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Abstract: The Internet of Things (IoT) is used in the Supply chain management (SCM) systems to respond to the globalization of complex and dynamic markets and competitiveness in various supply chain scopes. Despite the current buzz about IoT and its role in the supply chain, there is not enough empirical data or extensive expertise to guide its implementation. Therefore, this paper addresses the ambiguity of assessing the performance of the IoT based supply chain by integrating plithogenic set with both Best-Worst (BWM) and Vlse Kriterijumska Optimizacija Kompromisno Resenje (VIKOR) methods in a decision-making framework tailored for this field. The framework is based on 23 criteria that measure different aspects of the performance. The performance of the framework is assessed according to the plithogenic set theory and to the neutrosophic set theory using a case study of comparing the performance of IoT implantation with the SC of five e-commerce companies using three experts. The case study shows that the proposed framework has more consideration of the contradiction degree of each criteria to improve the accuracy of the evaluation results.

Keywords: supply chain management (SCM), Internet of Things (IoT), Multi-criteria decision-making (MCDM), VIKOR method, BWM, Plithogenic set

1. Introduction

Intensive competition is generated as a result of the globalization of international trade market, which increases challenging marketplace requirements. In order to obtain the competition requirements, it is necessary to develop an efficient and coordinated supply chain.

The supply chain (SC) is an integration of business processes (i.e., supplying, producing, distributing, and storing), that is converting raw material to final product or service that is utilized by customers which satisfy their needs. The SC is usually depicted by the flow of information, finance, and material through its stages, while the SCM is the organizing, implementing and monitoring of the networks [1]. Many supply chains are suffering from supply-demand incompatibility, overstocking, delivery delays, and many other issues. That is why traditional supply chains seem to be more complex, uncertain, and susceptible [2]. Thus, it becomes significant to develop a smarter and coordinated supply chain that integrates data, information, physical entities, and business processes altogether.

The variety of organization's standards, purposes, interests, and market strategies leads to ambiguous definitions of the IoT. Kevin Ashton (1999) imagined an interconnected physical world through the internet that enables sensors and platforms which allow a real-time feedback, in order to consolidate the monitoring and to secure communication [3]. The IoT may be defined as: "an intelligent infrastructure linking objects, information, and people through the computer networks, and where the RFID technology found the basis for its realization [4]". The main steps toward IoT are data collection, the transmission of data across the network, and data processing [5]. Data collection is the first step that is responsible for gathering the data about the network objects through main technologies such as sensors, RFID technology, or Near Field Communication (NFC) technology [3]. The moment that sensing technologies collected the data, it must be transmitted across the network through wired (e.g., coaxial cables, and optical fibers) or wireless (e.g., Wi-Fi) technologies [6]. In the last phase, transmitted data must be processed and then forwarded to the application.

The SCM based on IoT refers to the connection of physical objects in order to monitor the interaction of a firm with its supply chain, by focusing on information sharing toward facilitating the control and the coordination of supply chain processes [2]. The IoT based supply chain would possess the ability to have great connection across all supply chain phases, and provide intelligent decision-making in order to meet the customer expectations. The IoT is applied in a variety of fields such as transportation, energy, healthcare, retail, manufacturing, agriculture, and others.

Understanding the performance of IoT based SC requires effectively measuring the performance of all alternatives according to several sets of criteria. The evaluation of IoT based supply chain requires considering several aspects such as security, technological infrastructure, the functionality of the supply chain, and others that distinguish it from the traditional supply chain. As in many evaluations and decision-making problems, there is a defect of uncertain, vague, and incomplete information that may lead to a non-optimal decision. Thus, integrating the plithogenic set with neutrosophic set's triple components (truth-membership, falsity-membership, and indeterminacy-membership) should provide more accurate assessment results. Plithogenic set increases the accuracy and efficiency of decision-making. Plithogeny, introduced by Florentin Smarandache in 2017, is a generalization of neutrosophy. The plithogenic set is a set of elements, such that each element x is characterized by attribute values v that have a corresponding contradiction degree c(v, D) between them and a dominant attribute value D, and by an appurtenance degree d(x, v) of element x to the plithogenic set [7, 22].

For measuring the performance of IoT based SC, this research proposed a framework that integrates the best-worst method (BWM) and Vlse Kriterijumska Optimizacija Kompromisno Resenje (VIKOR) method under plithogenic environment. We present the BWM and VIKOR in the plithogenic environment because most of the evaluations face a problem of uncertainty of expert's judgment, where contradiction degree provides more accurate aggregation results of their evaluations. Thus, the features of the plithogenic set should efficiently lessen the problem of ambiguity and take into consideration the different judgments of decision-makers, helping to choose the optimal decision and obtain the best assessment of the IoT based supply chains.

The present research is organized as follows: Section 2 reviews some literature regarding the internet of things and its effect on the supply chain. Section 3 presents the background of the methods. Section 4 presents the steps of the proposed integrated framework for measuring the IoT based supply chain. Section 5 presents a case study of the proposed framework to evaluate the Ecommerce supply chain based on the IoT. The conclusions and the future directions of the research are presented in Section 6.

2. Literature review

There are many studies that focus on IoT and supply chain. For instance, Musa et al. (2016) reviewed the importance of RFID technology in SCM [8]. Zhou et al. (2015) introduce a framework of traceability of the supply chain based on IoT [9]. Zhang et al. (2017) studied the importance of real-time data acquiring based on IoT in the field of perishable foods [10]. Papert et al. (2017) developed a hypothetical IoT ecosystem model in order to assess the firms to establish their own ecosystem [11]. Li et al. (2017) proposed an efficient management platform to track and trace the pre-packaged food SC based on IoT [12]. Chen (2019) evaluated the performance of IoT based supply chain finance risk management performance using the fuzzy QFD method [13].

Different MCDM techniques have been applied in IoT context. Mashal et al. (2019) applied the AHP method to evaluate smart objects, applications, and providers of IoT [14]. Uslu et al. (2019) applied AHP and ANP methods in order to evaluate the difficulties faced by enterprises when adopting the IoT [15]. In order to evaluate the internet of cloud sensors search and selection, Nunes et al. (2017) used SAW, TOPSIS, and VIKOR methods [16]. Mohammadzadeh et al. (2018) applied the ANP method under fuzzy environment to recognise the most significant IoT technology challenges in Iran [17]. Nabeeh et al. (2019) applied neutrosophic AHP in order to evaluate the influential factors of IoT in enterprises as shown in Figure 1 [18]. On the other side, Ly et al. (2018) evaluate the success factors of IoT systems using fuzzy AHP method [19].

One of the major issues is uncertainty in the evaluation problems that may confuse decision-makers. As a generalization of the fuzzy set and intuitionistic fuzzy set, Florentin Smarandache introduced the neutrosophic set (1998) [20]. Van et al. (2018) proposed the application of neutrosophic QFD in order to solve the problem of green supplier selection [21]. They also studied the influence of IoT on the SC using neutrosophic AHP and neutrosophic DEMATEL [2]. The characteristics of the neutrosophic set are clearly detailed as follows.

