it must be integrated into the classroom setting. Classroom instruction enables students to gain insights into real-world environments and enhances their entrepreneurial competencies.

When developing such courses, educational institutions should provide student with opportunities to engage in teamwork, communicate with leaders and organizations, and participate in entrepreneurship-specific classes. Moreover, it is important to integrate entrepreneurial education with both professional and foundational courses, allowing students to better grasp the realities of the working world.

Higher mathematics is more than abstract theory—it serves as a foundation for developing critical and innovative thinking skills. The points explained below highlight how it shapes creative minds capable of solving real-world problems.

Role of Higher Mathematics in Shaping Innovative Thinkers

The primary aim of higher mathematics is to develop students capacity for abstract thinking, logical analysis, and spatial reasoning. It also help learners acquire proficient computational skills and fosters their ability to integrate and apply mathematical knowledge in practical situations. As a result, students become capable of identifying, analyzing, and solving complex problems independently.

In the context of higher education, the teaching of higher mathematics should be closely aligned with innovation and entrepreneurship education. The integration not only enhance students problem-solving capabilities but also plays a significant role in boosting their employability and contributing to the overall improvement of national talent quality.

By integrating higher mathematics with entrepreneurship, students can, for example, design a cost-effective delivery system for a small business using optimization models. This application helps them turn abstract mathematical concepts into practical solutions. As a result, students gain the skills to innovate and contribute to the growth of MSMEs.

2.3 The Critical Importance of Integrating Higher Mathematics Instruction with Innovation and Entrepreneurship Education

- Integrating Higher Mathematics instructional methods with innovation and entrepreneurship education can enhance students innovative capabilities.
- Enhance the applicability of skills and facilitate seamless employment.
- Foster the comprehensive growth of students.

Integrating Higher Mathematics instructional methods with innovation and entrepreneurship education can enhance students innovative capabilities.

Innovation serves as a fundamental driver of national advancement and a perpetual engine of development. As such, fostering students innovative capabilities is a paramount importance. In the context of the evolving landscape of innovation and entrepreneurship-particularly in relation to the growth of MSMEs-it becomes essential to reform traditional teaching approaches in higher mathematics. By doing so, students can be better equipped to meet the demands of this significant historical shift. The effective integration of higher mathematics instruction with innovation and entrepreneurship education not only enhances students creativity and divergent thinking but also strengthens their logical reasoning and analytical skills. This comprehensive development lays a robust foundation for nurturing genuine innovation and entrepreneurial competencies that are essential for contributing to the success and sustainability in MSMEs.

Enhance the applicability of skills and facilitate seamless employment

In increasingly competitive market economy, individuals must enhance their practical skills and entrepreneurial competencies to establish a strong presence in the challenging job market. Integrating higher mathematics teaching methods with innovation and entrepreneurship education not only strengthens students practical abilities but also, more importantly, develops their comprehensive competencies. This holistic approach enables students to adapt seamlessly to societal competition and effectively navigate the escalating challenges. By leveraging their personal initiative and applying by leveraging their personal initiative and applying mathematical knowledge, students can successfully secure employment opportunities and contribute to the growth and sustainability of Micro, Small and Medium Enterprises(MSMEs). Such enterprises play a pivotal role in driving economic development and innovation.

Foster the comprehensive growth of students

Under traditional pedagogical approaches, many students emerge as “high-achieving yet low-skilled” individuals-demonstrating strong academic performance and mastery of theoretical knowledge, yet lacking in well-rounded capabilities, particularly the adaptability and practical skills needed to meet societal and development demands. For instance, a large proportion of textbooks focus heavily on abstract theories and concepts, with limited connection to real-world applications. Additionally, some educators struggle to abandon outdated, teacher-centered instruction that prioritizes “teaching” over “learning” thereby neglecting student engagement and experiential learning.

Economic constraints further hinder the modernization of teaching methodologies, preventing them from aligning with the rapid pace of societal and industrial evolution. The core mission of higher education is to cultivate well-rounded talents-individuals who embody moral integrity, intellectual capability, physical health, aesthetic sensibility, practical competence. However, the current challenges in education significantly obstruct this objective.

To effectively address these issues, it is imperative to integrate higher mathematics education with the contemporary framework of innovation and entrepreneurship education. This integration can stimulate students intrinsic motivation and creative potential, empowering them to take an active role in their learning. In doing so, students will be better prepared to contribute to the innovative growth and sustainability of Micro, Small and Medim Enterprises(MSMEs), which form the backbone of economic development and societal transformation.

In higher mathematics classrooms, students often struggle to apply abstract concepts to real-world problems due to a lack of vocational training. For example, without understanding optimization, students can't solve practical MSME problems like cost reduction. Integrating interactive tools and case studies into lessons helps bridge this gap and fosters practical skills.

2.4 Innovative Higher Mathematics Teaching for Entrepreneurship

- Cultivating and Engaging Classroom Environment and Employing Heuristic Methods
- Delivering Classroom Instruction and Implementing Problem-Focused Learning
- Fostering Empathy and Using Analogies

Cultivating and Engaging Classroom Environment and Employing Heuristic Methods

When teaching higher mathematics, instructors should focus on guiding the classroom and employing problem based learning techniques to capture students attention and ignite their passion for learning. Educators can prompt discussions by asking questions related to the material, leading students to analyze problem scenarios, explore various solution strategies, and offer methods to tackle challenges through continuous dialogue and analysis. This process enhances students problem solving abilities.

