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RESEARCH ARTICLE

Acceptance Sampling Plans based on Percentiles of Exponentiated Inverse Kumaraswamy Distribution

M Rami Reddy[1]*, B Srinivasa Rao[2], K Rosaiah[3]

1 Assistant Professor, Freshman Engineering Department, Lakireddy Bali Reddy College of Engineering, Mylavaram, NTR District, 521230, Andhra Pradesh, India
2 Professor, Department of Mathematics & Humanities, R.V.R & J.C College of Engineering, Chowdavaram, Guntur, 522019, Andhra Pradesh, India
3 Professor, Department of Statistics, Acharya Nagarjuna University, Guntur, Andhra Pradesh, India

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* **Corresponding author**.

ramireddy.munnangi@gmail.com

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Abstract

Objectives: To prepare the percentile-based acceptance sampling plans for the Exponentiated Inverse Kumaraswamy Distribution (EIKD) at a specific truncation time to inspect the defective lots corresponding to the desired acceptance level. **Methods:** The failure probability value is estimated using the cumulative probability function F(.) at time 't' which is converted in terms of the scale parameter σ as 100th percentile using quantile function. The minimum size of the sample, Operating Characteristic (OC) and the minimum ratios are calculated for a required levels of consumer's as well as producer's risk. **Findings:** The percentile-based sampling plans are obtained through the minimal size of the sample 'n' under a truncated life test with a target acceptance number c in a manner that the proportion of accepting a lot which is not good (consumer's risk) would not be more than $1-p^*$. These values are calculated at $p^*=0.75,\ 0.90,\ 0.95,\ 0.99$. The function of probability of acceptance for variations in the quality of a lot (OC function) L(p) of the sample plan are evaluated for the acceptance values of c=1 and c=5. The minimum ratio values are calculated for the acceptability of the lot with producers' risk of $\gamma=0.05$ using the sampling plan. **Novelty:** The modernity of this study is the designing of the acceptance sampling plans to a non-normal data using an asymmetrical distribution that has all three shape parameters. Also, the monitor of the implementation and suitability of statistical quality control and process control aspects using Exponentiated Inverse Kumaraswamy Distribution when compared to other asymmetrical distributions which has at least one scale parameter.

Keywords: Sampling plans; Consumer's risk; Operating characteristics function; Truncated life tests; Producer's risk

1 Introduction

Acceptance sampling is used in the entire quality improvement process, in establishing the quality systems and in measuring the improvement and evaluation of consumer satisfaction. Also, acceptance sampling is essential where the cost of 100% examination is not feasible or acceptable. The implementation of acceptance sampling depends on the selection of various kinds of data and the related quality standards. The process of acceptance sampling is established with the help of OC curves that illustrate the association between the probability of accepting a lot and the lot quality standard for a specified sampling plan.

In the conventional methods of sampling plans the mean life of the product is considered as the quality standard. Most of the studies prepared the sampling plans with the assumption of means life. Whereas the mean life of the product is suitable only when the data is symmetrical, in case of asymmetrical data the median value based on the percentiles of the distribution is best average as considered to be the quality standard than the mean value. It admits that a non-normal distribution has a significant role in the construction of sampling plans when the data fails normality.

