On modeling of lifetime data using aradhana, sujatha, lindley and exponential distributions

Abstract

The modeling and statistical analysis of lifetime data are crucial for statisticians and researchers in almost all applied sciences including engineering, medical sciences/biological sciences, insurance, finance, amongst others. One parameter lifetime distributions that are popular in Statistics literature for modeling lifetime data are exponential and Lindley distributions. An extensive study has been carried out by Shanker et al., for modeling lifetime data using Lindley and exponential distributions and observed that there are many lifetime data where these distributions are not suitable from theoretical and applied point of view. Recently Shanker has introduced one parameter Lifetime distributions namely “Aradhana distribution” and “Sujatha distribution” for modeling lifetime data.

In the present paper the interrelationships and comparative studies of Aradhana, Sujatha, Lindley and exponential distributions have been made to model lifetime data. The relationships, their distributional properties and estimation of parameter have been discussed. The applications and goodness of fit of these distributions for modeling lifetime data through various examples from engineering, medical science and other fields have also been discussed and explained.

Keywords: aradhana distribution, sujatha distribution, lindley distribution, exponential distribution, statistical properties, estimation of parameter, goodness of fit

Introduction

The time to the occurrence of event of interest is known as lifetime or survival time or failure time in reliability analysis. The event may be failure of a piece of equipment, death of a person, development (or remission) of symptoms of disease, health code violation (or compliance). The modeling and statistical analysis of lifetime data are crucial for statisticians and researchers in almost all applied sciences including engineering, medical sciences/biological sciences, insurance and finance, amongst others.

Shanker has introduced one parameter continuous distributions named, “Aradhana distribution” and “Sujatha distribution” for modeling lifetime data from engineering and medical science and studied its various mathematical properties, estimation of its parameter, and its applications. A number of continuous distributions for modeling lifetime data have been introduced in statistical literature including exponential, Lindley, gamma, lognormal and Weibull, amongst others. The exponential, Lindley and the Weibull distributions are more popular in practice than the gamma and the lognormal distributions because the survival functions of the gamma and the lognormal distributions cannot be expressed in closed forms and both require numerical integration. Though Aradhana, Sujatha, Lindley and exponential distributions are of one parameter, Aradhana, Sujatha and Lindley distributions have advantage over the exponential distribution that the exponential distribution has constant hazard rate and mean residual life function whereas the Aradhana, Sujatha, and Lindley distributions have increasing hazard rate and decreasing mean residual life function. Further, Aradhana and Sujatha distributions of Shanker have flexibility over both Lindley and exponential distributions.

Aradhana, sujatha, lindley and exponential distributions

Shanker introduced a new one parameter continuous distribution named, ‘Aradhana distribution’ for modeling lifetime data from engineering and medical science. This distribution is a three-component mixture of an exponential (θ) distribution, a gamma (2θ) distribution and a gamma (3θ) distribution with their mixing proportions \( \frac{\theta}{\theta + 2\theta} \), \( \frac{2\theta}{\theta + 2\theta} \) and \( \frac{2\theta}{\theta + 2\theta} \) respectively. It has been shown by Shanker that Aradhana distribution is flexible than the Lindley distribution for modeling lifetime data in reliability and in terms of its hazard rate shapes and it gives better fit than Akash, Shanker, Lindley and exponential distributions in modeling lifetime data. Shanker has discussed its various mathematical and statistical properties including its shape, moment generating function, moments, skewness, kurtosis, hazard rate function, mean residual life function, stochastic orderings, mean deviations, distribution of order statistics, Bonferroni and Lorenz curves, Renyi entropy measure, stress-strength reliability, amongst others. Shanker has also obtained a Poisson mixture of Aradhana distribution named, “Poisson-Aradhana distribution (PAD)” for modeling count data.

Shanker introduced another one parameter continuous distribution named, ‘Sujatha distribution’ for modeling lifetime data from engineering and medical science. This distribution is also a three-component mixture of an exponential (θ) distribution, a gamma (2θ) distribution and a gamma (3θ) distribution with their mixing proportions \( \frac{\theta}{\theta + 2\theta} \), \( \frac{2\theta}{\theta + 2\theta} \) and \( \frac{2\theta}{\theta + 2\theta} \) respectively. It has been shown by Shanker that Sujatha distribution is flexible than the Lindley distribution for modeling lifetime data in reliability and...
in terms of its hazard rate shapes and it gives better fit than Lindley and exponential distributions in modeling lifetime data. Shanker et al. has discussed its various mathematical and statistical properties including its shape, moment generating function, moments, skewness, kurtosis, hazard rate function, mean residual life function, stochastic orderings, mean deviations, distribution of order statistics, Bonferroni and Lorenz curves, Renyi entropy measure, stress-strength reliability, amongst others. Shanker et al. has also obtained a Poisson mixture of Sujatha distribution named, “Poisson-Sujatha distribution (PSD)” for modeling count data.

The Lindley distribution is a two-component mixture of an exponential ($\theta$) distribution and a gamma ($2,\theta$) distribution with their mixing proportions $\frac{\alpha}{\alpha+\beta}$ and $\frac{\beta}{\alpha+\beta}$ respectively and is given by Lindley in the context of Bayesian Statistics as a counter example of fiducial Statistics. A detailed study about its various mathematical properties, estimation of parameter and application showing the superiority of Lindley distribution over exponential distribution for the waiting times before service of the bank customers has been done by Ghitany et al. The Lindley distribution has been generalized, extended, mixed, modified and its detailed applications in reliability and other fields of knowledge by different researchers including Sankaran, Zakerzadeh & Dolati, Nadarajah et al., Deniz & Ojeda, Bakouch et al., Shanker & Mishra, Shanker & Amanuel, Ghitany et al., Shanker et al. are some among others.