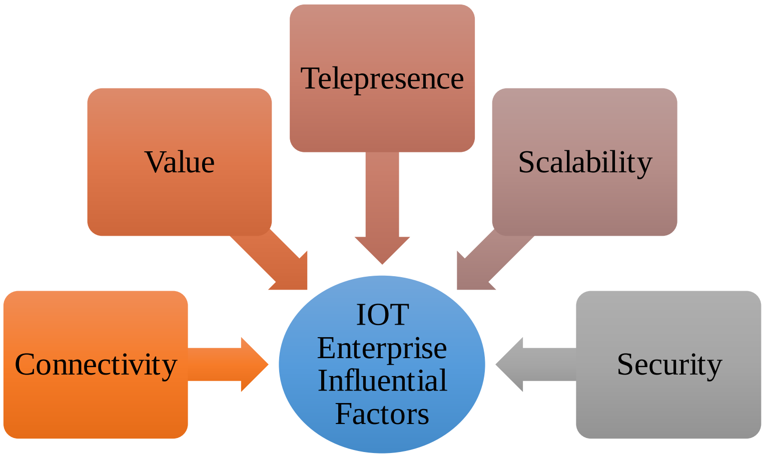

Figure 1: Effective Factors for IoT enterprise adoption [18]

3. Methods

In this study, two MCDM methods (BWM and VIKOR) are employed in order to measure IoT based supply chain performance. These methods are based on the plithogenic set in order to increase the precision of the evaluation procedure and solve the uncertainty problem in the assessment.

3.1 Basic concepts of the neutrosophic set

Definition 1. Let X be a universe of discourse. A single valued neutrosophic set (SVNS) N over X is an object with the form $N = \{\langle x, T_N(x),\ I_N(x),\ F_N(x)\rangle : x \in X\}$, where $T_N(x): X \to [0,1]$, $I_N(x): X \to [0,1]$ *and* $F_N(x): X \to [0,1]$ with $0 \le\ T_N(x) +\ I_N(x) +\ F_N(x) \le 3$ for all $x \in X$, where TN(x), IN(x) and FN(x) represent the truth-membership function, indeterminacy-membership function, and falsity-membership function, respectively. A Single Valued Neutrosophic (SVN) number is represented as $A = (a, b, c)\ where\ a, b, c\ \in [0,1]\ and\ a + b + c \le 3$.

Definition 2. Let $\tilde{a} = \langle (a1, a2, a3); \alpha, \theta, \beta\rangle$ be a SVNS, with truth membership Ta(x), indeterminate membership Ia(x), and falsity membership function Fa(x) as follows:

$$T_a(\mathrm{x}) = \begin{cases} \alpha_a\left(\frac{x-a_1}{a_2-a_1}\right) & if\ a_1 \le x \le a_2 \\ \alpha_a & if\ x = a_2 \\ \alpha_a\left(\frac{a_3-x}{a_3-a_2}\right) & if\ a_2 \le x \le a_3 \\ o & otherwise \end{cases} \tag{1}$$

$$I_a(\mathrm{x}) = \begin{cases} \frac{(a_2-x)}{(a_2-a_1)}\theta_a & if\ a_1 \le x \le a_2 \\ \theta_a & if\ x = a_2 \\ \frac{(x-a_3)}{(a_3-a_2)}\theta_a & if\ a_2 \le x \le a_3 \\ 1 & otherwise \end{cases} \tag{2}$$

$$F_a(\mathrm{x}) = \begin{cases} \frac{(a_2-x)}{(a_2-a_1)}\beta_a & if\ a_1 \le x \le a_2 \\ \beta_a & if\ x = a_2 \\ \frac{(x-a_3)}{(a_3-a_2)}\beta_a & if\ a_2 < x \le a_3 \\ 1 & otherwise \end{cases} \tag{3}$$

Definition 3. Let $\tilde{a} = \langle (a1, a2, a3); \alpha_a, \theta_a, \beta_a \rangle$ and $\tilde{b} = \langle (b1, b2, b3); \alpha_b, \theta_b, \beta_b \rangle$ be two triangular neutrosophic numbers (TNN). Then, we have:

- Addition of two TNN :

$$\tilde{a} + \tilde{b} = \langle (a1 + b1, a2 + b2, a3 + b3); \alpha_a \cap \alpha_b, , \theta_a \cup \theta_b, \beta_a \cup \beta_b \rangle \tag{4}$$

Subtraction of two TNN :

$$\tilde{a} - \tilde{b} = \langle (a1 - b3, a2 - b2, a3 - b1); \alpha_a \cap \alpha_b, , \theta_a \cup \theta_b, \beta_a \cup \beta_b \rangle \tag{5}$$

- Inverse of two TNN :

$$\tilde{a}^{-1} = \langle \left(\frac{1}{a3}, \frac{1}{a2}, \frac{1}{a1}\right); \alpha_a, \theta_a, \beta_a \rangle, Where\ (\tilde{a} \ne 0) \tag{6}$$

- Multiplication of two TNN:

$$\tilde{a}\tilde{b} = \begin{cases} \langle (a1b1, a2b2, a3b3); \alpha_a \cap \alpha_b, , \theta_a \cup \theta_b, \beta_a \cup \beta_b \rangle\ if\ (a3 > 0, b3 > 0) \\ \langle (a1b3, a2b2, a3b1); \alpha_a \cap \alpha_b, , \theta_a \cup \theta_b, \beta_a \cup \beta_b \rangle\ if\ (a3 < 0, b3 > 0) \\ \langle (a3b3, a2b2, a1b1); \alpha_a \cap \alpha_b, , \theta_a \cup \theta_b, \beta_a \cup \beta_b \rangle\ if\ (a3 < 0, b3 < 0) \end{cases} \tag{7}$$

- Division of two TNN:

$$\frac{\tilde{a}}{\tilde{b}} = \begin{cases} \langle \left(\frac{a1}{b3}, \frac{a2}{b2}, \frac{a3}{b1}\right); \alpha_a \cap \alpha_b, , \theta_a \cup \theta_b, \beta_a \cup \beta_b \rangle\ if\ (a3 > 0, b3 > 0) \\ \langle \left(\frac{a3}{b3}, \frac{a2}{b2}, \frac{a1}{b1}\right); \alpha_a \cap \alpha_b, , \theta_a \cup \theta_b, \beta_a \cup \beta_b \rangle\ if\ (a3 < 0, b3 > 0) \\ \langle \left(\frac{a3}{b1}, \frac{a2}{b2}, \frac{a1}{b3}\right); \alpha_a \cap \alpha_b, , \theta_a \cup \theta_b, \beta_a \cup \beta_b \rangle\ if\ (a3 < 0, b3 < 0) \end{cases} \tag{8}$$

3.2 Basic concepts of the plithogenic set

Smarandache (2017) introduced a generalization of neutrosophy that denotes to genesis, construction, improvement and advances of new objects from syntheses of conflicting or non-conflicting multiple old objects [22] which is known as plithogeny. The plithogenic set operations are plithogenic intersection $\wedge_P$, plithogenic union $\vee_P$, plithogenic complement $\neg_P$, plithogenic inclusion →, and plithogenic equality ↔.

In order to obtain more accurate results, the plithogenic set provides high consideration of uncertainty of information due to its two main features, the contradiction degree and the appurtenance degree. Contradiction (dissimilarity) degree function c(v,D) distinguishes between each attribute value and the dominant (greatest preferred) attribute value. The attribute value contradiction degree function c(v1, v2) is c: V×V → [0, 1], sustaining the next axioms:

- c(v1, v1) = 0, contradiction degree between the same the attribute values is zero;
- c(v1, v2) = c(v2, v1), symbolizing the distinction between two attribute values v1 and v2.