Numerous studies regarding the construction of sampling plans using non-normal distributions that has one or more parameters. In these studies, the common factor is that, at least one of the parameters is a scale parameter. Few of these on truncated life tests are Singh et al.[(1)] proposed the sampling plans considering the quality parameter as the mean lifetime of the test unit for generalised Pareto distribution with one scale parameter out the three parameters, Al-Omari et al.[(2)] proposed the sample plans with the assumption that the population mean as quality standard with one shape and one scale parameter Quasi Shanker distribution. Amjad D et al.[(3)] developed population mean based sampling plans for Tsallis q-exponential distribution that has one shape and one real parameter, some studies suggested that sampling plans using the mean cannot meet the necessity of the process on the precise strength of percentile or breaking stress. If it is concerned with the quality of a predefined less percentile, the population mean based acceptance sample plans could pass a lot which has the low percentile below the desired level of customers. If the data ascertained as non-normal a surpassing approach is essential to draw the sampling plans. Yasar Mahmood et al.[(4)] designed the sampling plans with median as standard average using a skewed Topp-Leone Gompertz distribution with one of parameters as scale parameter, Srinivasa Rao et al. designed percentile based acceptance plans based on Odd generalized exponential log logistic distribution[(5)] and Type-II Generalized Log Logistic Distribution[(6)] having one of the parameters is a scale parameter. Some more analogous approaches of sampling plans with at least one scale parameter are exponentiated inverted weibull distribution[(7)],new-weighted exponential distribution[(8)],Gumbel distribution[(9)] contemplated by B. Srinivasa Rao et al., Ghadah Alomani, Amer I. and Al-Omari[(10)] prepared the sampling plans based on two-parameter Xgamma distribution as α as the scale parameter.

These references exhibit the study of sampling plans with a distribution which is asymmetric and having at least one scale parameter. As we observed that there was no study of sampling plans using a non-normal distribution with all shape parameters, with this perception we are interested in the construction of acceptance sampling plans by assuming a distribution with all three shape parameters. This study emphasizes the applicability and adaptability of a non-normal distribution that has all shape parameters.

In this article we have selected the Exponentiated Inverse Kumaraswamy distribution, consisting of three shape parameters to prepare the percentile-based sample plans under a truncated life test. The Operating Characteristic (OC) function and minimum ratio values are determined at desired levels of consumer's and producer's risk. The suitability and efficiency of the distribution is observed with illustration by considering two real data sets and a comparative study is made with other non-normal distributions. The summary and conclusions of the study is given at the end.

2 Methodology

In this section the distributional properties of EIKD, the failure function and procedure for estimating the least possible size of the sample, Operating Characteristic (OC) function and minimum ratio value at desired level of producer's risk are discussed.

2.1 Exponentiated Inverse Kumaraswamy Distribution

The probability density function $f(x)$, cumulative distribution function $F(x)$, other distributional properties and estimation of parameters of the preferred Exponentiated Inverse Kumaraswamy distribution (EIKD) with all three shape parameters is well-defined and derived by Fatima et al.[(11)],

The probability density function of the EIKD is,

$$f(x) = \alpha\lambda\beta\,(1+x)^{-(\alpha+1)}\left(1-(1+x)^{-\alpha}\right)^{\lambda\beta-1};\ 0<x<\infty,\ \alpha,\lambda,\beta>0. \tag{1}$$

The cumulative probability function is,

$$F(x) = \left[1-(1+x)^{-\alpha}\right]^{\lambda\beta};\ \alpha,\lambda,\beta > 0,\ 0 < x < \infty, \tag{2}$$

here α, λ *and* β are shape parameters.

The Reliability & Hazard functions are,

$$R(x) = 1 - [1-(1+x)^{-\alpha}]^{\beta\lambda}$$

$$H(x) = \frac{\alpha\beta\lambda(1+x)^{-(\alpha+1)}\left[1-(1+x)^{-\alpha}\right]^{\lambda\beta-1}}{1-\left[1-(1+x)^{-\alpha}\right]^{\beta\lambda}}$$

The graphs of density function and cumulative probability function presented in Figure 1, the Reliability function and Hazard function in Figure 2 .