The key strength of problem based teaching is its capacity to fully engage students and boost their interest in learning. By introducing predetermined problems in class, teachers can significantly improve students critical thinking and learning efficiency. Consequently, educators actually lead classroom sessions by setting guiding questions and nurturing students abilities to independently identify, analyze, and solve issues, thereby enhancing their practical skills. This approach not only benefits their academic progress but also equips them with the competencies needed to success in the MSME(Micro, Small and Medium Enterprises) sector, where innovative problem-solving is essential for growth and competitiveness.

Delivering Classroom Instruction and Implementing Problem-Focused Learning

When higher mathematics, instructors should focus on guiding classroom and employing problem based learning techniques to capture students focus and ignite their interest in the subject. During lessons, educators can pose questions about the material, encouraging students to break the problems, explore various solution strategies, and discuss potential methods to resolve the issues through continuous analysis. This approach not only cultivates their problem solving skills but also deepens their understanding of the subject matter.

The primary advantage pf this teaching method is its ability to fully engage students method is its ability to fully engage students, fostering an environment where active thinking enhances learning efficiency. By presenting problems as a starting point, teachers can significantly boost students analytical capabilities. Through proactive classroom guidance, setting thought-innovation and sustaining provoking questions, and encouraging independent discovery, analysis, and resolution of problems, educators help improve students practical application skills.

This method is especially relevant for preparing graduates for the MSME(Micro, Small and Medium Enterprises) sector, where strong analytical and problem-solving skills are essential for driving innovation and sustaining competitive growth.

Fostering Empathy and Using Analogies

In the process of instruction, educators must be skilled at interpreting students perspectives. By thoughtfully examining how students think and approach problems, teachers can cover learning obstacles and clarify misconceptions, ultimately boosting the effectiveness of their teaching methods. As Shakespeare famously noted, “a thousand people have the thousand Hamlets int their hearts” which highlights how individuals interpret the same concept in unique ways. This insight is highly relevant in education-while instructors deliver the same lesson, students absorb, process, and apply information differently based on their personal understanding and context.

Recognizing this diversity, teachers should practice empathetic by turning into students learning needs and adjusting their teaching strategies accordingly. This includes using analogies- drawing comparisons between familiar and unfamiliar concepts-to help students form clearer connections and deepen their comprehension. For example, when teaching topics like triple integrals versus double integrals in advanced mathematics, drawing analogies allows student to identify patterns, compare concepts, and better grasp abstract ideas.

Entrepreneurs, like students, come from varied educational, cultural, and professional backgrounds. Training programs for MSME owners should adopt an empathetic and analogy-based approach to make complex business concepts more understandable. For instance, explaining profit and loss in a business context by comparing it to managing a household budget helps entrepreneurs relate the idea to their everyday experiences.

By understanding the distinct needs and learning styles of MSME participants, trainers can provide personalized, impactful education that enhances their practical skills. Analogies can simplify key areas such as supply chain management, financial planning, or customers retention, enabling entrepreneurs to make informed decisions and foster innovation in their ventures.

So, adopting empathy and analogy in teaching not only enriches students understanding of subjects like advanced mathematics but also strengthens educational outreach to MSMEs. This approach builds a bridge between theory and real world-application, empowering both learners and entrepreneurs to think critically, solve problems effectively, and succeed in their respective fields.

Students could use optimization models to help an reduce supply chain costs, or apply mathematical forecasting techniques to predict market trends for a small business. These practical examples show how mathematical knowledge can directly impact business operations. This approach helps build essential skills for managing and growing in MSMEs.

2.5 Inspiring Entrepreneurship in Students through the Teaching of Innovative Higher Mathematics in MSME Growth

Higher Mathematics is often considered a challenging discipline, requiring educators to consistently adopt creative and adaptive instructional strategies. By utilizing diverse teaching approaches, instructors can engage students more effectively, encourage active participation, and enhance their motivation to learn. These methods empower learners do not only absorb the content more efficiently but also to apply their knowledge in practical, real-world contexts.

When students are actively involved in the learning process, their curiosity and analytical abilities are stimulated. This dynamic learning environment fosters flexible thinking and a deeper understanding of complex mathematical concepts, which are essential for personal and professionals capable of contributing meaningfully to society.

This approach is particularly relevant to the development of Micro, Small and Medium Enterprises (MSMEs). As MSMEs play acritical role in economic growth and employment, it is important for aspiring entrepreneurs and professionals within this sector to posses strong analytical and problem-solving skills. By integrating higher mathematics education with MSME-focused training, individuals can better understand business operations, manage resources efficiently, and make data-driven decisions.

Innovative teaching methods-such as problem-based learning, case studies, and technology-enhanced instruction-can help students apply mathematical knowledge to challenges faced by MSMEs. For instance, understanding cost optimization, financial forecasting, and operational efficiency requires a solid grasp of mathematical principles. When these skills are developed through engaging and practical education, they contribute directly to the long-term success of MSMEs and the broader economy.

Finally, higher mathematics is taught not only improves student outcomes but also equips future entrepreneurs with the critical skills needed to drive innovation and sustainability in the MSME sector.

