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CUBIC RANK TRANSMUTED MODIFIED BURR III DISTRIBUTION: DEVELOPMENT, PROPERTIES, CHARACTERIZATIONS AND APPLICATIONS

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ABSTRACT

We propose a lifetime distribution with flexible hazard rate called cubic rank transmuted modified Burr III (CRTMBIII) distribution. We develop the proposed distribution on the basis of the cubic ranking transmutation map. The density function of CRTMBIII is symmetrical, right-skewed, left-skewed, exponential, arc, J and bimodal shaped. The flexible hazard rate of the proposed model can accommodate almost all types of shapes such as unimodal, bimodal, arc, increasing, decreasing, decreasing-increasing-decreasing, inverted bathtub and modified bathtub. To show the importance of proposed model, we present mathematical properties such as moments, incomplete moments, inequality measures, residual life function and stress strength reliability measure. We characterize the CRTMBIII distribution via techniques. We address the maximum likelihood method for the model parameters. We evaluate the performance of the maximum likelihood estimates (MLEs) via simulation study. We establish empirically that the proposed model is suitable for strengths of glass fibers. We apply goodness of fit statistics and the graphical tools to examine the potentiality and utility of the CRTMBIII distribution.

Keywords: Moments, Reliability, Characterizations, Maximum Likelihood Estimation.
1. INTRODUCTION

In recent decades, many continuous univariate distributions have been developed, however, various data sets from reliability, insurance, finance, climatology, biomedical sciences and other areas do not follow these distributions. Therefore, modified, extended and generalized distributions and their applications to problems in these areas is a clear need of day.

The modified, extended and generalized distributions are obtained by the introduction of some transformation or addition of one or more parameters to the well-known baseline distributions. These new developed distributions provide better fit to the data than the sub and competing models.

Shaw and Buckley (2009) proposed ranking quadratic transmutation map to solve financial problems.

1.1 Quadratic Ranking Transmutation Map

**Theorem 1.1**: Let $X_1$ and $X_2$ be independent and identically distributed (i.i.d.) random variables with the common cumulative distribution function $G(x)$. Then, the ranking quadratic transmutation map is

$$F_Y(x) = (1 + \lambda)G(x) - \lambda G^2(x), \quad \lambda \in [-1, 1].$$

**Proof**

Let $X_1$ and $X_2$ be i.i.d. random variables with the common cumulative distribution function $G(x)$. Now, consider the following order statistics:

$$X_{1:2} = \min (X_1, X_2) \quad \text{and} \quad X_{2:2} = \max (X_1, X_2)$$

let $Y = X_{1:2}$, with probability $\pi$, $Y = X_{2:2}$, with probability $1 - \pi$, where $0 \leq \pi \leq 1$. The cumulative distribution function of $Y$ is

$$F_Y(x) = \pi Pr(X_{1:2} \leq x) + (1 - \pi) Pr(X_{2:2} \leq x),$$

or

$$F_Y(x) = \pi \left[1 - \left[1 - G(x)\right]^2\right] + (1 - \pi) \left[G(x)\right]^2.$$

$$F_Y(x) = 2\pi G(x) + (1 - 2\pi) \left[G(x)\right]^2.$$ (2)

If we take $\lambda = 2\pi - 1$, the distribution in equation (2) is known as ranking quadratic transmutation map or transmuted distribution.

1.2 Cubic Ranking Transmutation Map

**Theorem 1.1**: Let $X_1, X_2$ and $X_3$ be i.i.d. random variables with the common cumulative distribution function $G(z)$. Then, the cubic ranking transmutation map is

$$F(x) = \lambda_1 G(x) + (\lambda_2 - \lambda_1) G^2(x) + (1 - \lambda_2) G^3(x), \quad \lambda_1 \in [0, 1], \quad \lambda_2 \in [-1, 1].$$ (3)

**Proof**
Consider the following order statistics:

\[X_{i3} = \min(X_1, X_2, X_i), \quad X_{23} \quad \text{and} \quad X_{33} = \max(X_1, X_2, X_3).\]

Let \(Y = X_{i3}\), with probability \(\pi_1\), \(Y = X_{23}\), with probability \(\pi_2\), \(Y = X_{33}\), with probability \(\pi_3\), where \(0 \leq \pi_i \leq 1\), \(\pi_3 = 1 - \pi_1 - \pi_2\) and \(\sum_{i=1}^{3} \pi_i = 1\).

