

Article

Testing of Grouped Product for the Weibull Distribution Using Neutrosophic Statistics

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Abstract: Parts manufacturers use sudden death testing to reduce the testing time of experiments. The sudden death testing plan in the literature can only be applied when all observations of failure time/parameters are crisp. In practice however, it is noted that not all measurements of continuous variables are precise. Therefore, the existing sudden death test plan can be applied if failure data/parameters are imprecise, incomplete, and fuzzy. The classical statistics have the special case of neutrosophic statistics when there are no fuzzy observations/parameters. The neutrosophic fuzzy statistics can be applied for the testing of manufacturing parts when observations are imprecise, incomplete and fuzzy. In this paper, we will design an original neutrosophic fuzzy sudden death testing plan for the inspection/testing of the electronic product or parts manufacturing. We will assume that the lifetime of the product follows the neutrosophic fuzzy Weibull distribution. The neutrosophic fuzzy operating function will be given and used to determine the neutrosophic fuzzy plan parameters through a neutrosophic fuzzy optimization problem. The results of the proposed neutrosophic fuzzy death testing plan will be implemented with the aid of an example.

Keywords: neutrosophic fuzzy statistics; fuzzy approach; neutrosophic fuzzy plan parameters; fuzzy optimization problem; risks

1. Introduction

In life testing experiments, a random sample of items is usually selected, and a single item is installed on a single tester for the lot sentencing. This type of testing is costly as the number of testers is equal to the number of items that are selected for the testing purpose. Alternatively, the group sampling scheme is applied for the testing of more than one item on the single tester. Sudden death testing is implemented in groups to reduce the testing/inspection cost of the product. In sudden death testing, a random sample of size n is equally distributed to g groups having r items in each of the g groups. Reference [1] proposed the sudden test for the Weibull distribution. According to Reference [1] “The specimens in each group are tested identically & simultaneously on different testers. The 1st group of specimens is run until the 1st failure occurs. At this point, the surviving specimens are suspended & removed from testing. An equal set of new specimens numbering is next tested until the 1st failure. This process is repeated until one failure is generated from each of the groups”. The sampling plan for sudden death testing has been considered by several authors in the literature, see for example References [1–3].

In the modern era, products are manufactured using advanced technology, which result in high quality and reliability. For the testing/inspection of a highly reliable product, it may not be possible to wait for the failures of the product for the lot sentencing. The two types of censoring widely applied to reduce the testing cost for a highly reliable product, are known as type-I censoring and type-II censoring. The testing is said to be type-I censoring if the time of experiment is fixed, and type-II if

the number of failures is specified for the testing/inspection of the product. The acceptance sampling plans for type-I and type-II censoring when the lifetime follows the Weibull distribution is designed by a number of researchers, including, for example, References [4–10].

The fuzzy approach is widely used when there is some uncertainty in the proportion of defectives. In practice, the experimenter may be indeterminate about the percentage of defectives. In this case, the traditional sampling plans can be applied for the inspection of the lot. Hence, a number of people have designed efficient sampling plans using the fuzzy approach, including, for example, References [11–26].

Parts manufacturers use sudden death testing to reduce the testing time of the experiment. The sudden death testing plan in the literature can only be applied when all observations of failure time/parameters are crisp. According to Reference [27], “all observations and measurements of continuous variables are not precise numbers but more or less non-precise. This imprecision is different from variability and errors. Therefore, lifetime data are also not precise numbers but more or less fuzzy. The best up-to-date mathematical model for this imprecision is so-called non-precise numbers”. Therefore, the existing sudden death test plan can be applied if failure data or parameters are imprecise, incomplete, and fuzzy. The classical statistics have the special case of the neutrosophic statistics when there are no fuzzy observations/parameters. Thus, the neutrosophic fuzzy statistics can be applied for the testing of manufacturing parts when observations are imprecise, incomplete, and fuzzy. Recently, the authors of Reference [28] introduced the neutrosophic statistics in the area of acceptance sampling plan.