In statistical literature, exponential distribution was the first widely used lifetime distribution model in areas ranging from studies on the lifetimes of manufactured items to research involving survival or remission times in chronic diseases. The main reason for its wide usefulness and applicability as lifetime model is partly because of the availability of simple statistical methods for it and partly because it appeared suitable for representing the lifetimes of many phenomenons such as various types of manufactured items.

Let $T$ be a continuous random variable representing the lifetimes of individuals in some population. The expressions for probability density function, $f(t)$, cumulative distribution function, $F(t)$, hazard rate function, $h(t)$, mean residual life function, $m(t)$, mean $\mu_t^*$, variance $\mu_t^*$, coefficient of variation ($C.V.$), coefficient of Skewness ($C.S.$), coefficient of kurtosis ($C.K.$), and index of dispersion ($\gamma$) of Aradhana and Sujatha distributions are summarized in Table 1 and of Lindley and exponential distributions are summarized in Table 2.

A table of values for coefficient of variation ($C.V$), coefficient of Skewness ($C.S$), coefficient of Kurtosis ($C.K.$), and index of dispersion ($\gamma$) for Aradhana, Sujatha and Lindley distributions for varying their parameter for comparative study are summarized in the Table 3.

The condition under which Aradhana, Sujatha, Lindley and exponential distributions are Over-dispersion ($\mu < \sigma^2$), equi-dispersion ($\mu=\sigma^2$) and under-dispersion ($\mu > \sigma^2$) of Aradhana, Sujatha, Lindley and exponential distributions for varying values of their parameter are presented in Table 4.

Graphs of coefficient of variation ($C.V$), coefficient of skewness ($C.S$), coefficient of kurtosis ($C.K.$) and index of dispersion ($\gamma$) for Aradhana, Sujatha, and Lindley distributions are presented for varying values of their parameter $\theta$ in Figure 1.

### Estimation of parameter

#### Estimate of the parameter of aradhana distribution

Let $(t_1,t_2,t_3, \ldots , t_n)$ be a random sample from Aradhana distribution. The maximum likelihood estimate (MLE) $\hat{\theta}$ of $\theta$ and the method of moment estimate (MOME) of $\theta$ is the solution of the following cubic equation

$$7\theta^3 + (2\theta - 1)\theta^2 + 2(\theta - 2)\theta - 6 = 0$$

#### Estimate of the parameter of sujatha distribution

Let $(t_1,t_2,t_3, \ldots , t_n)$ be a random sample from Sujatha distribution. The maximum likelihood estimate (MLE) $\hat{\theta}$ of $\theta$ and the method of moment estimate (MOME) of $\theta$ is the solution of the following cubic equation

$$7\theta^3 + (\theta - 1)\theta^2 + 2(\theta - 1)\theta - 6 = 0$$

#### Estimate of the parameter of lindley distribution

Let $(t_1,t_2,t_3, \ldots , t_n)$ be a random sample of size $n$ from Lindley distribution. The MLE $\hat{\theta}$ of $\theta$ and MOME $\hat{\theta}$ of $\theta$ is given by

$$\hat{\theta} = \frac{(\tau - 1) + \sqrt{\tau^2 - 4\tau}}{2\tau}, \quad \tau > 0,$$

where $\tau$ is the sample mean.

#### Estimate of the parameter of exponential distribution

Let $(t_1,t_2,t_3, \ldots , t_n)$ be a random sample of size $n$ from exponential distribution. The MLE $\hat{\theta}$ of $\theta$ and MOME $\hat{\theta}$ of $\theta$ is given by

$$\hat{\theta} = \frac{1}{\bar{t}}, \quad \tau$$

where $\bar{t}$ is the sample mean.

### Applications and goodness of fit

In this section the goodness of fit test of Aradhana, Sujatha, Lindley and exponential distributions for following sixteen real lifetime data-sets using maximum likelihood estimate have been discussed.

In order to compare Aradhana, Sujatha, Lindley and exponential distributions, $-2\ln L$, AIC (Akaike Information Criterion), AICC (Akaike Information Criterion Corrected), BIC (Bayesian Information Criterion), K-S Statistics (Kolmogorov-Smirnov Statistics) for all sixteen real lifetime data-sets have been computed and presented in Table 5. The formulae for computing AIC, AICC, BIC, and K-S Statistics are as follows:

$$AIC = -2\ln L + 2k, \quad AICC = AIC + \frac{2k(k+1)}{n-k-1}, \quad BIC = -2\ln L + k \ln n$$

$$D = \sup |F(x) - F_0(x)|, \quad \tau = k, \quad n = \text{the sample size and } F_0(x) \text{ is the empirical distribution function. The best fitting is the distribution which corresponds to lower values of } -2\ln L, \text{ AIC, AICC, BIC, and K-S statistics.}$$

The best fitting has been shown by making $-2\ln L$, AIC, AICC, BIC, and K-S Statistics in bold.

### Concluding remarks

In this paper an attempt has been made to find the suitability of
Aradhana, Sujatha, Lindley and exponential distributions for modeling real lifetime data from engineering, medical science and other fields. Firstly a table for values of the various characteristics of Aradhana, Sujatha, Lindley and exponential distributions has been presented for different values of their parameter which reflects their nature and behavior. The condition under which Aradhana, Sujatha, Lindley and exponential distributions are over-dispersed, equi-dispersed, and under-dispersed has been given. Several lifetime data from medical science, engineering and other fields of knowledge have been fitted using Aradhana, Sujatha, Lindley and exponential distributions to study the advantages and disadvantages of these distributions. The goodness of fit test of these distributions using Kolmogorov-Smirnov tests indicate that each has advantages and disadvantages for modeling lifetime data.

