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Introduction to Neutrosophic Reliability Theory

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Abstract

Reliability is one of the most important indicators of the quality of any system or product, ranging from the simplest machines as a product in any factory to the most complex system, such as phone or aircraft or missile engines, etc. The accuracy of these products indicates their high reliability, and therefore the customer or business owner will have confidence in products and will request more quantity. To reach the highest level of accuracy for the reliability of any system, the corresponding data must be very accurate. For this purpose, we proposed to add accuracy to reliability by adding data that contains more pieces of information about a specific product or problem. We introduced a new logic (Neutrosophic logic) of data instead of classical logic which gives us more accuracy of data that contain indeterminacy such as extremist, vague, and unclear data. We defined the neutrosophic reliability according to the modern neutrosophic logic by constructing a neutrosophic reliability function. We have used the type of series as an application of neutrosophic reliability and introduced some examples. Neutrosophic reliability theory can be applied in computer science and decision support systems.

Keywords: Neutrosophic probability, Neutrosophic Set, Neutrosophic reliability, Neutrosophic random variable, classical reliability, neutrosophic series reliability.

1.Introduction

In a world full of indeterminacy and therefore the traditional set with its boundaries of truth and false has not infused itself with the ability to reflect reality. For this reason, neutrosophic found its place in contemporary research as an alternative representation of the real world. Established by Florentin Smarandache [1, 2, 10, 11, 12], neutrosophy was presented as the study of "the origin, nature, and scope of neutralities, as well as their interactions with different identical spectra". Salama et al. introduced the neutrosophic crisp set theory and many applications in computer science and information system in [3-6] and [18-26]. The theory of reliability is considered as a collection of measures, mathematical systems, improving methods used to obtain solutions to some problems of prediction, estimation, optimal survival probabilities, expected life, or the life distributions of elements of the system. In (2020)

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Smarandache et al. introduced an approach for the reliability of data contained in a single-valued neutrosophic number and its application [32,33].

Reliability theory also considers some of the problems related to calculating the actual probability of providing some systems at (a certain time or at an optional time, or through a portion of the time during) which some systems are operating efficiently and accurately. that is, reliability of the system is a measure of a system's ability to operate successfully under conditions and for a specific period with the recent development in production systems, products have become more complex in their manufacture (a collection of components that work as an integrated system), which increases the probability that they will collapse if one component fails in them. One of the most important things in maintaining the system's reliability is the use of highly reliable components. In the classic procedure, we have encountered many problems in determining the reliability of any electrical system, device, product, etc. For example, some data are lost or the value of one of the vehicles is unclear or the basic component on which the system works are not identified (indeterminacy), or one of the paths of an electrical or electronic loop may be unclear or not specified, however, we need the reliability to be more exact and clear. In this case, we use the modern procedure to redefine the reliability according to neutrosophic logic introduced by Smarandache in 1995 [9], as neutrosophic logic allows dealing with all previous cases and others with high flexibility. Neutrosophic logic is considered as a generalization for the fuzzy logic and intuitionistic fuzzy logic [9, 10], and the fundamental concepts of neutrosophic set and Neutrosophic set introduced by Smarandache in [8, 9, 10]. Smarandache extended the fuzzy set to the neutrosophic set [10, 11, 12], introducing the neutrosophic components T, I, F, which represent the membership, indeterminacy, and non-membership values respectively, where] -0, 1+ [is the non-standard unit interval. In this paper, we presented the concept of reliability according to neutrosophic logic and called it neutrosophic reliability. Neutrosophic reliability is a new tool and one of the most important indicators in measuring the quality and reliability of systems in all fields.

2. Fundamentals

Neutrosophy theory is applied in different aspects of life to solve problems related to indeterminacy, such as mathematical, engineering, geography, medicine, psychology [9].

Definition 1 [10]

Neutrosophy is a generalization of dialectics (that depended on <A> and <anti- A> only), however in neutrosophic theory considered every entity <A> tends to be neutralized and balanced by < anti-A> and < non-A> entities - as a state of equilibrium. In a classical way <A>, <neut- A>, < anti-A> are disjoint two by two. But, since in many cases the borders between notions are vague, imprecise, <A>, <neut- A>, <anti- A> and <non- A> may have common parts two by two, or even all three of them as well.