By exploring the literature, and to the best of the author’s knowledge, there is no work on the design of neutrosophic fuzzy sudden death testing plan using the Weibull distribution. In this paper, we will design an original neutrosophic fuzzy sudden death testing plan for the inspection/testing of the electronic product or parts manufacturing. We will assume that the lifetime of the product follows the neutrosophic fuzzy Weibull distribution. The neutrosophic fuzzy operating function will be given and used to determine the neutrosophic fuzzy plan parameters through a neutrosophic fuzzy optimization problem. The results of the proposed neutrosophic fuzzy death testing plan will be implemented with the aid of an example.

2. Design of Proposed Plan

Suppose that $T_{Ni} \in \{T_L, T_U\} = i = 1, 2, 3, \dots, n_N$ being a random sample from the neutrosophic fuzzy Weibull distribution with neutrosophic fuzzy shape parameter m_N and neutrosophic fuzzy scale parameter λ_N . The neutrosophic fuzzy Weibull distribution is defined by:

$$F_N(t_N; m_N, \lambda_N) = 1 - \exp\left(-\left(t_N/\lambda_N\right)^{m_N}\right), t_N \geq 0 \quad (1)$$

Some more details on fuzzy based Weibull distribution can be seen in References [29,30].

It is assumed that items are tested identically and simultaneously in each group. We propose following a neutrosophic fuzzy sudden death testing plan. The quality characteristic beyond the lower specification limit L is defined as defective. Thus, the probability of defectiveness is given by:

$$p_N = p_{r_N}\{T_N < L\} = F_N(L) \quad (2)$$

For the given p_N , the corresponding $\lambda_N L$ from Equation (2) is given by:

$$w_N = -\ln(1 - p_N) = (\lambda_N L)^{m_N} \quad (3)$$

Step 1. Select a random sample $n_N \in \{n_L, n_U\}$ and distribute r items into $g_N \in \{g_L, g_U\}$ groups.

Step 2. Record first failure from i th group ($i = 1, 2, \dots, g_N$) and calculate neutrosophic fuzzy statistic $v_N = \sum_{i=1}^{g_N} Y_{iN}^m; g_N \in \{g_L, g_U\}, v_N \in \{v_L, v_U\}$.

Step 3. Accept lot of the product if $v_N \geq k_N L^m$, $k_N \in \{k_{aL}, k_{aU}\}$ is a neutrosophic fuzzy acceptance number.

The proposed plan has two neutrosophic fuzzy parameters $g_N \in \{g_L, g_U\}$ and $k_N \in \{k_{aL}, k_{aU}\}$. The proposed sampling plan is the extension of the plan proposed in Reference [1]. The proposed sampling plan reduces to the plan in Reference [1] when $g_L = g_U = g$ and $k_{aL} = k_{aU} = k$. The operational process of the proposed plan is also shown in Figure 1.

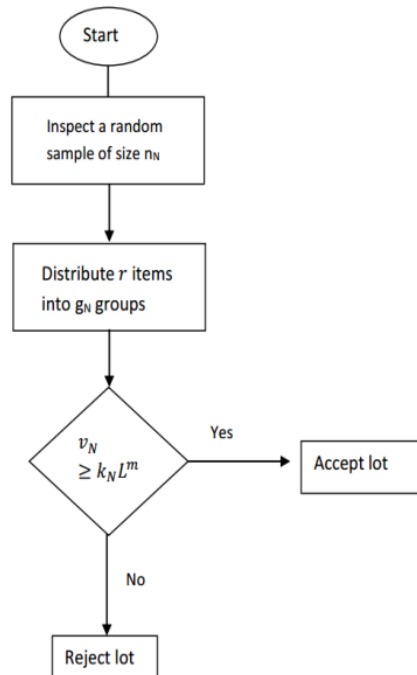


Figure 1. Operational procedure of proposed plan.

By following Reference [1] that Y_{iN}^m in $v_N = \sum_{i=1}^{g_N} Y_{iN}^m$ follows the i.i.d. neutrosophic exponential distribution with neutrosophic parameter $\lambda_N^{mN} r_N$, so v_N follows the neutrosophic fuzzy gamma distribution with neutrosophic parameters $(g_N, \lambda_N^{mN} r_N)$; $g_N \in \{g_L, g_U\}$. The neutrosophic fuzzy operating function (NFOC) will be derived as follows:

$$L(p_N) = 1 - G_{2g_N}(2r_N k_N w_N); k_N \in \{k_{aL}, k_{aU}\} \tag{4}$$

where G_{δ_N} is the neutrosophic fuzzy cumulative distribution function of the neutrosophic fuzzy gamma with a neutrosophic degree of freedom δ_N .