### Table 1 Characteristics of Aradhana and Sujatha Distributions

| Characteristic Formulas |
|-------------------------|
| **Aradhana distribution** |
| $f(t) = \frac{\theta^3}{\theta^2 + 2\theta + 2}(1+t)^2 e^{-\theta t}$ |
| $F(t) = 1 - \left[1 + \frac{\theta t(\theta t + 2\theta + 2)}{\theta^2 + 2\theta + 2}\right] e^{-\theta t}$ |
| $h(t) = \frac{\theta^3(1+t)^2}{\theta t(\theta t + 2\theta + 2) + (\theta^2 + 2\theta + 2)}$ |
| $m(t) = \frac{\theta^5 t^2 + 2\theta t(\theta + 2) + (\theta^2 + 4\theta + 6)}{\theta \left[\theta t(\theta t + 2\theta + 2) + (\theta^2 + 2\theta + 2)\right]}$ |
| $\mu_1 = \frac{\theta^3 + 4\theta + 6}{\theta(\theta^2 + 2\theta + 2)}$ |
| $\mu_2 = \frac{\theta^4 + 4\theta^3 + 18\theta^2 + 12\theta + 12}{\theta^2(\theta^2 + 2\theta + 2)^2}$ |
| $C.V. = \frac{\sigma}{\mu_1} = \frac{\sqrt{\theta^4 + 8\theta^3 + 24\theta^2 + 24\theta + 12}}{\theta^2 + 4\theta + 6}$ |
| $\sqrt{\beta_1} = \frac{2 \left(\theta^6 + 12\theta^5 + 54\theta^4 + 100\theta^3\right)}{(\theta^4 + 8\theta^3 + 24\theta^2 + 24\theta + 12)^{3/2}}$ |
| $\beta_2 = \frac{3 \left(3\theta^8 + 48\theta^7 + 304\theta^6 + 944\theta^5 + 1816\theta^4\right)}{(\theta^4 + 8\theta^3 + 24\theta^2 + 24\theta + 12)^2}$ |
| $\gamma = \frac{\sigma^2}{\mu_1} = \frac{\theta^4 + 8\theta^3 + 24\theta^2 + 24\theta + 12}{\theta(\theta^2 + 2\theta + 2)(\theta^2 + 4\theta + 6)}$ |

| **Sujatha distribution** |
| $f(t) = \frac{\theta^3}{\theta^2 + \theta + 2}(1+t^2) e^{-\theta t}$ |
| $F(t) = 1 - \left[1 + \frac{\theta t(\theta t + \theta + 2)}{\theta^2 + \theta + 2}\right] e^{-\theta t}$ |
| $h(t) = \frac{\theta^3(1+t^2)}{\theta t(1+t^2) + \theta^2 + \theta + 2}$ |
| $m(t) = \frac{\theta^2(t^2 + t + 1) + 2\theta(t+1) + 6}{\theta \left[(\theta^2 + \theta + 2) + \theta t(\theta t + \theta + 2)\right]}$ |
| $\mu_1 = \frac{\theta^2 + 2\theta + 6}{\theta(\theta^2 + \theta + 2)}$ |
| $\mu_2 = \frac{\theta^4 + 4\theta^3 + 18\theta^2 + 12\theta + 12}{\theta^2(\theta^2 + \theta + 2)^2}$ |
| $C.V. = \frac{\sigma}{\mu_1} = \frac{\sqrt{\theta^4 + 4\theta^3 + 18\theta^2 + 12\theta + 12}}{\theta^2 + 2\theta + 6}$ |
| $\sqrt{\beta_1} = \frac{2 \left(\theta^6 + 6\theta^5 + 36\theta^4 + 44\theta^3\right) + 54\theta^2 + 36\theta + 24}{(\theta^4 + 4\theta^3 + 18\theta^2 + 12\theta + 12)^{3/2}}$ |
| $\beta_2 = \frac{3 \left(3\theta^8 + 24\theta^7 + 172\theta^6 + 376\theta^5 + 736\theta^4\right)}{(\theta^4 + 4\theta^3 + 18\theta^2 + 12\theta + 12)^2}$ |
| $\gamma = \frac{\sigma^2}{\mu_1} = \frac{\theta^4 + 4\theta^3 + 18\theta^2 + 12\theta + 12}{\theta(\theta^2 + \theta + 2)(\theta^2 + 2\theta + 6)}$ |

Citation: Shanker R, Fesshaye H. On modeling of lifetime data using aradhana, sujatha, lindley and exponential distributions. Biom Biostat Int J. 2016;4(1):28–38. DOI: 10.15406/bbij.2016.04.00087
Table 2 Characteristics of Lindley and Exponential Distributions

|                | Lindley Distribution          | Exponential Distribution |
|----------------|------------------------------|--------------------------|
|                | \( f(t) = \frac{\theta^2}{\theta+1} (1+t)e^{-\theta t} \) | \( f(t) = \theta e^{-\theta t} \) |
|                | \( F(t) = 1 - \frac{\theta+1+\theta t}{\theta+1} e^{-\theta t} \) | \( F(t) = 1 - e^{-\theta t} \) |
|                | \( h(t) = \frac{\theta^2 (1+t)}{\theta+1+\theta t} \) | \( h(t) = \theta \) |
|                | \( m(t) = \frac{\theta + 2 + \theta t}{\theta(\theta+1+\theta t)} \) | \( m(t) = \frac{1}{\theta} \) |
|                | \( \mu_1' = \frac{\theta+2}{\theta(\theta+1)} \) | \( \mu_1' = \frac{1}{\theta} \) |
|                | \( \mu_2 = \frac{\theta^2 + 4\theta + 2}{\theta^2(\theta+1)^2} \) | \( \mu_2 = \frac{1}{\theta^2} \) |
|                | \( CV = \frac{\sigma}{\mu_1'} = \sqrt{\frac{\theta^2 + 4\theta + 2}{\theta+2}} \) | \( CV = \frac{\sigma}{\mu_1'} = 1 \) |
|                | \( \sqrt{\beta_1} = \frac{2(\theta^3 + 6\theta^2 + 6\theta + 2)}{(\theta^2 + 4\theta + 2)^{3/2}} \) | \( \sqrt{\beta_1} = 2 \) |
|                | \( \beta_2 = \frac{3(3\theta^3 + 24\theta^2 + 44\theta^2 + 32\theta + 8)}{(\theta^2 + 4\theta + 2)^2} \) | \( \beta_2 = 9 \) |
|                | \( \gamma = \frac{\sigma^2}{\mu_1'} = \frac{\theta^2 + 4\theta + 2}{\theta(\theta+1)(\theta+2)} \) | \( \gamma = \frac{\sigma^2}{\mu_1'} = \frac{1}{\theta} \) |

