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A Review on Neutrosophic Set and Its Development

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ABSTRACT

This review paper was presented as a feature of the procedure improvement in mathematical theory in uncertainty problem known as neutrosophic set. The objectives of this paper are to discuss the generalization of neutrosophic set and its development methods with the area of the study. Along these periods, there are different methodologies and developments toward neutrosophic perceptive, as indicated by the necessities in their different fields. This paper is expected to share the improvement of the neutrosophic set; some time recently, present and future talk.

Keywords: Neutrosophic Set, Truth, Indeterminacy, Falsity

INTRODUCTION

Many mathematical tools have been developed to model and solve real life problems. For problems that involve imprecision, vagueness and uncertainty, the concept of fuzzy set introduced by Zadeh (1965) has been the focus of many due to its ability to imitate human thinking and perception using linguistic information. Many theories were later introduced with the aim of addressing the issue of impreciseness but in different form of structures. Neutrosophic theory was recently proposed due to better option where the fuzzy set and fuzzy logic can't express the false membership information and intuitionistic fuzzy set and intuitionistic fuzzy logic is not able to handle the indeterminacy of information. This is due to vagueness and impreciseness of the information that always involve of opposite and neutral information.

Fundamental theory of neutrosophic term has emerged from philosophy word "neutrosophy" and its derivative "neutrosophic". Neutrosophy is a new branch of vagueness philosophy introduced by Smarandache in 1995 which is studying the origin, nature and scope of neutralities as well as their interactions with different additional spectra (F. Smarandache et al., 2001). Neutrosophic set is a generalization of fuzzy set and intuitionistic fuzzy set. In neutrosophic logic, a proposition has a degree of truth (T), a degree of indeterminacy (I), and degree of falsity (F). The fuzzy set theory claims that there exists a degree of membership function for every component level of participation for uncertainty problem (Zadeh, 1965). Then, in 1983, K. Atanassov introduced intuitionistic fuzzy set on a universe X as a generalization of fuzzy set where other than the degree of membership $\mu_A(x) \in [0,1]$ of every component x to a set A there also exist a degree of non-membership function denoted as $\nu_A(x) \in [0,1]$, such that for $x \in X$, $\mu_A(x) + \nu_A(x) \leq 1$ (Atanassov, 1986). The discussion of neutrosophy idea become reality when Smarandache introduced the concept of neutrosophic set where there exist the degree of indeterminacy $\omega_A(x) \in [0,1]$ in between degree of membership and degree of non-membership function for uncertainty problem. The

concept of neutrosophic set handles indeterminate data whereas fuzzy set and intuitionistic fuzzy set failed when the relation is indeterminate.

There are three elements in neutrosophic set which is truth (T), indeterminate (whether true or false) (I), and falsity (F). Element of T, I, F are not necessary intervals, but can be any sets such as discrete, continuous, open or closed or half-open and half-closed interval and intersection or union of the previous sets. In 2005, Wang et al. introduced single value neutrosophic set and interval-value neutrosophic set as a generalization of neutrosophic set (Wang et. al, 2005), (Wang et. al, 2012). These theories more applicable to use since they only take the unit interval [0, 1] for T, I, and F instead of use non-standard interval $]^{-}0,\ 1^{+}[$. Then, Smarandache introduced n-valued neutrosophic set or refined neutrosophic set as a generalization of single valued neutrosophic set and interval-valued neutrosophic set (Smarandache, 2013a). Some researcher called this theory as neutrosophic multisets (Broumi, Deli, & Smarandache, 2014a, 2014b, 2014c; Chatterjee, Majumdar, & Samanta, 2015). In year 2015, Smarandache extended this theory to symbolic neutrosophic theory where there is a refinement of neutrosophic numerical component and neutrosophic literal component (Smarandache, 2015b). Neutrosophic numerical components (*t, i, f*) are crisp numbers, intervals or in general subsets of the unitary standard or non-standard unit interval. Literal sub-component can be split into literal sub-truth, literal sub-indeterminacies and literal sub-falsehoods. The concept of literal sub-interdeminacies is more suitable use in decision making compare to another two literal sub-components due to the vagueness and imprecise information that need to be taken into considerable in solving the uncertainties problem such as voting for election, football games and rule of penalty.

