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E-Mail :
editor.ijasem@gmail.com
editor@ijasem.org

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New Extended Half Logistic Distribution – Properties and Estimation

Y.Ananda Reddy, M.Sc(Statistics);M.Sc(Mathematics)*1., G. Dhana Lakshmi, M.Sc(Statistics)* 2

ABSTRACT

In this paper, we proposed a New Extended Half Logistic Distribution (NEHLD) with some properties. We defined the NEHLD and also derived properties like moments, moment generating function, characteristic function and cumulative generating function. The method of Maximum Likelihood Estimation was used to estimate and evaluate the unknown parameters of the NEHLD illustrated by a life time data set.

Key words: Distribution; Half Logistic; Reliability; Hazard Function; Maximum Likelihood Estimation.

1. Introduction

Statistical distribution and dissemination play a vital role in analyzing and assessing the authentic scenario of the real world. Indeed, the fact that moderate number of distributions has been developed. There is always scope to developing distributions, analyzing their properties that are more flexible or to adjust real world scenarios. The researchers are continually urging for establishing new and more flexible distributions. For that reason, many new distributions have been emerged and studies. In current works, new distributions are outlined by means of including one or more parameters to a distribution functions. Such an addition of parameters makes the ensuing distribution richer for modeling life time data. The generalized distributions have been invented to characterize different phenomena. These generalized distributions are also having a greater number of parameters. Johnson *et al.* (1994) clearly emphasized the four parameter distributions that are much essential for the workable situations. Many authors were not having crystal-clear opinion on whether three parameters or more than three were necessary for a better analysis. Adding too many parameters to the distribution may not help for a successful inference. "This idea to add a shape parameter gave rise to several models, including the proportional hazards model (PHM), the power transformed model (PTM), the proportional odds model (POM), and the proportional reversed hazard model (PRHM)". In recent years, many of the distributions have been developed based on the beta distribution. The cumulative distribution function (cdf) of generalized beta distribution for the random variable (X) is defined by,

***1. HOD, Dept. of Statistics, Siva Sivani Degree College, Sec'Bad – 100**

*** 2. Lecturer, Dept. of Statistics, Siva Sivani Degree College, Sec'Bad – 100**

$$F(x) = \frac{1}{B(\alpha,\beta)} \int_0^{G(x)} t^{\alpha-1}(1-t)^{\beta-1}\, dt;\ t>0,\alpha,\beta>0 \quad (1)$$

where G(x) is the Cumulative Distribution Function of any other distribution. The above function is an example of invention of new distribution by addition of parameter(s). The following authors who studied the above class of distributions are "Eugene *et al.* (2002), Nadarajah and Kotz (2004, 2006), Famoye *et al.* (2005), Kozubowski and Nadarajah (2008), Akinsete *et al.* (2008), Akinsete and Lowe (2009)". By studying all these articles, we decided to develop a new generalized distribution.

Introducing a flexible distribution by adding a parameter that acts as both a shape parameter and a scale parameter ensures accuracy when fitting datasets in medicine, reliability engineering, and finance. This study has mainly focused on the shape or scale parameters which can accurately determine the new family distributions. The level of flexibility may increase due to introduce both parameters shape and scale.

For generalizing the existing probability distributions, a new family distribution is introduced by adding scale, shape and location parameters. One of the most interesting ways to add shape parameters to an existing distribution is exponentiation. Augmented family precursors from Mudholkar and Srivastava (1993) are defined by the following cdf.

$$G(x;c,\xi) = F(x;\xi)^c, c,\xi>0, x\in R, \quad (2)$$

where c is considered as the additional shape parameter.

The prominent authors like Marshall and Olkin initiated a novel introducing a single-scale parameter to a family distribution. Marshall-Olkin's (MO) (1997) cdf of family is as follows

$$G(x,\sigma,\xi) = \frac{F(x;\xi)}{\sigma+(1-\sigma)F(x;\xi)}, \sigma,\xi>0, x\in R, \quad (3)$$

where σ is taken as an extra parameter.