Table 3 Values of \( \mu_1', \mu_2, CV, \sqrt[3]{\beta_1}, \beta_2, \) and \( \gamma \) of Aradhana, Sujatha and Lindley distributions for varying values of the parameter \( \theta \)

| Values of \( \theta \) for Aradhana Distribution |
|-----------------------------------------------|
| 0.01 | 0.05 | 0.1 | 0.3 | 0.5 | 1 | 1.5 | 2 |
| 299.000 | 59.001 | 29.005 | 9.033 | 5.077 | 2.200 | 1.310 | 0.900 |
| 29999.990 | 1199.954 | 299.914 | 33.143 | 11.763 | 2.760 | 1.134 | 0.590 |
| CV | 0.579 | 0.587 | 0.597 | 0.637 | 0.676 | 0.755 | 0.813 | 0.853 |

Citation: Shanker R, Fesshaye H. On modeling of lifetime data using aradhana, sujatha, lindley and exponential distributions. Biom Biostat Int J. 2016;4(1):28-38. DOI: 10.15406/bbij.2016.04.00087
Table Continued

| Values of $\theta$ for Aradhana Distribution |
|---------------------------------------------|
| 1.155 | 1.155 | 1.155 | 1.167 | 1.193 | 1.295 | 1.402 | 1.496 |
| 5.000 | 5.000 | 5.001 | 5.024 | 5.087 | 5.381 | 5.758 | 6.135 |
| 100.334 | 20.338 | 10.340 | 3.669 | 2.317 | 1.255 | 0.865 | 0.656 |

| Values of $\theta$ for Aradhana Distribution |
|---------------------------------------------|
| 0.01 | 0.05 | 0.1 | 0.3 | 0.5 | 1 | 1.5 | 2 |
| 299.493 | 59.464 | 29.431 | 9.331 | 5.273 | 2.250 | 1.304 | 0.875 |
| 30000.737 | 1200.69 | 300.624 | 33.722 | 12.198 | 2.938 | 1.197 | 0.609 |
| CV | 0.578 | 0.583 | 0.589 | 0.622 | 0.662 | 0.762 | 0.839 | 0.892 |
| 1.155 | 1.154 | 1.151 | 1.140 | 1.146 | 1.248 | 1.397 | 1.536 |
| 5.000 | 4.998 | 4.992 | 4.955 | 4.945 | 5.170 | 5.656 | 6.215 |
| 100.172 | 20.192 | 10.214 | 3.614 | 2.313 | 1.306 | 0.918 | 0.696 |

| Values of $\theta$ for Aradhana Distribution |
|---------------------------------------------|
| 0.01 | 0.05 | 0.1 | 0.3 | 0.5 | 1 | 1.5 | 2 |
| 199.010 | 39.048 | 19.091 | 5.897 | 3.333 | 1.500 | 0.933 | 0.667 |
| 19999.020 | 799.093 | 199.174 | 21.631 | 7.556 | 1.750 | 0.729 | 0.389 |
| CV | 0.711 | 0.724 | 0.739 | 0.789 | 0.825 | 0.882 | 0.915 | 0.935 |
| 1.414 | 1.417 | 1.422 | 1.464 | 1.512 | 1.620 | 1.699 | 1.756 |
| 6.000 | 6.007 | 6.025 | 6.162 | 6.343 | 6.796 | 7.173 | 7.469 |
| 100.493 | 20.465 | 10.433 | 3.668 | 2.267 | 1.167 | 0.781 | 0.583 |

Table 4 Over-dispersion, equi-dispersion and under-dispersion of Aradhana, Sujatha, Lindley and exponential distributions for varying values of their parameter $\theta$.

| Distribution | Over-Dispersion $\theta < 1.283826505$ | Equi-Dispersion $\mu = \sigma^2$ | Under-Dispersion $\theta > 1.283826505$ |
|--------------|------------------------------------------|-------------------------------|---------------------------------|
| Aradhana     | $\theta < 1.283826505$                  | $\theta > 1.283826505$       |                                 |
| Sujatha      | $\theta < 1.364271174$                  | $\theta = 1.364271174$      | $\theta > 1.364271174$         |
| Lindley      | $\theta = 1.170086487$                 |                               |                                 |
| Exponential  | $\theta < 1$                           |                               | $\theta > 1$                    |

Citation: Shanker R, Fesshaye H. On modeling of lifetime data using aradhana, sujatha, lindley and exponential distributions. Biom Biostat Int J. 2016;4(1):28-38. DOI: 10.15406/bbij.2016.04.00087
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Table 5 MLE's, -2ln L, AIC, AICC, BIC, K-S Statistics of the fitted distributions of Data sets 1-16