CHAPTER 3

Chapter 3

INTEGRATING FERMATEAN NEUTROSOPHIC SETS WITH CODAS METHOD FOR EFFECTIVE MSME TECHNOLOGY INNOVATION

MSMEs (Micro, Small and Medium Enterprises) often face challenges such as limited resources, insufficient data, and high levels of uncertainty in decision-making. Unlike large organizations, MSMEs may not have access to extensive analytical tools or expert systems, making it difficult to make well-informed, risk decisions. These challenges create an environment of constant uncertainty and risk. Therefore, effective decision-making becomes crucial for MSMEs to navigate these difficulties.

There are various Multi-Criteria Decision-Making (MCDM) techniques available to support decision-making under uncertainty, including methods that incorporate different types of fuzzy logic, such as classical fuzzy sets, intuitionistic fuzzy sets, and Pythagorean fuzzy sets. While these approaches offer some capability in addressing imprecise or vague information, they often fall short when dealing with *higher degrees of uncertainty, hesitation, and indeterminacy*—especially in complex environments like MSMEs where data may be incomplete, conflicting, or highly subjective.

To overcome these limitations, the Fermatean Neutrosophic CODAS (Combinative Distance-based Assessment) method was chosen. This method extends traditional fuzzy and neutrosophic logic by allowing for a broader and more flexible representation of uncertainty through its Fermatean structure, which can better express the degrees of truth, indeterminacy, and falsity. By integrating this with the CODAS approach, which evaluates alternatives based on both Euclidean and Taxicab distances from the negative ideal solution, the decision-making process becomes more robust, especially in scenarios characterized by high ambiguity and limited information.

The **Fermatean Neutrosophic CODAS (Combinative Distance Based Assessment)** method addresses this need by enabling decision-makers to evaluate multiple conflicting criteria while accounting for uncertainty, vagueness, and incomplete information.

Fermatean Neutrosophic CODAS is used because it helps objectively evaluate and rank alternatives based on multiple criteria, providing a systematic approach to complex decision-making. It effectively handles both qualitative and quantitative data and minimizes subjective biases, making it reliable for various real-world decision problems, especially those with conflicting criteria.

CODAS (Combinative Distance-based Assessment) is a powerful method used in multi-criteria decision-making (MCDM) problems to evaluate and compare alternatives based on multiple criteria. By calculating the distance of each alternative from an ideal solution, CODAS helps in ranking alternatives objectively, ensuring that the decision-making process is more systematic and transparent. This approach is particularly useful when dealing with complex decision problems that involve conflicting criteria, as it allows for the simultaneous evaluation of various factors. Additionally, CODAS is flexible enough to handle both qualitative and quantitative data, making it applicable across a wide range of decision-making scenarios. Its robustness and ability to minimize the influence of subjective preferences make it an ideal tool for assessing alternatives in a comprehensive and reliable manner.

3.1 FERMATEAN NEUTROSOPHIC CODAS

Fermatean Neutrosophic CODAS (Combinative Distance-based Assessment) is a multi-criteria decision-making (MCDM) method that integrates the Fermatean Neutrosophic Set (FNS) framework into the CODAS method to handle uncertainty and indeterminacy more effectively when evaluating multiple alternatives against various criteria.

The MCDM Neutrosophic CODAS approach is explained in the following algorithm outlines the step-by-step procedure used to implement the Fermatean Neutrosophic CODAS method in this context.

ALGORITHM

STEP 1: Construct the Decision Matrix

Let the decision matrix be $D = [A_{ij}]$ where:

A_{ij}: alternative

C_j: criterion

A_{ij}= (T_{ij}, I_{ij}, F_{ij}): neutrosopic value for the alternative A_i under criterion C_j

STEP 2: Determine Criteria weights

Define a weight vector ω = (ω_1, ω_2, …, ω_n) for criteria C_1, C_2, …, C_n

Weight should satisfy $\sum_{j=1}^{n} \omega_j = 1$

STEP 3: Normalize the Decision Matrix

For benefit criteria:

$$T'_{ij} = \frac{T_{ij}}{max_i\, T_{ij}}, I'_{ij} = \frac{min_i I_{ij}}{I_{ij}}, F'_{ij} = \frac{min_i F_{ij}}{F_{ij}}$$

For cost criteria:

$$T'_{ij} = \frac{min_i T_{ij}}{T_{ij}}, I'_{ij} = \frac{I_{ij}}{max_i I_{ij}}, F'_{ij} = \frac{F_{ij}}{max_i F_{ij}}$$

STEP 4: Construct the weighted Normalized Decision Matrix

$$\tilde{A}_{ij} = (\omega_j . T'_{ij}, \omega_j . I'_{ij}, \omega_j . F'_{ij})$$

The Fermatean Neutrosophic Weighted Averaging (FNWA) operator is given below:

$$r_{ij} = \left(\sqrt[3]{1 - \prod_{k=1}^{d}(1 - T^3{}_{jk})^{w_k}}, \sqrt[3]{\prod_{k=1}^{d}(I^3{}_{jk})^{w_k}}, \sqrt[3]{\prod_{k=1}^{d}\left(1 - T^3{}_{jk}\right)^{w_k} - \prod_{k=1}^{d}\left(1 - T^3{}_{jk} - F^3{}_{jk}\right)^{w_k}}\right)$$

STEP 5: Determine the Negative Ideal Solution (NIS)