Cordeiro and Castro proposed (2011) developed a new family of generalized distributions defined by

$$G(x;k,m,\xi) = 1\text{-}\left(1-F(X;\xi)^k\right)^m, k,m,\xi>0, x\in R, \quad (4)$$

Undeniably the scale and shape parameters increase the degree of flexibility in the family distribution, but on the other hand the huge increase in the parameters, may also affect the calculation of mathematical functions making things more complex and complicated.

Attempts to introduce probability distributions with greater flexibility by introducing an additional parameter that is both a scale parameter and a shape parameter, thus providing higher accuracy for fitting to real data in applications such as reliability engineering, medicine, finance. Therefore, this paper aims to propose the latest method to introduce advanced statistical distributions. The proposed family can be named as the new extended half logistic distribution (NEHLD) family. Let X be a random variable follows the proposed family then the cumulative distribution function is given by

$$G(x;\gamma;\delta) = 1-\left[\frac{1-F(x,\delta)^2}{1-(1-\gamma)F(x,\delta)^2}\right]^{\gamma}, \gamma>0, \delta>0, x\in R \quad (5)$$

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2. New Extended Half Logistic Distribution

Here we introduced the New Extended Half Logistic Distribution (NEHLD). By considering the Half-Logistic distribution with scale parameter $\delta > 0$, the cdf and probability density function (pdf) of Half Logistic distribution are given by

$$F(x) = \frac{1-e^{-x/\delta}}{1+e^{-x/\delta}};\ x,\delta > 0 \qquad (6)$$

and $$f(x) = \frac{2e^{-x/\delta}}{\delta(1+e^{-x/\delta})^2};x,\delta > 0 \qquad (7)$$

The cdf of the NEHLD is given by

$$G(x;\delta,\gamma) = 1-\left[\frac{1-\left(\frac{1-e^{x/\delta}}{1+e^{-x/\delta}}\right)^2}{1-(1-\gamma)\left(\frac{1-e^{x/\delta}}{1+e^{-x/\delta}}\right)^2}\right]^\gamma$$

$$G(x,\delta,\gamma) = 1-\left[\frac{4}{4+\gamma\left(e^{x/\delta}+e^{-x/\delta}\right)-2\gamma}\right]^\gamma ;x \geq 0,\ \delta,\gamma > 0 \qquad (8)$$

The pdf of the NEHLD is

$$g(x;\delta,\gamma) = \frac{4^\gamma \gamma^2\left(e^{x/\delta}-e^{-x/\delta}\right)}{\delta\left[4+\gamma\left(e^{x/\delta}+e^{-x/\delta}-2\right)\right]^{\delta+1}};\ x \geq 0,\delta,\gamma > 0 \qquad (9)$$

Reliability function of NEHLD is given by

$$R(x) = 1-G(x)$$

$$= 1-\left[1-\left[\frac{4}{4+\gamma\left(e^{x/\delta}+e^{-x/\delta}\right)-2\gamma}\right]^\gamma\right]$$

$$R(x) = \left[\frac{4}{4+\gamma\left(e^{x/\delta}+e^{-x/\delta}\right)-2\gamma}\right]^\gamma \qquad (10)$$

Hazard function is given by

$$h(x) = \frac{g(x)}{R(x)}$$

$$= \frac{\dfrac{4^\gamma \gamma^2\left(e^{x/\delta}-e^{-x/\delta}\right)}{\delta\left[4+\gamma\left(e^{x/\delta}+e^{-x/\delta}-2\right)\right]^{\delta+1}}}{\left[\dfrac{4}{4+\gamma\left(e^{x/\delta}+e^{-x/\delta}\right)-2\gamma}\right]^\gamma}$$

$$h(x) = \frac{\gamma^2\left(e^{x/\delta}-e^{-x/\delta}\right)}{\delta\left[4+\gamma\left(e^{x/\delta}+e^{-x/\delta}-2\right)\right]} \qquad (11)$$

With different combination values of the parameters shapes of the distribution, density, reliability and hazard functions of the NEHLD are given from Figure 1 to Figure 4 respectively.