| Model    | Parameter Estimate | -2ln L | AIC  | AICC | BIC  | K-S Statistic |
|----------|--------------------|--------|------|------|------|---------------|
| Data 1   |                    |        |      |      |      |               |
| Aradhana | 1.346393           | 149.88 | 151.88 | 151.94 | 154.02 | 0.345         |
| Sujatha  | 1.350050           | 154.81 | 156.81 | 156.87 | 158.95 | 0.349         |
| Lindley  | 0.996116           | 162.56 | 164.56 | 164.62 | 166.70 | 0.371         |
| Exponential | 0.663647   | 177.66 | 179.66 | 179.73 | 181.80 | 0.402         |
| Aradhana | 0.0043272          | 952.58 | 954.58 | 954.62 | 957.18 | 0.186         |
| Sujatha  | 0.0043566          | 951.78 | 953.78 | 953.78 | 954.91 | 0.185         |
| Data 2   |                    |        |      |      |      |               |
| Lindley  | 0.028859           | 983.11 | 985.11 | 985.15 | 987.71 | 0.242         |
| Exponential | 0.014635   | 1044.87 | 1046.87 | 1046.91 | 1049.48 | 0.357         |
| Aradhana | 0.0040968          | 227.28 | 229.28 | 229.47 | 230.41 | 0.108         |
| Sujatha  | 0.0041232          | 227.17 | 229.17 | 229.36 | 230.30 | 0.107         |
| Lindley  | 0.0027321          | 231.47 | 233.47 | 233.66 | 234.61 | 0.149         |
| Exponential | 0.0013845 | 242.87 | 244.87 | 245.06 | 246.01 | 0.263         |
| Data 3   |                    |        |      |      |      |               |
| Aradhana | 0.0013454          | 1255.26 | 1257.26 | 1257.30 | 1259.86 | 0.069         |
| Sujatha  | 0.0013484          | 1255.54 | 1257.54 | 1257.58 | 1260.14 | 0.070         |
| Lindley  | 0.000897           | 1251.34 | 1253.34 | 1253.38 | 1255.95 | 0.098         |
| Exponential | 0.0004505 | 1280.52 | 1282.52 | 1282.56 | 1285.12 | 0.190         |

Figure 1 Graphs of coefficient of variation (C.V), coefficient of skewness ($\sqrt{\beta_1}$), coefficient of kurtosis ($\beta_2$) and index of dispersion ($\gamma$) for Aradhana, Sujatha, and Lindley distributions are for varying values of their parameter $\theta$.

Figure 1 Graphs of coefficient of variation (C.V), coefficient of skewness ($\sqrt{\beta_1}$), coefficient of kurtosis ($\beta_2$) and index of dispersion ($\gamma$) for Aradhana, Sujatha, and Lindley distributions are for varying values of their parameter $\theta$.

Table 5 MLE's, -2ln L, AIC, AICC, BIC, K-S Statistics of the fitted distributions of Data sets 1-16