The cumulative distribution function (cdf) of \(Y\) is

\[F_Y(x) = \pi_1 P(X_{i3} \leq x) + \pi_2 P(X_{23} \leq x) + (1 - \pi_1 - \pi_2) P(X_{33} \leq x),\]

where \(P(X_{i3} \leq x) = 1 - \left[1 - G(x)\right]^3\) and 
\(P(X_{23} \leq x) = 3G^2(x) - 2G^3(x)\) and 
\(P(X_{33} \leq x) = \left[G(x)\right]^3\).

Now, the cdf of \(Y\) becomes

\[F_Y(x) = 3\pi_1 G(x) + 3(\pi_2 - \pi_1)\left[G(x)\right]^2 + (1 - \pi_1)\left[G(x)\right]^3.\]  

(4)

If we take \(\lambda_1 = 3\pi_1\) and \(\lambda_2 = 3\pi_2\) the distribution in equation (4) is known as cubic ranking transmutation map or transmuted distribution of order 2.

**Definition 1.1:** The cdf and probability density function (pdf) for cubic rank transmuted distribution are given, respectively, by

\[F(x) = \lambda_1 G(x) + (\lambda_2 - \lambda_1)G^2(x) + (1 - \lambda_2)G^3(x), \quad \lambda_1 \in [0, 1], \quad \lambda_2 \in [-1, 1],\]

and

\[f(x) = g(x)\left[\lambda_1 + 2(\lambda_2 - \lambda_1)G(x) + 3(1 - \lambda_2)G^2(x)\right], x \in R\] 

(6)


Burr III (Burr; 1942) has wide range of applications in failure time modeling, reliability, business failure data, modeling finance, insurance data and quality control plans. Burr III (BIII) model accommodates only decreasing and inverted bathtub hazard rate functions (hrf). Transmuted Burr III (TBIII) accommodates only inverted bathtub hazard rate functions (Abdul-Moniem; 2015). The failure rate for modified Burr III (MBIII) can take only increasing, decreasing, inverted bathtub and modified bathtub shapes (Bhatti et al. 2019). Transmuted modified Burr III (TMBIII) accommodates only decreasing and inverted bathtub hazard rate functions (Ali and Ahmad; 2016). The hrf for the CRTMBIII distribution accommodates almost all shapes such as bimodal, arc, increasing, decreasing, decreasing-
increasing-decreasing, inverted bathtub (unimodal) and modified bathtub. Due to its flexible failure rate, it can be applicable to lifetime applications.

The basic motivations for proposing the CRTMBIII distribution are: (i) to generate distributions with symmetrical, right-skewed, left-skewed, exponential, arc, J and bimodal shaped; (ii) to obtain unimodal, bimodal, arc, increasing, decreasing, decreasing-increasing-decreasing, inverted bathtub and modified bathtub hazard rate function; (iii) to serve as the best alternative model for the current models to explore and modeling real data in economics, life testing, reliability, survival analysis manufacturing and other areas of research and (iv) to provide better fits than other sub-models.

This paper is sketched into the following sections. In Section 2, we develop and study the CRTMBIII distribution. We also present the basic structural properties and sub-models. We also study some plots of density and hazard rate functions. In Section 3, we derive mathematical properties such as moments, incomplete moments, inequality measures, residual and reverse residual life function and stress-strength reliability measure. In Section 4, two characterizations of the CRTMBIII distribution are studied. In Section 5, we address the parameters of the CRTMBIII distribution via maximum likelihood method. In Section 6, we evaluate the performance of the maximum likelihood estimates (MLEs) of the modal parameters via simulation study. In Section 7, we establish empirically that the proposed model is suitable for strengths of glass fibers. We apply goodness of fit statistics and graphical tools to examine the potentiality and utility of the CRTMBIII distribution. The concluding remarks are given in Section 8.

2. THE CRTMBIII DISTRIBUTION

Ali et al. (2015) studied modified Burr III (MBIII) distribution with its properties. Ali and Ahmad (2015) studied transmuted MBIII (TMBIII) distribution and its properties. The cdf and pdf of MBIII distribution are given, respectively, by

$$F(x) = \left(1 + \gamma x^{-\beta}\right)^{\frac{\alpha}{\gamma}}, \quad x \geq 0,$$

and

$$f(x) = \alpha \beta x^{-\beta-1} \left(1 + \gamma x^{-\beta}\right)^{\frac{\alpha}{\gamma} - 1}, \quad x > 0, \alpha > 0, \beta > 0, \gamma > 0.$$

