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Neutrosophic Multi-Criteria Decision Making Approach for IoT-Based Enterprises

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ABSTRACT The Internet of Things (IoT) connects billions of devices to afford inventive opportunities between things and people. The rapid development of products related to the IoT is a new challenge to keep security issues, lack of confidence, and understanding of the IoT. Analytical hierarchy process (AHP) is a classic multi-criteria decision making (MCDM) method used to analyze and scale complex problems and to obtain weights for the selected criteria. The vague and inconsistent information in real situations can lead to the decision maker's confusion. The decision makers cannot determine accurate judgments for all situations due to the conditions of uncertainty factors in real life; in addition to the limited knowledge and experience of decision makers. In this research, we present a neutrosophic AHP of the IoT in enterprises to help decision makers to estimate the influential factors. The estimation of influential factors can affect the success of the IoT-related enterprise. This study combines AHP methods with neutrosophic techniques to effectively present the criteria related to influential factors. The recommended alternatives are presented based on neutrosophic techniques satisfying the estimated influential factors for a successful enterprise. A case study is applied in Smart Village, Cairo, Egypt, to show the applicability of the proposed model. The smart village' consistency rate is measured after applying neutrosophic methodologies to reach to nearest optimum results. Additional case studies on the smart city in the U.K. and China have been presented to justify that our proposal can be used and replicated in different environments.

INDEX TERMS Multi-criteria decision making (MCDM), analytical hierarchal Process (AHP), neutrosophic sets, Internet of Things (IoT).

I. INTRODUCTION

IoT, widely regarded as a novel engine for information and communications technology industry, was estimated to lead market within next ten years [1]. The ramification of IoT on consumer and technical sectors make the extraordinary to reform industry revolution. IoT merges the power of internet with the competence of industries to conduct real world of factories, machine, goods, and infrastructure [2]. IoT empowers the control of things (networks, desktop, laptops, etc.) to ensure the delivery of perfect and smart enterprise, and to develop IoT products or services all over the world [3]. Mainly the current challenges face enterprises are security issues such as lack of confidence and understanding of IoT. Although IoT has positive effects on enterprises, it also has many negative impacts to be reduced or removed to guarantee the successful deliveries of IoT enterprise. The research estimates an IoT framework for small and medium enterprise. Based on literature review and expert interviews, five major influential factors have been detected. The five major influential factors are security, value, connectivity, intelligent, and telepresence as follows [4]:

1) **Security:** The right information can be integrated with specific legislation to restrict handling of IoT mechanisms and rules.
2) **Value:** The benefits that can impact on the attitude and the manner of behavior according to enterprises.
3) **Connectivity:** Backend systems behind IoT objects are vital to maintain keep smooth communications and successful deliveries offered by applications. The mean of connectivity in the proposed study is to keep all objects and people connected with the capabilities and technologies of IoT.

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4) **Intelligent:** IoT devices have a feature of intelligence to differentiate the usual Internet from IoT devices. Also IoT machines can intelligently receive input information and produce instructions in order to complete task.
5) **Telepresence:** The connections between different objects on internet via wireless technology can allow meetings without physical attendance. The reliable IoT products give consumer positive impression for the service.

MCDM can be referred as a formal and structured decision making methodology for dealing with complex problems and conflicting criteria [5]. Nowadays AHP is the most widespread method deals with MCDM problems [6]. AHP allows the use of both quantitative and qualitative criteria in evaluation. AHP basic steps are concluded in three consecutive steps which are decomposition, calculation of decision criteria weights, and calculate priorities of the candidate's alternatives [7]. Business environments can be threatened by uncertainties. The uncertain circumstances would force researchers to monitor and to manage the estimated misjudgment induced from uncertainty [8]. IoT applications, such as enterprise, marketing, healthcare, decision theory, and finance can be accelerated by the surrounding of influential factors [9]. Classical AHP can detect priorities for candidate's criteria in addition can compare, and rank alternatives. The classical AHP cannot deal with impression and vague information. In addition, the saaty comparison matrix has no systematic methodology to detect whether the matrix is inconsistent state or not. The AHP using Fuzzy approach has the same advantages of classical AHP in addition to dealing with vague or imprecise through one grade. Fuzzy AHP deals with membership function to detect preference relations [7]. Due to environment constraints, decision makers cannot consistently detect the membership function.

To overcome current challenges of MCDM methods, the MCDM is combined with fuzzy approaches to estimate possible solutions to grant enterprise successful as mentioned [10], [11]:

1) The existence of various and conflicting criteria, and alternatives.
2) Decision maker's different perspectives and interests.
3) Process of estimation to best criteria usually has vague and impression information.
4) Decision makers must have a great magnitude of cognitive in order to achieve optimal estimation under difficult circumstances [12]–[14].

The Neutrosophic sets model real world problems with respect to the conditions of all decision making situations [15]. This research illustrates AHP methods combined with neutrosophic techniques to be effectively present the criteria related to influential factors. Our proposed model helps decision makers to professionally estimate the influential factors to ensure success of related IoT services. The proposed model can efficiently deal with uncertain and inconsistent information by the use neutrosophic set. In addition, we can combine various decision makers' perspectives to achieve the ideal perspectives by handling the confliction and biasness between decision makers. To ensure the effectiveness of the model proposed, an efficient case study is applied to smart city Cairo, Egypt. In addition, a validation of case studies in UK and China is presented to ensure the replication of the proposed model.

Section 2 mentions literature review of the current knowledge include methodological contributions have been presented from other researchers. Section 3 presents some basics definition for neutrosophic environment. Section 4 illustrates methodology of the proposed model and the way to help decision makers in the estimation of the influential factors affecting the success of enterprise. Section 5 confirms the validity of proposed model by presenting a case study. Section 6 applies validation for the proposed model in UK and China. Section 7 concludes the research and points to the future of the work of research.

II. LITERATURE REVIEW

The method of MCDM, become a strategic issue for multiple decision makers in organizations, is developed for the selection process with ordinal preferences of criteria and alternatives. In [16], a case study is developed to MCDM considering the weights of criteria and decision makers. The globalization becomes an essential strategic decision power in the selection problems, the use of AHP perceived as an effective tool to be tackled. In [17], a case study developed a model to solve the selection problems using AHP methods. In [17], uses the techniques of AHP to assist the MCDM problems by comparing the weights of the summation of number of rank vote. The research of [18] uses AHP to solve MCDM problems in order to achieve to the best solution of candidates cloud services based on quality of service attributes. The researchers propose to use AHP methods in order to generate weights of the problem [19]. Researchers propose an AHP method to rate and select the appropriate suppliers with respect to evaluating criteria [17], [20]–[27]. The use of AHP in MCDM problems can be used to solve quantitative and qualitative problems, for obtaining the related alternatives, criteria, and sub criteria [28].

To overcome the classical challenges of AHP methods of relying on impression and vague information, the challenge of the existence of multiple decision makers, alternatives, and criteria, a fuzzy multi-criteria analysis framework is proposed to evaluate the performance of IoT in specific field of enterprises. The intuitionistic fuzzy is used to handle the vague and impression of the evaluation process [29]. The evolution of fuzzy multi-criteria group decision making model affords enterprises capabilities to appraise the performance of the IoT supply chain. Fuzzy and AHP methods are applied on a rule based decision support mechanism for evaluating the IoT influential factors [4] The expansion of classical AHP with fuzzy methods is convenient with MCDM environment. The fuzzy preference programming (FPP) reveals that the used weights cannot present the actual relations between alternatives and criteria, and the existence of confliction between criteria, which leads to a logarithmic fuzzy preference programming (LFPP) using the priority of the deviation of Fuzzy AHP [30]. Authors in [31]–[33] mentioned a hierarchy model combined with fuzzy sets to solve the problems of selection. The linguistics terms are used to assess the weights and to rate the evaluating factors. In [32] numerous researchers mention a systematic review of literature of the MCDM approaches for selection. In [33], [34] MCDM techniques illustrate how to overcome multiple, and conflicting objectives using fuzzy principles. In [35], illustrates fuzzy techniques for decision making to ensure achieving ideal decision with respect to different criteria and condition of market. The growth of shopping centers and business centers makes researchers find a way to view recommendation factors, which appear to be easier and more accessible than those by traditional ways. Intelligent interactive marketing IoT systems could perform effective ways between service providers and consumers [36]. In [37], a self-organized IoT aware system illustrated for online shopping by aggregating all possible preferences. In [4], illustrates a rule-based decision support system for IoT enterprise using fuzzy to detect the influential factor affected the success of IoT-enterprise

The AHP methods combined with fuzzy techniques can work with vague information but it is not the best way forward [40]. In [41], MCDM procedures are proposed via neutrosophic sets to deal with inconsistent and uncertain cases. An approach in [42] is used to predict cloud services qualification. The use of triangular neutrosophic numbers aid to work on inconsistent and ambiguous information. An efficient model is used to estimate solutions for estimation obstacles. The indeterminate and inconsistent data is powerfully handled using the neutrosophic sets by considering the level of truth, indeterminate, and false degrees. In [43] a general framework uses a single valued neutrosophic and rough set theories to handle the uncertainty and inconsistency. The proposed method improves the decisions and service in the use of IoT in smart city. The neutrosophic theory is an effective method for dealing with inconsistent data, the three ways decision according to neutrosophic set is proposed to achieve a reasonable effective decisions [44]. A neutrosophic three membership functions proposed to support the calculation of weights corresponding to alternatives and criterions for choosing the most appropriate alternative. The effective alternative resulted will improve quality of service, in addition will make a well-defined reduction in cost, and time.