| Model   | Parameter Estimate | -2ln L | AIC  | AICC | BIC  | K-S Statistic |
|---------|--------------------|--------|------|------|------|---------------|
| Data 1  |                    |        |      |      |      |               |
| Aradhana| 1.346393           | 149.88 | 151.88 | 151.94 | 154.02 | 0.345         |
| Sujatha | 1.350050           | 154.81 | 156.81 | 156.87 | 158.95 | 0.349         |
| Lindley | 0.996116           | 162.56 | 164.56 | 164.62 | 166.70 | 0.371         |
| Exponential | 0.663647   | 177.66 | 179.66 | 179.73 | 181.80 | 0.402         |
| Aradhana| 0.0043272          | 952.58 | 954.58 | 954.62 | 957.18 | 0.186         |
| Sujatha | 0.0043566          | 951.78 | 953.78 | 953.78 | 954.91 | 0.185         |
| Data 2  |                    |        |      |      |      |               |
| Lindley | 0.028859           | 983.11 | 985.11 | 985.15 | 987.71 | 0.242         |
| Exponential | 0.014635   | 1044.87 | 1046.87 | 1046.91 | 1049.48 | 0.357         |
| Aradhana| 0.0040968          | 227.28 | 229.28 | 229.47 | 230.41 | 0.108         |
| Sujatha | 0.0041232          | 227.17 | 229.17 | 229.36 | 230.30 | 0.107         |
| Lindley | 0.0027321          | 231.47 | 233.47 | 233.66 | 234.61 | 0.149         |
| Exponential | 0.0013845 | 242.87 | 244.87 | 245.06 | 246.01 | 0.263         |
| Data 3  |                    |        |      |      |      |               |
| Aradhana| 0.0013454          | 1255.26 | 1257.26 | 1257.30 | 1259.86 | 0.069         |
| Sujatha | 0.0013484          | 1255.54 | 1257.54 | 1257.58 | 1260.14 | 0.070         |
| Lindley | 0.000897           | 1251.34 | 1253.34 | 1253.38 | 1255.95 | 0.098         |
| Exponential | 0.0004505 | 1280.52 | 1282.52 | 1282.56 | 1285.12 | 0.190         |
| Model      | Parameter Estimate | -2ln L  | AIC    | AICC   | BIC    | K-S Statistic |
|------------|---------------------|---------|--------|--------|--------|---------------|
| Aradhana   | 0.029756            | 794.28  | 796.28 | 796.34 | 798.56 | 0.182         |
| Sujatha    | 0.029898            | 794.48  | 796.48 | 796.54 | 798.77 | 0.183         |
| Lindley    | 0.019841            | 789.04  | 791.04 | 791.10 | 793.32 | 0.133         |
| Exponential| 0.010018            | 806.88  | 808.88 | 808.94 | 811.16 | 0.198         |
| Aradhana   | 0.115577            | 989.49  | 991.49 | 991.52 | 994.39 | 0.399         |
| Sujatha    | 0.116194            | 985.69  | 987.69 | 987.72 | 990.59 | 0.396         |
| Lindley    | 0.077247            | 1041.64 | 1043.64| 1043.68| 1046.54| 0.448         |
| Exponential| 0.04006             | 1130.26 | 1132.26| 1132.29| 1135.16| 0.525         |
| Aradhana   | 0.013206            | 801.83  | 803.83 | 803.90 | 805.90 | 0.297         |
| Sujatha    | 0.013234            | 802.84  | 804.84 | 804.91 | 806.90 | 0.298         |
| Lindley    | 0.008804            | 763.75  | 765.75 | 765.82 | 767.81 | 0.245         |
| Exponential| 0.004421            | 744.87  | 746.87 | 746.94 | 748.93 | 0.166         |
| Aradhana   | 0.013364            | 608.87  | 610.87 | 610.96 | 612.65 | 0.278         |
| Sujatha    | 0.013394            | 609.39  | 611.39 | 611.48 | 613.17 | 0.279         |
| Lindley    | 0.008910            | 579.16  | 581.16 | 581.26 | 582.95 | 0.219         |
| Exponential| 0.004475            | 564.02  | 566.02 | 566.11 | 567.80 | 0.145         |
| Aradhana   | 0.290304            | 874.71  | 876.71 | 876.74 | 879.56 | 0.179         |
| Sujatha    | 0.289633            | 879.82  | 881.82 | 881.85 | 884.67 | 0.187         |
| Lindley    | 0.196045            | 839.06  | 841.06 | 841.09 | 843.91 | 0.116         |
| Exponential| 0.106773            | 828.68  | 830.68 | 830.72 | 833.54 | 0.077         |
| Aradhana   | 0.049506            | 350.55  | 352.55 | 352.69 | 353.95 | 0.415         |
| Sujatha    | 0.049887            | 352.47  | 354.47 | 354.61 | 355.87 | 0.418         |
| Lindley    | 0.0033021           | 323.27  | 325.27 | 325.42 | 326.67 | 0.345         |
| Exponential| 0.016779            | 305.26  | 307.26 | 307.40 | 308.66 | 0.213         |
| Aradhana   | 1.132874            | 116.06  | 118.06 | 118.18 | 119.59 | 0.169         |
| Sujatha    | 1.146073            | 115.54  | 117.54 | 117.66 | 119.07 | 0.164         |
| Lindley    | 0.823821            | 112.61  | 114.61 | 114.73 | 116.13 | 0.133         |
| Exponential| 0.532081            | 110.91  | 112.91 | 113.03 | 114.43 | 0.089         |
| Aradhana   | 0.276551            | 638.34  | 640.34 | 640.38 | 642.94 | 0.080         |
| Sujatha    | 0.284621            | 639.64  | 641.64 | 641.68 | 644.24 | 0.088         |
| Lindley    | 0.186571            | 638.07  | 640.07 | 640.12 | 642.68 | 0.058         |
| Exponential| 0.101245            | 658.04  | 660.04 | 660.08 | 662.65 | 0.163         |
| Aradhana   | 0.024537            | 193.60  | 195.60 | 195.91 | 196.31 | 0.453         |
| Sujatha    | 0.024634            | 193.94  | 195.94 | 196.25 | 196.65 | 0.454         |
| Lindley    | 0.01636             | 181.34  | 183.34 | 183.65 | 184.05 | 0.386         |
| Exponential| 0.008246            | 173.94  | 175.94 | 176.25 | 176.65 | 0.277         |
| Aradhana   | 1.123193            | 56.37   | 58.37  | 58.59  | 59.36  | 0.302         |
| Sujatha    | 1.136745            | 57.50   | 59.50  | 59.72  | 60.49  | 0.309         |
| Lindley    | 0.816118            | 60.50   | 62.50  | 62.72  | 63.49  | 0.341         |
| Exponential| 0.526316            | 65.67   | 67.67  | 67.90  | 68.67  | 0.389         |

**Table Continued**
Table Continued

| Model            | Parameter Estimate | -2ln L  | AIC    | AICC   | BIC    | K-S Statistic |
|------------------|--------------------|---------|--------|--------|--------|---------------|
| **Data Set 1**   |                    |         |        |        |        |               |
| Aradhana         | 0.094318           | 242.23  | 244.23 | 244.37 | 245.66 | 0.274         |
| Sujatha          | 0.095610           | 241.50  | 243.50 | 243.64 | 244.93 | 0.270         |
| Lindley          | 0.062988           | 253.99  | 255.99 | 256.13 | 257.42 | 0.333         |
| Exponential      | 0.032455           | 274.53  | 276.53 | 276.67 | 277.96 | 0.426         |
| **Data Set 2**   |                    |         |        |        |        |               |
| Aradhana         | 0.917023           | 219.90  | 221.90 | 221.96 | 224.13 | 0.350         |
| Sujatha          | 0.936119           | 221.61  | 223.61 | 223.67 | 225.84 | 0.362         |
| Lindley          | 0.659000           | 238.38  | 240.38 | 240.44 | 242.61 | 0.390         |
| Exponential      | 0.407941           | 261.74  | 263.74 | 263.80 | 265.97 | 0.434         |

**Data Set 1** The data set represents the strength of 1.5cm glass fibers measured at the National Physical Laboratory, England. Unfortunately, the units of measurements are not given in the paper, and they are taken from Smith & Naylor. The data (× 10^5) are presented below (after subtracting 65)

| Strength (MPa) |
|----------------|
| 0.55           |
| 0.74           |
| 0.77           |
| 0.81           |
| 1.24           |

**Data Set 2** The data is given by Birnbaum & Saunders on the fatigue life of 6061 – T6 aluminum coupons cut parallel to the direction of rolling and oscillated at 18 cycles per second. The data set consists of 101 observations with maximum stress per cycle 31,000 psi. The data (X × 10^3) are presented below (after subtracting 65)

| Observations |
|--------------|
| 5            |
| 43           |
| 55           |
| 64           |
| 69           |
| 76           |
| 84           |
| 98           |

**Data Set 3** The data set is from Lawless. The data given arose in tests on endurance of deep groove ball bearings. The data are the number of million revolutions before failure for each of the 23 ball bearings in the life tests

| Million Revolutions |
|---------------------|
| 17.88               |
| 68.44               |

