Assessing innovativeness of manufacturing firms using an intuitionistic fuzzy based MCDM framework

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Abstract

Purpose – The purpose of this paper is to provide a framework for assessing the overall innovativeness of manufacturing firms using a multi-attribute group decision-making methodology.

Design/methodology/approach – This study identifies the indicators of firms' innovativeness from the literature. The concept of neutrosophic numbers has been used to assign different importance weights to individual decision makers to account for the differences in their educational backgrounds and practical experience. An intuitionistic fuzzy based TOPSIS procedure is adapted for ranking the candidate firms based on their performance on identified criteria. The implementation of the proposed methodology is demonstrated through an explanatory example. Sensitivity analysis is carried out to judge the robustness of the proposed framework.

Findings – The proposed framework provides an efficient and reliable tool to subjectively evaluate and compare the innovativeness of manufacturing firms. The sensitivity analysis shows that the methodology is robust enough to absorb the noise factors/errors/variations, etc.

Research limitations/implications – Motivated by this work, future studies can consider developing an integrated innovativeness index for evaluation of innovativeness of manufacturing firms. The concept of interval valued intuitionistic fuzzy and neutrosophic sets can be utilized to reduce the margin of perceptual errors even further.

Practical implications – The study will provide the firms with a framework for benchmarking their innovative performance. The firms can analyze their current performance and reconfigure their resources and capabilities suitably to improve their competitive position.

Originality/value – This study is one of the few attempts that have been made to articulate a firm level innovativeness assessment tool for manufacturing firms operating in an industry sector. Advanced concepts of fuzzy and neutrosophic sets have been utilized to eliminate the chances of bias/perceptual errors that most often affect the quality of decisions in today's dynamic and uncertain decision-making environment.

Keywords Benchmarking, Innovativeness, Sensitivity analysis, Multi-criteria decision making, Intuitionistic fuzzy sets, Neutrosophic number

Paper type Research paper

1. Introduction

The rapid changing business environment has put strong pressure on the manufacturing firms to consider exploring novel ways of doing business in their endeavor to gain and maintain competitive edge. Innovation is widely considered as "the life blood of corporate survival and growth" (Zahra and Covin, 1994, p. 183). The business units that fail to appreciate importance of innovativeness are doomed to struggle for survival in today's volatile environments.

To understand what constitutes innovativeness of organizations, it is imperative to first know how it is different from, or related to, the two other connotations, namely, invention

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and innovation. Invention is the theoretical conception of the idea, whereas innovation is a broader term that includes subsequent application of ideas so generated to create or add economic value to existing products, processes or systems. Trott (2005) represented the relationship between invention and innovation explicitly in terms of an expression that equates the innovation with summation of theoretical conception, technical invention and commercial exploitation. Innovating involves combining available key enablers like knowledge, capabilities, skills and resources (Fagerberg, 2003) in a judicious manner to gain a competitive advantage, either through reducing production costs, the developing new products or modifying the existing ones.

Organizational innovativeness, in contrast to innovation, takes into consideration multiple innovations putting more emphasis on organizational characteristics than on specific innovation attributes (Damanpour, 1992). Some of the definitions of innovativeness are given in Table I.

Innovativeness is a precursor to innovation and indicates the ability of a firm to innovate (Avlonitis *et al.*, 1994; Hurley and Hult, 1998; Hult *et al.*, 2004; Wang and Ahmed, 2004).

Distinguishing innovativeness from capacity to innovate, Hurley *et al.* (2005) opined that innovativeness is a part of organizational culture, innovative capacity being one of its outcomes.

The capacity to innovate is often considered to be one of the most important factors that positively impact business performance of firms (Schumpeter, 1934; Burns and Stalker, 1961; Porter, 1990; Deshpande *et al.*, 1993; Hurley and Hult, 1998). The continuous creation and adoption of innovations puts a firm in a dominant competitive position (Porter, 1990; Lengnick-Hall, 1992; Banbury and Mitchell, 1995; Bates and Flynn, 1995; Lee *et al.*, 2003). Innovation is drawing increasing attention of most of the firms operating in the global economy as the key driver of competitiveness (Dervitsiotis, 2010) in anticipation of the unprecedented performance gains that stem from innovativeness.

Assessment of innovation of firms is of crucial importance in today's dynamic and competitive environments (Tohidi and Jabbari, 2012). One would find it difficult, if not impossible, to manage a phenomenon without having a means of measuring it

Definition	Author(s)
A firm's capacity or propensity to adopt innovations with a motive of bringing about continual improvement in their effectiveness and competitiveness	Damanpour (1991), Galunic and Rodan (1998), Walker (2008)
The degree to which an individual or other unit of adoption is relatively earlier in adopting new ideas than other members of a system	Rogers (2003)
A firm's receptivity and inclination to adopt new ideas that lead to the development and launch of new products	Rubera and Kirca (2012), Erickson and Jacobson (1992), Hurley and Hult (1998)
Basic willingness to depart from existing technologies and practices and venture beyond current state of art	Kimberly (1981)
A company's proclivity toward adoption of new technologies thus representing its ability to adapt to different environmental opportunities	Kitchell (1995)
A firm's tendency to engage in and support new ideas, novelty, experimentation, creative processes that may result in new products, services or technological processes	Lumpkin and Dess (1996)
That portion of a firm's culture that promotes and supports novel ideas, experimentation and openness to new ideas	Keskin (2006, p. 399)
Cultural readiness and appreciation for innovation An organization's overall innovative capability of introducing new products to the market, or opening up new markets, through combining strategic orientation with innovative behavior and process	Hult *et al.* (2004), Wang and Ahmed (2004)

Table I.
Definitions of organizational innovativeness

(Morris, 2008). The measurement of the performance of an innovation system makes comparisons possible and offers the basis for making policy decisions for effecting further improvement (Eggink, 2012).

Measurement of innovativeness is critical for practitioners and academicians, both. The literature has struggled for long with the issue of measurement of the innovative performance of companies (Hagedoorn and Cloodt, 2003). The diverse approaches, prescriptions and practices found in literature are confusing and contradictory (Adams *et al.*, 2006). Innovativeness measurement remains an underdeveloped research area as there is no generally accepted holistic framework for measuring overall innovativeness of manufacturing firms. Deshpande and Farley (2004) highlighted the weaknesses of scales currently available and emphasized the need for development of a universally reliable scale for innovativeness measurement. Crespell *et al.* (2006) also acknowledged the weaknesses of scales in use and called for the conceptualization of a robust, reliable and valid scale to measure organizational innovativeness.

The main objective of this paper is to develop an industry sector-level innovativeness assessment framework based on realistic measurement metrics. The measurement framework can provide useful information for making decisions such as – which areas need improvement, where to make investments and how to allocate resources, especially to mitigate the risks imminent during periods of economic downturns. In fact, all the stakeholders stand to benefit from research in the area of innovation.

Innovation management has of late started attracting attention of the researchers as it has wider implications for academicians and practitioners in particular and society in general. The studies in the domain of innovation adoption and innovativeness assessment can help a great deal in identifying and bridging the gap that exists between theory and practice.