Abdel-Basset et al. (2019) proposed a model to be applied to measure the performance of hospitals in Zagazig city in Egypt using the VIKOR method according to 11 evaluation standards based on plithogenic set [23]. Another application of the plithogenic set was applied in SC sustainability evaluation based on QFD [24].

Definition 4. [25] Let $\tilde{a} = (a1, a2, a3)$ and $\tilde{b} = (b1, b2, b3)$ be two plithogenic sets; operations are:

- Plithogenic intersection:

$$\left((a_{i1}, a_{i2}, a_{i3}), 1 \le i \le n\right) \wedge_p \left((b_{i1}, b_{i2}, b_{i3}), 1 \le i \le n\right)$$
$$= \left(\left(a_{i1} \wedge_F b_{i1}, \frac{1}{2}(a_{i2} \wedge_F b_{i2}) + \frac{1}{2}(a_{i2} \vee_F b_{i2}), a_{i2} \vee_F b_{i3}\right)\right), 1 \le i \le n. \quad (9)$$

- Plithogenic union:

$$\left((a_{i1}, a_{i2}, a_{i3}), 1 \le i \le n\right) \vee_p \left((b_{i1}, b_{i2}, b_{i3}), 1 \le i \le n\right)$$
$$= \left(\left(a_{i1} \vee_F b_{i1}, \frac{1}{2}(a_{i2} \wedge_F b_{i2}) + \frac{1}{2}(a_{i2} \vee_F b_{i2}), a_{i2} \wedge_F b_{i3}\right)\right), 1 \le i \le n. \quad (10)$$

where

$$a_{i1} \wedge_p b_{i1} = [1 - c(v_D, v_1)].t_{norm}(v_D, v_1) + c(v_D, v_1).t_{conorm}(v_D, v_1) \quad (11)$$
$$a_{i1} \vee_p b_{i1} = [1 - c(v_D, v_1)].t_{conorm}(v_D, v_1) + c(v_D, v_1).t_{norm}(v_D, v_1) \quad (12)$$

where, tnorm= $a \wedge_F b = ab$, tconorm $a \vee_F b = a + b - ab$

- Plithogenic complement (negation):

$$\neg\left((a_{i1}, a_{i2}, a_{i3}), 1 \le i \le n\right) = \left((a_{i3}, a_{i2}, a_{i1}), 1 \le i \le n\right) \quad (13)$$

The appurtenance degree d(x,v) of attribute value v is: $\forall x \in$ P, d: P×V→ P ([0, 1]z), so d(x, v) is a subset of [0, 1]z, and P([0, 1] z) is the power set of [0, 1] z, where z = 1, 2, 3, for fuzzy, intuitionistic fuzzy, and neutrosophic degrees of appurtenance respectively.

3.3 The Best-Worst Method (BWM)

BWM is one of the most efficient and useful methods in multi-criteria decision-making. The model of this method is used to find the weight of each selection criteria. The BWM was applied in several fields of research such as engineering sustainability [26], financial performance evaluation [27], sustainable supplier selection and order allocation [28], evaluating the community sustainability of supply chains [29], and Location Selection for Wind Farms [30].

In addition, there are several researches that used the BWM under the neutrosophic environment and applied it in different topics. For instance, Yucesan et al. (2019) applied neutrosophic BWM in the evaluation of the implant manufacturing according to five groups of criteria [31], while Lou et al. (2019) proposed an integrated MCDM framework based on the BWM in order to solve the personnel selection problem [32].

The best-worst method is based on pairwise comparisons of the selection standards on the basis of the decision-maker's preference. Thus, the BWM value is requiring fewer comparisons than the analytic hierarchy process (AHP). In order to handle the drawback of discrepancy in AHP comparison, decision-makers should identify the most preferred criterion (best) and the least preferred criterion (worst) and then stratify the pairwise comparison between these two criteria and the other criteria [33]. Moreover, BWM consists of less complexity of comparisons as it exploits only whole numbers. Finally, BWM is notable because the redundant comparisons are eradicated. [34]. The phases of the BWM are as follows:

- Step 1. The first step decision-maker identifies the set of selection criteria based on the problem nature N = {c_1, c_2, …, c_n}
- Step 2. Determine the best and the worst criteria.
- Step 3. Obtain the best-to-other vector AB = (aB1, aB2, … , aBn), which is decision-maker's judgment of the best criterion in comparison with other criteria - using a (1-9) scale, where aBn designates the judgment of the best criterion over criterion n . It is obvious that aBB = 1.
- Step 4. Establish the others-to-worst vector Aw = (aw1, aw2, … , awn), which is decision-maker's judgment of all criteria in comparison with the worst one - using a (1-9) scale, where awn designates the preference of criterion n over the worst criterion. It is also obvious that aww = 1.
- Step 5. Use the nonlinear programming model to find the optimal criteria weights (W1* , W2*, … , Wn*).

  Min ε

s.t.

$$\left|\frac{w_B}{w_j} - a_{Bj}\right| \leq \varepsilon \text{ , for all j}$$
$$\left|\frac{w_j}{w_w} - a_{jW}\right| \leq \varepsilon \text{ , for all j}$$
$$\sum_j w_j = 1 \quad (14)$$
$$w_j \geq 0 \text{ , for all j}$$

3.4 *The Vlse Kriterijumska Optimizacija Kompromisno Resenje (VIKOR) method*

VIKOR, proposed by Opricovic (1998), is a useful method to solve complex MCDM problems with inconsistent criteria that can assist decision maker to find the optimal alternative. There are several studies that applied the VIKOR method in different topics under uncertain environment. Hussain et al. (2019) integrated the VIKOR method with interval neutrosophic numbers in situations that need consideration of indeterminacy along with the certainty and uncertainty [35]. Wang et al. (2019) proposed a framework according to the VIKOR method based on the linguistic neutrosophic set, and it was applied in selecting problems of fault handling point [36].

The ranking of the alternatives is based on their distance to the ideal alternative. The main steps of VIKOR method are described as follows and illustrated in Figure 2:

- Step 1: Decision-maker evaluates the alternatives based on the selection standards. Build the decision matrix based on the decision-maker's assessment according to the weight of each criterion in contrast to the alternatives to be assessed.
- Step 2: Normalize the decision matrix using Equation 15.

$$(f_{ij})_{m\times n} = x_{ij} \Big/ \left(\sqrt{\sum_{i=1}^{m} x_{ij}^2}\right) \quad (15)$$

where m is the number of alternatives and n is the number of criteria.

- Step 3: Distinguish the beneficial and non-beneficial criteria based on the problem nature and the decision-maker's preference. Determine the best values $f_j^*$and worst values f_j^- of criteria. If f_j is beneficial criteria, then $f_j^* = \max(f_{ij})$ and $f_j^- = \min(f_{ij})$. On the other hand, if f_j is non-beneficial criteria, then $f_j^* = \min(f_{ij})$ and $f_j^- = \max(f_{ij})$.
- Step 4: Calculate the values of S_i (maximum group utility) and R_i (minimum individual regret of the opponent) by Equation 16 and 17:

$$S_i = \sum_{j=1}^{n} w_j * \frac{f_j^* - f_{ij}}{f_j^* - f_j^-} \quad (16)$$
$$R_i = \max\left[w_j * \frac{f_j^* - f_{ij}}{f_j^* - f_j^-}\right] \quad (17)$$

where w_j id the weight of criteria expressing their importance.