NIS = $(min_i T_{ij}, max_i I_{ij}, max_i F_{ij})$ $\forall$ j

STEP 6: Compute the Euclidean and Taxicab Distances from NIS

For each alternative A_i

Euclidean distance between two FN numbers

$\beta_1 = G(T_{\beta_1}, I_{\beta_1}, F_{\beta_1})$ and $\beta_2 = G(T_{\beta_2}, I_{\beta_2}, F_{\beta_2})$ are shown as follows:

$$E(\beta_1, \beta_2) = \sqrt{\frac{1}{3}\left(\left(\left|T_{\beta_1}{}^3 - T_{\beta_2}{}^3\right|\right)^2 + \left(\left|I_{\beta_1}{}^3 - I_{\beta_2}{}^3\right|\right)^2 + \left(\left|F_{\beta_1}{}^3 - F_{\beta_2}{}^3\right|\right)^2\right)}$$

Taxicab distance between two FN numbers $\beta_1 = G(T_{\beta_1}, I_{\beta_1}, F_{\beta_1})$ and $\beta_2 = G(T_{\beta_2}, I_{\beta_2}, F_{\beta_2})$ are determined:

$$E(\beta_1, \beta_2) = \sqrt{\frac{1}{3}\left(\left|{T_{\beta_1}}^3 - {T_{\beta_2}}^3\right| + \left|{I_{\beta_1}}^3 - {I_{\beta_2}}^3\right| + \left|{F_{\beta_1}}^3 - {F_{\beta_2}}^3\right|\right)}$$

STEP 7: Compute the Relative Assessment Matrix

$$\Psi_i = E_i + \tau . H_i$$

Where τ is a threshold parameter (usually a small positive constant, e.g., 0.02 or 0.05) to distinguish alternative with similar Euclidean distances.

STEP 8: Rank the Alternatives

Rank alternative in descending order of Ψ_i : the higher the value, the better alternative.

ILLUSTRATION

A decision-making team is evaluating 7 Alternatives Projects using the Fermatean Neutrosophic CODAS method. Each project is assessed based on 13 Criteria related to sustainability, technology, infrastructure, and social impact. Due to uncertainties and expert disagreements, the evaluations are given in the form of Fermatean Neutrosophic Numbers (FNNs).

The Alternatives are

A1: Education level of entrepreneurs

A2: Technical know-how and training of entrepreneur

A3: SME networks

A4: Project resources and capabilities

A5: Collaboration between industry and academia

A6: Government policies and programs

A7: Financial support by government to research initiatives

The Criteria are

C1: Renewable energy utilization

C2: Energy efficiency performance

C3: Technological innovation capacity

C4: Initial project cost

C5: Operational and maintenance expenses

C6: Environmental emissions or pollution levels

C7: Infrastructure accessibility and quality

C8: Digital inclusion and ICT access

C9: Job creation and local employment impact

C10: Resource consumption rate (e.g., water, fuel)

C11: Downtime or inefficiency losses

C12: Regulatory compliance cost

C13: Social development and community involvement

Each alternative is rated using Fermatean Neutrosophic Numbers (T, I, F), where the cube sum $T^3 + I^3 + F^3 \leq 2$. Using the Fermatean Neutrosophic CODAS method:

Rank the alternatives from least to most suitable for sustainable entrepreneurship investment.

3.1.2 A Framework for Fermatean Neutrosophic CODAS

Let decision-maker take part in the procedure for evaluation. The criteria have been assigned weights to represent their relative importance in the overall evaluation process.

In the considered criteria, indeterminacy can manifest in various forms. That may include ambiguous definitions of criteria, challenges with trade-offs and waiting, uncertain future performance, and uncertain preferences.

Based on this assumption of ambiguity, the judgements made by the decision-maker compiled using the linguistics variables listed in Table 3.1.2.1.

Table 3.1.2.1. Terms used in linguistics and their associated Spherical Neutrosophic Number

Linguistic Terms	(T, I, F)
Extremely High (EH)	(0.9, 0.6, 0.4)
High (H)	(0.8, 0.7, 0.5)
Above Average (AA)	(0.8, 0.6, 0.5)
Average (A)	(0.7, 0.7, 0.6)
Low (L)	(0.7, 0.6, 0.6)
Very Low (VL)	(0.6, 0.7, 0.7)

The following tables 3.1.2.2 elucidates the decisions with respect to the decision makers.

Table 3.1.2.2. Decisions of DM

ALTERNATIVE	A1	A2	A3	A4	A5	A6	A7
C1	EH	AA	A	VL	H	EH	L
C2	H	VL	L	EH	VL	AA	L
C3	A	EH	VL	AA	EH	L	VL
C4	EH	L	AA	VL	L	EH	AA
C5	H	VL	A	EH	VL	AA	L
C6	L	H	EH	VL	AA	L	EH
C7	VL	EH	AA	L	VL	EH	AA
C8	L	VL	EH	AA	EH	L	VL
C9	AA	L	VL	EH	L	AA	EH
C10	EH	VL	L	AA	EH	VL	L
C11	H	L	VL	EH	VL	AA	L
C12	L	EH	A	VL	EH	AA	VL
C13	VL	AA	EH	L	AA	VL	EH

STEP 1

Let the decision matrix be $D = [A_{ij}]$ where:

A_{ij}: alternative

C_j: criterion

A_{ij}= (T_{ij}, I_{ij}, F_{ij}): neutrosopic value for the alternative A_i under criterion C_j