III. BASIC DEFINITIONS OF NEUTRSOPHIC SETS

In this section, important definitions of neutrosophic set are clearly [42], [44]:

Definition 1: The neutrosophic set N characterized by three membership functions which are truth-membership function $T_{Ne}(x)$, indeterminacy-membership function $I_{Ne}(x)$ and falsity-membership function $F_{Ne}(x)$, where $x \in X$ and X be a space of points. Also $T_{Ne}(x) : X \to]^-0, 1^+[$, $I_{Ne}(x) : X \to]^-0, 1^+[$ and $F_{Ne}(x) : X \to]^-0, 1^+[$. There is no restriction on the sum of $T_{Ne}(x)$ $I_{Ne}(x)$, and $F_{Ne}(x)$, so $0^- \leq \sup T_{Ne}(x) + \sup I_{Ne}(x) + \sup F_{Ne}(x) \leq 3^+$.

Definition 2: A single valued neutrosophic set Ne over X taking the following form $X = \{\langle X, T_{Ne}(x), I_{Ne}(x), F_{Ne}(x)\rangle : X \in X\}$, where $T_{Ne}(x) : X \to [0,1]$, $I_{Ne}(x) : X \to [0,1]$ and $F_{Ne}(x) : X \to [0,1]$ with $0 \leq T_{Ne}(x) + I_{Ne}(x) + F_{Ne}(x) \leq 3$ for all $X \in X$. The single valued neutrosophic (SVN) number is symbolized by $Ne = (d, e, f)$, where $d, e, f \in [0, 1]$ and $d + e + f \leq 3$.

Definition 3: The single valued triangular neutrosophic number, $a = ((a_1, a_2, a_3) : \alpha_a, \theta_a, \beta_a)$ is a neutrosophic set on the real line set $\boldsymbol{R}$, whose truth, indeterminacy and falsity membership are as follows:

$$T_a(x) = \begin{cases} \alpha_a\left(\dfrac{x - a_1}{a_2 - a_1}\right) & (a_1 \leq x \leq a_2) \\ \alpha_a & (x = a_2) \\ 0 & otherwise, \end{cases} \tag{1}$$

$$I_a(x) = \begin{cases} \dfrac{(a_2 - x + \theta_a(x - a_1)}{(a_2 - a_1)} & (a_1 \leq x \leq a_2) \\ \theta_a & (x = a_2) \\ 1 & otherwise, \end{cases} \tag{2}$$

$$F_a(x) = \begin{cases} \dfrac{(a_2 - x + \beta_a(x - a_1)}{(a_2 - a_1)} & (a_1 \leq x \leq a_2) \\ \beta_a & (x = a_2) \\ \dfrac{(x - a_2) + \beta_a(a_3 - x))}{(a_3 - a_2)} & (a_2 \leq x \leq a_3) \end{cases} \tag{3}$$

where, $\alpha_a, \theta_a, \beta_a \in [0, 1]$ and $a_1, a_2, a_3 \in R, a_1 \leq a_2 \leq a_3$.

Definition 4: Let $a = \langle(a_1, a_2, a_3) ; \alpha_a, \theta_a, \beta_a\rangle$ and $b = \langle(b_1, b_2, b_3) ; \alpha_b, \theta_b, \beta_b\rangle$ be two single valued triangular neutrosophic numbers and $\gamma \neq 0$ be any real number. Then,

1. *Addition of two triangular neutrosophic numbers*

$$a + b = \langle(a_1 + b_1, a_2 + b_2, a_3 + b_3) ; \alpha_a \wedge \alpha_b, \theta_a \vee \theta_b, \beta_a \vee \beta_b\rangle$$

2. *Subtraction of two triangular neutrosophic numbers*

$$a - b = \langle(a_1 - b_3, a_2 - b_2, a_3 - b_1) ; \alpha_a \wedge \alpha_b, \theta_a \vee \theta_b, \beta_a \vee \beta_b\rangle$$

3. *Inverse of a triangular neutrosophic number*

$$a^{-1} = \left\langle\left(\frac{1}{a_3}, \frac{1}{a_2}, \frac{1}{a_1}\right) ; \alpha_a, \theta_a, \beta_a\right\rangle, \text{where} \quad (a \neq 0)$$

4. *Multiplication of triangular neutrosophic number by constant value*

$$\gamma a = \begin{cases} \langle(\gamma a_1, \gamma a_2, \gamma a_3) ; \alpha_a, \theta_a, \beta_a\rangle \ if (\gamma > 0) \\ \langle(\gamma a3, \gamma a_2, \gamma a_1) ; \alpha_a, \theta_a, \beta_a\rangle \ if (\gamma < 0) \end{cases}$$

5. *Division of triangular neutrosophic number by constant value*

$$\frac{a}{\gamma} = \begin{cases} \left\langle\left(\dfrac{a_1}{\gamma}, \frac{a_2}{\gamma}, \frac{a_3}{\gamma}\right) ; \alpha_a, \theta_a, \beta_a\right\rangle if (\gamma > 0) \\ \left\langle\left(\dfrac{a_3}{\gamma}, \frac{a_2}{\gamma}, \frac{a_1}{\gamma}\right) ; \alpha_a, \theta_a, \beta_a\right\rangle if (\gamma < 0) \end{cases}$$

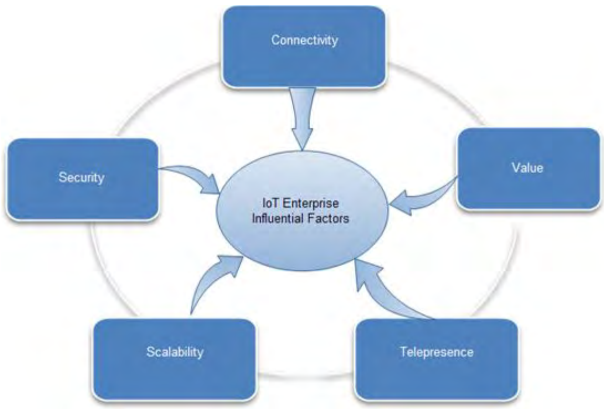

FIGURE 1. Influential Factors for IoT enterprise adoption.

6. *Division of two triangular neutrosophic numbers*

$$\frac{a}{b} = \begin{cases} \left\langle \left(\frac{a_1}{b_3}, \frac{a_2}{b_2}, \frac{a_3}{b_1} \right); \alpha_a \wedge \alpha_b, \theta_a \vee \theta_b, \beta_a \vee \beta_b \right\rangle \\ \quad if\,(a_3 > 0, b_3 > 0) \\ \left\langle \left(\frac{a_3}{b_3}, \frac{a_2}{b_2}, \frac{a_1}{b_1} \right); \alpha_a \wedge \alpha_b, \theta_a \vee \theta_b, \beta_a \vee \beta_b \right\rangle \\ \quad if\,(a_3 < 0, b_3 > 0) \\ \left\langle \left(\frac{a_3}{b_3}, \frac{a_2}{b_2}, \frac{a_1}{b1} \right); \alpha_a \wedge \alpha_b, \theta_a \vee \theta_b, \beta_a \vee \beta_b \right\rangle \\ \quad if\,(a_3 < 0, b_3 < 0) \end{cases}$$

7. *Multiplication of two triangular neutrosophic numbers*

$$ab = \begin{cases} \langle (a_1 b_1, a_2 b_2, a_3 b_3); \alpha_a \wedge \alpha_b, \theta_a \vee \theta_b, \beta_a \\ \quad \vee \beta_b \rangle \; if\,(a_3 > 0, b_3 > 0) \\ \langle (a_1 b_3, a_2 b_2, a_3 b_1); \alpha_a \wedge \alpha_b, \theta_a \vee \theta_b, \beta_a \\ \quad \vee \beta_b \rangle \; if\,(a_3 < 0, b_3 > 0) \\ \langle (a_3 b_3, a_2 b_2, a_1 b_1); \alpha_a \wedge \alpha_b, \theta_a \vee \theta_b, \beta_a \\ \quad \vee \beta_b \rangle \; if\,(a_3 < 0, b_3 < 0) \end{cases}$$

IV. RESEARCH METHODOLOGY

Saaty [6] illustrates the AHP as a widespread multi-criteria decision making technique for efficient decision making. AHP can be an imperative method for managers to solve complex and confusion problems. The AHP decomposes problems to sub-problems for the purpose of simplicity. AHP is imperative method for mangers to solve complex and confusion problems. The problem criteria can be calculated by using the pair-wise comparison judgment. Neutrosophic set is integrated with AHP technique; the relative significant factors are scaled by neutrosophic ratio. The relative effectives of criteria indicated using neutrosophic numbers. The proposed study illustrates the influential factors affecting the success of organization as mentioned in Fig.1. The applications of IoT used in enterprises are collecting data from different private or public domains [4]. The interconnected IoT devices can provide better opportunities, in both technical and business aspects, which have direct impacts on enterprises.