The paper is set out as follows: The following section reports from the literature, various approaches adopted for innovativeness measurement. Section 3 provides an overview of the fundamentals of neutrosophic and intuitionistic fuzzy set theory utilized in this study. The framework model for assessing innovativeness of firms is proposed and described in Section 4. The next section then, covers the implementation of the proposed methodology with the help of an illustrative example. Sensitivity analysis for judging the robustness of the proposed methodology is carried out in Section 6. The penultimate section discusses and analyses the obtained results. The concluding section presents the major implications and limitations of this work, and suggests certain directions for further research in the area in future.

2. Literature review

A literature review provides opportunities for further research in the field by identifying the conceptual content (Meredith, 1993) and highlighting the gaps in the extant literature. The literature survey in this study has been carried out from three different perspectives – dimensions of innovativeness, measurement approaches and past applications of the Intuitionistic fuzzy-TOPSIS (IF-TOPSIS).

2.1 Review on dimensions of innovativeness

Extensive literature review has been made to identify the dimensions of an organization's overall innovativeness. Five identified dimensions, as reported in the literature (Wang and Ahmed, 2004) and presented in Table II, are explained below.

Product innovativeness. Product innovativeness refers to designing and offering a good or service that is new or considerably improved in terms of its features or intended uses. Product innovativeness is very often considered as perceived newness, novelty, originality or uniqueness of a product (Henard and Szymanski, 2001).

Table II.
Dimensions of organizational innovativeness

S. No.	Type of innovativeness	References
1	Product innovativeness	Avlonitis *et al.* (1994), Masaaki and Scott (1995), Andrews and Smith (1996), Zirger (1997), Miller and Friesen (1983), Schmidt and Calantone (1998), Danneels and Kleinschmidt (2001), Henard and Szymanski (2001), Sethi *et al.* (2001), Garcia and Calantone (2002), Edmondson and Nembhard (2009), Bakar and Ahmad (2010), Oke (2013), Lyon *et al.* (2000), Schumpeter (1934) and North and Smallbone (2000)
2	Process innovativeness	Avlonitis *et al.* (1994), Kitchell (1997), Papinniemi (1999), Lyon *et al.* (2000), North and Smallbone (2000), Miller and Friesen (1983), Subramanian and Nilakanta (1996), Schumpeter (1934) and North and Smallbone (2000)
3	Market innovativeness	Ali *et al.* (1995), Andrews and Smith (1996), Capon *et al.* (1992), Cooper (1973), Miller (1983), Schumpeter (1934) and North and Smallbone (2000)
4	Behavioral innovativeness	Rousseau (1988), Hurt *et al.* (1977), Avlonitis *et al.* (1994), Rainey (1999), Lovelace *et al.* (2001), Miller and Friesen (1983), Hurley and Hult (1998) and North and Smallbone (2000)
5	Strategic innovativeness	Capon *et al.* (1992), Miller and Friesen (1983), Avlonitis *et al.* (1994), Besanko *et al.* (1996), Markides (1998) and Miller and Friesen (1983)

Process innovativeness. Process innovation is designing and introducing a production/delivery method that is significantly new. Process innovativeness improves the firms' ability to exploit their resources and capabilities.

Market innovativeness. Market innovativeness is devising and adopting a new marketing method with significant changes in the way a product is designed or packaged, placed, promoted or priced. Market innovativeness is highly related to product innovativeness, and often referred to as product-market innovativeness (Schumpeter, 1934; Cooper, 1973; Miller, 1983).

Behavioral innovativeness. Behavioral innovativeness is display of right attitude and commitment the stakeholders' reflected in the organizational behavior. It is perceptions of the work environment, referred to generally as organizational climate (Rousseau, 1988). Behavioral innovativeness can be present at different levels: individuals, teams and management.

Strategic innovativeness. Strategic innovation is adopting a new organizational method in the firm's business practices, workplace organization and conduct or in dealing with the outside world. Strategic innovation is "a fundamental re-conceptualization of what the business is all about that, in turn, leads to a dramatically different way of playing the game in an existing business" (Markides, 1998, p. 31).

2.2 Innovativeness measurement methods

While overall there is no dearth of innovation research, a comparatively small number of studies focus on innovativeness (Moos *et al.*, 2010, p. 1). Measurement of innovation in terms of inputs and outcomes does give an idea about innovativeness of a firm but cannot be regarded as an adequate measure of innovativeness. A brief description of the approaches that have been adopted and suggested for capturing innovativeness is given below.

Robertson (1971) proposed the cross-sectional method in which innovativeness is determined by measuring the number of new products owned or used by a firm at any given point of time or stage in the diffusion process. He assumed that innovative firms tend to use newly developed products at any given point of time. Cordero (1990) developed a model using outputs and resource indicators to assess an overall innovative performance of a firm by measuring the innovation process at every stage – planning stage, control stage, technical stage and commercialization stage. Avlonitis *et al.* (1994) defined innovativeness as a multidimensional concept and tried to measure it by examining the diverse innovations adopted by organizations across industries. Coombs *et al.* (1996) proposed the literature-based innovation output indicators (LBIOI) methodology. They utilize the new product announcements in trade and technical journals as indicators of innovation activities. They suggested that LBIOI should be used as a compliment to the existing indicators. The method is more suitable for measuring product innovation than process innovation.

Rogers (1998) defined the innovation process and discussed issues related to its measurement system. He also presented a review of earlier studies on innovation measurement in Australian context. Wang and Dickson (2000) used questionnaire method to measure technological innovation of small- and medium-sized manufacturing enterprises in China. They used the results of the questionnaires to construct an index system. Hagedoorn and Cloodt (2003) studied the innovative performance of large international firms, using a range of indicators such as R&D inputs, patents, patent citations, new product announcements, etc. Fell *et al.* (2003) developed a composite method of measuring innovativeness based on product categories and accounted for the time of adoption. Vermeulen *et al.* (2003) tested a conversion model for measuring the innovativeness of small and medium manufacturing and service firms in the Netherlands.

Adams *et al.* (2006) reviewed previous literature on innovation management measurement and reported an absence of a holistic framework. Maravelakis *et al.* (2006) presented most commonly used measures of innovation and described the difficulties in applying them to SMEs. Measuring and benchmarking innovation with fuzzy logic, through an innovation survey has also been presented. Ortiz *et al.* (2007) proposed a measurement system for technological innovation of products and processes. They used the sets of indicators identified by the experts to define a measurement system. The system makes possible a comparison among the companies Rothaermel and Hess (2007) developed a theoretical model to evaluate innovativeness of pharmaceutical firms at three different levels: individual level, firm level and network level. They collected and identified three types of variables – dependent variable (innovative output), independent variables (intellectual human capital R&D capability, etc.) and controlled variables (patents, firm size, etc.). Persaud (2005) and Yeoh (2009) considered R&D cost reduction and development time for innovations as criteria for the measurement of innovation performance.

Carayannis and Provance (2008) proposed a "3P" (Posture, Propensity and Performance) construct for assessing the innovation capabilities of a firm and proposed a composite innovativeness index based on three indicators: input, throughput, and output-oriented measures.

Tsai *et al.* (2008) used AHP to measure organizational innovativeness in a high-tech industry, using technical and administrative innovations as the indicators for R&D ranking.