Definition 2 [8,9]

Let U be a universe of discourse; then the neutrosophic set A is an object having the form

$$A = \{< x: T_A(x), I_A(x), F_A(x) >, x \in U\}. \quad (1)$$

Where the functions T, I, F: U → $]^{-}0,1^{+}[$ define respectively the degree of membership, the degree of indeterminacy, and the degree of non-membership of the element x ∈ U to the set A with the condition: $^{-}0 \leq T_A(x)+I_A(x)+F_A(x) \leq 3^{+}$.

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Definition 3 [7,8]

Let X be a space of points (objects) with generic elements in X denoted by x. An interval neutrosophic set A in X is characterized by truth-membership function, indeterminacy-membership function, and falsity-membership function. For each point x in X, we have that $T_A(x)$, $I_A(x)$, $F_A(x)$ subset [0 ,1].

Defination 4 [12]

Neutrosophic random variable is a random variable with some indeterminate if suppose Ω is a sample space of neutrosophic random experiment such as X is function define on Ω, such that the domain or codomain or the relationship between them may contain some indeterminacy,

$$X: \Omega \to \mathcal{R} \cup I \qquad (2)$$

Definition 5 [12,14]

Neutrosophic probability (or likelihood) is a particular case of the neutrosophic measure. It is an estimation of an event (different from indeterminacy) to occur, together with an estimation that some indeterminacy may occur, and the estimation that the event does not occur.

NP(E) = (chance that event E occurs, indeterminate chance that E occurs or not, a chance that event does not occur)

NP(E) =(ch(E), ch(neut A) ,ch(anti A)) = (T ,I ,F **)** (3)

3. Classical Reliability

Reliability function

Let $\mathcal{T}$ denote the lifetime of a system, the reliability of that system at the point in time t, that

$R(t) = P(\mathcal{T} > t)$, it is called the reliability at the time t, and we can define it as the probability that the time at which the system could fail is greater than t.

We can find the reliability by cumulative distribution function for a random variable $\mathcal{T}$ as:

$$R(t) = \int_t^{\infty} f(t)\ dt = 1 - P(\mathcal{T} > t) = 1 - F(t). \text{ [15,30]} \qquad (4)$$

Example (1) Suppose that the company offers a two-year guarantee of its product. So the probability of this product operates as expected during the guarantee should be large. As a measure of reliability, probability can be used to indicate the life of that product (not failed). Let $\mathcal{T}$ is denoted the time of life product will not fail during this period, for example, if R= P($\mathcal{T}$ > 720 days), that is: This standard is a useful indicator for measuring how this product does its intended function.

If R= 0.999, this means that one in a thousand units can fail for two years.

Example (2) What is the probability of mission success, if seven helicopters are sent on a mission and five must succeed for a mission to be successful? Bearing in mind that the probability of a certain type of helicopter surviving a mission is 0.9 [15].

Solution:-

If the number of successes is 5 or more, this indicates to the mission will be a success. Hence, the probability of mission success or mission reliability is:

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$$R_s(t) = \sum_{i=k}^{m} \binom{m}{i} R^i R^{m-i} = \sum_{i=5}^{7} \binom{7}{i} R^i R^{7-i}$$

$$=\binom{7}{5}0.91^5(0.09)^2 + \binom{7}{6}0.91^6(0.09)^1 + \binom{7}{7}0.91^7(0.09)^0 = 0.9806.$$

4. Modern Reliability (Neutrosophic Reliability)

Let $\mathcal{T}$ be a Neutrosophic random variable representing the time of the system failure, and t be the interval of the operation of this system. We defined the reliability according to Neutrosophic probability as follow:

$NR(t) = \int_t^\infty f_N(t)dt = NP(\mathcal{T} > t)$, where t can be an interval or set or neutrosophic number maybe contain some indeterminacy, and $f_N(t)$ is the neutrosophic probability distribution.

Then, $NR(t)$ is the neutrosophic reliability with respect to a neutrosophic probability distribution.