Table 3.1.2.3. Decision matrix

ALTERNATIVE	A1	A2	A3	A4	A5	A6	A7
C1	(0.9,0.6,04)	(0.8,0.6,0.5)	(0.7,0.7,0.6)	(0.6,0.6,0.7)	(0.8,0.7,0.5)	(0.9,0.6,0.4)	(0.7,0.6,0.6)
C2	(0.8,0.7,0.5)	(0.6,0.7,0.7)	(0.7,0.6,0.6)	(0.9,0.6,0.4)	(0.6,0.6,0.7)	(0.8,0.6,0.5)	(0.7,0.6,0.6)
C3	(0.7,0.7,0.6)	(0.9,0.6,0.4)	(0.6,0.6,0.7)	(0.8,0.6,0.5)	(0.9,0.6,0.4)	(0.7,0.6,0.6)	(0.6,0.7,0.7)
C4	(0.9,0.6,0.4)	(0.7,0.6,0.6)	(0.8,0.6,0.5)	(0.6,0.7,0.7)	(0.7,0.6,0.6)	(0.9,0.6,0.4)	(0.8,0.6,0.5)
C5	(0.8,0.7,0.5)	(0.6, 0.6, 0.7)	(0.7, 0.7, 0.6)	(0.9, 0.6, 0.4)	(0.6, 0.7, 0.7)	(0.8, 0.6, 0.5)	(0.7, 0.6, 0.6)
C6	(0.7,0.6,0.6)	(0.8, 0.7, 0.5)	(0.9, 0.6, 0.4)	(0.6, 0.7, 0.7)	(0.8, 0.6, 0.5)	(0.7, 0.6, 0.6)	(0.9, 0.6, 0.4)
C7	(0.6,0.7,0.7)	(0.9, 0.6, 0.4)	(0.8, 0.6, 0.5)	(0.7, 0.6, 0.6)	(0.6, 0.7, 0.7)	(0.9, 0.6, 0.4)	(0.8, 0.6, 0.5)
C8	(0.7,0.6,0.6)	(0.6, 0.7, 0.7)	(0.9, 0.6, 0.4)	(0.8, 0.6, 0.5)	(0.9, 0.6, 0.4)	(0.7, 0.6, 0.6)	(0.6, 0.6, 0.7)
C9	(0.8,0.6,0.5)	(0.7, 0.6, 0.6)	(0.6, 0.7, 0.7)	(0.9, 0.6, 0.4)	(0.7, 0.6, 0.6)	(0.8, 0.6, 0.5)	(0.9, 0.6, 0.4)
C10	(0.9,0.6,0.4)	(0.6, 0.7, 0.7)	(0.7, 0.6, 0.6)	(0.8, 0.6, 0.5)	(0.9, 0.6, 0.4)	(0.6, 0.7, 0.7)	(0.7, 0.6, 0.6)
C11	(0.8,0.7,0.5)	(0.7, 0.6, 0.6)	(0.6, 0.7, 0.7)	(0.9, 0.6, 0.4)	(0.6, 0.6, 0.7)	(0.8, 0.6, 0.5)	(0.7, 0.6, 0.6)
C12	(0.7,0.6,0.6)	(0.9, 0.6, 0.4)	(0.8, 0.6, 0.5)	(0.6, 0.6, 0.7)	(0.9, 0.6, 0.4)	(0.8, 0.6, 0.5)	(0.6, 0.7, 0.7)
C13	(0.6,0.6,0.7)	(0.8, 0.6, 0.5)	(0.9, 0.6, 0.4)	(0.7, 0.6, 0.6)	(0.8, 0.6, 0.5)	(0.6, 0.7, 0.7)	(0.9, 0.6, 0.4)

STEP 2

Define a weight vector ω = $(\omega_1, \omega_2, \ldots, \omega_n)$ for criteria $C_1, C_2, \ldots, C_n$

Weight should satisfy $\sum_{j=1}^{n} \omega_j = 1$

Table 3.1.2.4 Criteria weight

CRITERIA	WEIGHT
C1	0.016
C2	0.141
C3	0.047
C4	0.063
C5	0.055
C6	0.009
C7	0.018
C8	0.059
C9	0.325
C10	0.089
C11	0.12
C12	0.044
C13	0.014

STEP 3

Normalize the decision matrix

For benefit criteria:

$$T'_{ij} = \frac{T_{ij}}{max_i\, T_{ij}}, I'_{ij} = \frac{min_i I_{ij}}{I_{ij}}, F'_{ij} = \frac{min_i F_{ij}}{F_{ij}}$$

For cost criteria:

$$T'_{ij} = \frac{min_i T_{ij}}{T_{ij}}, I'_{ij} = \frac{I_{ij}}{max_i I_{ij}}, F'_{ij} = \frac{F_{ij}}{max_i F_{ij}}$$