Neutrosophic and its variant methods such as rough neutrosophic set, complex neutrosophic set, neutrosophic soft expert set and neutrosophic soft set (Broumi, 2013; Lupianez, 1996; Maji, 2013; M. Şahin, Alkhazaleh, & Uluçay, 2015) are widely used since their algorithm can help to solve the problem in real life situation The comparative analysis of neutrosophic set and its variant are discussed more detail in section 2. The hybrid theory of neutrosophic set where apply in many areas such as in medical diagnosis (Broumi et al., 2014b, 2014c; Broumi & Smarandache, 2014b; Chatterjee et al., 2015; Pramanik & Mondal, 2015; Said, Talea, Bakali, & Smarandache, 2016a; P. P. Wang, Mordeson, Wierman, & Smarandache, 2015; Ye, 2015; Ye & Fu, 2016), decision-making process (Abdel-baset, Hezam, & Smarandache, 2016; Broumi, 2014; Broumi & Smarandache, 2013; Kour & Basu, 2015; Lirong Jian, Liu, & Lin, 2011; Mandal, 2015; Mondal, Pramanik, & Smarandache, 2016; Mukherjee, 2015; Pramanik, 2016; Pramanik, Banerjee, & Giri, 2016; M. Şahin et al., 2015; Said et al., 2016a; Said, Talea, Bakali, & Smarandache, 2016b; Smarandache, 2014b; Teodorescu, 2016; Tian, Wang, Zhang, Chen, & Wang, n.d.; Wang et al., 2005; Ye, 2014b, 2014c, 2014d, 2014e) and pattern recognition (Chatterjee et al., 2015; Guo & Cheng, 2009; Said et al., 2016a; Smarandache, n.d.; Ye, 2014a; Ye & Fu, 2016).

NEUTROSOPHIC SET AND ITS DEVELOPMENT

Definition of Neutrosophic Set (NS)

Let N be an universe of discourse, with a generic element in N denoted by x, the neutrosophic (NS) set is an object having the form

$$A = \{\langle x, (\mu_A(x), \omega_A(x), \vartheta_A(x)\rangle : x \in N\} \quad (1)$$

where the functions μ, ω, $\vartheta : N \rightarrow]^{-}0,\ 1^{+}[$ define respectively the degree of membership (or Truth), the degree of indeterminacy, and the degree of non-membership (or Falsehood) of the element $x \in N$ to the set A with the condition

$$0^- \leq \mu_A(x) + \omega_A(x) + \vartheta_A(x) \leq 3^+ \quad (2)$$

NS takes the value from real standard or non-standard subsets of $]^-0, 1^+[$. But in technical applications the real value of the interval [0, 1] will be use since $]^-0, 1^+[$ will be difficult to apply in the real applications such as in scientific and engineering problems. Therefore, the membership value use is

$$A = \{\langle x, (\mu_A(x), \omega_A(x), \vartheta_A(x)\rangle : x \in N\} \text{ and } \mu_A(x), \omega_A(x), \vartheta_A(x) \in [0, 1]$$

There is no restriction on the sum of $\mu_A(x), \omega_A(x), \vartheta_A(x)$. So,

$$0 \leq \mu_A(x) + \omega_A(x) + \vartheta_A(x) \leq 3 \quad (3)$$

Comparative analysis of neutrosophic set

Problems in economics, engineering, environmental science, social science, medical sciences and most of problems in everyday life have various uncertainties. Instead, uncertainty theories such as probability theory, fuzzy set theory, rough set theory, soft set theory, intuitionistic set theory, vague set theory are well known as mathematical tools dealt with uncertainties problem. Its variant or hybrid method also proposed by many researchers to solve uncertainties problem.

Smarandache and his research group combined the neutrosophic paper and published in the International Journal of Information Science and Engineering, Neutrosophic Sets and Systems, the primary version in 2013. Table 1 shows some of the neutrosophic and its hybrid method with a neutrosophic set operator which is a union, intersection, complement, addition and multiplication. Neutrosophic logic properties used are disjunction, conjunction, negation and implication. The theorem and subcomponent used in the existing research paper is also summarized in Table 1.