Zheng *et al.* (2009) developed an innovation performance audit system based on measurements. They created a framework of key performance indicators and then collected data from high-tech industries to test and validate their framework. Liu *et al.* (2010) derived a weighted measurement index from objective and subjective data and used it to measure innovation. The results suggested that product innovation, process innovation and strategic innovation are the most important dimensions of organizational innovation. European Commission (2001) introduced two approaches to measure technological Innovation – a subjective approach, which usually involves surveys and interviews and an objective approach based on innovation counts. Dervitsiotis (2010) described an integrated framework for the systematic assessment of an organization's innovation management quality and suggested the ways to measure and improve it. He provided a holistic or systems view of the innovation process, paying attention to all its elements. A survey of literature shows that self-evaluation method for measuring innovativeness has also been proposed by various researchers (Carter and Williams, 1959; Wind and Mahajan, 1997; Gebert *et al.*, 2003; Crespell *et al.*, 2006). In this method, the dimensions of innovativeness identified by the firm are rated on an interval scale by firm employees.

2.3 Review on IF-TOPSIS applications

The TOPSIS method is an important method for MADM problems. Some of its applications are covered in Table III.

3. Intuitionistic fuzzy-TOPSIS procedure

The proposed IF-TOPSIS is an efficient procedure for solving multi-attribute decision-making problems where the decision environment is fraught with high degree of vagueness and indeterminacy of information and subjectivity of judgments.

As hinted in the flowchart shown in Figure 1, the various steps taken in the IF-TOPSIS procedure are described here:

- Step 1: determination of the importance weights of the panel of decision makers (DMs).

Table III. Applications of IF-TOPSIS

Area of application area	Author(s)
R&D manager selection	Ashtiani *et al.* (2009)
Supplier selection	Boran *et al.* (2009)
Virtual enterprise partner selection	Ye (2010)
Investment decisions	Tan (2011), Zhang and Yu (2012)
General framework	Chen and Tsao (2008)
Assessment of command and control system	Li *et al.* (2009)
Selection of air-conditioning systems for municipal library	Park *et al.* (2011)
Evaluation of renewable energy technologies for electricity generation	Boran *et al.* (2012)

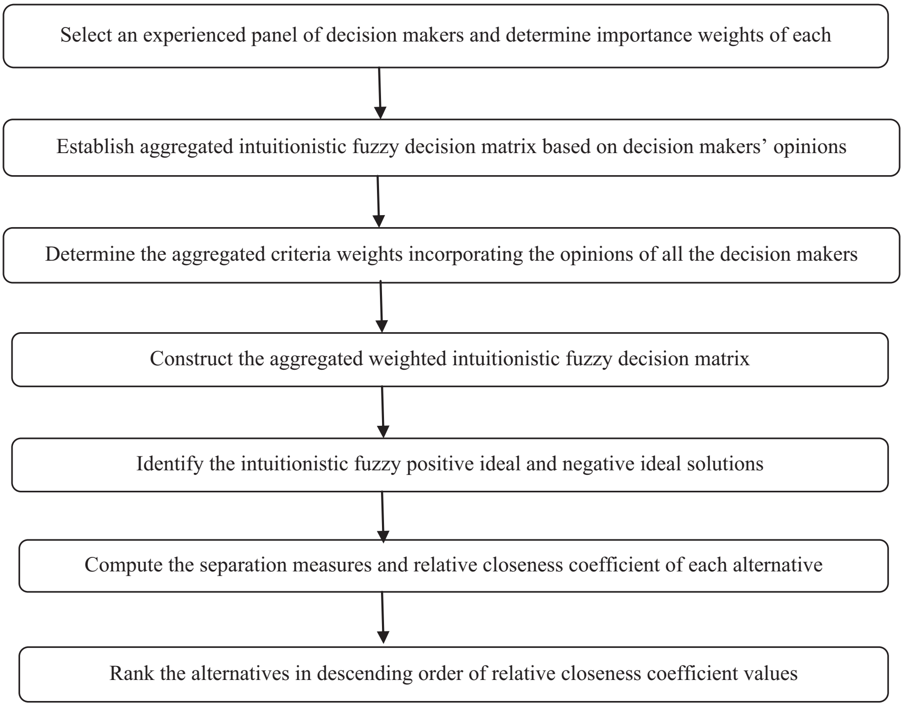

Figure 1. Flowchart of IF-TOPSIS procedure

Constitute a group of DMs and determine the importance of each one of them. Let $\mathrm{DM}_k = \{\mathrm{DM}_1, \mathrm{DM}_2, \mathrm{DM}_k, \ldots, \mathrm{DM}_l\}$ be the set of k DMs. The importance of each DM is expressed in terms of neutrosophic numbers.

Let $A_i = \{\langle x, T_{A_i}(x), I_{A_i}(x), F_{A_i}(x)\rangle : x \in X\}$, be a neutrosophic number defined for rating the kth DM. The weight of kth DM can then be obtained as (Biswas *et al.*, 2015):

$$\psi_k = \frac{1-\sqrt{\left\{(1-T_k(x))^2+(I_k(x))^2+(F_k(x))^2\right\}/3}}{\sum_{k=1}^{l}\left(1-\sqrt{\left\{(1-T_k(x))^2+(I_k(x))^2+(F_k(x))^2\right\}/3}\right)}, \quad (1)$$

and:

$$\sum_{k=1}^{l} \psi_k = 1.$$

The linguistic scale used for assigning importance weights to DMs is presented in Table IV:

- Step 2: construction of the aggregated intuitionistic fuzzy decision matrix (IFDM).

Let $R^{(k)} = (x_{ij}^{k})_{n\times m}$ be an IFDM representing the rating of alternatives A_i based on the opinions of k DMs. The opinions of DMs are considered and an aggregated IFDM is obtained utilizing IFWA operator given by Xu (2007):

$$\mathrm{R} = [x_{ij}]_{n\times m},$$

$$x_{ij} = \mathrm{IFWA}\left\{x_{ij}^{(1)}, x_{ij}^{(2)}, \ldots, x_{ij}^{(k)}, \ldots, x_{ij}^{(l)}\right\},$$

$$= \lambda_1 x_{ij}^{(1)} \oplus \lambda_2 x_{ij}^{(2)} \oplus \cdots \oplus \lambda_k x_{ij}^{(k)} \oplus \cdots \oplus \lambda_l x_{ij}^{(l)}\Big\},$$

$$= \left[1-\prod_{k=1}^{l}\left(1-\mu_{ij}^{(k)}\right)^{\lambda_k}, \prod_{k=1}^{l}\left(v_{ij}^{(k)}\right)^{\lambda_k}, \prod_{k=1}^{l}\left(1-\mu_{ij}^{(k)}\right)^{\lambda_k} - \prod_{k=1}^{l}\left(v_{ij}^{(k)}\right)^{\lambda_k}\right], \quad (2)$$

where $x_{ij} = \{\mu_{A_i(x_j)},\ v_{A_i(x_j)} v_j,\ v_{A_i(x_j)}\}$ $(i = 1, 2, \ldots, n; j = 1, 2, \ldots, m)$.

The linguistic terms used for evaluating each one of the alternatives according to their performance on various criteria are shown in Table V:

- Step 3: determination of the importance weights of criteria.