**Data Set 4** The data is from Picciotto and arose in test on the cycle at which the Yarn failed. The data are the number of cycles until failure of the yarn

| Cycles |
|--------|
| 86     |
| 264    |
| 166    |
| 93     |
| 400    |
| 20     |

Citation: Shanker R, Fesshaye H. On modeling of lifetime data using aradhana, sujatha, lindley and exponential distributions. Biom Biostat Int J. 2016;4(1):28-38. DOI: 10.15406/bbij.2016.04.00087
**Data Set 5** This data represents the survival times (in days) of 72 guinea pigs infected with virulent tubercle bacilli, observed and reported by Bjerkedal.

| 12 | 15 | 22 | 24 | 24 | 32 | 32 | 33 | 34 | 38 | 38 | 43 | 44 |
|----|----|----|----|----|----|----|----|----|----|----|----|----|
| 48 | 52 | 53 | 54 | 54 | 55 | 56 | 57 | 58 | 58 | 59 | 60 | 60 |
| 60 | 60 | 61 | 62 | 63 | 65 | 65 | 67 | 68 | 70 | 70 | 72 | 73 |
| 75 | 76 | 81 | 83 | 84 | 85 | 87 | 91 | 95 | 96 | 98 | 99 |
| 109 | 110 | 121 | 127 | 129 | 131 | 143 | 146 | 146 | 175 | 175 | 211 | 233 |
| 258 | 258 | 263 | 297 | 341 | 341 | 376 |

**Data Set 6** This data is related with behavioral sciences, collected by Balakrishnan et al. [27]. The scale “General Rating of Affective Symptoms for Preschoolers (GRASP)” measures behavioral and emotional problems of children, which can be classified with depressive condition or not according to this scale. A study conducted by the authors in a city located at the south part of Chile has allowed collecting real data corresponding to the scores of the GRASP scale of children with frequency in parenthesis.

| 19(16), | 20(15), | 21(14), | 22(9), | 23(12), | 24(10), | 25(6), | 26(9), | 27(8), | 28(5), | 29(6), |
|---------|---------|---------|--------|---------|---------|--------|--------|---------|---------|---------|
| 30(4), | 31(3), | 32(4), | 33, | 34, | 35(4), | 36(2), | 37(2), | 39 | 42 | 44 |

**Data Set 7** The data set reported by Efron represent the survival times of a group of patients suffering from Head and Neck cancer disease and treated using radiotherapy (RT).

| 6.53 | 7 | 10.42 | 14.48 | 16.1 | 22.7 | 34 | 41.55 | 42 | 45.28 | 49.4 | 53.62 | 63 |
| 64 | 83 | 84 | 91 | 108 | 112 | 129 | 133 | 133 | 139 | 140 | 140 | 146 |
| 149 | 154 | 157 | 160 | 160 | 165 | 146 | 149 | 154 | 157 | 160 | 160 | 165 |
| 173 | 176 | 218 | 225 | 241 | 248 | 273 | 277 | 297 | 405 | 417 | 420 | 440 |
| 523 | 583 | 594 | 1101 | 1146 | 1147 |

**Data Set 8** The data set reported by Efron represent the survival times of a group of patients suffering from Head and Neck cancer disease and treated using a combination of radiotherapy and chemotherapy (RT+CT).

| 12.20 | 23.56 | 23.74 | 25.87 | 31.98 | 37 | 41.35 | 47.38 | 55.46 | 58.36 | 63.47 | 68.46 | 78.26 |
| 74.47 | 81.43 | 84 | 92 | 94 | 110 | 112 | 119 | 127 | 130 | 133 | 140 | 146 |
| 155 | 159 | 173 | 179 | 194 | 195 | 209 | 249 | 281 | 319 | 339 | 432 | 469 |
| 519 | 633 | 725 | 817 | 1776 |

**Data set 9** This data set represents remission times (in months) of a random sample of 128 bladder cancer patients reported in Lee & Wang.

| 0.08 | 2.09 | 3.48 | 4.87 | 6.94 | 8.66 | 13.11 | 23.63 | 0.20 | 2.23 | 3.52 | 4.98 | 6.97 |
| 9.02 | 13.29 | 0.40 | 2.26 | 3.57 | 5.06 | 7.09 | 9.22 | 13.80 | 25.74 | 0.50 | 2.46 | 3.64 |
| 5.09 | 7.26 | 9.47 | 14.24 | 25.82 | 0.51 | 2.54 | 3.70 | 5.17 | 7.28 | 9.74 | 14.76 | 6.31 |
| 0.81 | 2.62 | 3.82 | 5.32 | 7.32 | 10.06 | 14.77 | 32.15 | 2.64 | 3.88 | 5.32 | 7.39 | 10.34 |
| 14.83 | 34.26 | 0.90 | 2.69 | 4.18 | 5.34 | 7.59 | 10.66 | 15.96 | 36.66 | 1.05 | 2.69 | 4.23 |
| 5.41 | 7.62 | 10.75 | 16.62 | 43.01 | 1.19 | 2.75 | 4.26 | 5.41 | 7.63 | 17.12 | 46.12 | 1.26 |
| 2.83 | 4.33 | 5.49 | 7.66 | 11.25 | 17.14 | 79.05 | 1.35 | 2.87 | 5.62 | 7.87 | 11.64 | 17.36 |
| 1.40 | 3.02 | 4.34 | 5.71 | 7.93 | 11.79 | 18.11 | 1.46 | 4.40 | 5.85 | 8.26 | 11.98 | 19.13 |
| 1.76 | 3.25 | 4.50 | 6.25 | 8.37 | 12.02 | 20.2 | 3.31 | 4.51 | 6.54 | 8.53 | 12.03 |
| 20.28 | 2.02 | 3.36 | 6.76 | 12.07 | 21.73 | 2.07 | 3.36 | 6.93 | 8.65 | 12.63 | 22.69 |