Neutrosophic Fuzzy Non-Linear Optimization

Let α and β respectively be the producer’s risk and consumer’s risk. The plan parameters $g_N \in \{g_L, g_U\}$ and $k_N \in \{k_{aL}, k_{aU}\}$ will be determined $L(C_{AQL}) \geq 1 - \alpha$ at acceptable quality level (AQL = p_1) and $L(C_{LQL}) \leq \beta$ at limiting quality level (LQL = p_2). Therefore, the neutrosophic fuzzy plan parameters of the proposed plan will be determined by following the neutrosophic fuzzy non-linear optimization problem:

$$\text{minimize } n_N \in \{n_L, n_U\} \tag{5}$$

$$L(C_{AQL}) = (1 - G_{2g_N}(2r_N k_N w_{N0})) \geq 1 - \alpha, k_N \in \{k_L, k_U\}; g_N \in \{g_L, g_U\} \tag{6}$$

$$L(C_{LQL}) = (1 - G_{2g_N}(2r_N k_N w_{N1})) \leq \beta, k_N \in \{k_L, k_U\}; g_N \in \{g_L, g_U\} \tag{7}$$

The plan parameters $g_N \in \{g_L, g_U\}$ and $k_N \in \{k_{aL}, k_{aU}\}$ will be determined through Equations (5)–(7) using the grid search method. The following algorithm is used to determine the plan parameters.

Step 1. Specify the value of r .

Step 2. Determine the values of g_N and k_N using the search grid method through Equations (5)–(7).

Step 3. Choose the parameters for the plan where indeterminacy interval in g_N is minimum.

The combinations that have smaller values of $n_N \in \{n_L, n_U\}$ are selected and reported in Tables 1 and 2. Table 1 reports for $g_N \in \{g_L, g_U\}$ and $k_N \in \{k_{aL}, k_{aU}\}$ when $r = 5$ and Table 2 reports for $g_N \in \{g_L, g_U\}$ and $k_N \in \{k_{aL}, k_{aU}\}$ when $r = 10$. From Tables 1 and 2, we noted the following trend in $g_N \in \{g_L, g_U\}$ and $k_N \in \{k_{aL}, k_{aU}\}$.

1. For the fixed values of neutrosophic parameters, $g_N \in \{g_L, g_U\}$ and $k_N \in \{k_{aL}, k_{aU}\}$ decrease as r increases from 5 to 10.
2. For the fixed values of neutrosophic parameters, $g_N \in \{g_L, g_U\}$ and $k_N \in \{k_{aL}, k_{aU}\}$ decrease as LQL increases.

Table 1. The neutrosophic plan optimal parameters when $r = 5$.

p_1	p_2		g_N	k_N	$L(C_{AQL})$	$L(C_{LQL})$
0.001	0.002	Min	19	2473.2	0.952163	0.099984
		Max	21	2717.5	0.962712	0.095018
	0.003	Min	8	783.6	0.953490	0.099964
		Max	10	953.3	0.975800	0.095052
	0.004	Min	6	462.9	0.969175	0.099899
		Max	8	592.6	0.988845	0.095073
	0.006	Min	4	222.1	0.973434	0.099858
		Max	6	311.3	0.994680	0.095147
	0.008	Min	3	132.6	0.970167	0.099792
		Max	5	201.2	0.996239	0.095123
	0.010	Min	3	106.0	0.983213	0.099699
		Max	5	160.8	0.998555	0.095117
	0.015	Min	2	51.5	0.971999	0.099838
		Max	4	89.4	0.998831	0.095418
0.020	Min	2	38.6	0.983592	0.099255	
	Max	4	66.9	0.999599	0.095298	
0.0025	0.005	Min	19	987.8	0.952444	0.099978
		Max	21	1085.3	0.962975	0.095069
	0.010	Min	6	184.6	0.969462	0.099904
		Max	8	236.3	0.988989	0.095133
	0.015	Min	4	88.5	0.973691	0.099564
		Max	6	123.9	0.994785	0.095364
	0.020	Min	3	52.7	0.983439	0.099924
		Max	5	80.0	0.996321	0.095083
	0.025	Min	3	42.1	0.983490	0.099512
		Max	5	63.8	0.998600	0.095342
0.030	Min	2	25.6	0.958424	0.099282	
	Max	4	44.4	0.997442	0.095051	
0.050	Min	2	15.2	0.984044	0.099320	
	Max	4	26.3	0.999624	0.096062	