DMs might give different opinions about the same criteria. Hence, their opinions need to be considered and combined into one. Linguistic terms shown in Table VI are used to rate the importance of criteria by every DM.

Linguistic term	Interval valued neutrosophic number (IVNN)	Equivalent single-valued neutrosophic numbers (SVNNs)
Very important (VI)	{[0.85, 0.95], [0.20, 0.30], [0.20, 0.30]}	{0.90, 0.10, 0.10}
Important (I)	{[0.70, 0.90], [0.10, 0.30], [0.10, 0.20]}	{0.80, 0.20, 0.15}
Medium (M)	{[0.40, 0.60], [0.30, 0.50], [0.40, 0.50]}	{0.50, 0.40, 0.45}
Unimportant (UI)	{[0.30, 0.40], [0.50, 0.70], [0.60, 0.80]}	{0.35, 0.60, 0, 70}
Very unimportant (VUI)	{[0.05, 0.15], [0.70, 0.90], [0.85, 0.95]}	{0.10, 0.80, 0.90}

Table IV. Importance weights of decision makers

Let $w_j^{(k)} = \{\mu_j^k,\ v_j^k,\ \pi_j^k\}$ be an intuitionistic fuzzy number assigned to criteria x_j by the kth DM. Then the weights of the criteria are computed using the IFWA operator proposed by Xu (2007):

$$w_j = \text{IFWA}\left\{w_j^{(1)}, w_j^{(2)}, \ldots, w_j^{(k)}, \ldots, w_j^{(l)}\right\},$$

$$= \lambda_1 w_j^{(1)} \oplus \lambda_2 w_j^{(2)} \oplus \cdots \oplus \lambda_k w_j^{(k)} \oplus \cdots \oplus \lambda_l w_j^{(l)}\right\},$$

$$= \left[1 - \prod_{k=1}^{l}\left(1-\mu_j^{(k)}\right)^{\lambda_k}, \prod_{k=1}^{l}\left(v_j^{(k)}\right)^{\lambda_k}, \prod_{k=1}^{l}\left(1-\mu_j^{(k)}\right)^{\lambda_k} - \prod_{k=1}^{l}\left(v_j^{(k)}\right)^{\lambda_k}\right], \tag{3}$$

where $w_j = (\mu_j, \nu_j, \pi_j)$ and $W = (w_1, w_2, \ldots, w_j, \ldots, w_m)$:

- Step 4: construction of aggregated weighted IFDM.

After determining the aggregated IFDM, $\text{R} = [x_{ij}]_{n \times m}$ and weights of criteria W, the aggregated weighted IFDM is constructed using to the Equation (3):

$$\text{R} \times W = \left\{\left\langle x, \mu_{A_i}(x) \cdot \mu_w(x), v_{A_i}(x) + v_w(x) - v_{A_i}(x) \cdot v_w(x)\right\rangle | x \in X\right\}, \tag{4}$$

and:

$$\pi_{a_i \cdot w}(x) = 1 - v_{A_i}(x) - v_w(x) - \mu_{A_i}(x) \cdot \mu_w(x) + v_{A_i}(x) \cdot v_w(x),$$

$$\text{R}' = \begin{bmatrix} (\mu_{A_1 \cdot w}(x_1), v_{A_1 \cdot w}(x_1), \pi_{A_1 \cdot w}(x_1)) & (\mu_{A_1 \cdot w}(x_2), v_{A_1 \cdot w}(x_2), \pi_{A_1 \cdot w}(x_2)) & \ldots & (\mu_{A_1 \cdot w}(x_n), v_{A_1 \cdot w}(x_n), \pi_{A_1 \cdot w}(x_n)) \\ (\mu_{A_2 \cdot w}(x_1), v_{A_2 \cdot w}(x_1), \pi_{A_2 \cdot w}(x_1)) & (\mu_{A_i \cdot w}(x_2), v_{A_i \cdot w}(x_2), \pi_{A_1 \cdot w}(x_2)) & \ldots & (\mu_{A_2 \cdot w}(x_n), v_{A_2 \cdot w}(x_n), \pi_{A_2 \cdot w}(x_n)) \\ \ldots & \ldots & \ldots & \ldots \\ (\mu_{A_m \cdot w}(x_1), v_{A_m \cdot w}(x_1), \pi_{A_m \cdot w}(x_1)) & (\mu_{A_m \cdot w}(x_2), v_{A_m \cdot w}(x_2), \pi_{A_m \cdot w}(x_2)) & \ldots & (\mu_{A_m \cdot w}(x_n), v_{A_m \cdot w}(x_n), \pi_{A_m \cdot w}(x_n)) \end{bmatrix},$$

Linguistic term	IF N (μ_k, υ_k, π_k)
Extremely bad (EB)/Extremely low (EL)	{0.10, 0.90, 0.00}
Very bad (VB)/Very low (VL)	{0.10, 0.75, 0.15}
Bad (B)/Low (L)	{0.25, 0.60, 0.15}
Medium bad (MB)/Medium low (ML)	{0.40, 0.50, 0.10}
Fair (F)/Medium (M)	{0.50, 0.40, 0.10}
Medium good (MG)/Medium high (MH)	{0.60, 0.30, 0.10}
Good (G)/High (H)	{0.70, 0.20, 0.10}
Very good (VG)/Very high (VH)	{0.80, 0.10, 0.10}
Extremely good (EG)/Extremely high (EH)	{1.00, 0.00, 0.00}

Table V. Linguistic scale for rating firm performance

Linguistic term	IF N (μ_k, υ_k, π_k)
Very unimportant (VU)	{0.10, 0.90, 0.00}
Unimportant (U)	{0.35, 0.60, 05}
Medium (M)	{0.50, 0.45, 0.05}
Important (I)	{0.75, 0.20, 0, 05}
Very important (VI)	{0.90, 0.10, 0.00}

Table VI. Linguistic terms for rating the criteria

$$R' = \begin{bmatrix} r'_{11} & r'_{12} & \dots & r'_{1j} \\ r'_{21} & r'_{22} & \dots & r'_{2j} \\ \dots & \dots & \dots & \dots \\ r'_{i1} & r'_{i2} & \dots & r'_{ij} \end{bmatrix},$$

where $r^i_{ij} = (\mu_{A_i \cdot w}(x_j),\ v_{A_i \cdot w}(x_j),\ \pi_{A_i \cdot w}(x_j))$ is an element of the aggregated weighted IFDM:

- Step 5: identification of intuitionistic fuzzy positive-ideal solution (IFPIS) and intuitionistic fuzzy negative-ideal solution (IFNIS).