The importance of IoT has been suggested by numerous of researchers for the connection of internet based between different devices [1], [2]. However, the process of decision making for IoT-enterprise faces the conditions of uncertainty, and inconsistency of data. The interconnected devices of IoT makes the opportunity of accompanied many influential issues that affecting the performance of enterprise. Fig. 2 presents the enterprise's model and the corresponding hierarchal levels. We present the main enterprise hierarchal levels which are [45]:

- **Strategic Level:** the top managers achieve the strategic enterprise goals by operating some activities and judgments, indeed the strategic polices will influence on the success and performance of enterprises. The environment in strategic level is under the conditions of uncertainty.
- **Tactical Level:**the middle managers develop planning to achieve objectives and targets of strategic levels. Since characteristics of decisions in strategic level are taken generally for whole enterprise, the decisions in tactical levels would be clearer than in strategic levels. The way makes decisions be more rapid and customized.
- **Operational Level:**the decisions in operational level deal with daily operations to complete the vision and strategy of strategic and tactical levels. The implementation of operational levels can be performed by enterprise's junior managers.

The hierarchal process transforms data from loose irrelevant data to useful information, reaching knowledge and final levels for decision. Enterprise model illustrates the competitive strategy, enterprise strategy, and enterprise structures [45], [46]. The enterprise structure includes different applications of inventory, facilities, sales, sourcing, and others. Fig. 3. Represents details about IoT structure [1], [47]:

- **IoT Formal Definition**: interconnected objects over network without human intervene. Anybody can access from anyplace the required content to achieve personnel, business, or medical tasks.
- **Enterprise IoT Applications**: enterprises gain great benefits to merge the current applications with the technologies of IoT. The enterprise IoT applications are supply chain, connected cars, retail, farming and others.
- **IoT Reference layers**: The IoT architectures can be built by the use of reference layers and definitions.

Fig. 4. combines enterprise with IoT which evolves the need for novel techniques of decision making. The challenges face the traditional decision makings problems of uncertainty, inconsistency, vague, and impression. The traditional steps of decision making can identifies problems in enterprise, identifies the surrounding criterions, performs priorities for set of available alternatives, and evaluates the efficiency of decisions. Absolutely, the traditional steps for decision making cannot handle the current challenges. So there is a necessary to combine neutrosophic theory to enhance the performance of decision making process. The main steps of

FIGURE 2. Enterprise Models and hierarchical levels for obtaining final decision.

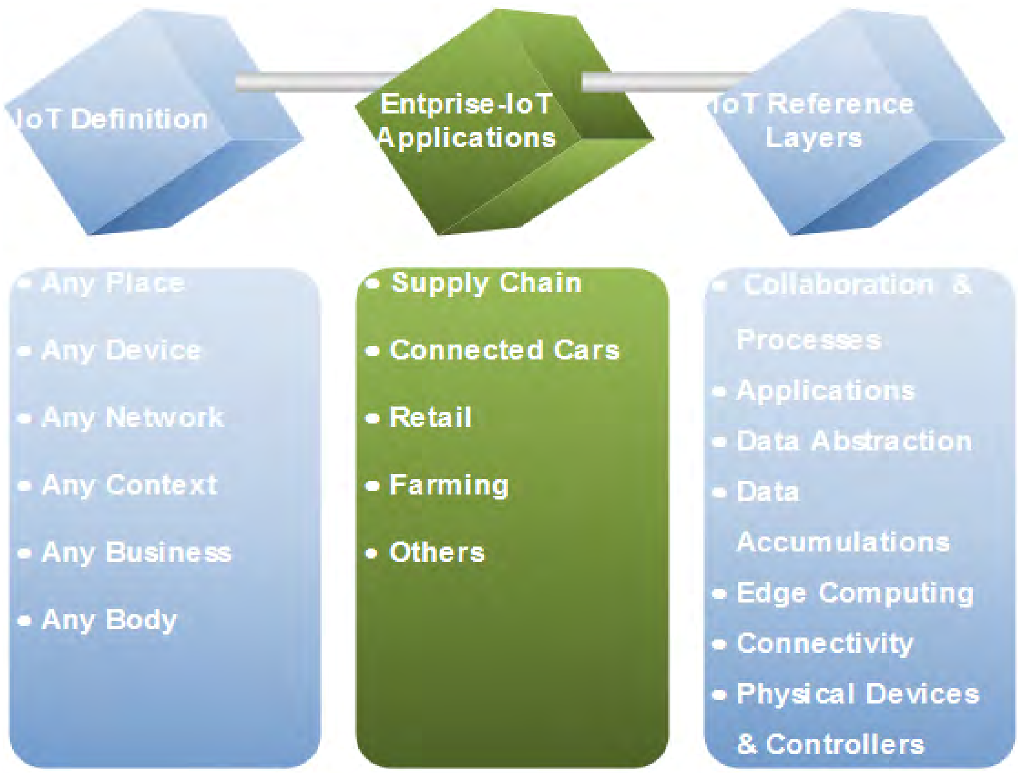

FIGURE 3. IoT definitions, applications, and IoT reference models.

the proposed methodology are presented in Fig. 5, and the detailed descriptions are as follows:

Step 1: Determine the objective of your study; decompose problem hierarchy to represent the goal, criteria, and the possibility of alternatives.

Step 2: Decision makers use neutrosophic scale presented in table 1 to make comparison between criteria and alternatives via linguistic terms. The decision maker presents that criteria 1 is strongly important than criteria 2. The triangle neutrosophic scaled as $\langle (2, 3, 4)\, 0.40, 0.65, 0.60\rangle$. Conversely, if the decision maker presents that criteria 2 is slightly significant than criteria 1, then the triangle neutrosophic scale would be as $1/\langle (2, 3, 4)\, 0.40, 0.65, 0.60\rangle$.

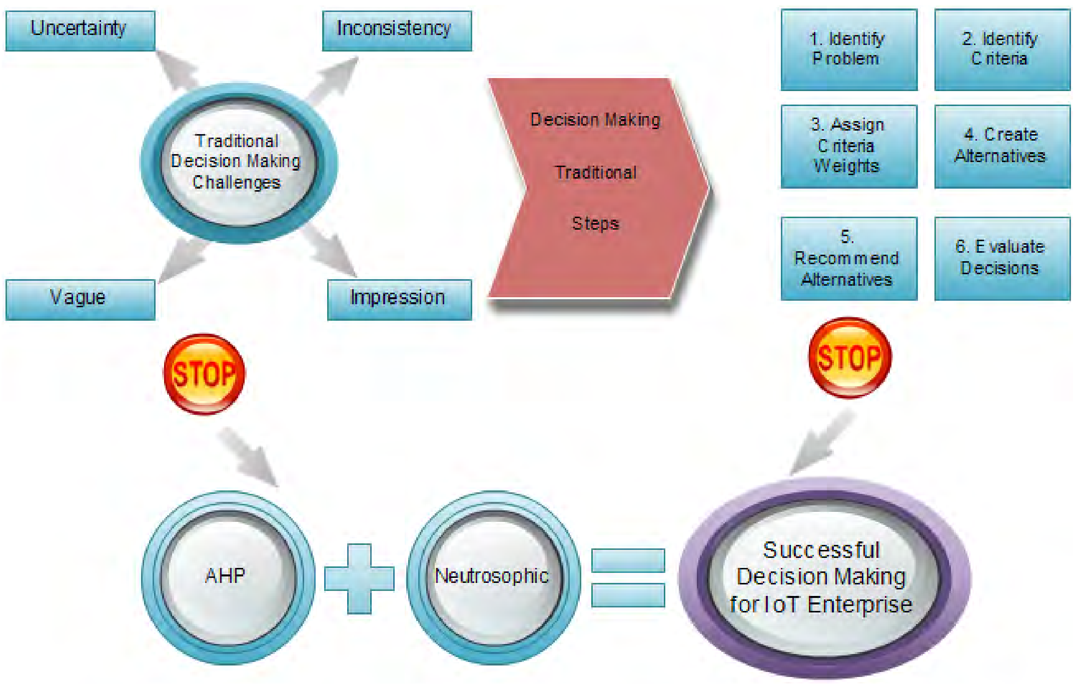

FIGURE 4. Enterprise based IoT for successful decision making.