The Benefit Criteria are

C1: Renewable energy utilization

C2: Energy efficiency performance

C3: Technological innovation capacity

C7: Infrastructure accessibility and quality

C8: Digital inclusion and ICT access

C9: Job creation and local employment impact

C13: Social development and community involvement

Table 3.1.2.5. Benefit criteria

ALTERNATIVE	A1	A2	A3	A4	A5	A6	A7
C1	(1,1.17,1)	(0.89,1.17,0.80)	(0.78,1,0.67)	(0.67,1.17,0.57)	(0.89,1,0.80)	(1,1.17,1)	(0.78,1.17,0.67)
C2	(0.89,1,0.80)	(0.67,1,0.57)	(0.78,1.17,0.67)	(1,1.17,1)	(0.67,1.17,0.57)	(0.89,1.17,0.80)	(0.78,1.17,0.67)
C3	(0.78,1,0.67)	(1,1.17,1)	(0.67,0.86,0.57)	(0.89,1.17,0.80)	(1,1.17,1)	(0.78,1.17,0.67)	(0.67,0.67,1)
C7	(0.67,1,0.57)	(1,1.17,1)	(0.89,1.17,0.80)	(0.78,1.17,0.67)	(0.67,1,0.57)	(1,1.17,1)	(0.89,1.17,0.80)
C8	(0.78,1.17,0.670	(0.67,1,0.57)	(1,1.17,1)	(0.89,1.17,0.80)	(1,1.17,1)	(0.78,1.17,0.67)	(0.67,1.17,0.57)
C9	(0.89,1.17,0.80)	(0.78,1.17,0.67)	(0.67,1,0.57)	(1,1.17,1)	(0.78,1.17,0.67)	(0.89,1.17,0.80)	(1,1.17,1)
C13	(0.67,1.17,0.57)	(0.89,1.17,0.80)	(1,1.17,1)	(0.78,1.17,0.67)	(0.89,1.17,0.80)	(0.67,1,0.57)	(1,1.17,1)

The Cost Criteria

C4: Initial project cost

C5: Operational and maintenance expenses

C6: Environmental emissions or pollution levels

C10: Resource consumption rate

C11: Downtime or inefficiency losses

C12: Regulatory compliance cost

Table 3.1.2.6. Cost criteria

ALTERNATIVE	A1	A2	A3	A4	A5	A6	A7
C4	(0.67,1,0.57)	(0.86,1,0.86)	(0.75,1,0.71)	(1,1.17,1)	(0.86,1,0.86)	(0.67,1,0.57)	(0.75,1,0.71)
C5	(0.75,1.17,0.71)	(1,1,1)	(0.86,1.17,0.86)	(0.67,1,0.57)	(1,1.17,1)	(0.75,1,0.71)	(0.86,1,0.86)
C6	(0.86,1,0.86)	(0.75,1.17,0.71)	(0.67,1,0.57)	(1,1.17,1)	(0.75,1,0.71)	(0.86,1,0.86)	(0.67,1,0.57)
C10	(0.67,1,0.57)	(1,1.17,1)	(0.86,1,0.86)	(0.75,1,0.71)	(0.67,1,0.57)	(1,1.17,1)	(0.86,1,0.86)
C11	(0.75,1,0.71)	(0.86,1,0.86)	(1,1.17,1)	(0.67,1,0.57)	(1,1,1)	(0.75,1,0.71)	(0.86,1,0.86)
C12	(0.86,1,0.86)	(0.67,1,0.57)	(0.75,1,0.71)	(1,1,1)	(0.67,1,0.57)	(0.75,1,0.71)	(1,1.17,1)

STEP 4

$$\tilde{A}_{ij} = (\omega_j . T'_{ij} , \omega_j . I'_{ij} , \omega_j . F'_{ij})$$

The Fermatean Neutrosophic Weighted Averaging (FNWA) operator is given below:

$$r_{ij} = \left(\sqrt[3]{1-\prod_{k=1}^{d}(1-T^3{}_{jk})^{w_k}}, \sqrt[3]{\prod_{k=1}^{d}(I^3{}_{jk})^{w_k}}, \sqrt[3]{\prod_{k=1}^{d}\left(1-T^3{}_{jk}\right)^{w_k}-\prod_{k=1}^{d}\left(1-T^3{}_{jk}-F^3{}_{jk}\right)^{w_k}}\right)$$

Table 3.1.2.7. Weighted Averaging

ALTERNATIVES	WEIGHTED AVERAGING
A1	(0.81, 0.64, 0.56)
A2	(1.00, 0.63, -0.75)
A3	(0.71, 0.65, 0.69)
A4	(0.86, 0.61 0.49)
A5	(1.00, 0.61, 0.05)
A6	(0.79, 0.61, 0.59)
A7	(0.80, 0.61, 0.59)

STEP 5

The Negative Ideal Solution (NIS)

NIS = $(min_i T_{ij}, max_i I_{ij}, max_i F_{ij})$ $\forall$ j

Table 3.1.2.8. Negative Ideal Solution

ALTERNATIVES	NIS
C1	(0.6, 0.6, 0.7)
C2	(0.6, 0.6, 0.7)
C3	(0.6, 0.6, 0.7)
C4	(0.6, 0.6, 0.7)
C5	(0.6, 0.6, 0.7)
C6	(0.6, 0.6, 0.7)
C7	(0.6, 0.6, 0.7)
C8	(0.6, 0.6, 0.7)
C9	(0.6, 0.6, 0.7)
C10	(0.6, 0.6, 0.7)
C11	(0.6, 0.6, 0.7)
C12	(0.6, 0.6, 0.7)
C13	(0.6, 0.6, 0.7)

STEP 6 EUCLIDEAN AND TAXICAB DISTANCE

Euclidean distance between two FN numbers

$\beta_1 = G(T_{\beta_1}, I_{\beta_1}, F_{\beta_1})$ and $\beta_2 = G(T_{\beta_2}, I_{\beta_2}, F_{\beta_2})$ are shown as follows:

$$E(\beta_1, \beta_2) = \sqrt{\frac{1}{3}\left(\left(\left|{T_{\beta_1}}^3 - {T_{\beta_2}}^3\right|\right)^2 + \left(\left|{I_{\beta_1}}^3 - {I_{\beta_2}}^3\right|\right)^2 + \left(\left|{F_{\beta_1}}^3 - {F_{\beta_2}}^3\right|\right)^2\right)}$$