Table 1. Cont.

p_1	p_2		g_N	k_N	$L(C_{AQL})$	$L(C_{LQL})$	
0.005	0.010	Min	19	492.7	0.952885	0.099908	
		Max	21	541.3	0.963371	0.095048	
	0.015	Min	8	155.8	0.954335	0.099875	
		Max	10	189.5	0.976377	0.095086	
	0.020	Min	6	91.9	0.969849	0.099547	
		Max	8	117.5	0.989243	0.095381	
	0.030	Min	4	43.9	0.974240	0.099688	
		Max	6	61.5	0.994931	0.095194	
	0.040	Min	3	26.1	0.971200	0.099658	
		Max	5	39.5	0.996491	0.096118	
	0.050	Min	3	20.8	0.983945	0.099161	
		Max	5	31.5	0.998668	0.095215	
0.100	Min	2	7.4	0.984787	0.099317		
	Max	4	12.8	0.999658	0.096182		
0.01	0.020	Min	19	245.1	0.953835	0.099928	
		Max	21	269.2	0.964273	0.095309	
	0.030	Min	8	77.3	0.955450	0.099925	
		Max	10	94.0	0.977123	0.095270	
	0.040	Min	5	39.2	0.950025	0.099569	
		Max	7	52.0	0.982409	0.095945	
	0.050	Min	4	26.1	0.955741	0.099193	
		Max	6	36.5	0.988705	0.095461	
	0.100	Min	3	10.2	0.984642	0.096525	
		Max	5	15.3	0.998813	0.096244	
	0.150	Min	2	4.8	0.975190	0.099150	
		Max	4	8.3	0.999095	0.096094	
0.200	Min	2	3.5	0.986232	0.098790		
	Max	4	6.0	0.999729	0.099160		
0.03	0.060	Min	19	80.1	0.957244	0.099165	
		Max	21	87.9	0.967418	0.095266	
	0.090	Min	8	25.0	0.959516	0.099143	
		Max	10	30.3	0.980098	0.096447	
	0.120	Min	5	12.6	0.954365	0.096610	
		Max	7	16.6	0.985015	0.096118	
	0.150	Min	4	8.3	0.960407	0.096094	
		Max	6	11.5	0.990833	0.096298	
	0.300	Min	2	2.2	0.954964	0.097352	
		Max	5	4.5	0.999285	0.098199	
	0.05	0.100	Min	18	44.9	0.953778	0.098375
			Max	20	49.4	0.965643	0.096049
0.150		Min	8	14.5	0.963878	0.099439	
		Max	10	17.6	0.982585	0.095869	
0.200		Min	5	7.2	0.960131	0.097749	
		Max	7	9.5	0.987505	0.096649	
0.250		Min	4	4.7	0.965761	0.095135	
		Max	6	6.5	0.992691	0.096047	
0.500		Min	2	1.2	0.961324	0.080608	
		Max	6	2.7	0.999915	0.095643	

Table 2. The neutrosophic plan optimal parameters when $r = 10$.