- Step 5: Calculate the value of concordance index Q_i by Equation 18.

$$Q_i = v\left[\frac{S_i - S^*}{S^- - S^*}\right] + (1-v)\left[\frac{R_i - R^*}{R^- - R^*}\right] \quad (18)$$

where $S^- = max_i S_i$, $S^* = min_i S_i$, $R^- = max_i R_i$, $R^* = min_i R_i$, and v is the weight of strategy of maximum group utility, usually equal to 0.5.

- Step 6: The alternatives are ranked according to Q_i descending order, where the optimal alternative has the minimum Q value.
- Step 7: There are two conditions that should be satisfied in regard to this rank:

Condition 1 (acceptable advantage):

$$Q(A^2) - Q(A^1) \geq \frac{1}{m-1} \quad (19)$$

where A^1 is the first alternative in Q ranking and A^2 is the second, and m is the number of alternatives.

Condition 2 (acceptable stability): as the ranking of Q, A^1 must be the superior in the ranking of S and R. In case that one condition is not satisfied, a set of alternatives is proposed:

If condition 2 is not satisfied, then A^1 and A^2 are compromise solutions;

If condition 1 is not satisfied, then $A^1, A^2, \dots, A^m$ are compromise solutions, where A^m is determined by Equation 20.

$$Q(A^m) - Q(A^1) < \frac{1}{m-1} \quad (20)$$

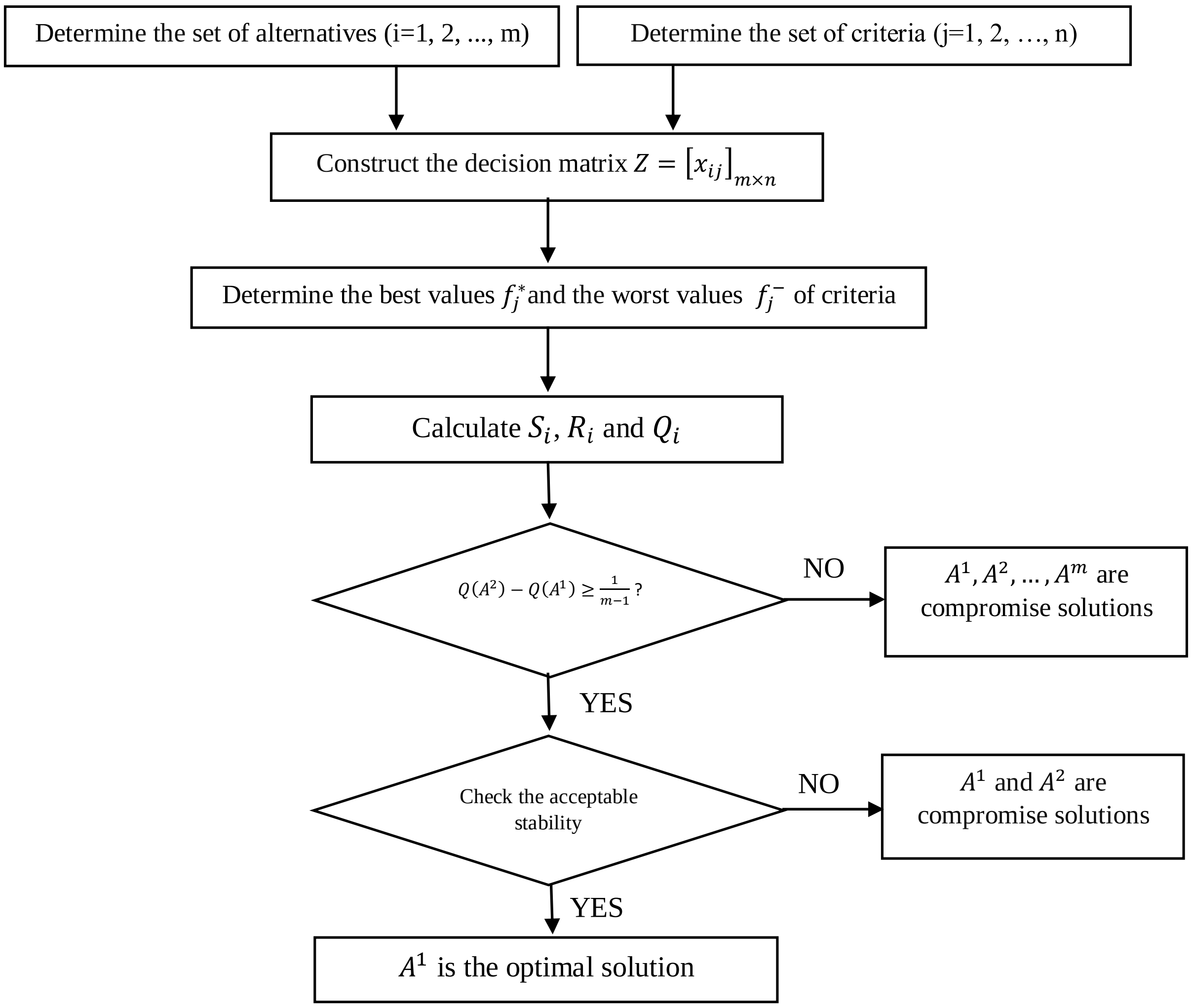

Figure 2: Flow Chart of VIKOR Method

4. Proposed framework

This research proposes an integrated framework to assess the performance of the supply chain based on the IoT under uncertainty environment. The BWM method identifies the weights of the performance criteria based on the pairwise comparison of the best and worst criteria among the rest of the criteria, while VIKOR method evaluates the performance of the IoT based supply chains according to the selection criteria. The importance of this approach lies in handling the high level of uncertainty resulted from the scarce of expertise in the field. Plithogenic set it powerful in handling uncertain judgments by considering the truth-membership function, falsity-membership function, and indeterminacy-membership function. In addition, the features of the plithogenic set operations provide more accurate results. This framework utilizes the advantages of plithogenic set operation, BWM, and VIKOR method to provide a more accurate evaluation. The steps of the proposed framework are as described below and illustrated in Figure 3:

- Phase 1: As in all evaluation problems, acquire the evaluation information by integrating a committee of decision-makers. $DM = \{ d_1, d_2, \dots, d_k\}$. Define a set of criteria that measures the performance of the IoT based SC. $C = \{c_1, c_2, \dots, c_n\}$, and the alternatives (IoT based supply chains) that need to be evaluated $A = \{a_1, a_2, \dots, a_m\}$.

In this research, the proposed framework examines the performance of the IoT based supply chain according to 23 criteria (Table 2) that measure the financial cost, service quality, resource consumption, degree of customer satisfaction, functionality, technological infrastructure, and security. For validating the proposed framework we rank five Ecommerce companies that are managed according to IoT based supply chain rendering to their performance.