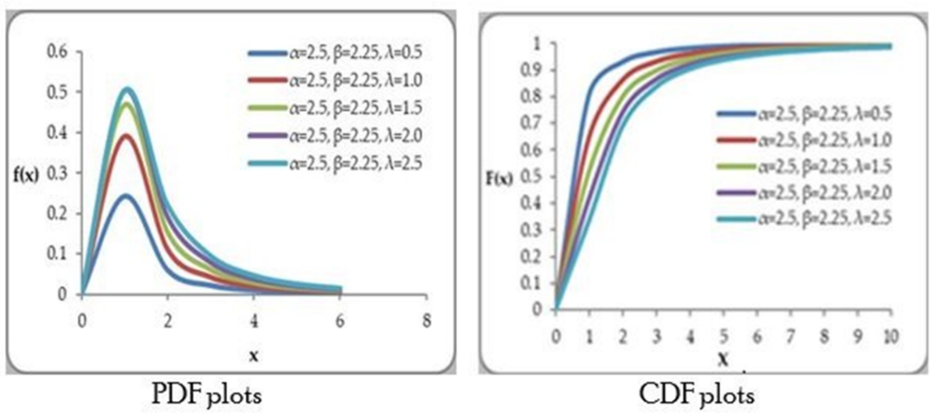

Fig 1. The pdf and cdf plots of EIKD

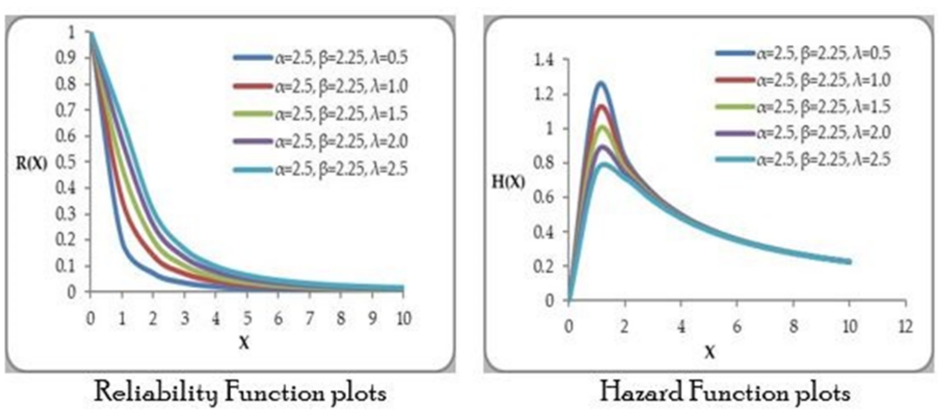

Fig 2. The Reliability & Hazard function plots of EIKD

Distributional Properties of EIKD:

$$Mean = \lambda\beta\, B\left(1-\frac{1}{\alpha}, \beta\lambda\right),\ \alpha > 1$$

$$Variance = \lambda\beta\, B\left(1-\frac{2}{\alpha},\ \beta\lambda\right) - \left\{\lambda\beta\, B\left(1-\frac{1}{\alpha},\beta\lambda\right)\right\}^2,\ \alpha > 2$$

Quantile Function

$$Q(u) = \left[\left(1-(u)^{\frac{1}{\beta\lambda}}\right)^{\frac{-1}{\alpha}} -1\right] \quad where\ \ u \sim U(0,1) \tag{3}$$

For $u = \frac{1}{2}$ in $Q(u)$

$$Median = \left[\left(1-(0.5)^{\frac{1}{\beta\lambda}}\right)^{\frac{-1}{\alpha}} -1\right]$$

2.2 Failure function of EIKD

The sampling plans are prepared with the help of failure function of the selected distribution and the single sampling plan is considered as the base plan in computing the minimum sampling size, OC values and minimum ratios. Tripathi H [12] suggested the construction the base plan with respect to "Transmuted Rayleigh distribution". The failure function of EIKD is obtained by considering its C.D.F and derived in the following way.

Let us consider the lifetime t follow Exponentiated Inverse Kumaraswamy distribution and its cdf F(.) is,

$$F(t) = \left[1-\left(1+\frac{t}{\sigma}\right)^{-\alpha}\right]^{\beta\lambda},\ t \geq 0,\ \sigma > 0. \tag{4}$$

As 0< q <1, the 100$^{\text{th}}$ percentile is,

$$t_q = \sigma\left[\left(1-q^{\frac{1}{\beta\lambda}}\right)^{-\frac{1}{\alpha}} -1\right]$$

$$\sigma = \frac{t_q}{\left[\left(1-q^{\frac{1}{\beta\lambda}}\right)^{-\frac{1}{\alpha}} -1\right]}$$

Substituting σ in Equation (4), then

$$F(t) = \left[1-\left\{1+\frac{t}{t_q}\left[\left(1-q^{\frac{1}{\beta\lambda}}\right)^{-\frac{1}{\alpha}} -1\right]\right\}^{-\alpha}\right]^{\beta\lambda}$$

Rewriting $F(t)$ as

$$F(t) = \left[1-\left\{1+\delta\left[\left(1-q^{\frac{1}{\beta\lambda}}\right)^{-\frac{1}{\alpha}} -1\right]\right\}^{-\alpha}\right]^{\beta\lambda} \tag{5}$$

where $\delta = \frac{t}{t_q}$.