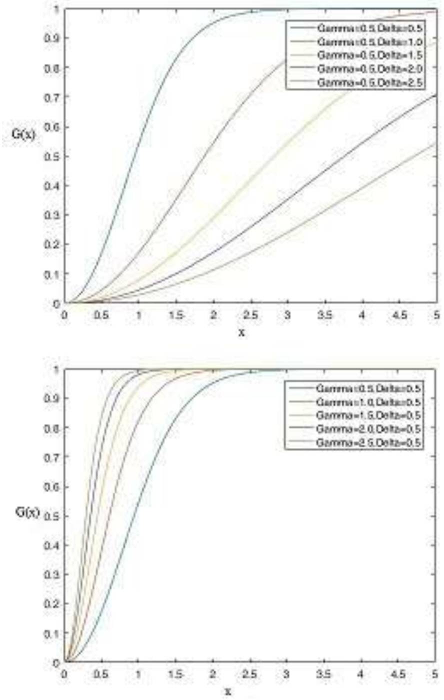

Figure 1: Some shapes of the cdf of the NEHLD

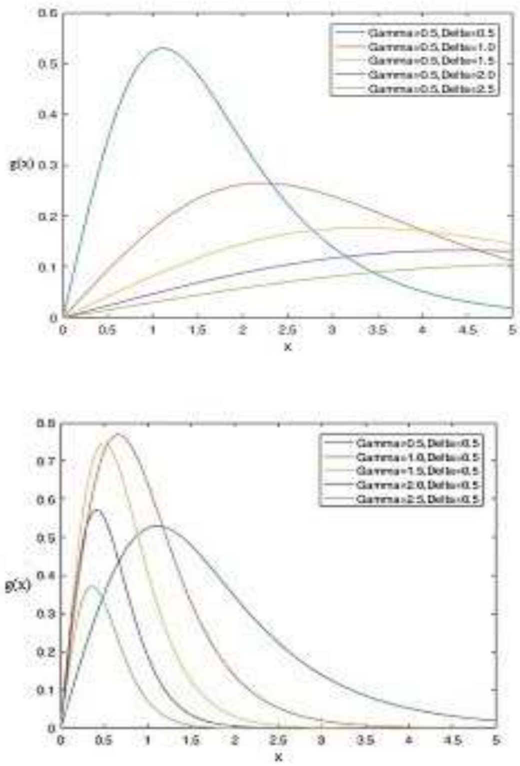

Figure 2: Shapes of the pdf of NEHLD

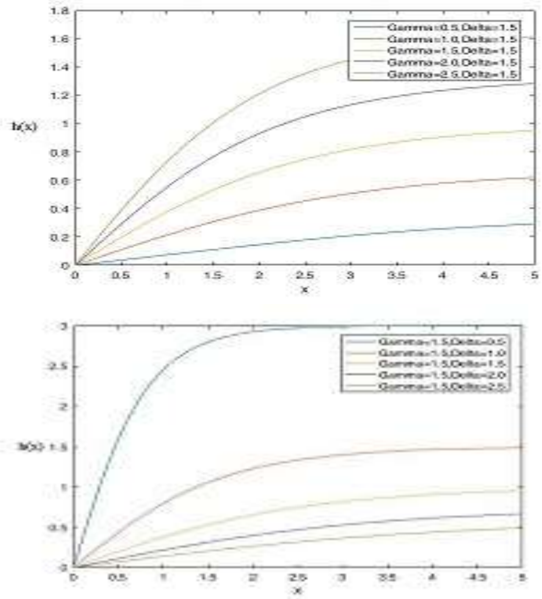

Figure 3: Shapes of the hazard function of NEHLD

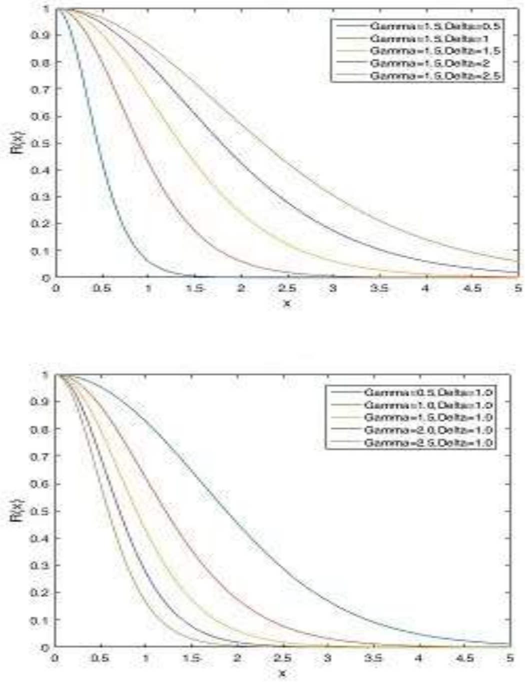

Figure 4: Shapes of the reliability function of NEHLD

3. PROPERTIES OF THE NEHLD

Here, we study the properties of NEHLD such as quantile function, r^{th} moment, MGF, CF and CGF.

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Quantile Function:

The quantile function of the NEHLD is given by

$$q = 1 - \left[\frac{1 - \left(\frac{1 - e^{x/\delta}}{1 + e^{-x/\delta}} \right)^2}{1 - (1-\gamma)\left(\frac{1 - e^{x/\delta}}{1 + e^{-x/\delta}} \right)^2} \right]^{\gamma}$$

$$x_q = \delta * \ln \left[\left(\frac{2\left(1 - (1-q)^{1/\gamma}\right)}{\gamma (1-q)^{1/\gamma}} + 1 \right) \pm \sqrt{\left(\frac{2\left(1 - (1-q)^{1/\gamma}\right)}{\gamma (1-q)^{1/\gamma}} + 1 \right)^2 - 1} \right]$$

(12)

Moments

The r[th] moment of the NEHLD is given by

$$\mu_r^{'} = \int_{-\infty}^{\infty} x^r g(x, \delta, \gamma)\, dx$$

$$= \int_{-\infty}^{\infty} x^r \frac{4^{\gamma} \gamma^2 \left(e^{x/\delta} - e^{-x/\delta}\right)}{\delta \left[4 + \gamma\left(e^{x/\delta} + e^{-x/\delta} - 2\right)\right]^{\delta+1}}\, dx$$