Table 1: Evaluation Criteria of IoT based supply chain [37, 38]

Main aspects	**Criteria**
Financial cost A	Hardware costs A1
	Software costs A2
	Implementation costs A3
	Maintenance cost A4
Service quality B	Service level B1
	Service flexibility B2
	System reliability B3
	Distribution network quality B4
Resource consumption C	Total number of services C1
	Rate of actual work C2
	Request frequency /min C3
Degree of customer satisfaction D	Time delivery rate D1
	Order accuracy D2
	Complaint response time D3
	After-sales support D4
Functionality E	Technical compliance of the devices E1
	Operational feasibility of devices E2
Technological infrastructure F	Competence of the system F1
	the association abilities with other systems F2
	the transferability of the system F3
Security G	Level of access control G1
	the level of device verification G2
	the level of encryption G3

- Phase 2: Apply the BWM (as discussed in section 3.3) to compute the weights of the criteria that measure the performance of the IoT based supply chain.
  - Step 1: Regulate the most preferred and the least preferred criteria according to the decision-maker's preference.
  - Step 2: Construct the Best-to-Other vector and Others-to-Worst vector.
  - Step 3: Use the BWM model (14) to find the weight vector.
- Phase 3: Construct the evaluation matrix based on plithogenic aggregation operation.

Table 2: Triangular neutrosophic scale for decision matrix

Importance Linguistic variable	Triangular neutrosophic scale
Very Weakly important (VWI)	((0.10, 0.2,0.3), 0.1,0.2,0.15)
Weakly important (WI)	((0.15,0.3,0.50), 0.6,0.2,0.3)
Partially important (PI)	((0.40,0.35,0.50), 0.6,0.1,0.2)
Equal important (EI)	(0.5,0.6,0.70),0.8,0.1,0.1)
Strong important (SI)	((0.65,0.7,0.80),0.9,0.2,0.1)
Very strongly important (VSI)	((0.8,0.75,0.95),0.7,0.2,0.2)
Absolutely important (AI)	((0.95,0.90,0.95),0.9,0.10,0.10)

- Step 1: Construct the evaluation matrices in order to evaluate alternatives according to the corresponding criteria by decision-makers based on triangular neutrosophic scale as shown in Table 1.
- Step 2: In this step, aggregate the evaluation matrices using plithogenic operator as shown in Equations 10, 11, and 12. In this step, the contradiction degree of each criterion should be considered in order to provide more accurate aggregation results.
- Step 3: To make the computations easier, apply the de-neutrosophication of the aggregated evaluation matrix using Equation 21

$$S(a) = \frac{1}{8}(a_1 + b_1 + c_1) \times (2 + \alpha - \theta - \beta) \quad (21)$$

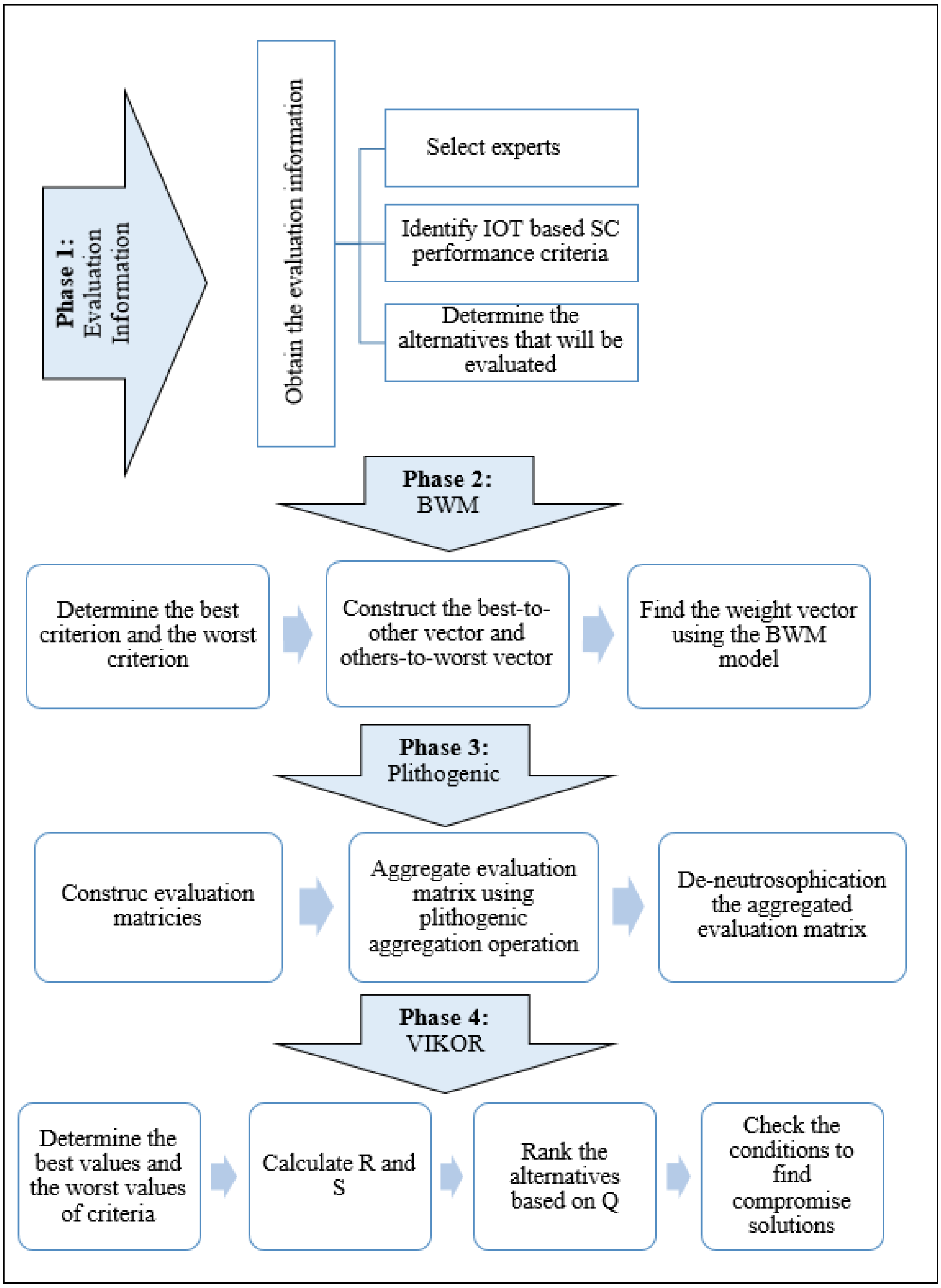

Figure 3: Phases of the Proposed Framework

➢ Phase 4: Using VIKOR method, rank the IoT based SCs based on their performance evaluation.

- Step 1: Define the best values and the worst values of criteria.
- Step 2: Calculate S_i and R_i.
- Step 3: Rank the alternatives based on the concordance index Q_i
- Step 4: Check the conditions to find compromise solutions.

5. Case study: Evaluation of IoT based Ecommerce supply chains

The proposed framework based on the plithogenic set is used to measure the IoT based Ecommerce supply chains performance. The evaluation is obtained by a group of three experts (e): Ecommerce management expert (e_1), IT expert (e_2), and supply chain expert (e_3). After the response to questions are collected, the assessment of Ecommerce companies managed according to IoT based supply chain is conducted as follows:

- Phase 1: The performance evaluation of the IoT based Ecommerce supply chain is based on 23 criteria. Evaluate the five companies according to their performance. The judgment of the performance is based on three experts.
- Phase 2: In order to evaluate the weights of the 23 criteria, BWM is applied. Experts define the competence of the system as the most sufficient criterion, and the level of device verification as the least important criterion. According to the importance rating scale, best-to-other and others-to-worst vectors where determined as in Table 3 and 4. After applying BWM model, the weight vector resulted is presented in Table 5 and Figure 4. As results show, the competence of the system (F1) has the highest weight (0.10961), while the level of device verification (G1) has the lowest weight (0.00645).