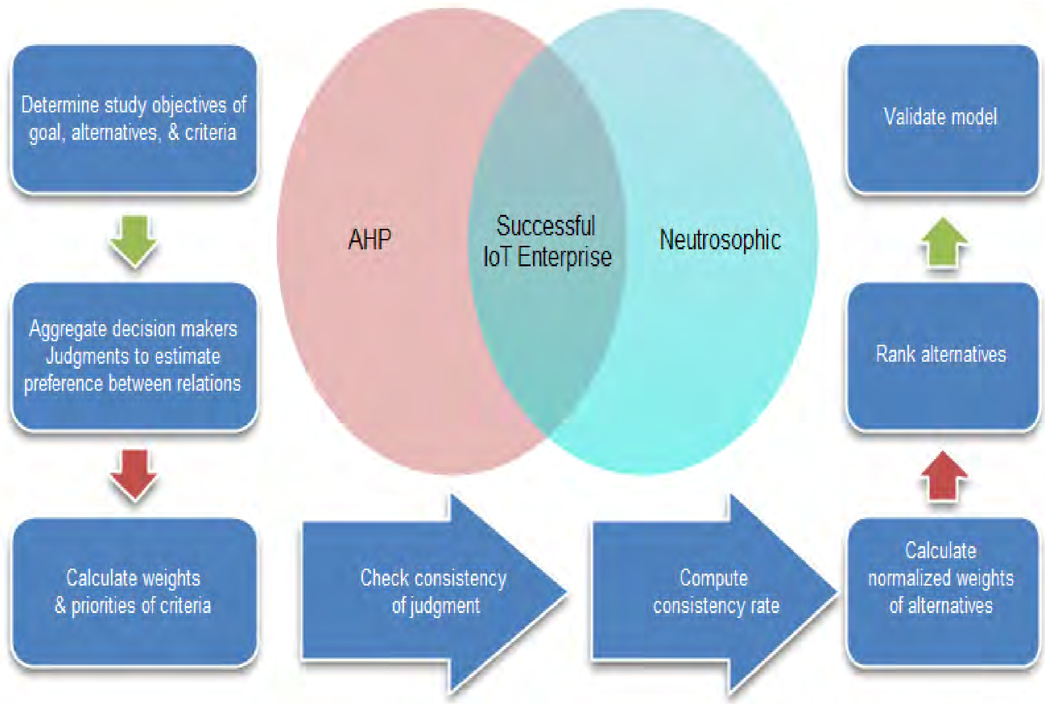

FIGURE 5. The neutrosophic AHP steps for successful IoT Enterprise.

The following form 4 presents the pairwise matrices of comparing different criteria with each other

$$A^k = \begin{pmatrix} r_{11}^k & \cdots & r_{1n}^k \\ \vdots & \ddots & \vdots \\ r_{n1}^k & \cdots & r_{mn}^k \end{pmatrix} \tag{4}$$

where r_{ij}^k represents the k^{th} *decision maker based on the relation of preference of* i^{th} *over* j^{th} *criteria.* The triangular neutrosophic scale is in the form of $r_{ij}^k = \left\langle \left(l_{ij}^k, m_{ij}^k, u_{ij}^k \right); T_{ij}^k, I_{ij}^k, F_{ij}^k \right\rangle$, Such that $l_{ij}^k, m_{ij}^k, u_{ij}^k$ are the lower, median and upper bound of neutrosophic number,

TABLE 1. **THE triangular neutrosophic scale of AHP.**

Saaty scale	*Explanation*	*Neutrosophic Triangular Scale*
1	Equally significant	$1 = \langle\langle 1,1,1\rangle ;0.50,0.50,0.50\rangle$
3	Slightly significant	$3 = \langle\langle 2,3,4\rangle ;0.30,0.75,0.70\rangle$
5	Strongly significant	$5 = \langle\langle 4,5,6\rangle ;\langle 0.80,0.15,0.20\rangle$
7	very strongly significant	$7 = \langle 6,7,8\rangle ,0.90,0.10,0.10\rangle$
9	Absolutely significant	$9 = \langle 9,9,0\rangle ;1.00,0.00,0.00\rangle$
2	sporadic values between two close scales	$2 = \langle 1,2,3\rangle ;0.40,0.60,0.65\rangle$
4		$4 = \langle 3,4,5\rangle ;0.35,0.60,0.40\rangle$
6		$6 = \langle 5,6,7\rangle ;0.70,0.25,0.30\rangle$
8		$8 = \langle 7,8,9\rangle ;0.85,0.10,0.15\rangle$

$T_{ij}^{k}, I_{ij}^{k}, F_{ij}^{k}$" are the truth-membership, indeterminacy and falsity membership functions respectively of triangular neutrosophic number. For instance, r_{21}^{3} is the preference relation of second criteria and first criteria, corresponding to the third decision makers and has the following neutrosophic scale:$r_{21}^{3} = \langle (6, 7, 8) ; 0.90, 0.10, 0.10\rangle$.

Step 3: considering not only one decision maker to estimate the preferences between relations, the aggregated r_{ij} as follow.

$$r_{ij} = \frac{\sum_{k=1}^{k} \left\langle \left(l_{ij}^{k}, m_{ij}^{k}, u_{ij}^{k} \right) ; T_{ij}^{k}, I_{ij}^{k}, F_{ij}^{k} \right\rangle}{k} \tag{5}$$

The average values for the estimated preferences are calculated via the aggregated pair-wise comparison matrix as follows:

$$A = \begin{pmatrix} r_{11} & \cdots & r_{1n} \\ \vdots & \ddots & \vdots \\ r_{n1} & \cdots & r_{mn} \end{pmatrix} \tag{6}$$

Convert the neutrosophic scales to crisp values by apply score functions of r_{ij} as mentioned in [48]:

$$s(r_{ij}) = \left| l_{ij} \times m_j \times u_{ij}) \frac{T_{ij} + I_{ij} + F_{ij}}{9} \right| \tag{7}$$

where l, m, u denotes lower, median, upper of the scale neutrosophic numbers, T, I, F are the truth-membership, indeterminacy, and falsity membership functions respectively of triangular neutrosophic number**.**

Step 4: Based on the preceding matrix, weights and priorities are calculated as presented

TABLE 2. **Upper bound of paire-wise comparison matrix.**

N	4×4	4×4	n>4
CR≤	0.58	0.90	1.12

1. Calculate the average row:

$$w_i = \frac{\sum_{j=1}^{n} (x_{ij})}{n}; i = 1, 2, 3, \ldots .m; j = 1, 2, 3, \ldots , n \tag{8}$$

2. The normalization of crisp value is calculated using the following equation

$$w_i^m = \frac{w_i}{\sum_{i=1}^{m} w_i}; i = 1, 2, 3, \ldots , m. \tag{9}$$

Step 5: Check the consistency of decision makers of judgments

Transitive is used to determine the consistency of judgments matrix .Such that if the pair-wise comparison has a transitive relation i.e. $a_{ik} = a_{ij}a_{jk}$ for all $i, j, andk$, then a pair-wise comparison matrix considered to be consistent. Therefore a transitive relation i.e. $(l_{ik}, m_{ik}, u_{ik}) = \left(l_{ij}, m_{ij}, u_{ij}\right) . \left(l_{jk}, m_{jk}, u_{jk}\right)$ is proposed to detect the consistency. The consistency rate (CR) is very important for calculations, since CR is the computed ratio between the consistency index (CI) and a random consistency index (RI). The rate of (CR) cannot be more than 0.1 with respect to comparison matrix, such that the proposed matrix is less than or equal to 4×4 . If upper bound of the CR for the proposed matrix illustrated as shown in table 2 [42], the matrix is state of inconsistence.

The following steps show the calculation of CI and CR:

1. The comparison matrix's columns are multiplied by its corresponding priority. The summation of all rows resulting of values in form of vector called "weighted sum".
2. The values for weighted sum vector are divided by each criteria's equivalent priority
3. Calculate the mean for the preceding step values stands for $\lambda_{\max}$.
4. The consistency index (CI) is computed as mentioned:

$$CI = \frac{\lambda_{\max} - n}{n - 1}, \tag{10}$$

where n is the number of the compared criteria.

5. Compute the consistency ratio, which is defined as:

$$CR = \frac{CI}{CR}, \tag{11}$$

where RI is the random produced matrix consistency index and illustrated in table 3.

TABLE 3. Saaty table for random consistency index (RI) per different number of criteria.

0	2	3	4	5	6	7	8	9	10
0.0	0.0	0.58	0.90	1.12	1.24	1.32	1.4	1.45	1.49

Step 6: Decision makers who could make repetitive exercise in case of inconsistency of matrix of classical AHP. In neutrosophic AHP, only decision makers involved in repairing the pair-wise comparison matrix could improve consistency degree by following to the next steps. To ensure the consistency, the inconsistent elements should be selected on the pair-wise comparison matrix using the induced matrix illustrated in [42]. The theorem and corollaries can be used as mentioned in [49]. Major steps are used to identify inconsistency of pair-wise comparison matrix to improve the degree of consistency rate mentioned:

1. Formulate the neutrosophic induced matrix

$$I = A \times A - n \times A$$

2. Detect the largest preference relation $\tilde{r}_{ij}$ such that has the largest lower, median and upper-bound of triangular number.
3. Detect the i[th] row and j[th] column which encompass inconsistent triangular neutrosophic number. Compute dot product of row vector $Ro_i = (r_{i1}, r_{i2}, \ldots, r_{in})$ and column vector $Co_j^T = (r_{1j}, r_{2j}, \ldots, r_{nj})$, *where* Co_i^T *is the transpose vector of* Co_j.
4. The dot product

$$P = Ro_i.Co_j^T = (r_{i1}r_{1j}, r_{i2}r_{2j}, \ldots, r_{in}r_{nj}) \quad (12)$$

5. Compute elements far from r_{ij} in vector P according to the mentioned formula:

$$b = P - r_{ij} \quad (13)$$

such that P is the prejudice vector.
6. Use prejudice to detect inconsistency by modifying element A of original pair-wise comparison matrix's element.
7. The inconsistent elements are defined to be the largest lower, median and upper bounds in addition to be far from scratch in the prejudice vector.
8. In order to reach to the consistency of judgments the inconsistent elements must be modified

Step 7: Calculate the normalized weights of alternatives as in criteria weight calculation process. An alternative score can be achieved by multiplying each alternative to its corresponding weight with respect to corresponding criteria

Step 8: Rank alternatives according to highest score value.