$$\mu_r^{'} = 2\gamma^2 \sum_{i=0}^{\infty} \sum_{j=0}^{\gamma-1} \binom{i+\gamma}{\gamma} \binom{\gamma-1}{j} (1-\gamma)^i (-1)^j M_{r,2(i+j)+1}$$

(13)

Where

$$M_{r,2(i+j)+1} = \int_{-\infty}^{\infty} x^r f(x) \left[F(x)\right]^{2(i+j)+1} dx$$

Moment Generating Function:

In this sub secession we calculate the Moment Generating Function by using the moment function. The Moment Generating Function of the NEHLD is given by

$$M_x(t) = \sum_{r=0}^{\infty} \frac{t^r}{r!} \mu_r^{'}$$

$$= \sum_{r=0}^{\infty} \frac{t^r}{r!} 2\gamma^2 \sum_{i=0}^{\infty} \sum_{j=0}^{\gamma-1} \binom{i+\gamma}{\gamma} \binom{\gamma-1}{j} (1-\gamma)^i (-1)^j M_{r,2(i+j)+1}$$

$$M_x(t) = 2\gamma^2 \sum_{r=0}^{\infty} \sum_{i=0}^{\infty} \sum_{j=0}^{\gamma-1} \frac{t^r}{r!} \binom{i+\gamma}{\gamma} \binom{\gamma-1}{j} (1-\gamma)^i (-1)^j M_{r,2(i+j)+1}$$

(14)

Characteristic Function:

The characteristic function is given by

$$\phi_x(t) = \sum_{r=0}^{\infty} \frac{(it)^r}{r!} \mu_r^{'}$$

$$= \sum_{r=0}^{\infty} \sum_{i=0}^{\infty} \sum_{j=0}^{\gamma-1} \frac{(it)^r}{r!} 2\gamma^2 \binom{i+\gamma}{\gamma} \binom{\gamma-1}{j} (1-\gamma)^i (-1)^j M_{r,2(i+j)+1}$$

$$\phi_x(t) = 2\gamma^2 \sum_{r=0}^{\infty} \sum_{i=0}^{\infty} \sum_{j=0}^{\gamma-1} \frac{(it)^r}{r!} \binom{i+\gamma}{\gamma} \binom{\gamma-1}{j} (1-\gamma)^i (-1)^j M_{r,2}$$