Table 3: Best-to-Others Vector

Best-to-Others	A1	A2	A3	A4	B1	B2	B3	B4	C1	C2	C3	
	0.1	0.5	0.2	0.5	0.6	0.2	0.3	0.6	0.4	0.6	0.8	
F1	D1	D2	D3	D4	E1	E2	F1	F2	F3	G1	G2	G3
	0.8	0.7	0.4	0.4	0.5	0.4	0.1	0.5	0.3	0.3	0.9	0.9

Table 4: Others-to-Worst Vector

Others-to-Worst		**G2**	
A1	0.9	D1	0.2
A2	0.4	D2	0.2
A3	0.9	D3	0.6
A4	0.4	D4	0.5
B1	0.3	E1	0.5
B2	0.8	E2	0.6
B3	0.8	F1	0.9
B4	0.3	F2	0.4
C1	0.6	F3	0.7
C2	0.3	G1	0.7
C3	0.2	G2	0.1
		G3	0.2

Table 5: Evaluation Criteria Weights

Criteria	**weight**	**Criteria**	**Weight**
A1	0.10861	D1	0.02015
A2	0.03224	D2	0.02303
A3	0.08059	D3	0.04030

A4	0.03224	D4	0.04030
B1	0.02686	E1	0.03224
B2	0.08059	E2	0.04030
B3	0.05373	F1	0.10961
B4	0.02686	F2	0.03224
C1	0.04030	F3	0.05373
C2	0.02686	G1	0.05373
C3	0.02015	G2	0.00645
		G3	0.01791

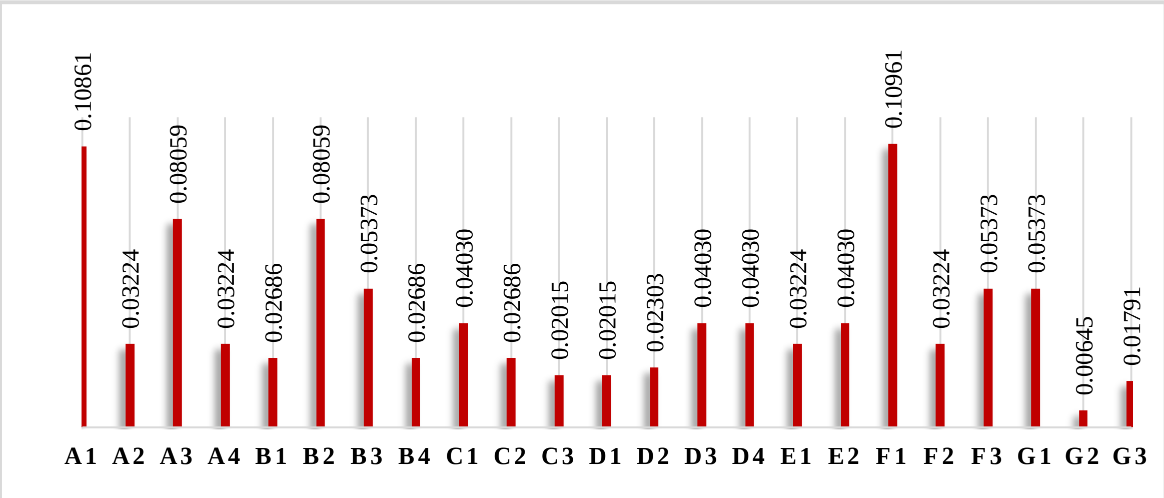

Figure 4: Weights of the Criteria

- Phase 3: Construct the evaluation matrix according to the three expert's judgments based on the triangular neutrosophic linguistic scale in Table 1, as shown in Table 6. Then, the plithogenic aggregation operator is used in combining the evaluations of the three experts. The equidistant contradiction degree (the dominant attribute value is 0) of the criteria was defined to ensure more accurate aggregation, as shown in Table 7. Using Equation 21, calculate the crisp evaluation matrix as shown in Table 8.
- Phase 4: In this phase, the target is to rank the five Ecommerce companies by VIKOR. Table 9 shows the normalized evaluation matrix. The values of S_i, R_i and Q_i were calculated as shown in Table 10 using Equations 16, 17, and 18 respectively. The w_j values, found by BWM in phase 2, was determined from Table 5. As the results show, company 5 in the top of the ranking, while company 3 at the end. According to VIKOR conditions, company 5 has the best rank, and it satisfies condition 1 ($0.27649 - 0 > 1/4$), and also satisfies condition 2 (company 1 is superior in ranking of S and R as well as Q), so company 1 is the optimal solution.

5.1 Results Discussion and Sensitivity Analysis

- As the results of BWM show, the competence of the system and the hardware costs are the most important metric considered to evaluate the IoT based Ecommerce supply chains. The second level of IoT based Ecommerce supply chains performance measure is implementation costs and service flexibility. The last level of criteria consist of the level of device verification and level of encryption, with weights 0.00645 and 0.01791, respectively.
- According to VIKOR method results, the ranking of companies varies based on parameter v. The ranking of Ecommerce companies based on their performance as follows (v=0.5): company 5> company 1 > company 4 > company 2 > company 3, as Figure 5 shows.

- It is important to mention the impact of chaining the weight of the strategy v within interval [0, 1]. The sensitivity analysis on v is shown in Table 11. As Figure 6 shows, usually company 5 is in the top of ranking while company 2 is at the end.
- One of the main contributions of this framework is using the plithogenic aggregation operation based on the contradiction degree between the criteria. In order to show the importance of the proposed framework, a comparison with neutrosophic set is constructed on the same steps of the framework (Figure 7). The results of the proposed framework under neutrosophic set show that the ranking of Ecommerce companies based on their performance are as follows (v=0.5) company 2> company 3 > company 1 > company 4 > company 5 (Table 12).