In general, the life test procedure terminates the life test at a pre-assigned time "t", to the necessary possibility of declining the substandard lot is at least p^*, and to allow the maximum possible defectives in the lot for accepting is c. The percentile-based sampling plans is to estimate the least possible sample size "n" under a truncated life test at a specified level of acceptance 'c' such that the probability of accepting a bad lot (consumer's risk) would not be more than $1 - p^*$. If the true 100^{th} percentile t_q is less than a given percentile t_q^0, then the lot would be considered as a bad lot. Therefore, we can assume that the probability p^* is the level of confidence that a lot, which is not good would be rejected with a probability of at least p^* when $t_q < t_q^0$. Hence, for a specified p^*, the intended "acceptance sampling plan" would be established as a triplicate $(n, c, \delta) = \left(n, c, \frac{t}{t_q^0}\right)$ where $\delta = \frac{t}{t_q^0}$.

2.3 Minimum Sample Size

The present sample plan for a specific p^*, is considered as $\left(n, c, \frac{t}{t_q^0}\right)$. In the computation of smallest sample size, we apply binomial distribution. It is required to obtain the least non-negative number n for the assumed level of (p^*, t_q^0 , c) to assure the percentile $t_q > t_q^0$ must fulfil the condition as,

$$\sum_{i=0}^{c} \binom{n}{i} p_0^i (1 - p_0)^{n-i} \le (1 - p^*) \tag{6}$$

Where $p_0 = F_t(\delta_0)$ is considered as the probability of a defect through the factor of time $t = \delta t_q^0$ for a particular lifetime of t_q^0 at 100^{th} percentile. Where p_0 is based on $\delta_0 = \frac{t}{t_q^0}$,

since $\frac{\partial F_t(\delta)}{\partial \delta} > 0$, which is a non-diminishing function of δ.

2.4 Operating Characteristic (OC) function

The probability of acceptance for variations in a lot of quality is defined as OC function denoted by L(p) of sample plan $\left(n, c, \frac{t}{t_q^0}\right)$ as a relation of $p = F_t(\delta)$ for $\delta = \frac{t}{t_q}$.

Represented as

$$L(p) = \sum_{i=0}^{c} \binom{n}{i} p^i (1 - p)^{n-i} \tag{7}$$

Therefore, we have

$$p = F_t(\delta) = F\left(\frac{t}{t_q^0}\frac{1}{d_q}\right) \tag{8}$$

where $d_q = \frac{t_q}{t_q^0}$.

2.5 Minimum ratios at Producer's Risk

In quality control theory the probability of a lot being rejected is named as producer's risk when $t_q > t_q^0$. For a destined value of the producer's risk, say γ, our attention is to estimate the value of d_q to make sure that the producer's risk should be equal or under γ if any sample plan $\left(n, c, \frac{t}{t_q}\right)$ is prepared for an assured confidence level p^*. Hence, we need to determine the smallest value d_q in accordance with the Equation (7) as