V. THE NEUTROSOPHIC AHP DECISION SUPPORT FOR IOT INFLUENTIAL FACTORS OF ENTERPRISE

The proposed case study has been applied on smart village big data in Egypt. A smart village enterprise exposes some common characteristics to delivers insight to customers. Although smart applications pioneered by enterprises, but decision makers cannot detect the impact of related consequences. The influential factors of IoT enterprise are security, value, connectivity, intelligent, and telepresence which presented in table 4. The enterprise needs to make evaluation of influential factors in order to insure good IoT connectivity system and to attain a successful IoT-related enterprise. The IoT enterprise alternatives for using of big data tools for are (1) Spark, (2) KNIME, and (3) Hadoop. The five criteria in for enterprise decision makers are (1) security, (2) value, (3) connectivity, (4) telepresence, and (5) intelligent.

TABLE 4. Main five variable's operational definitions.

Main variables	Operational definition
Security	The protective degree of employees and enterprises when they exchange information across departments.
Value	A subjective opinion of using IoT technology from users.
Connectivity	The capability that permits enterprises to make constant communication between IoT facilities and objects by the use of IoT technology
Intelligent	The degree of understanding from IoT machines when operators need to take information from them or give them an instruction to complete work
Telepresence	The subjective feelings caused by IoT devices to employees and end users.

TABLE 5. Information about decision makers.

Biographical characteristics about job	Interviewers
Job	IT managers
Sector	Service and sales
Experience	5 years
Enterprise Location	Egyptian organization

Step 1: Draw the hierarchy of IoT influential factors of enterprises process as in Fig 6, and mention information about decision makers and interviewers as mentioned in table 5.

Step 2: A session has been performed with strategic level of enterprise directors and decision makers in order to make comparisons and average preferences between criterions and alternatives using neutrosophic scales in table 1.

Step 3: an aggregated pairwise comparison matrix represents the average preferences and judgments of decision makers and, modeled in the form of neutrosophic scales as mentioned in table 6. For sake of simplicity, the aggregated pair-wise comparison matrix has been converted into crisp values using Eq. (7) and results represented in table 8.

Step 4: Compute the criteria's weight

1. Calculate the average of row using the presented using Eq. (8) $w_1 = 1.6202$ $w_2 = 1.4888$ $w_3 = 1.0986$ $w_4 = 0.9096$ $w_5 = 0.623$.

TABLE 6. Neutrosophic pair-wise comparison matrix of criteria.

Criteria	*C1*	*C2*	*C3*	*C4*	*C5*
C_1	$\langle\langle 1,1,1\rangle;0.50,0.50,0.50\rangle$	$\langle\langle 3,4,5\rangle;0.60,0.35,0.40\rangle$	$\langle\langle 1,2,3\rangle;0.40,0.65,0.60\rangle$	$\langle\langle 6,7,8\rangle;0.90,0.10,0.10\rangle$	$\langle\langle 4,5,6\rangle;0.80,0.15,0.20\rangle$
C_2	$1/\langle\langle 3,4,5\rangle;0.60,0.35,0.40\rangle$	$\langle\langle 1,1,1\rangle;0.50,0.50,0.50\rangle$	$\langle\langle 4,5,6\rangle;0.80,0.15,0.20\rangle$	$\langle\langle 6,7,8\rangle;0.90,0.10,0.10\rangle$	$\langle\langle 6,7,8\rangle;0.90,0.10,0.10\rangle$
C_3	$1/\langle\langle 1,2,3\rangle;0.40,0.65,0.60\rangle$	$1/\langle\langle 4,5,6\rangle;0.80,0.15,0.20\rangle$	$\langle\langle 1,1,1\rangle;0.50,0.50,0.50\rangle$	$\langle\langle 1,2,3\rangle;0.40,0.65,0.60\rangle$	$\langle\langle 4,5,6\rangle;0.80,0.15,0.20\rangle$
C_4	$1/\langle\langle 6,7,8\rangle;0.90,0.10,0.10\rangle$	$1/\langle\langle 6,7,8\rangle;0.90,0.10,0.10\rangle$	$1/\langle\langle 1,2,3\rangle;0.40,0.65,0.60\rangle$	$\langle\langle 1,1,1\rangle;0.50,0.50,0.50\rangle$	$\langle\langle 3,4,5\rangle;0.60,0.35,0.40\rangle$
C_5	$1/\langle\langle 4,5,6\rangle;0.80,0.15,0.20\rangle$	$1/\langle\langle 6,7,8\rangle;0.90,0.10,0.10\rangle$	$1/\langle\langle 4,5,6\rangle;0.80,0.15,0.20\rangle$	$1/\langle\langle 3,4,5\rangle;0.60,0.35,0.40\rangle$	$\langle\langle 1,1,1\rangle;0.50,0.50,0.50\rangle$

TABLE 7. Crisp values of judgments of neutrosophic pair-wise matrix.

Criteria	*C1*	*C2*	*C3*	*C4*	*C5*
C_1	1	1.848	1.38	2.03	1.843
C_2	0.541	1	1.843	2.03	2.03
C_3	0.72	0.542	1	1.388	1.843
C_4	0.49	0.49	0.72	1	1.848
C_5	0.542	0.49	0.542	0.541	1

TABLE 8. The comparison matrix of criteria after modification.

Criteria	*C1*	*C2*	*C3*	*C4*	*C5*
C_1	$\langle\langle 1,1,1\rangle;0.50,0.50,0.50\rangle$	$\langle\langle 3,4,5\rangle;0.60,0.35,0.40\rangle$	$\langle\langle 1,2,3\rangle;0.40,0.65,0.60\rangle$	$\langle\langle 6,7,8\rangle;0.90,0.10,0.10\rangle$	$\langle\langle 1,1,1\rangle;0.50,0.50,0.50\rangle$
C_2	$1/\langle\langle 3,4,5\rangle;0.60,0.35,0.40\rangle$	$\langle\langle 1,1,1\rangle;0.50,0.50,0.50\rangle$	$\langle\langle 4,5,6\rangle;0.80,0.15,0.20\rangle$	$\langle\langle 6,7,8\rangle;0.90,0.10,0.10\rangle$	$\langle\langle 6,7,8\rangle;0.90,0.10,0.10\rangle$
C_3	$1/\langle\langle 1,2,3\rangle;0.40,0.65,0.60\rangle$	$1/\langle\langle 4,5,6\rangle;0.80,0.15,0.20\rangle$	$\langle\langle 1,1,1\rangle;0.50,0.50,0.50\rangle$	$\langle\langle 1,2,3\rangle;0.40,0.65,0.60\rangle$	$\langle\langle 4,5,6\rangle;0.80,0.15,0.20\rangle$
C_4	$1/\langle\langle 6,7,8\rangle;0.90,0.10,0.10\rangle$	$1/\langle\langle 6,7,8\rangle;0.90,0.10,0.10\rangle$	$1/\langle\langle 1,2,3\rangle;0.40,0.65,0.60\rangle$	$\langle\langle 1,1,1\rangle;0.50,0.50,0.50\rangle$	$\langle\langle 3,4,5\rangle;0.60,0.35,0.40\rangle$
C_5	$1/\langle\langle 4,5,6\rangle;0.80,0.15,0.20\rangle$	$1/\langle\langle 6,7,8\rangle;0.90,0.10,0.10\rangle$	$1/\langle\langle 4,5,6\rangle;0.80,0.15,0.20\rangle$	$1/\langle\langle 3,4,5\rangle;0.60,0.35,0.40\rangle$	$\langle\langle 1,1,1\rangle;0.50,0.50,0.50\rangle$

2. The normalization illustrated to normalize the crisp value, the criteria's corresponding normalized weights mentioned using Eq. (9): $w_1 = 0.282\ w_2 = 0.259\ w_3 = 0.19\ w_4 = 0.15\ w_5 = 0.10$.

It's obvious that $\sum w_i = 1$.

The arrangement of criteria with respect to priorities is C_1, C_2, C_3, C_4 and C_5 respectively.

Step 5: Check consistency of judgments.