Let J_1 and J_2 be benefit criteria and cost criteria, respectively. The IFPIS A^* and IFNIS A^- are obtained as:

$$A^* = \left(\mu_{A^*w}(x_j), v_{A^*w}(x_j)\right), \tag{5}$$

and:

$$A^- = \left(\mu_{A^-w}(x_j), v_{A^-w}(x_j)\right), \tag{6}$$

where:

$$\mu_{A^*w}(x_j) = \left(\left(\max_i \mu_{A_i \cdot w}(x_j) | j \in J_1\right), \left(\min_i \mu_{A_i \cdot w}(x_j) | j \in J_2\right)\right),$$

$$v_{A^*w}(x_j) = \left(\left(\min_i v_{A_i \cdot w}(x_j) | j \in J_1\right), \left(\max_i v_{A_i \cdot w}(x_j) | j \in J_2\right)\right),$$

$$\mu_{A^-w}(x_j) = \left(\left(\min_i \mu_{A_i \cdot w}(x_j) | j \in J_1\right), \left(\max_i \mu_{A_i \cdot w}(x_j) | j \in J_2\right)\right),$$

and:

$$v_{A^-w}(x_j) = \left(\left(\max_i v_{A_i \cdot w}(x_j) | j \in J_1\right), \left(\min_i v_{A_i \cdot w}(x_j) | j \in J_2\right)\right).$$

- Step 6: computation of the separation measures of alternatives.

For measuring the distance between an alternative's innovative performance and identified positive/negative ideal solutions, all represented as intuitionistic fuzzy sets, the normalized distance measure proposed by Szmidt and Kacprzyk (2000) is used. The separation measures, S^* and S^- of each alternative from IFPIS and IFNIS are calculated using the following equations (Szmidt, and Kacprzyk, 2000):

$$S^* = \sqrt{1/2n \sum_{j=1}^{n} \left[\left(\mu_{A_i \cdot w}(x_j) - \mu_{A^*w}(x_j)\right)^2 + \left(v_{A_i \cdot w}(x_j) - v_{A^*w}(x_j)\right)^2 + \left(\pi_{A_i \cdot w}(x_j) - \pi_{A^*w}(x_j)\right)^2\right]}, \tag{7}$$

and:

$$S^- = \sqrt{1/2n \sum_{j=1}^{n} \left[\left(\mu_{A_i.w}(x_j) - \mu_{A^-w}(x_j)\right)^2 + \left(v_{A_i.w}(x_j) - v_{A^-w}(x_j)\right)^2 + \left(\pi_{A_i.w}(x_j) - \pi_{A^-w}(x_j)\right)^2\right]} \tag{8}$$

- Step 7: compution of the relative closeness coefficient.

The relative closeness coefficient of each firm is calculated:

$$C_{i^*} = \frac{S_{i^-}}{S_{i^*} + S_{i^-}}, \tag{9}$$

where $0 \leqslant C_{i*} \leqslant 1$:

- Step 8: ranking the alternatives based on their relative closeness coefficient.

The relative closeness coefficient values are indicators of innovative performance of the firms under consideration. The firms are arranged in descending order of C_{i^*} values.

4. Application of IF-TOPSIS to innovativeness assessment problem

The innovativeness assessment problem is considered as a multi-criteria decision-making problem with following particulars.

Alternatives: four firms – Firm A, Firm B, Firm C, and Firm D, all from white goods industry.

DMs: four experts – two from industry and two from academia.

Criteria: five innovativeness dimensions – product innovativeness ($X1$), process innovativeness ($X2$), market innovativeness ($X3$), behavioral innovativeness ($X4$) and strategic innovativeness ($X5$).

The hierarchical structure of the problem is shown in Figure 2.

The concept of neutrosophic sets is used for deciding weights of DMs and IF-TOPSIS technique is employed for evaluation of firms based on their innovative performance. The various steps followed in the solution of innovativeness assessment problem are described hereunder:

- Step 1: determine the weights of the DMs.

The views and opinion of the DMs regarding criteria importance and innovative performance of the firms might differ due to differences in their educational and professional backgrounds. To ensure a realistic assessment of criteria importance and innovative performance of the firms, due importance weights are assigned to the DMs in linguistic terms listed in Table IV. The linguistic terms along with their equivalent single-valued neutrosophic numbers, derived from interval valued neutrosophic numbers using Accumulated arithmetic operator (Pramanik and Mondal, 2015), are presented in Table VII.

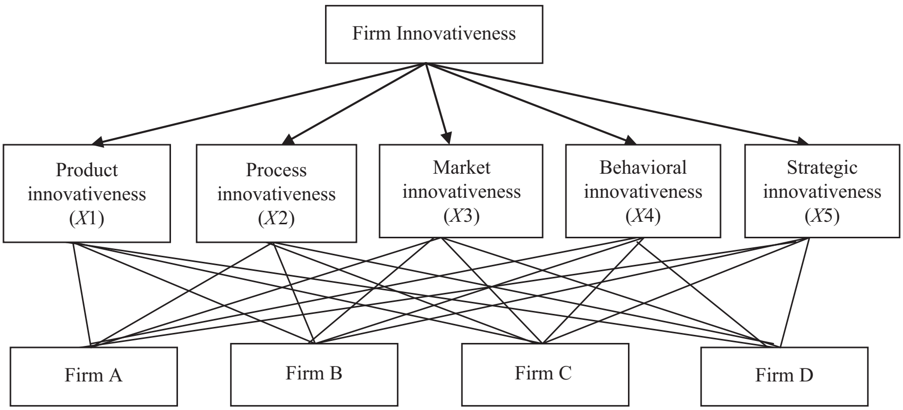

Figure 2.
Hierarchical structure of the innovativeness assessment problem

The priority weight of DM1 is, for example, computed using Equation (1) as:

$$\psi_1 = \frac{1-\sqrt{0.01+0.01+0.01/3}}{(4-\sqrt{0.03/3}-\sqrt{0.6125/3}-\sqrt{0.1025/3}-\sqrt{0.1025/3})} = 0.292.$$

Similarly, the weights of other three DMs can be obtained as: $\psi_2 = 0.178$, $\psi_3 = 0.265$ and $\psi_4 = 0.265$. Thus, the weight vector of the four DMs $\psi = (0.292, 0.178, 0.265, 0.265)$:

- Step 2: construct the aggregated IFDM for the problem.

The linguistic assessments of the innovative performance of all the firms by the panel of DMs on the five criteria are shown in Table VIII. The linguistic terms and the associated IFNs listed in Table II are used for the purpose.

The assessment of all the DMs are combined and aggregated using Equation (2). The aggregated value of Firm A – $X1$ combination, as an illustration, is computed as:

$$\begin{pmatrix} \left(1-(1-0.7)^{0.292} \times (1-0.8)^{0.178} \times (1-0.7)^{0.265} \times (1-0.7)^{0.265}\right), \\ \left(0.2^{0.292} \times 0.1^{0.178} \times 0.2^{0.265} \times 0.2^{0.265}\right), \\ 1-\left[\left(1-(1-0.7)^{0.292} \times (1-0.8)^{0.178} \times (1-0.7)^{0.265} \times (1-0.7)^{0.265}\right)\right] \\ -\left[\left(0.2^{0.292} \times 0.1^{0.178} \times 0.2^{0.265} \times 0.2^{0.265}\right)\right] \end{pmatrix},$$

$$= (0.721,\ 0.177,\ 0.102).$$

The aggregated IFDM based on aggregation of DMs' opinions is presented in Table IX:

- Step 3: determine the criteria importance based on opinion of chosen panel of DMs.

Five identified criteria are rated by the panel of DMs using linguistic scale given in Table VI and the importance of each criterion is expressed in linguistic terms in Table X.