P_1	P_2		g_N	k_N	$L(C_{AQL})$	$L(C_{LQL})$
0.001	0.002	Min	19	1236.6	0.952163	0.099984
		Max	21	1358.7	0.962724	0.095049
	0.003	Min	8	391.8	0.953490	0.099964
		Max	10	476.6	0.975815	0.095115
	0.004	Min	6	231.5	0.969147	0.099791
		Max	8	296.3	0.988845	0.095073
	0.006	Min	4	111.1	0.973396	0.099670
		Max	6	155.6	0.994688	0.095301
	0.008	Min	3	66.3	0.970167	0.099792
		Max	5	100.6	0.996239	0.095123
	0.010	Min	3	53.0	0.983213	0.099699
		Max	5	80.4	0.998555	0.095117
	0.015	Min	2	25.8	0.971899	0.099239
		Max	4	44.7	0.998831	0.095418
0.020	Min	2	19.3	0.983592	0.099255	
	Max	4	33.4	0.999602	0.095903	
0.0025	0.005	Min	19	493.9	0.952444	0.099978
		Max	21	542.6	0.963004	0.095147
	0.010	Min	6	92.3	0.969462	0.099904
		Max	8	118.1	0.989014	0.095364
	0.015	Min	4	44.3	0.973597	0.099096
		Max	6	61.9	0.994805	0.095754
	0.020	Min	3	26.4	0.970450	0.099229
		Max	5	40.0	0.996321	0.095083
	0.025	Min	3	21.1	0.983387	0.098644
		Max	5	31.9	0.998600	0.095342
0.030	Min	2	12.8	0.958424	0.099282	
	Max	4	22.2	0.997442	0.095051	
0.050	Min	2	7.6	0.984044	0.099320	
	Max	4	13.1	0.999629	0.097616	
0.005	0.010	Min	19	246.4	0.952809	0.099739
		Max	21	270.6	0.963430	0.095205
	0.015	Min	8	77.9	0.954335	0.099875
		Max	10	94.7	0.976451	0.095405
	0.020	Min	6	46.0	0.969713	0.099008
		Max	8	58.7	0.989294	0.095848
	0.030	Min	4	22.0	0.974054	0.098745
		Max	6	30.7	0.994970	0.095980
	0.040	Min	3	13.1	0.970920	0.098260
		Max	5	19.7	0.996529	0.097257
0.050	Min	3	10.4	0.983945	0.099161	
	Max	5	15.7	0.998686	0.096635	
0.100	Min	2	3.7	0.984787	0.099317	
	Max	4	6.4	0.999658	0.096182	

Table 2. Cont.

P1	P2		g_N	k_N	$L(C_{AQL})$	$L(C_{LQL})$	
0.01	0.020	Min	19	122.6	0.953686	0.099588	
		Max	21	134.6	0.964273	0.095309	
	0.030	Min	8	38.7	0.955176	0.099196	
		Max	10	47.0	0.977123	0.095270	
	0.040	Min	5	19.6	0.950025	0.099569	
		Max	7	26.0	0.982409	0.095945	
	0.050	Min	4	13.1	0.955231	0.097616	
		Max	6	18.2	0.988843	0.096790	
	0.100	Min	3	5.1	0.984642	0.096525	
		Max	5	7.6	0.998847	0.099210	
	0.150	Min	2	2.4	0.975190	0.099150	
		Max	3	3.3	0.995249	0.097215	
0.200	Min	2	1.8	0.985482	0.090371		
	Max	4	3.0	0.999729	0.099160		
0.03	0.060	Min	19	40.1	0.956814	0.098132	
		Max	21	43.9	0.967745	0.096233	
	0.090	Min	8	12.5	0.959516	0.099143	
		Max	10	15.1	0.980490	0.098475	
	0.120	Min	5	6.3	0.954365	0.096610	
		Max	7	8.3	0.985015	0.096118	
	0.150	Min	4	4.2	0.958944	0.091311	
		Max	7	6.5	0.995704	0.098411	
	0.300	Min	2	1.1	0.954964	0.097352	
		Max	3	1.5	0.988671	0.098094	
	0.05	0.100	Min	18	22.5	0.952981	0.096593
			Max	20	24.7	0.965643	0.096049
0.150		Min	8	7.3	0.962650	0.095621	
		Max	10	8.8	0.982585	0.095869	
0.200		Min	5	3.6	0.960131	0.097749	
		Max	8	5.3	0.993116	0.097357	
0.250		Min	4	2.4	0.963476	0.086889	
		Max	8	4.1	0.998501	0.098851	
0.500		Min	2	0.6	0.961324	0.080608	
		Max	8	1.7	0.999996	0.099397	