The pair-wise comparison matrix is consistent if and only if there exist a transitive relation such $a_{ik} = a_{ij}a_{jk}$ for all i, j, and k. The consistent degree is calculated as illustrated in next steps:

1. Compute the "weighted sum" for each row $w_1 = 1.547\ w_2 = 1.306\ w_3 = 0.955\ w_4 = 0.762\ w_5 = 0.578$.
2. Divide the weighted sum vector's value by the criteria's corresponding priority as follows: $w_1 = 5.482\ w_2 = 5.038\ w_3 = 4.990\ w_4 = 4.810\ w_5 = 5.326$.
3. Calculate the average of the preceding step results which is stand for $\lambda_{\max}$, then $\lambda_{\max} = 5.1295$.
   Since $\lambda_{\max}$ still neutrosophic number, then apply de-neutrosophic as mentioned
4. Calculate the consistency index (CI) as mentioned:

$$CI = \frac{\lambda_{\max} - n}{n - 1} = \frac{5.1295 - 5}{4} = 0.03,$$

where n represent the number of proposed criteria.

5. Calculate the consistency ratio as illustrated:

$$CR = \frac{CI}{RI} = \frac{0.03}{1.12} = 0.02$$

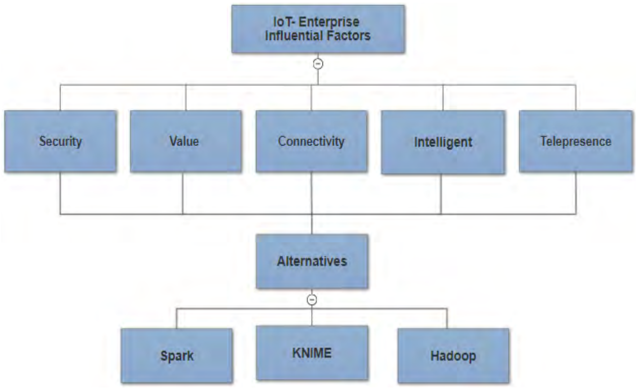

FIGURE 6. AHP decision support for IoT influential factors of enterprises.

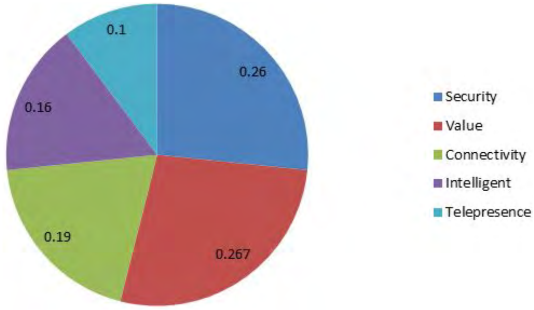

FIGURE 7. The evaluation criteria performed weights.

Step 6: Since the proposed pair-wise comparison is 5 x 5, then CR must be less than 1.12 as illustrated in table 2, the resulting CR is an appropriate ratio to the comparison matrix. However, we can enhance the resulted CR ratio to be near to 0.1 in order to achieve the high degree of consistency.

1. Create the induced matrix $I = A.A - n.$A.

$$\begin{matrix} -0.1 & -2.9 & 1.72 & 0.57 & 4.485 \\ 1.795 & -0.02 & -2.225 & -1.34 & 2.05 \\ -0.2 & 1.28 & -0.01 & -0.61 & -0.545 \\ 0.25 & 0.73 & 0.42 & -0.1 & -2.32 \\ -0.706 & 0.09 & 0.41 & 1.195 & -0.01 \end{matrix}$$

2. The largest preference relation r_{15}.
3. The dot product P $= Ro_1 \cdot Co_5^T = Ro_1 = (1, 1.8488, 1.38, 2.03, 1.843)$ $Co_5^T = (1.843, 2.03, 1.843, 1.848, 1)$ $P = (1.843, 3.7, 2.5, 3.7, 1.843)$
4. Compute elements that far from r_{ij} in vector P according to the mentioned formula:

$$P - r_{15} = (0, 1.875, 0.657, 1.857, 0)$$

5. The consistent elements in b is all elements that contain rather negative or zero values other elements are needed to be enhanced.
6. The comparison matrix's consistency is enhanced by modifying r_{15} as mentioned in table 8.

The normalized weight values of the preceding matrix in table 8 will be as mentioned: $w_1 = 0.260$ $w_2 = 0.267$ $w_3 = 0.19$ $w_4 = 0.16$ $w_5 = 0.11$

The priorities of criteria are presented in Fig.7 as follows: C_2, C_1, C_3, C_4 and C5 respectively so that, security and value are the most important criteria according to company's directors.

By computing λ_{max} as we mentioned previously with details, we found that $\lambda_{max} = 5.07$ Compute the consistency index (CI) as follows:

$$CI = \frac{\lambda_{max} - n}{n-1} = \frac{5.07-5}{4} = 0.017$$
$$CR = \frac{CI}{RI} = \frac{0.017}{1.12} = 0.01$$

Consistency rate is optimized near to 0.1, with respect to saaty as mentioned in table 2. It is apparent that when CR became close to 0.1, we were able to reduce the consistency rate CR from 0.02 to 0.01. The resulted CR is considered to be efficient with the comparison of the value 1.12 as mentioned in table 2.

The proposed criteria examined for its applicability and benefits using four criteria proposed in [40]

- Correlation: interdependency between criteria showed using the correlation coefficient of Spearman as mentioned:

$$\rho = 1 - \frac{6 * \sum D_i^2}{n * (n^2 - 1)} \tag{14}$$

where ρ is the correlation coefficient, $D_i = x_i - y_j$ represent the difference between the value of ranked criteria values, such that n is the number of criteria. There is a strong correlation between criterions as shown in the following computations:

$$\begin{aligned} \rho_{Security-Value} &= 0.99, \\ \rho_{Security-Intelligent} &= 0.92, \\ \rho_{Security-Telepresence} &= 0.93, \\ \rho_{Security-Connectivity} &= 0.96, \\ \rho_{Value-Intelligent} &= 0.91, \\ \rho_{Value-Telepresence} &= 0.99, \\ \rho_{Value-Connectivity} &= 0.98, \\ \rho_{Connectivity-Intelligent} &= 0.90, \\ \rho_{Connectivity-Telepresence} &= 0.94, \\ \rho_{Intelligent-Telepresence} &= 0.97. \end{aligned}$$

Step 7: compute alternative's weights with respect to criteria.

Repeat the de-neutrosophic process to neutrosophic scales into crisp values by the use of Eq. (7), use the methods of calculation of weights of criteria, and then compute the alternative's normalized weight as mentioned:

- The alternatives of comparison matrix with respect to security criteria are mentioned in table 9. Such that, A_1, A_2 and A_3 are corresponding to Spark, KNIME and Hadoop respectively.

TABLE 9. The alternatives of pair-wise comparison matrix according to security.

Alternatives	A_1	A_2	A_3
A1	$\langle\langle 1,1,1\rangle;0.50,0.50,0.50\rangle$	$\langle\langle 4,5,6\rangle;0.80,0.15,0.20\rangle$	$\langle\langle 6,7,8\rangle;0.90,0.10,0.10\rangle$
A2	$1/\langle\langle 4,5,6\rangle;0.80,0.15,0.20\rangle$	$\langle\langle 1,1,1\rangle;0.50,0.50,0.50\rangle$	$\langle\langle 1,2,3\rangle;0.40,0.65,0.60\rangle$
A3	$1/\langle\langle 6,7,8\rangle;0.90,0.10,0.10\rangle$	$1/\langle\langle 1,2,3\rangle;0.40,0.65,0.60\rangle$	$\langle\langle 1,1,1\rangle;0.50,0.50,0.50\rangle$

TABLE 10. The alternatives of pair-wise comparison matrix according to value.

Alternatives	A_1	A_2	A_3
A_1	$\langle\langle 1,1,1\rangle;0.50,0.50,0.50\rangle$	$\langle\langle 1,2,3\rangle;0.40,0.65,0.60\rangle$	$\langle\langle 6,7,8\rangle;0.90,0.10,0.10\rangle$
A_2	$1/\langle\langle 1,2,3\rangle;0.40,0.65,0.60\rangle$	$\langle\langle 1,1,1\rangle;0.50,0.50,0.50\rangle$	$\langle\langle 3,4,5\rangle;0.60,0.35,0.40\rangle$
A_3	$1/\langle\langle 6,7,8\rangle;0.90,0.10,0.10\rangle$	$1/\langle\langle 3,4,5\rangle;0.60,0.35,0.40\rangle$	$\langle\langle 1,1,1\rangle;0.50,0.50,0.50\rangle$

TABLE 11. The alternatives of pair-wise comparison matrix according to connectivity.