Example (3) Neutrosophic Weibull Distribution [7]

Alhasan, Florentin (2019), define Weibull distribution according to neutrosophic logic as:

$$f_N(X) = \frac{\beta_N}{\alpha_N^{\beta_N}} X^{\beta_N - 1} e^{-(X/\alpha_N)^{\beta_N}} \ , X > 0$$

And the reliability of neutrosophic Weibull as:

$$NR(t) = \int_t^\infty f_N(t)dt = NP(\mathcal{T} > t) = e^{-(X/\alpha_N)^{\beta_N}}$$

Such that, the parameters of Weibull distribution as a number neutrosophic. that is, it may be a set or interval.

To find the neutrosophic reliability, we take the following example:

Suppose the product be an electric generator produced with a high capacity of the trademark that has a Weibull distribution with parameter α=1, β=[1.5,2].
Estimate the reliability of the electric generator after the expiration of a five years warranty operation.
The neutrosophic reliability is:

$$NR(t) = e^{-(X/\alpha_N)^{\beta_N}}$$

Since the shape parameter is determined β=[1.5,2].

When β= 1.5 and α=1
Then, $NR(5) = e^{-(5/1)^{1.5}} = 14 \times 10^{-4}$

And,
when β= 2 and α=1
$NR(5) = e^{-(5/1)^2} = 10^{-5}$
Thus, the reliability of the electric machine operation after 5 years has the range between $[14 \times 10^{-4}, 10^{-5}]$.

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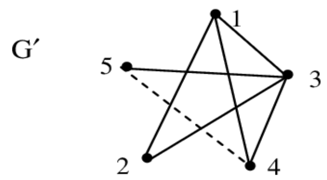
5. System Neutrosophic Reliability Modeling

The reliability of the system is depended on the reliability of its components and therefore all its subsystems and components have to be studied to design and analyze the reliability of a system. This can be done through the formulation based on a logical and mathematical model of the system that shows the structure function.

If we take any system that contains vertices and edges, some of them work, others fail, and others are indeterminacy. Each component of the system is identified as passing from one vertice to another.



Figure(1): the system contains indeterminacy

In figure(1), the graph of the system is a neutrosophic graph since it contains the edge < 5,4> is indeterminacy edge.

The device is considered successful if there is a successful path from the source to the sink. The device will be considered as indeterminacy if at least one path is indeterminacy (unclear) from the source to sink in this case the device is unsuccessful. We define the neutrosophic reliability according to modern logic (neutrosophic logic) as follow:

5.1 Structure-Function of Neutrosophic Reliability

The reliability for any system at the time t is denoted by R(t), where t < T can be defined as the probability of the operation of the system within the interval [0, t].

Let's define the structure-function of neutrosophy reliability based on the classical reliability after adding the new component which is the indeterminacy component to truth and falsity components.

In classical reliability, the structure-function of reliability of a device is: [35]

Let $X_1, X_2, \dots, X_i, \dots, X_n$ are components of a system (device), and

$\varphi(x_1, x_2, \dots\dots, x_n) = \varphi(X)$,

$\varphi : \{0,1\}^n \to \{0,1\}$ is structure- function defined as:

$$\varphi(X) = \begin{cases} 1 & device\ is\ \ working\ at\ [0,t] \\ 0 & device\ is\ fails\ at\ [0,t] \end{cases}$$

The neutrosophic reliability is a triple function (truth, indeterminacy, falsehood) that indicates the status of the device (works, indeterminacy, not work) given the status of each component as in the following:

$\varphi_N(x_1, x_2, \dots\dots, x_n) = \varphi_N(X)$, is the neutrosophic structure-function of reliability device.

$\varphi_N : \{0,1,I\}^n \to \{0,1,I\}$

Such that,

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$$x_i = \begin{cases} 1 & if\ component\ i\ working\ during\ time\ [0,t] \\ I & if\ component\ i\ indetermincy\ during\ [0,t] \\ 0 & if\ component\ i\ fails\ during\ time\ [0,t] \end{cases} \quad (5)$$

The performance of the device is measured by the triple random variables, that is

$$\varphi_N(X) = \begin{cases} 1 & device\ is\ working\ at\ [0,t] \\ I & device\ is\ idetermincy\ at\ [0,t] \\ 0 & device\ is\ fails\ at\ [0,t] \end{cases} \quad (6)$$