3. Application of Proposed Plan

The application of the proposed plan will be given on the ball bearing quality assurance, as the quality characteristic is measurable and as there is a chance that some observations may be fuzzy. Suppose that the ball bearing manufacturer is interested in applying the proposed sampling plan, but is not certain how to select suitable plan parameters for the testing of his product. Suppose he decides to install five items on the single tester. Let $AQL = AQL = 0.001$, $LQL = 0.010$, $\alpha = 0.05$ and $\beta = 0.10$. From Table 1, we have $g_N \in \{3, 5\}$ and $k_N \in \{106.0, 160.8\}$. Hence, he can select g between 3 and 5. Suppose experimenter decides to select a random sample size $n = 25$ and $g = 5$.

Step 1. Select a random sample 25 and distribute five items into five groups.

Step 2. Perform sudden death testing and note down the first failure from each of the five groups ($i = 1, 2, \dots, 5$). The number of first failures from the five groups are $Y_1 = [220, 230]$, $Y_2 = [300, 320]$, $Y_3 = 285$, $Y_4 = [155, 165]$ and $Y_5 = [365, 375]$. The lifetime of ball bearing follows

the neutrosophic Weibull distribution with parameter $m_N \in \{2, 2\}$ and lower specification limit $L = 200$. The statistic v_N is calculated as:

$$v_N = \sum_{i=1}^{g_N} Y_{iN}^m; g_N \in \{3, 5\}, v_N \in \{106.0, 160.8\}$$

$v_N = [220^2, 230^2] + [300^2, 320^2] + [285^2, 285^2] + [155^2, 165^2] + [365^2, 375^2] = [376875, 404375]$. Now $k_N L^{m_N} \in \{4240000, 6432000\}$. As $v_N < k_N L^{m_N}$, so reject the lot of ball bearing product.

4. Comparison Study

In this section, we will compare the efficiency of the proposed plan using the neutrosophic statistics and the sudden death sampling plan proposed in Reference [2] using the classical (crisp) statistics in terms of plan parameter g . For fair comparison, we will consider the same plan parameter values. By comparing Table 1 of the proposed plan with Table 1 of Reference [2] when $r = 5$, it can be seen that the proposed plan provides smaller values of g as compared to the plan in Reference [2]. For easy reference, we present the comparison in g_N between the proposed plan and Reference [2] in Table 3. For example, when AQL = 0.001 and LQL = 0.002 in Table 3, the proposed plan has a minimum value of $g = 17$ and a maximum value of $g = 21$, while the plan in [2] provides a crisp value of $g = 231$. Therefore, the proposed plan needs a sample size of $n = r * g$ between 85 and 105. By comparison, the existing plan needs a sample size of 1155 for the testing of the same lot of the product. From Table 3, we note that the proposed plan has a smaller g_N for all combinations of AQL and LQL. Therefore, the proposed plan required a smaller sample size for the inspection of the same product. Hence, less inspection cost is needed when the proposed sampling plan is implemented.

Table 3. The comparison of proposed plan with the plan in Reference [2].

p_1	p_2	Proposed Plan	Existing Plan
		g_N	g
0.001	0.002	[19, 21]	231
	0.003	[8, 10]	154
	0.004	[6, 8]	115
	0.006	[4, 6]	77
	0.008	[3, 5]	58
0.05	0.100	[18, 20]	34
	0.150	[8, 10]	16
	0.200	[5, 7]	8

5. Concluding Remarks

In this paper, we have designed a neutrosophic fuzzy sudden death testing plan for the inspection/testing of the electronic product or parts manufacturing. The NFOC and neutrosophic fuzzy non-linear optimization problem are used to evaluate the proposed sampling plan. The proposed plan can be applied for the testing of parts when some observations or parameters are fuzzy. The proposed plan is the extension of a sudden death plan based on classical statistics. However, the proposed plan is more flexible than the plan based on classical statistics. Some tables are given and discussed with the help of a ball bearing example. The proposed plan can be applied for testing products in the automobile, aerospace and electronics industries. The proposed plan has the limitation that it can only be applied when the failure time follows the neutrosophic fuzzy Weibull distribution. The proposed plan for some other distribution can be considered as future research. The proposed sampling plan using big data can also be considered as future research.

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