Smarandache utilized the basic operator in logic, which is union, intersection, complement, addition and multiplication in presenting neutrosophic application (Smarandache et al., 2001). Wang et al. introduced single value neutrosophic set and interval-value neutrosophic set with defined properties that give another generalization of neutrosophic theory (Wang et al., 2005). Meanwhile, Salama and Alblowi hybrid up the neutrosophic set and neutrosophic topology. This paper additionally talked about all the essential operator to neutrosophic set which is topology (A. Salama, 2013). Next, Chi and Peide stretch out TOPSIS strategy to interval value neutrosophic set by utilizing the interval notation for neutrosophic subcomponent (Smarandache, 2014a). Broumi and Smarandache introduced interval-valued neutrosophic soft rough sets which combine interval valued neutrosophic soft set and rough sets and studied some of its basic properties (Broumi & Smarandache, 2014a). Further, in 2014, Smarandache extend the study of neutrosophic logic to n-valued refined neutrosophic logic for application in physic (Smarandache, 2013a). Another named for n-valued refined neutrosophic set is neutrosophic multisets. Chatterjee extends the neutrosophic multiset to single valued neutrosophic multiset (Chatterjee et al., 2015). The basic operator and properties of this theory are also proven. Broumi, Deli and Smarandache continued studying of relation on neutrosophic multiset and present the properties of them (Broumi, Deli, & Smarandache, 2014d). Neutrosophic multisets theory also apply in decision making for example in selection problem (Mondal & Pramanik, 2015) and medical diagnosis (Broumi et al., 2014a).

Recently, Broumi et al. applied the interval valued and soft set by introducing interval valued neutrosophic soft set (Broumi et al., 2014b). The basic operator and properties was used in his research for proving part. Next, the hybrid of neutrosophic multisets and other

uncertainty methods such as rough multisets (Girish & Jacob John, 2011) and soft multisets are introduced (Alkhazaleh, Salleh, & Hassan, 2011). In 2016, Asyraf and Nasruddin introduced the neutrosophic vague soft expert set theory as their new theory to solve the problem in the selection of the several alternatives (Al-Quran & Hassan, 2016).

Table 1: Some of the neutrosophic and its hybrid method with operator and subcomponent

Uncertainty concept/ Author's Name / Year	Operator and Subcomponent
NS and NL (Smarandache et al., 2001)	Basic four set operator (union, intersection, different, compliment)
Interval valued NS (Wang et al., 2005)	Interval {[x,y]} and basic operator (x,y)
Single-valued NS (Wang et al., 2012)	Basic four set operators
Generalized NS and NS topology (A. Salama, 2013)	Basic four set operators
Extand TOPSIS to interval NS (Smarandache, 2014a)	Interval value
Interval-Valued Neutrosophic Rough Sets (Broumi & Smarandache, 2014a)	Interval, neutrophic rough set
n-Valued Refined Neutrosophic Logic (Smarandache, 2013a)	More than one set
Generalized neutrosophic soft (Broumi, 2013)	Parameter soft set
Relation on Interval valued Neutrosophic Soft Set (Broumi et al., 2014d)	Interval, soft set
Neutrosophic Refined relation and their properties (Broumi et al., 2014b)	Neutrosophic refine set
Single valued Neutrosophic Multiset (Chatterjee et al., 2015)	Neutrosophic multiset
Neutrosophic Soft Multiset Theory (Broumi et al., 2014c)	Soft Multiset and neutrosophic multiset
Refined Literal Indeterminacy and the Multiplication Law of Subindeterminacies (Smarandache, 2015a)	Refine of neutrosophic component (T, I, F)
Neutrosophic vague soft expert set theory (Al-Quran & Hassan, 2016)	Vague soft expert set

The research of distance and similarity measure, relation and mapping, ranking and ordering for neutrosophic set also explored by many researchers. Table 2 summarized some of this area in neutrosophic environment. The distance and similarity measure for neutrosophic theory and its hybrid methods were widely proposed. Decision making environment, especially for diagnosis of patient diseases where the most application areas of the study. Majumdar and Samant studied about the similarity and the entropy of neutrosophic set and proposed the properties of them (Majumdar & Samanta, n.d.). Next, Ye discussed the similarity measure between interval neutrosophic set (Ye, 2014b). Ye et al. also introduced a generalized distance and similarity measures between single valued neutrosophic multisets (SVNMs) (Ye, 2015). That method was applied to a medical diagnosis problem to obtain the outcome of patient diseases. Then, Pramanik et al. proposed cosine similarity measure of the neutrosophic set for multi-attribute decision making problem. The properties of cosine similarity measure were present with algorithm in this paper (Bengal et. al, 2015).