$$\sum_{i=0}^{c} \binom{n}{i} p^i (1 - p)^{n-i} \tag{9}$$

with $p = F\left(\frac{t}{t_q^0}\frac{1}{d_q}\right)$

3 Results and discussion

The proposed sampling plans are discussed depending on the percentiles of a selected probability model that possess all three shape parameters. Said G. Nassr et al. [13] designed the sampling plans based on three-parameter inverted Topp–Leone model whereas one of them is a scale parameter. The prime objective of these plans is to attain the least possible size of the sample that needs to be inspected form the lot. The smallest size of the sample(n) satisfies Equation (6) is evaluated for a specific q, $\frac{t}{t_q^0}$, p^* values. Alternately, we need only $\frac{t}{\sigma}$, p^* to compute the smallest sample size, when the mean is considered as the quality standard. The proposed procedure is to obtain the smallest size of the sample n. In case, the required size of sample values is estimated using the 50$^{\text{th}}$ percentile then it would happen to be "the smallest sample size required to test that the population median life exceeds a given specified value". It is understood that the "median" is a better approximation as average value than the population mean in decision making regarding the quality of a lot. Hence, we may possibly assure that a sampling plan established using the population median of the selected probability model (EIKD) is more reasonable and inexpensive than that of population mean regarding n. Here, we presented the smallest sample sizes in **Supplementary Table A** for " $q = 0.50$; p^* = 0.75, 0.90, 0.95, 0.99; c = 0 to 10; δ = 0.1, 0.2, 0.4, 0.6, 0.8, 1.0, 1.5, 2.0, 2.5, 3.0".

The Operating Characteristic (OC) function values are evaluated using Equation (7) for the sample plan of $\left(n, c, \frac{t}{t_{0.5}^0}\right)$. These function values for " $p^* = 0.75,\ 0.90,\ 0.95,\ 0.99$; q=0.50 $\delta = 0.1,\ 0.2,\ 0.4,\ 0.6,\ 0.8,\ 1.0,\ 1.5,\ 2.0,\ 2.5,\ 3.0$ and $\frac{t_{0.5}}{t_{0.5}^0} = 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0$" are exhibited for the acceptance number c = 1 & 5 in **Supplementary Table B and C** respectively.

The values of minimum ratio of $d_{0.5}$ to approve the lot with producers' risk $\gamma = 0.05$ are calculated with the help of Equation (9) of the sample plan $\left(n, c, \frac{t}{t_{0.5}^0}\right)$ as in **Supplementary Table A**, that are catalogued in **Supplementary Table D**.

These results of the sampling plans demonstrate that when the termination ratio (δ) and consumer's risk (β) increases the sample size decreases. The designed sampling plan results through EIKD are compared with the results of New Weibull–Pareto Distribution [14] (NWPD), Type-II Generalized Log Logistic Distribution [6] (TGLLD), and New-Weighted Exponential Distribution [8] (NWED). The comparative study is displayed in Table 1. It is clear evidence that a distribution with all three shape parameters (EIKD) provides comparatively minimum sample size like other distributions.

Table 1. Comparative study

		NWPD		TGLLD		NWED		EIKD	
β	c	δ=1.0	δ=1.5	δ=1.0	δ=1.5	δ=1.0	δ=1.5	δ=1.0	δ=1.5
0.25	1	15	8	5	3	5	4	5	3
	5	40	23	14	11	14	11	14	10
0.1	1	21	11	7	4	7	5	7	4
	5	50	28	19	14	17	12	17	12
0.05	1	25	14	8	5	8	6	8	5
	5	56	31	20	15	18	13	18	13
0.01	1	34	19	11	6	11	7	11	7
	5	69	38	23	16	22	16	22	15

The motive of any statistical quality measures is to optimise or minimise the consumer's and producer's risk, Facchinetti et al. [15] explained the Designing of single acceptance sample plans in an optimization-based approach under generalized beta distribution. The execution and applicability of the sampling plans are discussed with an application to electric carts data by A.I. Al-Omari et al. [16] corresponding to life tests for Akash distribution, and an application to Breaking Stress of Carbon Fibers Data by Shrahili et al. [14] with life tests depends on Percentiles of New Weibull–Pareto Distribution. The applicability of the present study based on EIKD is demonstrated with two real time illustrative examples.

3.1 Illustrative Examples

In this portion, the sampling plans prepared in the above sections are illustrated in two examples with real data sets.