**Data Set 10** This data set is given by Linhart & Zucchini, which represents the failure times of the air conditioning system of an airplane.

| 23 | 261 | 87 | 7 | 120 | 14 | 62 | 47 | 225 | 71 | 246 | 21 | 42 |
| 20 | 5 | 12 | 120 | 11 | 3 | 14 | 71 | 11 | 14 | 11 | 16 | 90 |
| 1 | 16 | 52 | 95 |

**Citation:** Shanker R, Fesshaye H. On modeling of lifetime data using aradhana, sujatha, lindley and exponential distributions. Biom Biostat Int J. 2016;4(1):28-38. DOI: 10.15406/bbij.2016.04.00087
Data Set 11 This data set used by Bhaumik et al.,\textsuperscript{31} is vinyl chloride data obtained from clean upgradient monitoring wells in mg/l

|     | 5.1 | 1.2 | 1.3 | 0.6 | 0.5 | 2.4 | 0.5 | 1.1 | 8   | 0.8 | 0.4 | 0.6 | 0.9 |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 0.4 | 2   | 0.5 | 5.3 | 3.2 | 2.7 | 2.9 | 2.5 | 2.3 | 1   | 0.2 | 0.1 | 0.1 |
| 1.8 | 0.9 | 2   | 4   | 6.8 | 1.2 | 0.4 | 0.2 |     |     |     |     |     |     |

Data Set 12 This data set represents the waiting times (in minutes) before service of 100 Bank customers and examined and analyzed by Ghitany et al.,\textsuperscript{7} for fitting the Lindley distribution

|     | 0.8 | 0.8 | 1.3 | 1.5 | 1.8 | 1.9 | 1.9 | 2.1 | 2.6 | 2.7 | 2.9 | 3.1 | 3.2 |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 3.3 | 3.5 | 3.6 | 4.0 | 4.1 | 4.2 | 4.2 | 4.3 | 4.3 | 4.4 | 4.4 | 4.6 | 4.7 |
| 4.7 | 4.8 | 4.9 | 4.9 | 5.0 | 5.3 | 5.5 | 5.7 | 5.7 | 6.1 | 6.2 | 6.2 | 6.2 |
| 6.3 | 6.7 | 6.9 | 7.1 | 7.1 | 7.1 | 7.1 | 7.4 | 7.6 | 7.7 | 8.0 | 8.2 | 8.6 |
| 8.6 | 8.6 | 8.8 | 8.8 | 8.9 | 8.9 | 9.5 | 9.6 | 9.7 | 9.8 | 10.7| 10.9| 11.0|
| 11.0| 11.1| 11.2| 11.2| 11.5| 11.9| 12.4| 12.5| 12.9| 13.0| 13.1| 13.3| 13.6|
| 13.7| 13.9| 14.1| 15.4| 15.4| 17.3| 17.3| 18.1| 18.2| 18.4| 18.9| 19.0| 19.9|
| 20.6| 21.3| 21.4| 21.9| 23.0| 27.0| 31.6| 33.1| 38.5|     |     |     |     |

Data Set 13 This data is for the times between successive failures of air conditioning equipment in a Boeing 720 airplane. Proshcan\textsuperscript{74, 57, 48, 29, 502, 12, 70, 21, 29, 386, 59, 27, 153, 26, 326}

|     | 74  | 57  | 48  | 29  | 502 | 12  | 70  | 21  | 29  | 386 | 59  | 27  | 153 |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|

Data Set 14 This data set represents the lifetime’s data relating to relief times (in minutes) of 20 patients receiving an analgesic and reported by Gross & Clark\textsuperscript{33}

|     | 1.1 | 1.4 | 1.3 | 1.7 | 1.9 | 1.8 | 1.6 | 2.2 | 1.7 | 2.7 | 4.1 | 1.8 | 1.5 |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 1.2 | 1.4 | 3   | 1.7 | 2.3 | 1.6 | 2   |     |     |     |     |     |     |     |

Data Set 15 This data set is the strength data of glass of the aircraft window reported by Fuller et al.,\textsuperscript{34}

|     | 18.83| 20.8 | 21.657| 23.03| 23.23| 24.05| 24.321| 25.5 | 25.52| 25.8 | 26.69| 26.77| 26.78|
|-----|-----|------|-------|------|------|-------|--------|------|------|------|------|------|------|
| 27.05| 27.67| 29.9 | 31.11 | 33.2 | 33.73| 33.76 | 33.89  | 34.76 | 35.75| 35.91| 36.98| 37.08|
| 37.09| 39.58| 44.045| 45.29 | 45.381|     |     |     |     |     |     |     |     |     |

Data Set 16 The following data represent the tensile strength, measured in GPa, of 69 carbon fibers tested under tension at gauge lengths of 20mm\textsuperscript{35}

|     | 1.312| 1.314| 1.479 | 1.552| 1.700| 1.803| 1.861| 1.865| 1.944| 1.958| 1.966| 1.997|
|-----|------|------|-------|------|------|------|------|------|------|------|------|------|
| 2.006| 2.021| 2.027| 2.055 | 2.063| 2.098| 2.140| 2.179| 2.224| 2.240| 2.253| 2.270|
| 2.272| 2.274| 2.301| 2.301 | 2.359| 2.382| 2.382| 2.426| 2.434| 2.435| 2.478| 2.490|
| 2.511| 2.514| 2.535| 2.554 | 2.566| 2.570| 2.586| 2.629| 2.663| 2.662| 2.648| 2.684|
| 2.697| 2.726| 2.770| 2.773 | 2.800| 2.809| 2.818| 2.821| 2.848| 2.880| 2.954| 3.012|
| 3.067| 3.084| 3.090| 3.096 | 3.128| 3.233| 3.433| 3.585| 3.585| 3.858|

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Conflict of interest
None.

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