The reliability of a component p_i is the probability that the component i is working correctly. The component i of the device is indeterminacy probability denoted by I_i, and the component failure probability, q_i, is the probability that the component has failed (not working). And we can denote the triple components as follow:

$$p_i = NP\{X_i = 1\},$$

$$q_i = NP\{X_i = 0\} \text{ and}$$

$$d_i = NP\{X_i = I\} \quad (7)$$

Such that, ***NP*** the Neutrosophic Probability [14,12] that an event A occurs is

$$NP(X) = \{ch(X), ch(neutX), ch(antiX)\} = (T, I, F),$$

where *T, I, F* are standard or nonstandard subsets of the nonstandard unitary interval]-0, 1+[, and *T* is the chance that *X* occurs, denoted ch(*X*); *I* is the indeterminate chance related to *X*, ch(neut *X*); and *F* is the chance that *X* does not occur, ant(*X*).

Using the reliability neutrosophic to improve system reliability, such as series, parallel, composed series-parallel, or mixed.

5-2 Neutrosophic Reliability Of Series System

When we configured the reliability of the system, for example, **type *series***: that is in a series system, a failure of any component in the series system, implies failure for the whole system.

If we have N of the components, which contains some indeterminacy components implies the system is a failure. That is if at least one of the components that are indeterminacy is a failure.

Let $X_1, X_2, \dots, X_i, \dots, X_n$ are components of the system (device), if consider X_i that component is indeterminacy maybe more one, and *N*=1,2,…, i,..,n.

The neutrosophic structure-function of a series system with N components is

$$\varphi_N(X) = X_1 X_2 \dots X_i \dots X_n$$

X_i Indictor to the indeterminacy component

Such that $\varphi_N(X) = X_1 X_2 \dots X_i \dots X_n = (T_i, I_i, F_i), i = 1,2, \dots, n$ (8)

If the series system is successful, the structure-function must be equal to (1,1,1), otherwise, it's a failure. To find the reliability neutrosophic series its equal to the neutrosophic probability that all the components in the series system are true.

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If the components N are independent,

Then $NR = Np_1 \dots \dots . Np_n = NR_1 \dots \dots . NR_n$. (9)

Example (4)

Suppose a device is series types contains 4 components and the components have exponential lifetimes and give constant failure rate of each component, 0.3, 0.2, 0.1, 0.4 respectively per 20 days,

In classical reliability, $R(t) = e^{-\lambda t}$

If we suppose the 1st component is A, then $R_A(t) = e^{-0.3t} = 0.00247$

, the 2nd component is B, then $R_B(t) = e^{-0.2t}$ = 0.0183

, the third component is C, then $R_c(t) = e^{-0.1t}$= 0.1353

And the fourth component is D, then $R_D(t) = e^{-0.4t}$

Hence $R(t = 20) = e^{-0.3t}.e^{-0.2t}.e^{-0.1t}.e^{-0.4t} = e^{-1.0t} = e^{(-1)(20)} = 2.06115 \times 10^{-9}$

Now, if these components have the neutrosophic exponential distribution and neutrosophic time series [13, 14], in this case, we can consider the constant failure rate is an undetermined number or set or internal which forms the number Neutrosophic, if the constant failure rate in each component as [0.28,0.32], [0.17, 0.28],[0.09, 0.17], [0.32, 0.42] respectively per 20 days.

Therefore, to find the Neutrosophic reliability of the above components, A, B, C, and D as follow:

$NR_A(t) = e^{-[0.28,0.32]t}$, if $\lambda_N = 0.28$ implies that $NR_A(t) = e^{-5.6} = 0.00369$

if $\lambda_N = 0.32$ implies that $NR_A(t) = e^{-6.4} = 0.00166$

$NR_B(t) = e^{-[0.17,0.28]t}$, if $\lambda_N = 0.17$ implies that $NR_B(t) = e^{-3.4} = 0.03337$

if $\lambda_N = 0.28$ implies that $NR_B(t) = e^{-5.6} = 0.00369$

$NR_c(t) = e^{-[0.09,0.17]t}$, if $\lambda_N = 0.09$ implies that $NR_c(t) = e^{-1.8} = 0.16529$

if $\lambda_N = 0.17$ implies that $NR_c(t) = e^{-3.4} = 0.03337$

$NR_D(t) = e^{-[0.32,0.42]t}$, if $\lambda_N = 0.32$ implies that $NR_D(t) = e^{-6.4} = 0.00166$

if $\lambda_N = 0.41$ implies that $NR_D(t) = e^{-8.2} = 2.746 \times 10^{-4}$

hence, $NR(t = 20) = [3.38949 \times 10^{-8}, 5.6318 \times 10^{-11}]$.