(15)

Cumulative Generating Function:

By taking the logarithm for Moment Generating Function, we obtain Cumulative Generating Function i.e.

$$k_x(t) = \ln\left(M_x(t)\right)$$

$$k_x(t) = \ln\left(2\gamma^2 \sum_{r=0}^{\infty} \sum_{i=0}^{\infty} \sum_{j=0}^{\gamma-1} \frac{t^r}{r!} \binom{i+\gamma}{\gamma} \binom{\gamma-1}{j} (1-\gamma)^i (-1)^j M_{r,}\right.$$

(16)

Order Statistics

Suppose $X_1, X_2, \ldots\ldots, X_n$ is a random sample from the pdf of NEHLD. Let $X_{(1)}, X_{(2)}, \ldots\ldots, X_{(n)}$ denotes the ordered statistics obtained from a random sample of NEHLD. The probability density and the cumulative distribution functions of the k^{th} order statistics, say $Y = X_{(k)}$ are as follows.

$$f_Y(y) = \frac{n!}{(k-1)!(n-k)!} F^{k-1}\left[1-F(y)\right]^{n-k} f(y)$$

(17)

and $F_Y(y) = \sum_{j=k}^{n} \binom{n}{j} F^j(y)\left[1-F(y)\right]^{n-j}$

4. Maximum Likelihood Estimation

The most preferred method to estimate and evaluate the unknown and unidentified parameters is the Maximum Likelihood Estimation which is shortly known as MLE. This method is extensively used as it is asymptotically consistent, unbiased and normal as the sample size tends to large. The MLE, to estimate the parameters of certain distributions does not yield explicit solutions from complete/censored samples. However, the MLE method is currently one of the most used methods of estimation, for its versatile and provides reliable results. These parameters are obtained by maximizing the likelihood function of the model under consideration.

By using the MLE method, we can estimate the parameters of NEHLD. The likelihood and log likelihood functions are given by

$L = \prod_{i=1}^{n} g(x_i, \delta, \gamma)$ and

$$\log L = \log\left[\prod_{i=1}^{n} g(x_i, \delta, \gamma)\right]$$

$$= \log\left[\frac{2^{n\gamma}\gamma^{2n}\prod_{i=1}^{n}\left(\frac{e^{x_i/\delta} - e^{-x_i/\delta}}{2}\right)}{\delta^n \prod_{i=1}^{n}\left(2+\gamma\left(\frac{e^{x_i/\delta}+e^{-x_i/\delta}}{2}\right)-1\right)^{\delta+1}}\right]$$

$$\log L = n\gamma\log 2 + 2n\log\gamma + \sum_{i=1}^{n}\log B_i - n\log\delta - (\gamma+1)\sum_{i=1}^{n}\log\left[2+\gamma(A_i-1)\right]$$

where $A_i = \frac{e^{x_i/\delta}+e^{-x_i/\delta}}{2}$ and $B_i = \frac{e^{x_i/\delta}-e^{-x_i/\delta}}{2}$

We can obtain the Maximum Likelihood estimates of the parameters δ and γ by solving the first derivatives of the equations.

$$\frac{\partial \log L}{\partial \delta} = 0$$

$$\frac{\partial}{\partial\delta}\left(n\gamma\log 2 + 2n\log\gamma + \sum_{i=1}^{n}\log B_i - n\log\delta - (\gamma+1)\sum_{i=1}^{n}\log\left[2+\gamma(A_i-1)\right]\right) = 0$$

$$-\frac{n}{\delta} - \sum_{i=1}^{n}\frac{\left(e^{x_i/\delta}+e^{-x_i/\delta}\right)x_i}{\delta^2\left(e^{x_i/\delta}-e^{-x_i/\delta}\right)} + \left(\gamma^2+\gamma\right)\sum_{i=1}^{n}\frac{\left(e^{x_i/\delta}-e^{x_i/\delta}\right)x_i}{\delta^2\left(4+\gamma\left(e^{x_i/\delta}+e^{-x_i/\delta}-2\right)\right)} = 0$$