Table 6: Three Expert's Evaluation Matrix

		A1	A2	A3	A4	B1	B2	B3	B4	C1	C2	C3	D1	D2	D3	D4	E1	E2	F1	F2	F3	G1	G2	G3
Company 1	DM1	AI	EI	VSI	AI	EI	PI	SI	VWI	EI	SI	SI	VSI	VSI	SI	AI	VSI	VSI	SI	PI	WI	AI	VS	SI
	DM2	PI	PI	WI	EI	SI	VSI	VSI	AI	SI	SI	SI	VS	AI	AI	VSI	VSI	VSI	AI	EI	VSI	AI	AI	AI
	DM3	VSI	EI	WI	EI	VWI	VWI	EI	VSI	VSI	SI	SI	SI	AI	AI	AI	VWI	VWI	EI	VWI	VWI	EI	EI	VWI
Company 2	DM1	SI	PI	EI	AI	PI	EI	EI	WI	PI	PI	EI	SI	AI	EI	VSI	SI	EI	VSI	WI	WI	VSI	EI	PI
	DM2	WI	WI	WI	EI	SI	VSI	VSI	AI	VSI	VSI	VSI	VSI	AI	AI	VSI	VSI	VSI	AI	EI	VSI	AI	AI	AI
	DM3	VSI	EI	AI	AI	VWI	VSI	EI	VSI	VSI	SI	EI	SI	VSI	AI	AI	VWI	VWI	EI	VWI	VWI	EI	EI	VWI
Company 3	DM1	VSI	AI	SI	VSI	SI	SI	SI	AI	EI	SI	VSI	VSI	AI	PI	AI	EI	EI	SI	EI	EI	PI	WI	VWI
	DM2	SI	SI	SI	SI	EI	SI	SI	VSI	EI	SI	VSI	VSI	VSI	AI	AI	VSI	VSI	AI	EI	VSI	AI	VSI	AI
	DM3	VSI	EI	VSI	VSI	VWI	VWI	EI	VSI	VSI	SI	AI	SI	EI	WI	WI	VWI	VWI	EI	VWI	VWI	EI	EI	VWI
Company 4	DM1	AI	VSI	VSI	AI	EI	EI	VSI	VSI	PI	EI	EI	AI	AI	VSI	AI	SI	VSI	EI	PI	PI	WI	WI	VWI
	DM2	SI	VSI	VSI	SI	EI	SI	SI	VSI	EI	SI	VSI	VSI	VSI	AI	AI	VSI	VSI	AI	EI	VSI	AI	VSI	AI
	DM3	VSI	VWI	VSI	VI	VWI	VWI	EI	VSI	VSI	WI	VSI	AI	AI	SI	AI	VWI	VWI	EI	EI	AI	EI	EI	EI
Company 5	DM1	VSI	WI	SI	VSI	WI	PI	PI	VWI	WI	WI	WI	EI	SI	SI	EI	EI	EI	EI	PI	PI	VSI	EI	EI
	DM2	WI	WI	WI	PI	SI	VSI	VSI	AI	SI	SI	SI	VSI	AI	AI	VSI	VSI	VSI	AI	EI	VSI	AI	AI	AI
	DM3	VSI	EI	AI	AI	VWI	VWI	EI	VSI	VSI	SI	SI	SI	AI	WI	WI	AI	VSI	EI	VWI	VWI	EI	EI	AI

Table 7: Aggregated Evaluation Matrix

Contradiction degree	**0**	**0.043**		**0.957**
	A1	A2	…	G3
Company 1	⟨(0.304,0.688,0.99); 0.75,0.15, 0.175⟩	⟨(0.132,0.54,0.93); 0.75,0.1, 0.125⟩	…	⟨(0.944,0.513,0.3); 0.45,0.175, 0.15⟩
Company 2	⟨(0.078,0.625,995); 0.73,0.2, 0.200⟩	⟨(0.06,0.463,0.9); 0.7,0.125, 0.175⟩	…	⟨(0.913,0.413,0.17); 0.425,0.15, 0.15⟩
Company 3	⟨(0.416,0.74,1); 0.75,0.2, 0.175⟩	⟨(0.338,0.7,0.981); 0.9,0.125, 0.1⟩	…	⟨(0.89,0.375,0.113); 0.3,0.175, 0.138⟩
Company 4	⟨(0.494,0.775,1); 0.8,0.175, 0.15⟩	⟨(0.092,0.475,0.965); 0.4,0.2, 0.175⟩	…	⟨(0.938,0.575,0.245); 0.65,0.125, 0.113⟩
Company 5	⟨(0.096,0.638,0.99); 0.675,0.2, 0.23⟩	⟨(0.038,0.45,0.901); 0.7,0.15, 0.2⟩	…	⟨(0.994,0.825,0.659); 0.875,0.1, 0.1⟩

Table 8: Crisp Evaluation Matrix

	A1	A2	A3	A4	B1	B2	…	F1	F2	F3	G1	G2	G3
Company 1	0.59708	0.50577	0.37252	0.64020	0.36431	0.32495	…	0.71670	0.28558	0.33604	0.78219	0.73973	0.46672
Company 2	0.49348	0.42727	0.57815	0.79660	0.32154	0.65168	…	0.72738	0.25231	0.33604	0.73672	0.69531	0.39744
Company 3	0.63917	0.67507	0.69131	0.66567	0.43550	0.45347	…	0.71670	0.40111	0.52102	0.58052	0.48615	0.34233
Company 4	0.70182	0.38793	0.66507	0.72577	0.34632	0.36052	…	0.68751	0.52324	0.71330	0.59427	0.54268	0.52990
Company 5	0.48720	0.40808	0.59677	0.67318	0.30154	0.32495	…	0.68751	0.28558	0.40886	0.73672	0.69531	0.82862

Table 9: Normalized Evaluation Matrix

	A1	A2	A3	…	G1	G2	G3
Company 1	0.0405045	0.029064	0.015767	…	0.069514	0.062172	0.024749
Company 2	0.0283441	0.021248	0.038905	…	0.063173	0.056269	0.018385
Company 3	0.0487870	0.05442	0.05707	…	0.040245	0.028223	0.013994
Company 4	0.0533448	0.016299	0.047904	…	0.038248	0.031895	0.030411
Company 5	0.0288259	0.020224	0.043251	…	0.065915	0.058712	0.083386
Best (f^+)	0.0283441	0.016299	0.015767	…	0.038248	0.028223	0.013994
Worst (f^-)	0.0533448	0.05442	0.05707	…	0.069514	0.062172	0.083386

Table 10: VIKOR Method Results

Alternatives	S_i	Rank (S)	R_i	Rank (R)	Q_i (v=0.5)	Rank (Q)
Company 1	0.428163	2	0.0756318	2	0.27649	2
Company 2	0.482287	4	0.10960727	5	0.76355	4
Company 3	0.608172	5	0.10706501	3	0.97116	5
Company 4	0.438928	3	0.10860727	4	0.67077	3
Company 5	0.341968	1	0.06552981	1	0.00000	1

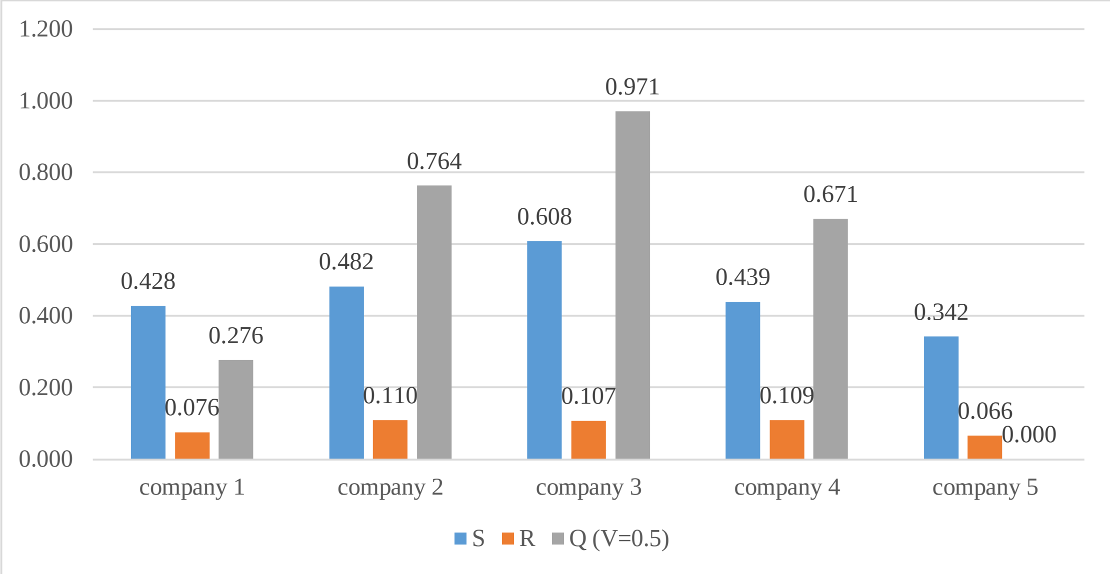

Figure 5: Ranking of 5 Companies

Table 11: The Ranking of Companies using different v values

	v=0		**v=0.25**		**v=0.5**		**v=0.75**		**v=1**	
Alternatives	Q_i	Rank	Q_i	Rank	Q_i	Rank	Q_i	Rank	Q_i	Rank
Company 1	0.22919	2	0.25284	2	0.27649	2	0.30014	2	0.32379	2
Company 2	1.00000	5	0.88178	4	0.76355	4	0.64533	4	0.52711	4
Company 3	0.94232	3	0.95674	5	0.97116	5	0.98558	5	1.00000	5
Company 4	0.97731	4	0.82404	3	0.67077	3	0.51750	3	0.36423	3
Company 5	0.00000	1	0.00000	1	0.00000	1	0.00000	1	0.00000	1