Similarly, give an example of the neutrosophic reliability of neutrosophic Weibull, see[7].

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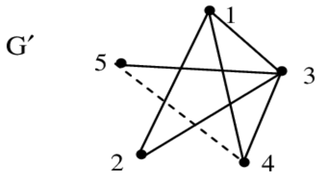
6. Some Applications

1- In the design of an electric cable Extension, the Direct Current which contains three, L, N, and E, is the earth, when the Loop Electric Circuit for work, we need to only L and N without E, in this case, we consider E is indeterminacy line.

2- In any neutrosophic graph, see [16,27,28,29,31,33,34] of the network of any system which contains some indeterminacy edge or indeterminacy vertices. Then in any graph system which contains some indeterminacy edge and indeterminacy vertices, this implies reliability Neutrosophic.



3- In an electrical circulation, we notice some time in the power of the electric current that the electric current does not reach 220 volts, or very invalid that maybe half the power or the power is excessive, and this means that nothing works in electronic systems, such as TV, freeze, Air conditioner,.., etc.

4- To ensure that the vehicle engine works at full capacity and gives the required services, there are three essential factors that we need to consider which are the production of sparks, fuel circulation, and flow of air. in any one of them does not good work, there is indeterminacy hence reliability Neutrosophic.

5- In the field of medicine, to know to measure the quality of a drug for any disease, we need here very high and accurate reliability of a drug to ensure people's lives.

6- In psychology,[2] we need high reliability to measure the balance in a personality(Neutrosophic personality), or in measuring the level of intelligence of children, whenever all the data, including extreme or abnormal ones, are taken into account, the more accurate the data will be.

7- Reliability In Neutrosophic correlation, whenever reliability is a measure of data quality and then give a good Neutrosophic correlation, see [3,4,5]

8- S., H., A.Salama (2016) [6] defined in a neutrosophic graph, every path from a node to other nodes (vertices) contains three functions (every component has weight), maybe this weight is value or area or time and distance.

9- The use of Neutrosophic reliability in knowing the reliability of the devices used for early detection of the Corona COVID 19 virus, as well as the devices for examination (such as a swab, oximeter, laser, or thermal devices for measuring temperature), as well as the reliability of data in modeling Scientific mathematical to study the type of virus or study the virus series.

10- In communications, we need high reliability for quality image compression or message encryption.

Example (5)

To ensure that the vehicle engine works at full capacity and gives the required services, there are three essential factors that we need to consider which are the production of sparks, fuel circulation, and flow of air.

Production of spark. The spark plugs generate the sparks inside the engine. The engine needs to have an efficient quantity of sparks to ensure that the engine works efficiently reliability. If any of the plugs work inefficiently, it will negatively impact the overall performance of the engine.

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Fuel circulation. If there are any issues with fuel intake as a result of a blockage in the fuel injections or malfunctioning of any of the injections or shortage in fuel pumping as a result of issues with the fuel pump, it would impact the overall performance of the engine as this will impact the quantity of fuel inside the engine.

6. Conclusions

To obtain a high level of reliability of any product such as the system of machine or medicine, engineering, psychology, a measure of statistic or mathematic, etc. we need accurate and whole data. In this paper, we proposed a new concept whith neutrosophic reliability that depends on classical data and indeterminacy data together. This means that we need to study all data including vague, unclear data. We defined the structure-function for reliability according to the modern logic duch as "neutrosophic logic" that depends on triplet functions (truth, falsehood, indeterminacy) and it's using neutrosophic probability. The series of neutrosophic reliability was also discussed in this paper and some examples were illustrated.

For future work, we'll apply the neutrosophic reliability to improving many methods of reliability in networks, (series or parallel or compound) systems, and many other fields that require high accuracy (high reliability) in its systems. And we can find the neutrosophic reliability for any distribution (Expositional, Gamma, Normal, etc.) and any probability function.

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