(18)

$$\frac{\partial \log L}{\partial \gamma} = 0$$

$$\frac{\partial}{\partial\gamma}\left(n\gamma\log 2 + 2n\log\gamma + \sum_{i=1}^{n}\log B_i - n\log\delta - (\gamma+1)\sum_{i=1}^{n}\log\left[2+\gamma(A_i-1)\right]\right) = 0$$

$$n\log 2 + \frac{2n}{\gamma} - \left[(\gamma+1)\sum_{i=1}^{n}\frac{e^{x_i/\delta}+e^{-x_i/\delta}-2}{4+\gamma\left(e^{x_i/\delta}+e^{-x_i/\delta}-2\right)} + \sum_{i=1}^{n}\left\{\frac{4+\gamma\left(e^{x_i/\delta}+e^{-x_i/\delta}-2\right)}{2}\right\}\right] = 0$$

(19)

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The second order derivatives of the log likelihood function of NEHLD with respect to the parameter δ and γ are

$$\frac{\partial^2 \log L}{\partial \delta^2} = \frac{\partial}{\partial \delta}\left(-\frac{n}{\delta} - \sum_{i=1}^{n} \frac{\left(e^{x_i/\delta} + e^{-x_i/\delta}\right)x_i}{\delta^2\left(e^{x_i/\delta} - e^{-x_i/\delta}\right)} + \left(\gamma^2 + \gamma\right)\sum_{i=1}^{n} \frac{\left(e^{x_i/\delta} - e^{x_i/\delta}\right)x_i}{\delta^2\left(4 + \gamma\left(e^{x_i/\delta} + e^{-x_i/\delta} - 2\right)\right)}\right)$$

$$= \left\{\frac{n}{\delta^2} - \sum_{i=1}^{n} \frac{x_i^2 - 2x\delta A_i B_i}{\left[\delta^2 B_i\right]^2} + \left(\gamma^2 + \gamma\right)\sum_{i=1}^{n} \frac{-x_i^2\gamma + (\gamma - 2)x_i^2 A_i - x_i B_i\left(4\delta + 2\delta\gamma\left(A_i - 1\right)\right)}{\left[\delta^2\left[2 + \gamma\left(A_i - 1\right)\right]\right]^2}\right\} \quad (20)$$

$$\frac{\partial^2 \log L}{\partial \gamma^2} = \frac{\partial}{\partial \gamma}\left(\log 2 + \frac{2n}{\gamma} - \left[(\gamma + 1)\sum_{i=1}^{n} \frac{e^{x_i/\delta} + e^{-x_i/\delta} - 2}{4 + \gamma\left(e^{x_i/\delta} + e^{-x_i/\delta} - 2\right)} + \sum_{i=1}^{n}\left\{\frac{4 + \gamma\left(e^{x_i/\delta} + e^{-x_i/\delta} - 2\right)}{2}\right\}\right]\right)$$

$$= -\frac{2n}{\gamma^2} + \left\{(\gamma + 1)\sum_{i=1}^{n} \frac{\left[e^{x_i/\delta} + e^{-x_i/\delta} - 2\right]^2}{\left[4 + \gamma\left(e^{x_i/\delta} + e^{-x_i/\delta} - 2\right)\right]^2}\right\} - 2\sum_{i=1}^{n} \frac{\left[e^{x_i/\delta} + e^{-x_i/\delta} - 2\right]}{\left[4 + \gamma\left(e^{x_i/\delta} + e^{-x_i/\delta} - 2\right)\right]} \quad (21)$$

$$\frac{\partial^2 \log L}{\partial \delta\, \partial \gamma} = \frac{\partial^2 \log L}{\partial \gamma\, \partial \delta} = \sum_{i=1}^{n} \frac{xB_i\left[4\gamma + 2 + \gamma^2\left(A_i - 1\right)\right]}{\delta^2\left[2 + \gamma\left(A_i - 1\right)\right]^2}$$