Smarandache introduced a new method of measuring similarity between two neutrosophic soft sets and its application in pattern recognition problems by using neutrosophic set and soft

set (Smarandache, n.d.). Ye and Smarandache studied the similarity measure of refined single-valued neutrosophic sets and its multicriteria decision making method (Ye & Smarandache, 2014b). Meantime, Sahin defined two measurement functions such that score function and accuracy function to rank single valued neutrosophic numbers and extend the idea of interval neutrosophic numbers (R. Şahin, n.d.). But, until now there have been no many studies on multicriteria decision making methods based on the grade-accuracy functions in which criterion values for alternatives are single valued neutrosophic sets or interval neutrosophic sets. There also another generalizes of neutrosophic set that introduced the raw properties of similarity measure and applied it to a different area. Table 2 summarized some of the field of study for neutrosophic set.

Table 2: Some of the field of study for neutrosophic set

Author's Name / Year	Area of study for neutrosophic set
(Majumdar & Samanta, n.d.)	Similarity and entropy, basic operator
(Ye, 2014b)	Similarity, interval neutrosophic set
(Ye, 2015)	Similarity, interval neutrosophic set
(Bengal et al., 2015)	Cosine similarity measure
(Smarandache, n.d.)	Similarity, neutrosophic soft set
(Broumi & Smarandache, 2014b)	Similarity, refined neutrosophic component
(R. Şahin, n.d.)	Ranking order
(Pramanik & Mondal, 2015)	Cosine similarity measure of rough neutrosophic set

Comment on generalization of Neutrosophic Set

Neutrosophic set is a generalization of intuitionistic fuzzy set, paraconsistent set and fuzzy set. Hence, neutrosophic set generalizes the intuitionistic set, which include the incomplete set theories when $0 < n < 1$, $0 \leq \mu, \omega, \vartheta \leq 1$, the fuzzy set when $n = 1$ and $\omega = 0$, and $0 \leq \mu, \omega, \vartheta \leq 1$, the classical set for $n = 1$ and $\omega = 0$, with μ, ϑ either 0 or 1, the paraconsistent set for $n > 1$, with all $\mu, \omega, \vartheta < 1^+$, the faillibilist set for $\omega > 0$, the paradoxist set when $\mu = \vartheta = 1$ and the pseudoparadoxist set when $0 < \omega < 1$, $\mu = 1$ and $\vartheta > 0$ or $\mu > 0$ and $\vartheta = 1$. Smarandache remark's that contrasted with different type of sets, for neutrosophic set every component has three components which are subsets (not numbers as in fuzzy set) and considers a subset, also to intuitionistic fuzzy set, of "indeterminacy" - because of surprising parameters covered up in a few sets, and let the better furthest reaches of the segments than even bubble more than 1 (over-burden) and the second rate points of confinement of the segments to try and stop under 0 (underdried).

Smarandache studied the neutrosophy philosophy and presented the concept of neutrosophic set and neutrosophic logic after he attempted to combine the neutrosophy (neutral) into proposition like how many percent of truth (t %), percent of indeterminate (i %) and percent of false (f %). This discussion also can be linked to how many percent is matched, neither agree nor disagree, and disagree for each impression. Before that, there also have uncertainty methods that were already proposed by mathematician involving a percentage of opinion such as probability set.

For theoretical contribution, neutrosophic set can explain the difference between absolute membership and relative membership since the neutrosophic unit interval is $]^-0, 1^+[$. Absolute membership is equal to 1^+ and relative is equal to 1. Fuzzy set and Intuitionistic fuzzy set cannot recognize between these two memberships since the sum of the membership for fuzzy

set and intuitionistic fuzzy set is equal to 1. However, the non - standard interval is not applicable to many applications. Wang et al., has introduced a single value neutrosophic set and interval values neutrosophic set of simplifying from non-standard unit interval to standard interval [0, 1].