The evaluation of all the DMs is aggregated using Equation (3). The sample calculations for criterion $X1$ are shown below:

$$w_1 = \begin{bmatrix} 1-(1-0.90)^{0.292} \times (1-0.90)^{0.178} \times (1-0.75)^{0.265} \times (1-0.50)^{0.265}, \\ (0.10)^{0.292} \times (0.10)^{0.178} \times (0.20)^{0.265} \times (0.45)^{0.265}, \\ (1-0.90)^{0.292} \times (1-0.90)^{0.178} \times (1-0.75)^{0.265} \times (1-0.50)^{0.265} \\ -(0.10)^{0.292} \times (0.10)^{0.178} \times (0.20)^{0.265} \times (0.45)^{0.265} \end{bmatrix},$$

$$= (0.805, 0.179, 0.016).$$

Decision maker	Linguistic rating	IVNN	SVNN
DM1	VI	{[0.85, 0.95], [0.20, 0.30], [0.20, 0.30]}	(0.90, 0.10, 0.10)
DM2	M	{[0.40, 0.60], [0.30, 0.50], [0.40, 0.50]}	(0.50, 0.40, 0.45)
DM3	I	{[0.70, 0.90], [0.10, 0.30], [0.10, 0.20]}	(0.80, 0.20, 0.15)
DM4	I	{[0.70, 0.90], [0.10, 0.30], [0.10, 0.20]}	(0.80, 0.20, 0.15)

Table VII. Assignment of importance weights to the DMs

Criterion	Firm	Innovative performance DM1	DM2	DM3	DM4
*X*1	Firm A	G(0.7, 0.2, 0.1)	VG(0.8, 0.1, 0.1)	G(0.7, 0.2, 0.1)	G(0.7, 0.2, 0.1)
	Firm B	MG(0.6, 0.3, 0.1)	G(0.7, 0.2, 0.1)	F(0.5, 0.4, 0.1)	VG(0.8, 0.1, 0.1)
	Firm C	EG(0.9, 0.1, 0.0)	MG(0.6, 0.3, 0.1)	VG(0.8, 0.1, 0.1)	G(0.7, 0.2, 0.1)
	Firm D	MG(0.6, 0.3, 0.1)	G(0.7, 0.2, 0.1)	G(0.7, 0.2, 0.1)	G(0.7, 0.2, 0.1)
*X*2	Firm A	MG(0.6, 0.3, 0.1)	G(0.7, 0.2, 0.1)	MG(0.6, 0.3, 0.1)	MG(0.6, 0.3, 0.1)
	Firm B	F(0.5, 0.4, 0.1)	MG(0.6, 0.3, 0.1)	G(0.7, 0.2, 0.1)	EG(0.9, 0.1, 0.0)
	Firm C	VG(0.8, 0.1, 0.1)	G(0.7, 0.2, 0.1)	VG(0.8, 0.1, 0.1)	MG(0.6, 0.3, 0.1)
	Firm D	F(0.5, 0.4, 0.1)	F(0.5, 0.4, 0.1)	MG(0.6, 0.3, 0.1)	MG(0.6, 0.3, 0.1)
*X*3	Firm A	VG(0.8, 0.1, 0.1)	G(0.7, 0.2, 0.1)	VG(0.8, 0.1, 0.1)	F(0.5, 0.4, 0.1)
	Firm B	G(0.7, 0.2, 0.1)	MG(0.6, 0.3, 0.1)	MG(0.6, 0.3, 0.1)	VG(0.8, 0.1, 0.1)
	Firm C	VG(0.8, 0.1, 0.1)	VG(0.8, 0.1, 0.1)	G(0.7, 0.2, 0.1)	F(0.5, 0.4, 0.1)
	Firm D	VG(0.8, 0.1, 0.1)	G(0.7, 0.2, 0.1)	G(0.7, 0.2, 0.1)	VG(0.8, 0.1, 0.1)
*X*4	Firm A	G(0.7, 0.2, 0.1)	G(0.7, 0.2, 0.1)	VG(0.8, 0.1, 0.1)	G(0.7, 0.2, 0.1)
	Firm B	MG(0.6, 0.3, 0.1)	F(0.5, 0.4, 0.1)	MG(0.6, 0.3, 0.1)	MG(0.6, 0.3, 0.1)
	Firm C	VG(0.8, 0.1, 0.1)	VG(0.8, 0.1, 0.1)	G(0.7, 0.2, 0.1)	VG(0.8, 0.1, 0.1)
	Firm D	G(0.7, 0.2, 0.1)	MG(0.6, 0.3, 0.1)	MG(0.6, 0.3, 0.1)	G(0.7, 0.2, 0.1)
*X*5	Firm A	VG(0.8, 0.1, 0.1)	G(0.7, 0.2, 0.1)	VG(0.8, 0.1, 0.1)	F(0.5, 0.4, 0.1)
	Firm B	G(0.7, 0.2, 0.1)	MG(0.6, 0.3, 0.1)	MG(0.6, 0.3, 0.1)	VG(0.8, 0.1, 0.1)
	Firm C	MG(0.6, 0.3, 0.1)	VG(0.8, 0.1, 0.1)	G(0.7, 0.2, 0.1)	F(0.5, 0.4, 0.1)
	Firm D	VG(0.8, 0.1, 0.1)	G(0.7, 0.2, 0.1)	G(0.7, 0.2, 0.1)	VG(0.8, 0.1, 0.1)

Table VIII. Assessment of innovative performance of candidate firms

Firm	Innovative performance *X*1	*X*2	*X*3	*X*4	*X*5
Firm A	(0.721, 0.177, 0.102)	(0.620, 0.279, 0.101)	(0.726, 0.163, 0.111)	(0.721, 0.246, 0.033)	(0.726, 0.163, 0.111)
Firm B	(0.664, 0.225, 0.110	(0.726, 0.219, 0.055)	(0.694, 0.199, 0.107)	(0.584, 0.379, 0.037)	(0.694, 0.199, 0.107)
Firm C	(0.794, 0.146, 0.060)	(0.742, 0.151, 0.107)	(0.716, 0.173, 0.110)	(0.777, 0.167, 0.055)	(0.652, 0.239, 0.108)
Firm D	(0.674, 0.225, 0.101)	(0.556, 0.343, 0.101)	(0.761, 0.136, 0.103)	(0.659, 0.288, 0.053)	(0.761, 0.136, 0.103)

Table IX. Aggregated intuitionistic fuzzy decision matrix

Criterion	DM1	DM2	DM3	DM4
*X*1	VI (0.90, 0.10, 0.00)	VI (0.90, 0.10, 0.00)	I (0.75, 0.20, 0.05)	M (0.50, 0.45, 0.05)
*X*2	I (0.75, 0.20, 0.05)	I (0.75, 0.20, 0.05)	I (0.75, 0.20, 0.05)	VI (0.90, 0.10, 0.00)
*X*3	I (0.75, 0.20, 0.05)	I (0.75, 0.20, 0.05)	M (0.50, 0.45, 0.05)	I (0.75, 0.20, 0.05)
*X*4	M (0.50, 0.45, 0.05)	VI (0.90, 0.10, 0.00)	M (0.50, 0.45, 0.05)	M (0.50, 0.45, 0.05)
*X*5	M (0.50, 0.45, 0.05)	I (0.75, 0.20, 0.05)	I (0.75, 0.20, 0.05)	I (0.75, 0.20, 0.05)

Table X. Linguistic assessment of the criteria importance

The weights of other four criteria are similarly obtained to give a weight vector:

$$W_{\{X1,\ X2,\ X3,\ X4,\ X5\}} = \begin{bmatrix} (0.805,\ 0.179,\ 0.016) \\ (0.804,\ 0.166,\ 0.030) \\ (0.700,\ 0.248,\ 0.052) \\ (0.625,\ 0.344,\ 0.031) \\ (0.694,\ 0.254,\ 0.053) \end{bmatrix}.$$

- Step 4: construct the aggregated weighted IFDM.