(22)

Asymptotic Confidence Interval

Here an attempt has been made to derive the asymptotic confidence intervals of the unknown parameters δ and γ. Using large sample approach and assume that the distribution of MLE's of (δ, γ) which are approximately multivariate normal with mean (δ, γ) and variance-covariance matrix I^{-1}, where I^{-1} is observe information matrix which is given as

$$I^{-1} = \begin{bmatrix} \frac{\partial^2 \log L}{\partial \delta^2} & \frac{\partial^2 \log L}{\partial \delta \partial \gamma} \\ \frac{\partial^2 \log L}{\partial \delta \partial \gamma} & \frac{\partial^2 \log L}{\partial \gamma^2} \end{bmatrix}^{-1}_{\delta=\delta, \gamma=\gamma}$$

$$= \begin{bmatrix} \operatorname{var}(\delta) & \operatorname{cov}(\delta, \gamma) \\ \operatorname{cov}(\delta, \gamma) & \operatorname{var}(\gamma) \end{bmatrix}$$

5. Data Analysis:

In this section, we present the application of the proposed NEHLD for a real data set to illustrate its potentiality. The following real data sets are considered to estimate the unknown parameters of the proposed model by the maximum likelihood method. We considered the statistics – Cramer- Von mises (W) and Anderson-Darling (A) which are described in details by Chen and Balakrishnan (1995). In general, the smaller values of these statistics, the better fit to the data and also find another statistic – Kolmogorov Smirnov (KS) test, MLE, Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC), Consistent Akaike Information Criterion (CAIC), Minimum value of the log likelihood, Standard errors of the MLEs for better assessment.

Data set 1:

The data set is of the tests on the endurance of deep groove ball bearings. The data are the number of million revolutions before failure for each of the 23 ball bearings in life test given by Lawless (1982) and they are : 17.88, 8.92, 33.0, 41.52, 42.12, 45.60, 48.80, 51.84, 51.96, 54.12, 55.56, 67.80, 68.44, 68.64, 68.88, 84.12, 93.12, 98.64, 105.12, 105.84, 127.92, 128.04 and 173.40.

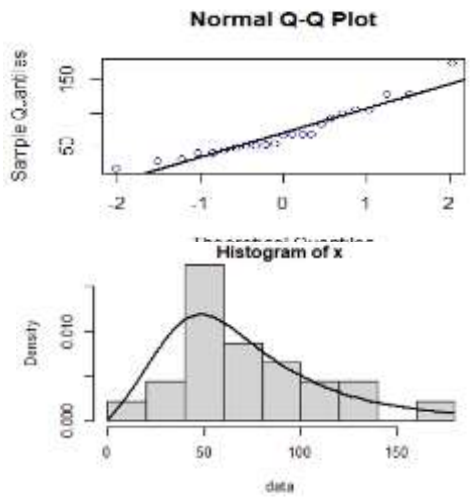

Figure 4: Q-Q Plot and Histogram for Data Set 1

Data set 2:

Data consists of 30 observations of March Precipitation (in inches) in Minneapolis/St Paul are given by Hinkley (1977). The sample observation values are as follows: 0.77, 1.74, 0.81, 1.20, 1.95, 1.20, 0.47, 1.43, 3.37, 2.20, 3.00, 3.09, 1.51, 2.10, 0.52, 1.62, 1.31, 0.32, 0.59, 0.81, 2.81, 1.87, 1.18, 1.35, 4.75, 2.48, 0.96, 1.89, 0.90, and 2.05.