Example 1: The given data set provides the times in between consecutive "failures of air conditioning (AC) equipment in a Boeing 720 aeroplane", which are {12, 21, 26, 27, 29, 29, 48, 57, 59, 70, 74, 153, 326, 386, 502}. To give the assurance of the confidence level with our acceptance sampling plans, the above lifetimes should follow the Exponentiated inverse Kumaraswamy distribution. So, it is required to check the goodness of fit to the data. This can be done by the familiar QQ plot technique, and we obtained R=0.9612. Figure 3 justifies that the Exponentiated inverse Kumaraswamy distribution established as good fit for the given data than the normal distribution. Suppose an analyst wishes to determine the actual unidentified 50$^{\text{th}}$ percentile lifetime for the "failures of air conditioning (AC) equipment in a Boeing 720 aeroplane" considered to be minimum of 20 and the life test will be finished at 20, that leads to the ratio $\frac{t}{t^0_{0.5}} = 1.0$. Hence, with the allowable number of defective items as c=5 and the level of confidence $p^* = 0.75$, the analyst can obtain the required size of sample n from **Supplementary Table A**, is necessarily at least 14; therefore, the sample plan for this data is taken as

$$\left(n, c, \frac{t}{t^0_{0.5}}\right) = (14,\ 5,\ 1.0) \tag{10}$$

Which enables us to consider that the lot should be agreed only if the number of items with failure time less than or equal to the scheduled failure time of 20, was at most 5 among the first 14 observations. Because there is only one item less than or equal to 20 in the considered data set of 15 values, the analyst would have accepted the lot, with an assumption of the 50th percentile failure time $t_{0.5}$ of minimum 20 with " $p^* = 0.75$ ". The OC values in Equation (10) and with an assurance level $p^* = 0.75$, for EIKD can be obtained from **Supplemetary Table C** as

Table 2.

$\frac{t_{0.5}}{t^0_{0.5}}$	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
OC	0.2120	0.6898	0.8883	0.9561	0.9809	0.9909	0.9953	0.9974	0.9985

It states that when the true 50th percentile is same as the expected 50th percentile $\left(\frac{t_{0.5}}{t^0_{0.5}} = 1.0\right)$, the probability of rejecting a good lot is nearly 0.7880 (1-0.2120), whereas this probability is close to 0.0439, when the true 50th percentile is 2.5 times more or equal to expected 50th percentile. From **Supplementary Table D**, the analyst can have the values of $d_{0.5}$ for various values of c and $\frac{t_{0.5}}{t^0_{0.5}}$ in order to assure that the producers' risk is less than 0.05. Here the ratio value of $d_{0.5}$ will be 2.1249 for c=5, $\frac{t_{0.5}}{t^0_{0.5}}$ =2.5 and $p^* = 0.75$, which indicates that the item will have a 50th percentile life as 2.1249 times than the expected 50th percentile life according to the above sample plan, we can accept the product with at least 0.75 probability.