Taxicab distance between two FN numbers $\beta_1 = G(T_{\beta_1}, I_{\beta_1}, F_{\beta_1})$ and $\beta_2 = G(T_{\beta_2}, I_{\beta_2}, F_{\beta_2})$ are determined:

$$E(\beta_1, \beta_2) = \sqrt{\frac{1}{3}\left(\left|{T_{\beta_1}}^3 - {T_{\beta_2}}^3\right| + \left|{I_{\beta_1}}^3 - {I_{\beta_2}}^3\right| + \left|{F_{\beta_1}}^3 - {F_{\beta_2}}^3\right|\right)}$$

Table 3.1.2.9. Euclidean Distance

ALTERNATIVE	A1	A2	A3	A4	A5	A6	A7
C1	0.34	0.21	0.13	0	0.22	0.34	0.10
C2	0.22	0.07	0.10	0.34	0	0.21	0.10
C3	0.13	0.34	0	0.21	0.34	0.10	0.07
C4	0.34	0.10	0.21	0.07	0.10	0.34	0.21
C5	0.22	0	0.13	0.34	0.07	0.21	0.10
C6	0.10	0.22	0.34	0.07	0.21	0.10	0.34
C7	0.07	0.34	0.21	0.10	0.07	0.34	0.21
C8	0.10	0.07	0.34	0.21	0.34	0.10	0
C9	0.21	0.10	0.07	0.34	0.10	0.21	0.34
C10	0.34	0.07	0.10	0.21	0.34	0.07	0.10
C11	0.22	0.10	0.07	0.34	0	0.21	0.10
C12	0.15	0.41	0.28	0	0.41	0.28	0.13
C13	0	0.21	0.34	0.10	0.21	0.07	0.34

Table 3.1.2.10. Taxicab Distance

ALTERNATIVE	A1	A2	A3	A4	A5	A6	A7
C1	0.51	0.41	0.36	0	0.46	0.51	0.29
C2	0.46	0.21	0.29	0.51	0	0.41	0.29
C3	0.36	0.51	0	0.41	0.51	0.29	0.21
C4	0.51	0.29	0.41	0.21	0.29	0.51	0.41
C5	0.46	0	0.36	0.51	0.21	0.41	0.29
C6	0.29	0.46	0.51	0.21	0.41	0.29	0.51
C7	0.21	0.51	0.41	0.29	0.21	0.51	0.41
C8	0.29	0.21	0.51	0.41	0.51	0.29	0
C9	0.41	0.29	0.21	0.51	0.29	0.41	0.51
C10	0.51	0.21	0.29	0.41	0.51	0.21	0.29
C11	0.46	0.29	0.21	0.51	0	0.41	0.29
C12	0.29	0.51	0.41	0	0.51	0.41	0.21
C13	0	0.41	0.51	0.29	0.41	0.21	0.51

STEP 7

$$\Psi_i = E_i + \tau . H_i$$

Where τ is a threshold parameter (usually a small positive constant, e.g., 0.02 or 0.05) to distinguish alternative with similar Euclidean distances.

Table 3.1.2.11. Relative Assessment Matrix

ALTERNATIVE	RELATIVE ASSESSMENT MATRIX
A1	2.55
A2	2.35
A3	2.41
A4	2.43
A5	2.51
A6	2.69
A7	2.24

STEP 8

Rank alternative in descending order of Ψ_i : the higher the value, the better alternative.

Table 3.1.2.12. Ranking

ALTERNATIVE	TOTAL SCORE	RANK
A1	2.55	6
A2	2.35	2
A3	2.41	3
A4	2.43	4
A5	2.51	5
A6	2.69	7
A7	2.24	1

Fuzzy-based paper related to MSME decision-making was referred to, and the same set of input values for alternatives and criteria was considered to ensure consistency in comparison. While the original paper utilized fuzzy logic to handle uncertainty, this study extends the analysis by applying Fermatean Neutrosophic Sets to the same values.

Fermatean sets provide a more expressive framework by incorporating degrees of truth, indeterminacy, and falsity, which allows for a richer and more flexible representation of expert opinions. This approach enhances the ability to deal with high levels of uncertainty and hesitation often encountered in MSME environments, offering a deeper and more realistic insight into the decision-making process.