After determining the aggregated IFDM, $R = [x_{ij}]_{n \times m}$ and weights of criteria, W, the aggregated weighted IFDM, $R' = [R \otimes W]$is constructed using to the Equation (4) and presented in Table XI:

- Step 5: derive the IFPIS and IFNIS from aggregated weighted IFDM.

The IFPIS A^* and IFNIS A^- are obtained using Equations (5) and (6) as:

$$A^* = \left\{ \begin{matrix} (0.639,\ 0.299,\ 0.062), (0.596,\ 0.293,\ 0.111), (0.532,\ 0.350,\ 0.118), \\ (0.486,\ 0.454,\ 0.060), (0.528,\ 0.355,\ 0.117) \end{matrix} \right\},$$

and:

$$A^- = \left\{ \begin{matrix} (0.535,\ 0.364,\ 0.101), (0.447,\ 0.453,\ 0.101), (0.485,\ 0.398,\ 0.117), \\ (0.365,\ 0.593,\ 0.042), (0.453,\ 0.432,\ 0.115) \end{matrix} \right\}.$$

- Step 6: calculate the separation measures.

The separation measures for the firms are calculated using Equations (7) and (8). The separation measure for Firm A is calculated as:

$$S^* = \sqrt{1/2 \times 5 \begin{bmatrix} (0.580-0.639)^2 + (0.498-0.596)^2 + (0.508-0.532)^2 + (0.450-0.486) + (0.504-0.528)^2 \\ + (0.324-0.299)^2 + (0.399-0.293)^2 + (0.371-0.350)^2 + (0.506-0.454) + (0.375-0.355)^2 \\ + (0.096-0.062)^2 + (0.103-0.111)^2 + (0.121-0.118)^2 + (0.044-0.060) + (0.121-0.117)^2 \end{bmatrix}},$$

$$= 0.057,$$

and:

$$S^- = \sqrt{1/2 \times 5 \begin{bmatrix} (0.580-0.535)^2 + (0.498-0.447)^2 + (0.508-0.485)^2 + (0.450-0.365) + (0.504-0.453)^2 \\ + (0.324-0.364)^2 + (0.399-0.453)^2 + (0.371-0.398)^2 + (0.506-0.593) + (0.375-0.432)^2 \\ + (0.096-0.101)^2 + (0.103-0.101)^2 + (0.121-0.117)^2 + (0.044-0.042) + (0.121-0.115)^2 \end{bmatrix}},$$

$$= 0.056.$$

The values of separation measures of all the alternatives are computed similarly:

- Step 7: compute the relative closeness coefficient.

The relative closeness coefficient of each firm is calculated using Equation (9). For example, the relative closeness coefficient for Firm A is calculated as:

$$C_{1^*} = \frac{0.056}{0.057 + 0.056} = 0.495.$$

	Innovative performance				
Firm	$X1$	$X2$	$X3$	$X4$	$X5$
Firm A	(0.580, 0.324, 0.096)	(0.498, 0.399, 0.103)	(0.508, 0.371, 0.121)	(0.450, 0.506, 0.044)	(0.504, 0.375, 0.121)
Firm B	(0.535, 0.364, 0.101	(0.584, 0.349, 0.067)	(0.485, 0.398, 0.117)	(0.365, 0.593, 0.042)	(0.481, 0.402, 0.116)
Firm C	(0.639, 0.299, 0.062)	(0.596, 0.293, 0.111)	(0.501, 0.378, 0.121)	(0.486, 0.454, 0.060)	(0.453, 0.432, 0.115)
Firm D	(0.542, 0.364, 0.094	(0.447, 0.453, 0.101)	(0.532, 0.350, 0.118)	(0.412, 0.593, 0.042)	(0.528, 0.355, 0.117)

Table XI. Aggregated weighted intuitionistic fuzzy decision matrix

The relative closeness coefficient of other three firms can similarly be calculated. Table XII provides the values of separation measures and relative closeness coefficients for all the firms.

The graphical representation of the study results is presented in Figure 3:

- Step 8: rank the firms in descending order of relative closeness coefficient values.

The relative innovative performance of firms based on relative closeness coefficient scores is as follows: Firm C > Firm A > Firm B > Firm D.

5. Sensitivity analysis

Sensitivity analysis shows the influence of minor changes in the values of an independent variable on a particular dependent variable under given set of assumptions. It is used to ascertain the robustness of a methodology used in a study. The analysis can be conducted by making slight changes in the value(s) of one or more input parameter(s), either one at a time or simultaneously.

In this work, sensitivity analysis has been carried out by conducting five experiments by considering different set of criteria weights. The experimental set up is presented in Table XIII.

The results of sensitivity analysis are shown in Figure 4.

It is evident from the analysis that there is only one instance i.e. Experiment 4, out of total 5 experiments conducted for the purpose, where the change in criteria weights has resulted in any change in ranking order. Here too, the top two ranks remain unaffected. The analysis shows that the methodology adopted is robust enough to deal with innovativeness assessment problem in a reliable manner.

6. Results and discussion

It is well accepted that a good innovativeness assessment framework can provide the firms with a means to know their relative position *vis-à-vis* competition and formulate

Table XII. Separation measures of each firm

Firm	S^*	S^-	C_{i^*}
Firm A	0.057	0.056	0.495
Firm B	0.081	0.057	0.413
Firm C	0.037	0.100	0.732
Firm D	0.094	0.043	0.314