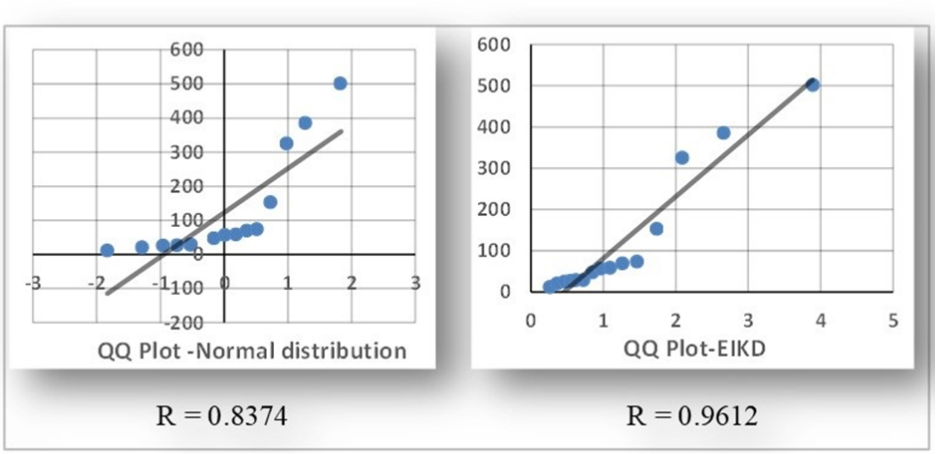

Fig 3. QQ plots of Normal Distribution and EIKD

Example 2: The other data set regarding the "failure or censoring times of 36 appliances subjected to an automatic life test". The figures specified here are the failure times: "11, 35, 49, 170, 329, 381, 708, 958, 1062, 1167, 1594, 1925, 1990, 2223, 2327, 2400, 2451, 2471, 2551, 2565, 2568, 2694, 2702, 2761, 2831, 3034, 3059, 3112, 3214, 3478, 3504, 4329, 6367, 6976, 7846, 13403".

Suppose an examiner wants to set up the actual unknown median lifetime of the data set about the "failure or censoring times of 36 appliances related to an automatic life test" considered in this example to be at least 100 and this life test is supposed to be finished at 250, where the ratio $\frac{t}{t^0_{0.5}}$=2.5. The goodness of fit test of these 36 values was confirmed that the Exponentiated Inverse Kumaraswamy model is a rational goodness of fit for these 36 values with R=0.9754. Figure 4 justifies that this model establishes a satisfactory goodness of fit for example-2 than the normal distribution. Hence, for c=5 and $p^* = 0.90$, the examiner would locate from **Supplementary Table A** that the size of the sample need to be minimum of 9 and the corresponding sample plan is $\left(n, c, \frac{t}{t_{0.5}^{0}}\right) = (9,\ 5,\ 2.5)$. Since, there are only 4 values with failing time fewer to 250 from this dataset of 36 values, the investigator may accept the lot, assuming that 50th percentile life-time $t_{0.5}$ of at least 100 with $p^* = 0.90$ level of confidence.

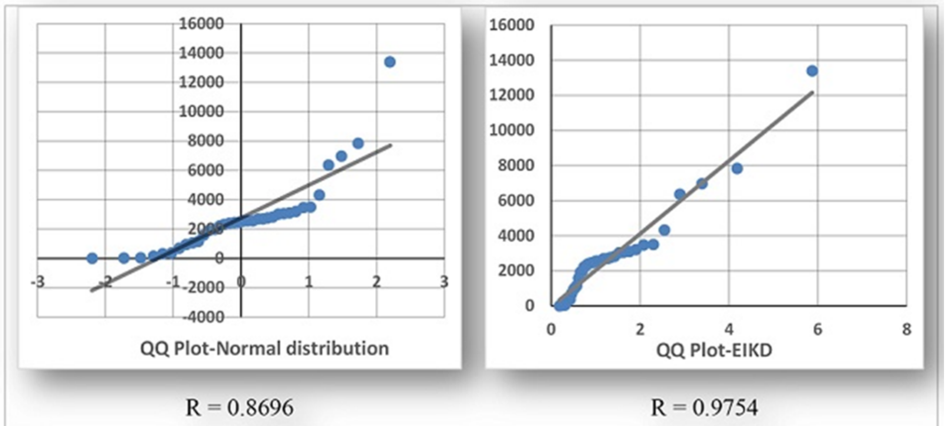

Fig 4. QQ plots of Normal distribution and EIKD

4 Conclusion

This article provides the minimum sample size that is necessary to conclude whether a lot is to be accepted or rejected based on its prescribed 50th percentile (median) with the help of a non-normal distribution (EIKD) with all shape parameters. The present study facilities the implementation of sampling plans to any real time application based on a distribution like EIKD can perform with better results when compared to any other similar distribution. In realistic situations, generally, a sample is assumed with a specified number. If that sample size is small, then we may take the help of the tables presented in this chapter of acceptance sampling plans to choose the number of imperfections (c) allowed and the maximum value for the median to be accepted or rejected with a specified probability of acceptance p^*. Also, our study describes the probability function of acceptance of the lot corresponding its variations in terms of the operating characteristic function. This study supports the execution of advanced sampling plans like Group sampling plans, Hybrid group sampling plans, sequential sampling plans etc., based on a distribution like EIKD.

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