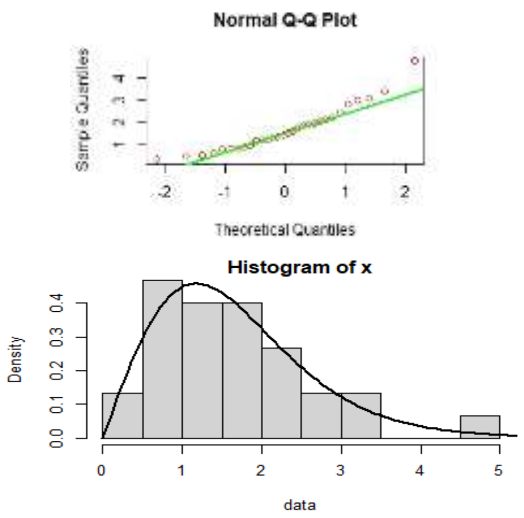

Figure 5: Q-Q Plot and Histogram for Data Set 1

Data set 3:

The data represents the survival times of 72 infected with virulent tubercle bacilli was report by Haq (2016). The survival time of the observations are as follows: 1.63, 1.63, 1.68, 1.71, 1.72, 1.76, 1.83, 1.95, 1.96, 1.97, 2.02, 2.13, 2.15, 2.16, 2.22, 2.30, 2.31, 0.1, 0.33, 0.44, 0.56, 0.59, 0.72, 0.74, 0.77, 0.92, 0.93, 0.96, 1.00, 1.00, 1.05, 1.02, 1.07, 0.7, 0.08, 1.08, 1.08, 1.09, 1.12, 1.13, 1.15, 1.16, 1.20, 1.21, 1.22, 1.22, 1.24, 1.3, 1.34, 1.36, 1.39, 1.44, 1.46, 1.53, 1.59, 1.60, 2.40, 2.45, 2.51, 2.53, 2.54, 2.54, 2.78, 2.93, 3.27, 3.42, 3.47, 3.61, 4.02, 4.32, 4.58, 5.55.

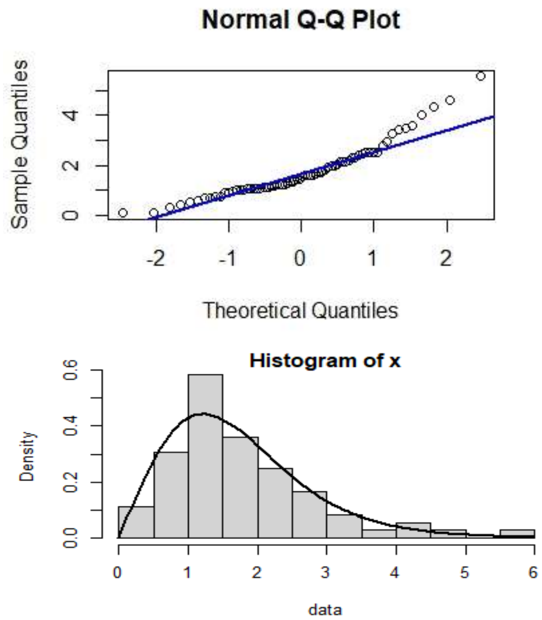

Figure 6: Q-Q Plot and Histogram for Data Set 1

It is obvious that the inferences drawn form the above three graphs prove NEHLD density function in collaboration with the histogram can provide more information. Histogram is provided a closer fit by the NEHLD. From the above observations, it is clear that the NEHLD model plays a vital role in accessing the information effectively and efficiently.

Table.1: Comparison of test statistics for different data sets

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Test Statistic	Data Set-1	Data Set-2	Data Set-3
W	0.03347025	0.01523	0.07729
A	0.1903106	0.11845	0.5103
K-S test	D = 0.1232, p-value = 0.8347	D = 0.0541, p-value = 1	D = 0.08452, p-value = 0.6825
MLE(δ,γ)	13.82267, 0.32327	3.55253,4.071856	3.644618,4.036472
AIC	231.6079	80.69767	197.7625
BIC	233.8788	83.50006	202.3158
CAIC	232.2079	81.14211	197.9364
Minimum log likelihood	113.8039	38.34883	96.88123
SE(MLEs)	9.0179, 0.27566	7.23, 7.7690	4.5129, 4.7040

6. Conclusion:

In this article, we have studied a new probability distribution called New Extended Half logistic distribution (NEHLD). The structural properties of this distribution have been studied and inferences on the parameters have also been mentioned. The real-life data sets were judicious use of the NEHLD.

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