This generalization is a powerful theory in explaining the indeterminate situation, especially in the decision-making process. For example, Ye proposed the correlation coefficient under single value neutrosophic set environment by introduced the weighted correlation coefficient between each alternative and ideal alternative (Smarandache, 2013b). The studied is continued by rank of all alternatives and the best choice is selected based on the weighting and ranking order. Ye give the examples of investment company which wants to invest a sum of money in the best option and manufacturing company which wants to select the best global provider. There also many researcher generalize and hybrid the single value neutrosophic set and interval value neutrosophic set in decision making process (Abdel-baset et al., 2016; Kour & Basu, 2015; Pramanik, 2016; Pramanik et al., 2016; Ye, 2014d).

Compared to fuzzy set and intuitionistic fuzzy set, they only have operators regarding truth and falsity membership. In 2015, Smarandache introduced symbolic neutrosophic set where there exist numerical subcomponent and literal subcomponent (Smarandache, 2015b). Literal subcomponent will split depending on the needed accuracy whether for truth membership (T_1, T_2, …, T_n) or indeterminacy membership (I_1, I_2, …, I_n) or falsehood membership (F_1, F_2, …, F_n). Meanwhile, at the same year Smarandache et al., introduced refined neutrosophic set or neutrosophic multiset where there exist the truth membership sequence $(T_A^1(x),T_A^2(x),...,T_A^p(x))$, the indeterminacy membership sequence $(I_A^1(x),I_A^2(x),...,I_A^p(x))$ and the falsity membership sequence $(F_A^1(x),F_A^2(x),...,F_A^p(x))$ (Smarandache et al., 2014a). This theory was employed in many positions as an extended of neutrosophic set application. Application in medical diagnosis is the most research that using the neutrosophic multisets theory (Chatterjee et al., 2015; Deli, Broumi, & Smarandache, 2015)(Pramanik & Mondal, 2015). The idea was explained that there are many patients with different disease and difference interval of time.

The variant method such as rough neutrosophic set, complex neutrosophic set, neutrosophic soft set, neutrosophic soft multiset, neutrosophic soft expert set, neutrosophic goal programming and time neutrosophic soft set are also widely explore and applied in various application (Abdel-baset et al., 2016; Ali & Smarandache, 2016; Alkhazaleh, 2016; Maji, 2013; M. Şahin et al., 2015),(Broumi et al., 2014c).

CONCLUSION AND FUTURE WORK

The neutrosophic set and logic attempt to better model of the imprecise and non-determinism problem. Smarandache with his group of research try to explain the paradoxical result, even in science not talking in the humanities, where the paradox is very common to evaluate the peculiarities, to illustrate the contradictions and conflicting theories from three different perspectives. For example, for each true from a specific point of view, false from another one, and perhaps indeterminate from the third of the view. Neutrosophic relation prediction applied to more of one subject where neutrosophic predicate is a vague, incomplete, or not well-known attribute, property or function of the subject. It is kind of three valued set function.

The idea of Smarandache about neutrosophic is; this logic is nearer to the human personality thinking. It logic gets the imprecision of information or semantic inaccuracy gotten by different researchers and that is the reason μ, ω and ϑ are subsets and not really

single-components, uncertainty because of inadequate learning or obtaining mistakes or stochasticity that is the reason the subset ω exists, and unclearness because of unclear or misunderstanding of information that is the reason μ, ω, ϑ are subsets and ω exists. This situation specifically, for the appurtenance to the neutrosophic sets.

As a conclusion, the concept of neutrosophic set and logic is suitable to explore and flesh out in mathematical modelling and uncertainty problem because it is a relatively novel concept introduced by Smarandache (2005). There also have many application areas of neutrosophic set to be discovered such as medicine, political analysis, and social economies. Lastly, neutrosophic theory has a better represented concept because of the third component represent which is indeterminate (neither true nor false) for uncertainty element.

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