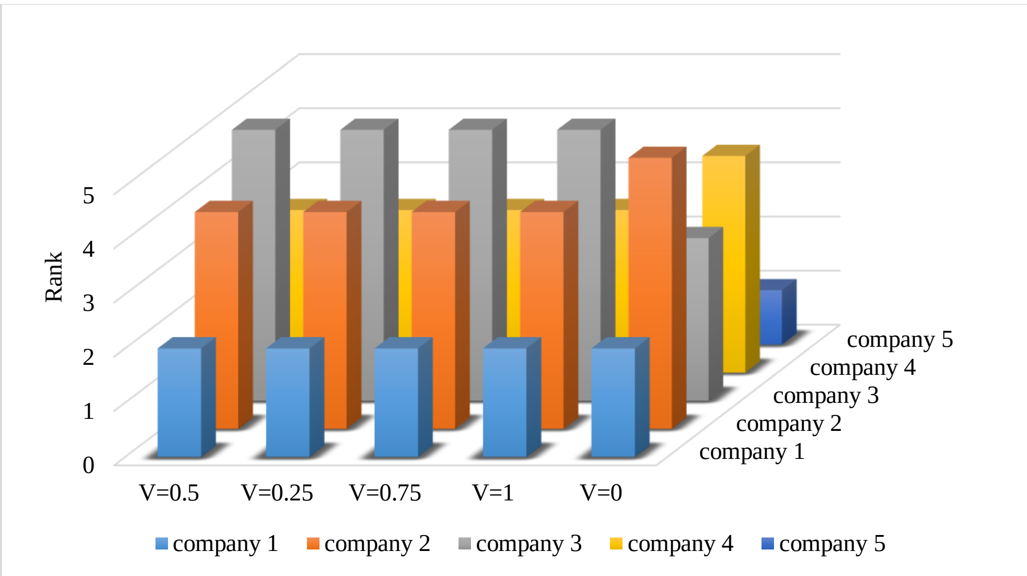

Figure 6: The Ranking of Companies using different v values

Table 12: The Ranking of Companies using different v values according to neutrosophic set theory

	v=0		v=0.25		v=0.5		v=0.75		v=1	
Alternatives	Q_i	Rank	Q_i	Rank	Q_i	Rank	Q_i	Rank	Q_i	Rank
Company 1	0.61344	3	0.58151	3	0.54959	3	0.51766	4	0.48574	4
Company 2	0.00000	1	0.00000	1	0.00000	1	0.00000	1	0.00000	1
Company 3	0.32677	2	0.28984	2	0.25291	2	0.21597	2	0.17904	2
Company 4	0.98666	4	0.79200	4	0.59735	4	0.40269	3	0.20803	3
Company 5	1.00000	5	1.00000	5	1.00000	5	1.00000	5	1.00000	5

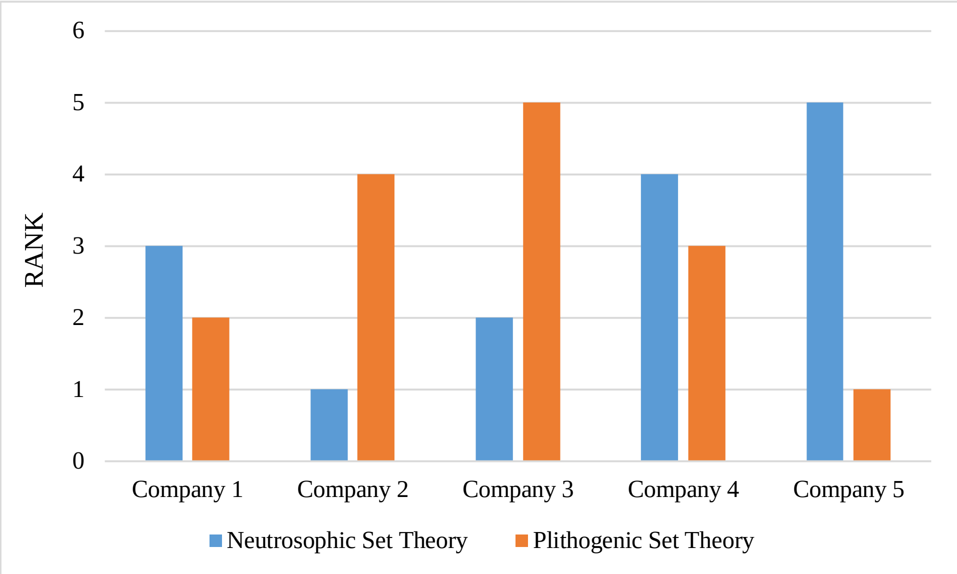

Figure 7: Comparison of Companies ranking using plithogenic set theory vs. neutrosophic set theory

6. Conclusion

This study formulates the problem of performance evaluation of IoT based supply chains as an MCDM by using a hybrid BWM and VIKOR methods. Most evaluation problems present insufficiencies from the existence of different decision-makers, alternatives, and criteria. That is why the proposed framework is based on the plithogenic set. The neutrosophic theory provides highly accurate results in vague, uncertain, inconsistent and incomplete information which exists in real life judgments. Meanwhile, it takes into account the truth, indeterminacy and falsity degrees for each evaluation.

VIKOR method helps evaluating the alternatives weights compared to the evaluation criteria. The weights of the criteria were calculated using the BWM. The proposed framework presents an accurate result which is useful in large scale problems with large criteria and alternatives. The first phase of this framework defines the evaluation information, such as a group of experts, criteria, and alternatives. The second phase comprises the calculation of weights by using BWM method based on the plithogenic set. The final phase, based also on the plithogenic set, ranks the alternatives according to their performance.

A case study of IoT based Ecommerce supply chain assessment validates the accuracy and reliability of the suggested framework. Based on the literature, there are 23 criteria that measure the performance of the five Ecommerce companies. According to three experts' judgments and using a proposed framework based on the BWM, the results show that the top three evaluation criteria are: competence of the system F1, hardware costs A1, implementation costs A3. These criteria have a higher priority to be considered in the evaluation of IoT based supply chains.

In this proposed framework, the weight of the decision-makers is not considered. So, decision-makers' weights should be considered to have a more accurate judgment in such evaluation processes. In addition, to prove the validity and to improve the accuracy of the proposed framework, it can be applied to other fields.

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