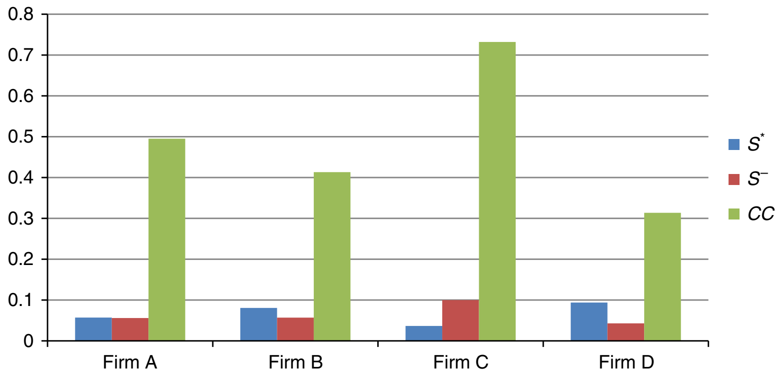

Figure 3. Separation measures and relative closeness coefficients of firms

Table XIII.
Sensitivity analysis

Experiment	Criteria weight assignment	Relative closeness coefficients Firm A	Firm B	Firm C	Firm D	Ranking order
Current study	*X*1 (0.805, 0.179, 0.016) *X*2 (0.804, 0.166, 0.030) *X*3 (0.700, 0.248, 0.052) *X*4 (0.625, 0.344, 0.031) *X*5 (0.694, 0.254, 0.053)	0.495	0.413	0.732	0.314	Firm C > Firm A > Firm B > Firm D
Experiment 1: (equal weights assigned to all criteria by all DMs)	*X*1 (0.900, 0.100, 0.000) *X*2 (0.900, 0.100, 0.000) *X*3 (0.900, 0.100, 0.000) *X*4 (0.900, 0.100, 0.000) *X*5 (0.900, 0.100, 0.000)	0.618	0.565	0.668	0.476	Firm C > Firm A > Firm B > Firm D
Experiment 2: (same weights assigned to all criteria by a DM)	*X*1 (0.745, 0.019, 0.364) *X*2 (0.745, 0.019, 0.364) *X*3 (0.745, 0.019, 0.364) *X*4 (0.745, 0.019, 0.364) *X*5 (0.745, 0.019, 0.364)	0.545	0.420	0.694	0.352	Firm C > Firm A > Firm B > Firm D
Experiment 3 (same weights assigned by all DMs to criterion)	*X*1 (0.900, 0.100, 0.000) *X*2 (0.750, 0.200, 0.050) *X*3 (0.500, 0.450, 0.050) *X*4 (0.500, 0.450, 0.050) *X*5 (0.750, 0.200, 0.050)	0.443	0.419	0.572	0.379	Firm C > Firm A > Firm B > Firm D
Experiment 4 (random weights)	*X*1 (0.745, 0.219, 0.036) *X*2 (0.500, 0.450, 0.050) *X*3 (0.660, 0.286, 0.053) *X*4 (0.745, 0.219, 0.036) *X*5 (0.584, 0.363, 0.053)	0.429	0.322	0.511	0.331	Firm C > Firm A > Firm D > Firm B
Experiment 5 (random weights)	*X*1 (0.755, 0.231, 0.014) *X*2 (0.500, 0.450, 0.050) *X*3 (0.558, 0.389, 0.052) *X*4 (0.873, 0.120, 0.007) *X*5 (0.500, 0.450, 0.050)	0.457	0.377	0.516	0.341	Firm C > Firm A > Firm B > Firm D

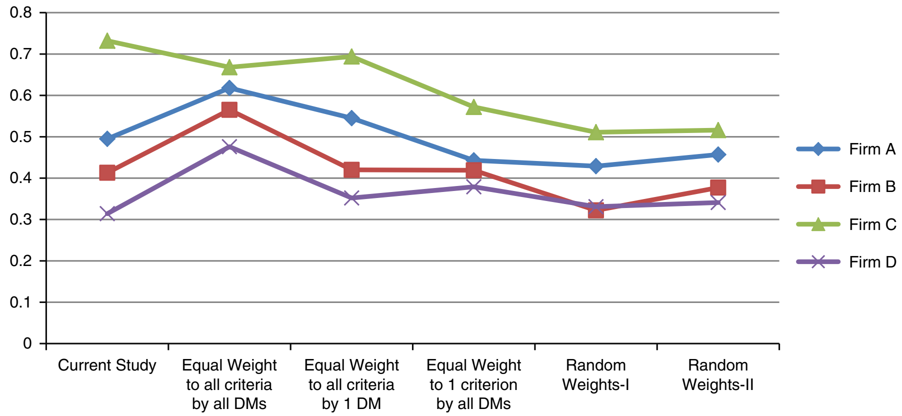

Figure 4.
Effect of changes in criteria weights on relative closeness coefficient

appropriate strategies in their bid to ensure continued existence and sustained growth. The results of the study provide a real status check as to where a firm is today *vis-à-vis* where it wants to be tomorrow. The goals can then be reset and strategies developed to achieve the same.

The review of extant literature highlighted the need for development of an integrated framework for assessing innovativeness of firms based on multiple dimensions. To that end, an intuitionistic fuzzy based framework for comparative evaluation of innovative performance of candidate firms is proposed in this paper. The concept of neutrosophic sets is utilized to compute the DM weights.

The chances of bias in evaluations are high if people are asked to provide quantitative estimates of vague or imprecise items (Karwowski and Mital, 1986). In such decision environments, the IFNs prove to be an excellent tool to model the subjectivity and imprecision associated with the decision-making process in a rational and realistic manner. The paper explains the step by step implementation of the IF-TOPSIS procedure as applied to industry level innovativeness assessment problem. The technique involves identifying the positive and negative solutions and computing the distance of each alternative from these ideal solutions through separation measures. The relative closeness coefficients derived there from are valid and direct measure of the overall performance of alternatives being compared. The CC_i score for the firms – Firm A, Firm B, Firm C and Firm D are found to be 0.495, 0,413, 0.732 and 0.314, respectively giving a ranking order of: Firm C > Firm A > Firm B > Firm D.

Though the relative closeness coefficients reflects the overall innovativeness, an indirect reference to innovativeness status of a firm in respect of a particular dimension can be made by comparing firm's performance value for that innovativeness dimension with the corresponding value in the identified negative-ideal and positive-ideal solutions. A cause-and-effect analysis can then be carried out to identify the factors responsible for a particle level of achievement. Conscious efforts can be directed toward overcoming the barriers and getting the push in the desired direction from drivers of innovation.

Sensitivity analysis of the study results attests to the robustness of the adopted methodology. So, the proposed conceptual framework is a very useful assessment tool from adequacy, capability and effectiveness perspectives.

7. Research implications and directions for further research

This study contributes significantly to academic knowledge and has considerable practical relevance and managerial implications. The proposed innovativeness assessment method has the advantage of assessing the overall innovativeness of a firm system, taking into account multiple attributes.

The framework can be used by the firms to know the current level of innovativeness exhibited by them. The firms can compare their status with benchmarked performance and reprioritize their organizational activities to keep pace with the competition. The highly innovative firms carve a specific niche for themselves and enjoy a healthy reputation in the market.

The society stands to benefit from the studies related to innovativeness assessment. Measurement of any phenomenon is precursor to its growth and improvement. The innovativeness exhibited in adoption of green practices can contribute to issues related with sustainability. Innovative practices can bring about tremendous cost reduction in a firm's production operations. The benefits accruing from development of improved materials and cost-effective methods of manufacture resulting from innovations can be passed on to the consumers in the form of lower prices. Further, availability of products at affordable prices helps improve the quality of life that people lead.

Assessment of innovativeness of manufacturing has remained a neglected research area. This and such other works would stimulate research in this area. Future studies can consider using interval valued IFNs to substantially reduce the margin of perceptual errors that generally creeps in due to subjectivity involved in expression of preferences and opinions by the DMs. Other hybrid MCDM techniques such as grey relational analysis based on neutrosophic and IF sets, AHP based on interval valued IF sets, etc., can be adapted to innovativeness assessment problem. Use of other sophisticated criteria weight determination methods can be considered.

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