Alternatives	A_1	A_2	A_3
A_1	$\langle\langle 1,1,1\rangle;0.50,0.50,0.50\rangle$	$\langle\langle 6,7,8\rangle;0.90,0.10,0.10\rangle$	$\langle\langle 4,5,6\rangle;0.80,0.15,0.20\rangle$
A_2	$1/\langle\langle 6,7,8\rangle;0.90,0.10,0.10\rangle$	$\langle\langle 1,1,1\rangle;0.50,0.50,0.50\rangle$	$\langle\langle 3,4,5\rangle;0.60,0.35,0.40\rangle$
A_3	$1/\langle\langle 4,5,6\rangle;0.80,0.15,0.20\rangle$	$1/\langle\langle 3,4,5\rangle;0.60,0.35,0.40\rangle$	$\langle\langle 1,1,1\rangle;0.50,0.50,0.50\rangle$

1. Calculate the average of row using the presented Eq. (8):

$$w_1 = 1.624 \quad w_2 = 0.974 \quad w_3 = 0.736$$

2. The normalization illustrated to normalize the crisp value, the criteria's corresponding normalized weights mentioned using Eq. (9):

$$w_1 = 0.48 \quad w_2 = 0.29 \quad w_3 = 0.22$$

- The alternatives of comparison matrix with respect to value criteria have been mentioned in table 10.
  The value criteria and its corresponding alternatives of normalized weights are mentioned as mentioned:
  1. Calculate the average of row by the use of the presented Eq. (8):

  $$w_1 = 1.47 \quad w_2 = 1.189 \quad w_3 = 0.677$$

  2. The normalization illustrated to normalize the crisp value, the criteria's corresponding normalized weights mentioned in Eq. (9):

  $$w_1 = 0.44 \quad w_2 = 0.35 \quad w_3 = 0.209$$

- The alternatives of comparison matrix with respect to connectivity criteria have been mentioned in table 11. The connectivity criteria and its corresponding alternatives of normalized weights are mentioned as mentioned:
  1. Calculate the average of row using the presented Eq. (8):

  $$w_1 = 1.624 \quad w_2 = 1.11 \quad w_3 = 0.694$$

  2. The normalization illustrated to normalize the crisp value, the criteria's corresponding normalized weights mentioned in Eq. (9):

  $$w_1 = 0.47 \quad w_2 = 0.32 \quad w_3 = 0.20$$

- The pair-wise comparison matrix of alternatives with respect to intelligent criteria shown in table 12. The Intelligent criteria and its corresponding alternatives of normalized weights are mentioned as follows:
  1. Calculate the average of row by the use of the presented Eq. (8):

  $$w_1 = 1.47 \quad w_2 = 1.111 \quad w_3 = 0.677$$

TABLE 12. The alternatives of pair-wise comparison matrix according to intelligent.

Alternatives	A_1	A_2	A_3
A_1	$\langle\langle 1,1,1\rangle;0.50,0.50,0.50\rangle$	$\langle\langle 1,2,3\rangle;0.40,0.65,0.60\rangle$	$\langle\langle 6,7,8\rangle;0.90,0.10,0.10\rangle$
A_2	$1/\langle\langle 6,7,8\rangle;0.90,0.10,0.10\rangle$	$\langle\langle 1,1,1\rangle;0.50,0.50,0.50\rangle$	$\langle\langle 4,5,6\rangle;0.80,0.15,0.20\rangle$
A_3	$1/\langle\langle 6,7,8\rangle;0.90,0.10,0.10\rangle$	$1/\langle\langle 4,5,6\rangle;0.80,0.15,0.20\rangle$	$\langle\langle 1,1,1\rangle;0.50,0.50,0.50\rangle$

TABLE 13. The alternatives of pair-wise comparison matrix according to telepresence.

Alternatives	A_1	A_2	A_3
A_1	$\langle\langle 1,1,1\rangle;0.50,0.50,0.50\rangle$	$\langle\langle 6,7,8\rangle;0.90,0.10,0.10\rangle$	$\langle\langle 1,2,3\rangle;0.40,0.65,0.60\rangle$
A_2	$1/\langle\langle 1,2,3\rangle;0.40,0.65,0.60\rangle$	$\langle\langle 1,1,1\rangle;0.50,0.50,0.50\rangle$	$\langle\langle 3,4,5\rangle;0.60,0.35,0.40\rangle$
A_3	$1/\langle\langle 1,2,3\rangle;0.40,0.65,0.60\rangle$	$1/\langle\langle 3,4,5\rangle;0.60,0.35,0.40\rangle$	$\langle\langle 1,1,1\rangle;0.50,0.50,0.50\rangle$

2. The normalization illustrated to normalize the crisp value, the criteria's corresponding normalized weights mentioned in Eq. (9):

$$w_1 = 0.45 \quad w_2 = 0.34 \quad w_3 = 0.20$$

- The pair-wise comparison matrix of alternatives with respect to telepresence criterion is presented in table 13. The telepresence criteria and its corresponding alternatives of normalized weights are mentioned as mentioned:
  1. Calculate the average of row by the use of the presented Eq. (8):

$$w_1 = 1.47 \quad w_2 = 1.187 \quad w_3 = 0.75$$

  2. The normalization illustrated to normalize the crisp value, the criteria's corresponding normalized weights mentioned in Eq. (9):

$$w_1 = 0.43 \quad w_2 = 0.34 \quad w_3 = 0.22$$

The weight of three alternatives of the smart village according to each criterion is mentioned in Fig.8. For sake of description, Fig 9, 10, and 11 present a detail analysis for each alternatives with respect to the related criteria.

Multiply each criterion by its corresponding weights to obtain the score value

The alternatives relative score value is as mentioned:

$$\begin{bmatrix} 0.48 & 0.44 & 0.47 & 0.45 & 0.43 \\ 0.29 & 0.35 & 0.320.340.34 & & \\ 0.22 & 0.20 & 0.20 & 0.20 & 0.22 \end{bmatrix} \times \begin{bmatrix} 0.260 \\ 0.267 \\ 0.19 \\ 0.16 \\ 0.11 \end{bmatrix} = \begin{bmatrix} 0.45 \\ 0.32 \\ 0.20 \end{bmatrix}$$

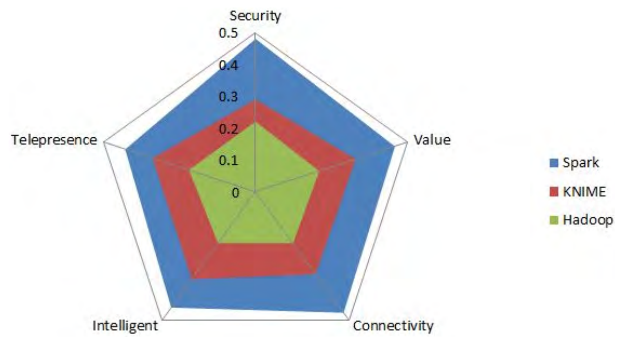

FIGURE 8. Comparison of three alternatives according to different criteria.

Step 8: Rank the recommended alternatives according to highest score value as mentioned in Fig 12.

VI. VALIDATION IN THE UK AND CHINA

It is imperative for the working proposal to be validated in different context, including different countries, institutions and sectors. Without any exception, our proposal has been validated in the UK and China to ensure that it can be replicated, reusable and adaptable. We follow the steps described between Section 3 and Section 6. We also interview five representatives in the UK and five representatives in China to make comparative studies and understand any differences due to different locations, cultures and emphasis. Each representative presents the core values for each business. We focus on results similar to between Fig.9 and 12. We can then successfully analyze rational behind.

Fig.13 shows results for comparison of Spark alternative according to different criteria in the UK. All these five representatives have similar values and rating scores under 0.5, since they believe that maintaining a good balance in all the

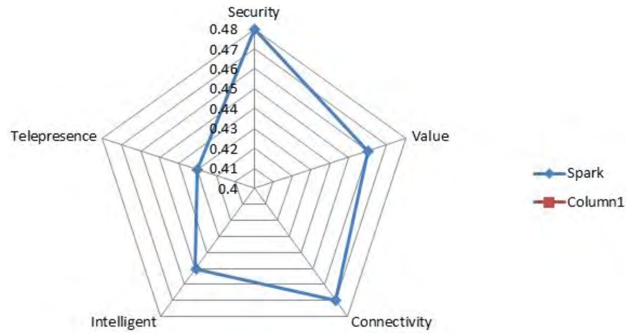

FIGURE 9. Comparison of Spark alternative according to different criteria.

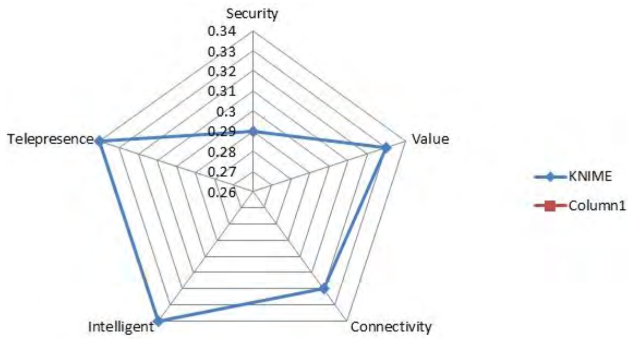

FIGURE 10. Comparison of KNIME alternative according to different criteria in Egypt.

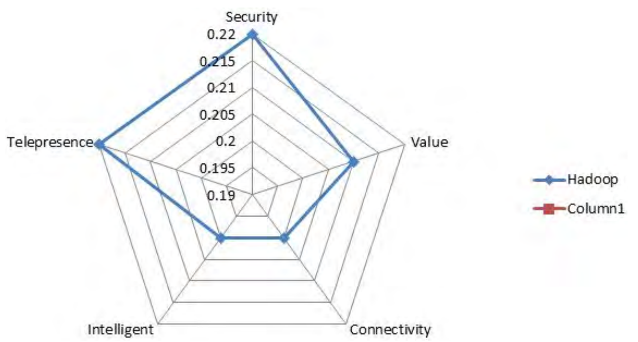

FIGURE 11. Comparison of Hadoop alternative according to different criteria in Egypt.