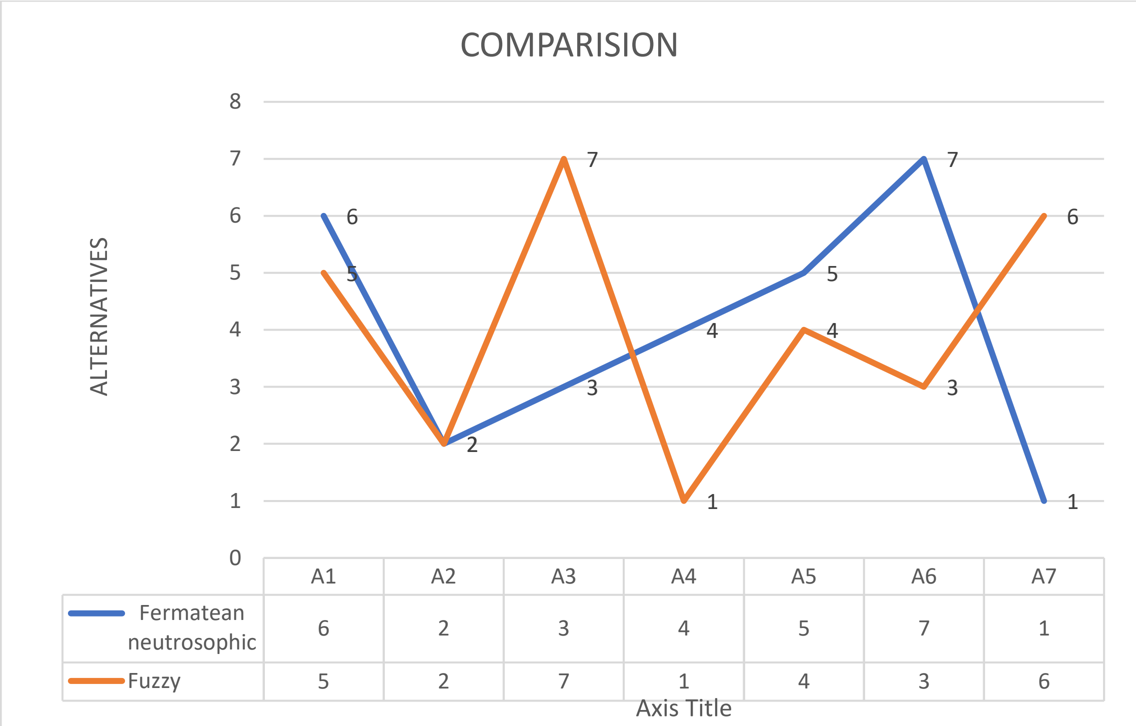
Table 3.1.2.13 Fuzzy Set Ranking

ALTERNATIVE	SCORE	RANK
A1	0.016	5
A2	0.141	2
A3	0.009	7
A4	0.325	1
A5	0.018	4
A6	0.12	3
A7	0.014	6

Therefore, the Fermatean Neutrosophic CODAS method was applied, as it effectively incorporates degrees of truth, indeterminacy, and falsity, offering a more realistic representation of expert judgments. Upon applying this method, a new set of rankings was obtained, which showed noticeable differences compared to the original results. A comparative analysis was performed, and the differences in rankings are visually represented in the graph below. The coloured lines in the graph indicate the variation between the original method and the Fermatean Neutrosophic CODAS results, demonstrating the influence of managing indeterminacy in multi-criteria decision-making.

The **blue line** represents the rankings obtained using the **Fermatean Neutrosophic** approach, and the **red line** shows the rankings from the **fuzzy sets** approach. The variations between the two highlight how considering higher indeterminacy can influence decision outcomes in MSMEs.

GRAPH



Comparison Between Fuzzy and Fermatean Neutrosophic Codas

The comparative analysis between the existing fuzzy-based approach and the proposed Fermatean Neutrosophic CODAS method reveals notable differences in the ranking of MSME alternatives. While the original paper identified a **Project Resources and Capabilities** as the most preferred, the Fermatean Neutrosophic approach **Financial support by government to research initiatives** ranked as the top priority among the seven MSMEs.

CONCLUSION

SUMMARY AND CONCLUSION

The outcomes of this study highlight the vital role that higher mathematics education can play in shaping successful entrepreneurs, particularly within the MSME sector. Integrating mathematics with entrepreneurial training in higher education is critically important for preparing students to successfully sustain and grow within the MSME sector. Mathematics provides essential skills such as problem-solving, financial analysis, risk assessment, and strategic planning, all of which are fundamental to entrepreneurial success. By embedding strong mathematical foundations into entrepreneurship education, institutions can equip future entrepreneurs with the analytical thinking and precision necessary to make informed decisions, manage resources effectively, and adapt to the dynamic challenges of the business world. This integration not only enhances the sustainability of MSMEs but also drives innovation and economic development at a broader scale.

To make this understanding more practical and impactful, the Fermatean Neutrosophic CODAS method was employed to analyze and rank seven strategic alternatives under thirteen relevant criteria, forming a robust technology innovation model specifically considered for Technology innovation in MSME sector. Among the seven alternatives analyzed, the highest-ranked alternative was **A7: Financial support to research initiatives**, highlighting its paramount importance in the entrepreneurial journey.

A2: Technical know-how and training of entrepreneur achieved the least rank assessment and was ranked first among the seven MSMEs. This indicates it best satisfies the sustainability criteria and is the most suitable for innovation. A3: MSME networks and A4: Project resources and capabilities followed by, while A5: Collaboration between industry and academia followed by, A1: Education level of entrepreneurs followed by, A6: Government policies and programs showing room for improvement in several key areas such as scalability and innovation.

By suggesting this top alternative to students, the goal is to instill in them the understanding that research-driven innovation, supported by adequate financial backing, is key to sustaining and scaling within the MSME landscape. This also encourages a mindset of proactive planning, strategic thinking, and continuous learning.

Ultimately, such an approach helps students go beyond theoretical knowledge - motivating them to take real initiatives, align with industry needs, and contribute meaningfully to the MSME ecosystem. This empowers them not only to become successful entrepreneurs but also to be valuable contributors to the broader economic and innovation landscape.

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