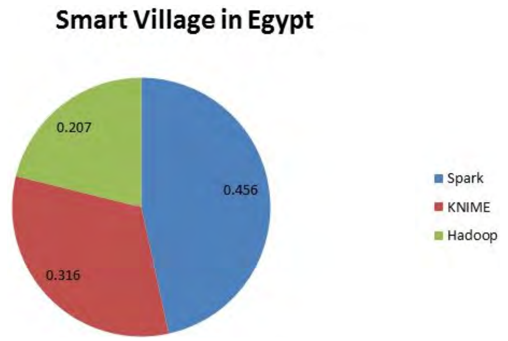

FIGURE 12. The priorities of smart village alternatives with respect to related criteria in Egypt.

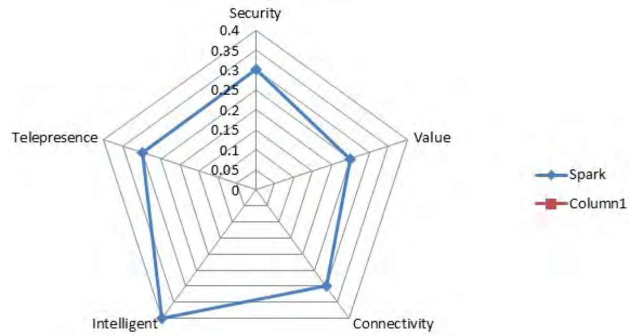

FIGURE 13. Comparison of Spark alternative according to different criteria in the UK.

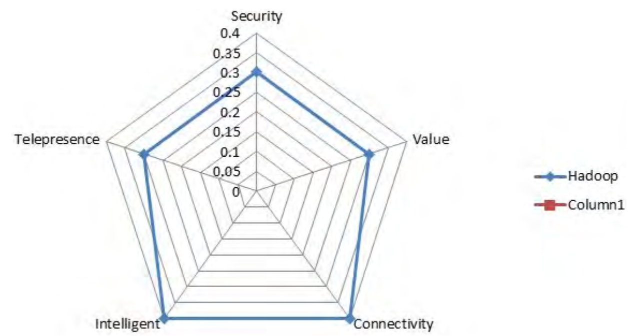

FIGURE 14. Comparison of Hadoop alternative according to different criteria in the UK.

factors are necessary. Even if the levels of competitions can be high and the extents of uncertainty can be volatile, the best approach for them is to maintain all key factors smartly stable and steady, rather than being excellent in one or two factors. Even so, Intelligent has the highest scores and the value has the lowest scores even the differences are not far. This is because services should be adaptable to meet market demands and customers' requests.

Fig. 14 shows results for comparison of Hadoop alternative according to different criteria in the UK. All the scores are below 0.5, but are more well-balanced since these five representative firms consider they are all important. Intelligent and connectivity are considered the most important criteria as follows. First, a lot of services have been completed by Hadoop. More requests have been made about increasing the scale of deployment and services due to the demands on IoT, Edge Computing and AI. Connectivity has been expanded on connecting different smart cities, smart services, smart devices and smart robots, particularly in London. Therefore, the scores for Intelligent and Connectivity are higher than the other three, which have the same score of 0.4 each.

Fig.15. shows results for comparison of Spark alternative according to different criteria. Connectivity is the most important criteria as reflected by five Chinese representative firms since all services and users must be online and connected. In China, there are millions of users. Disconnecting from any services, business transactions and online visits may result in millions of financial loss. Due to the restrictions in

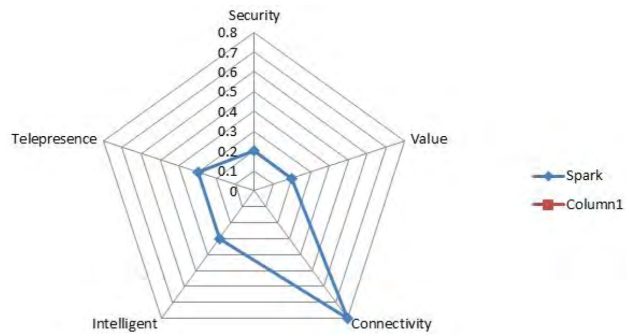

FIGURE 15. Comparison of Spark alternative according to different criteria in China.

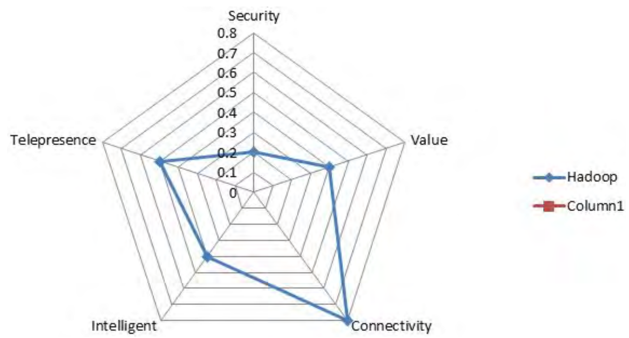

FIGURE 16. Comparison of Hadoop alternative according to different criteria in China.

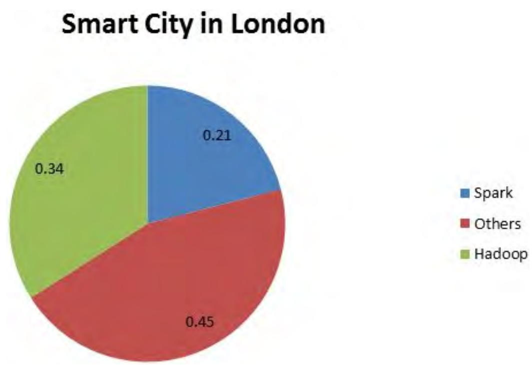

FIGURE 17. The priorities of smart village alternatives with respect to related criteria in London.

FIGURE 18. The priorities of smart village alternatives with respect to related criteria in Shanghai.

some security setting, then connectivity can only go for 0.8 at most. The other scores are as low as between 0.2 and 0.3.

Fig.16 shows results for comparison of Hadoop alternative according to different criteria. It has a similar shape like Fig.15, except it has higher scores for value, intelligent, and telepresence. In other words, it means Hadoop services are more mature and more established than Spark services. Hadoop was in used by IoT services earlier than Spark. However, security still remains challenges for IoT services in China.

Comparing between services in the UK and China, we can identify that UK service providers and users are more concerned that services should be well-balanced in all important criteria. Differences between them are smaller. Whereas in China, the most important factor is the connectivity to ensure all payment and business transactions can be made efficiently and quickly. Millions of financial transactions can be made on the daily basis. The reason for a low security and privacy scores is because all personal data and information have to be supplied for all transactions. If user data can be made anonymous and ways to provide real-time user authentication can be made, this can enhance the level of security. It is perhaps because in order to ensure a stable and fast connection, security and privacy tend to be regarded on a lower scale in these five representative providers in China.

Unfortunately, KNIME is not common in the UK and China. There are local solutions developed by service providers. Due to this reason, they are classified under "others". Figure 17 and 18 show the priorities of smart village alternatives with respect to related criteria in London and Shanghai respectively. Both are big cities and thus their orientation is presented as the smart city. In London, others consist of 45%; Hadoop has 34% and Spark has 21% of percentage of usage and deployment. There is a trend that others may still go up, since there are more varieties of different solutions on offer.

Fig.18 shows interesting results. Alibaba is one of the biggest IT service providers in China. Hence, the difference is there are Spark and Hadoop services offered by Alibaba or non-Alibaba. Continentally, it has 20% each for Spark and Hadoop services by Alibaba (Ali) and 20% each for Spark and Hadoop services by non-Alibaba services. The remaining 20% is for all other services not using Spark and Hadoop. Shanghai is one of the busiest and most competitive cities in the world and it has millions of different services on offer. Interestingly a lot of IoT and IT can be classified into Ali and non-Ali services as reflected by our findings.

VII. CONCLUSIONS AND FUTURE WORK

Finally, our proposed model can be used to estimate influential factors of IoT-related enterprise. We aid decision makers to identify the ideal solutions. Our proposed model can deal with vague, impression, and inconsistent information. We enhance decision judgment by the use of AHP combined with neutrosophic sets. By using neutrosophic equations, the proposed alternatives have been chosen effectively using neutrosophic rather than decision maker judgments. The consistency rate approve that the use of neutrosophic sets will enhance the inconsistent information that exist in decision maker judgments matrix. We also replicated our proposal in the UK and China. We discussed results and explained the rationale for getting different scores. Results show that our work can be adapted and replicated in different settings and countries for IoT research. Similarly, our findings for the smart city in UK and China were presented.

The future work we are ongoing to predict the influential factors affecting enterprise by the use of variant multi-criteria decision analysis methodologies, so that our research contributions can be transferrable to other domains. In addition to, perform optimization of decision judgment matrices using evolutionary algorithms.

A. LIMITATION OF PROPOSED RESEARCH

More involvements from more companies will make our research better.

B. COMPETING INTERESTS

The authors announce that there is no discrepancy of interests concerning the publication of this research.

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