Here, the CRTMBIII distribution is introduced with the help of (7) and (8). The cdf and pdf of the CRTMBIII distribution are given, respectively, by

$$F(x) = \lambda_1 \left(1 + \gamma x^{-\beta}\right)^{\frac{\alpha}{\gamma}} + \left(\lambda_2 - \lambda_1\right) \left(1 + \gamma x^{-\beta}\right)^{-\frac{2\alpha}{\gamma}} + \left(1 - \lambda_2\right) \left(1 + \gamma x^{-\beta}\right)^{-\frac{3\alpha}{\gamma}}, \quad x \geq 0,$$

and

$$f(x) = \alpha \beta x^{-\beta-1} \left[\lambda_1 \left(1 + \gamma x^{-\beta}\right)^{\frac{\alpha}{\gamma}} + 2 \left(\lambda_2 - \lambda_1\right) \left(1 + \gamma x^{-\beta}\right)^{-\frac{2\alpha}{\gamma}} + 3 \left(1 - \lambda_2\right) \left(1 + \gamma x^{-\beta}\right)^{-\frac{3\alpha}{\gamma}}\right], \quad x > 0,$$

with $\alpha > 0, \beta > 0, \gamma > 0, \lambda_1 \in [0,1], \lambda_2 \in [-1,1]$. 
In future, the pdf in (11) is denoted by $X$-CRTMBIII$(\alpha, \beta, \gamma, \lambda_1, \lambda_2)$.

### 2.1. Structural Properties

For $X$-CRTMBIII$(\alpha, \beta, \gamma, \lambda_1, \lambda_2)$, the survival, hazard, cumulative hazard, reverse hazard functions and the Mills ratio are given, respectively, by

$$S(x) = 1 - \left[ \frac{\lambda_1 (1 + \gamma x^{-\beta})^{\frac{\alpha}{\gamma}} + (\lambda_2 - \lambda_1) \left(1 + \gamma x^{-\beta} \right)^{2\alpha} + (1 - \lambda_2) \left(1 + \gamma x^{-\beta} \right)^{3\alpha}}{\lambda_1 (1 + \gamma x^{-\beta})^{\frac{\alpha}{\gamma}} + (\lambda_2 - \lambda_1) \left(1 + \gamma x^{-\beta} \right)^{2\alpha} + (1 - \lambda_2) \left(1 + \gamma x^{-\beta} \right)^{3\alpha}} \right], \quad x \geq 0,$$

(11)

$$h(x) = \frac{\alpha \beta x^{-\beta-1} \left[ \frac{\lambda_1 (1 + \gamma x^{-\beta})^{\frac{\alpha}{\gamma}} + 2(\lambda_2 - \lambda_1) \left(1 + \gamma x^{-\beta} \right)^{2\alpha} + 3(1 - \lambda_2) \left(1 + \gamma x^{-\beta} \right)^{3\alpha}}{\lambda_1 (1 + \gamma x^{-\beta})^{\frac{\alpha}{\gamma}} + (\lambda_2 - \lambda_1) \left(1 + \gamma x^{-\beta} \right)^{2\alpha} + (1 - \lambda_2) \left(1 + \gamma x^{-\beta} \right)^{3\alpha}} \right]}{1 - \left[ \frac{\lambda_1 (1 + \gamma x^{-\beta})^{\frac{\alpha}{\gamma}} + (\lambda_2 - \lambda_1) \left(1 + \gamma x^{-\beta} \right)^{2\alpha} + (1 - \lambda_2) \left(1 + \gamma x^{-\beta} \right)^{3\alpha}}{\lambda_1 (1 + \gamma x^{-\beta})^{\frac{\alpha}{\gamma}} + (\lambda_2 - \lambda_1) \left(1 + \gamma x^{-\beta} \right)^{2\alpha} + (1 - \lambda_2) \left(1 + \gamma x^{-\beta} \right)^{3\alpha}} \right]},$$

(12)

$$r(x) = \frac{\alpha \beta x^{-\beta-1} \left[ \frac{\lambda_1 + 2(\lambda_2 - \lambda_1) \left(1 + \gamma x^{-\beta} \right)^{2\alpha} + 3(1 - \lambda_2) \left(1 + \gamma x^{-\beta} \right)^{3\alpha}}{\lambda_1 + (\lambda_2 - \lambda_1) \left(1 + \gamma x^{-\beta} \right)^{2\alpha} + (1 - \lambda_2) \left(1 + \gamma x^{-\beta} \right)^{3\alpha}} \right]}{1 - \left[ \frac{\lambda_1 + (\lambda_2 - \lambda_1) \left(1 + \gamma x^{-\beta} \right)^{2\alpha} + (1 - \lambda_2) \left(1 + \gamma x^{-\beta} \right)^{3\alpha}}{\lambda_1 + (\lambda_2 - \lambda_1) \left(1 + \gamma x^{-\beta} \right)^{2\alpha} + (1 - \lambda_2) \left(1 + \gamma x^{-\beta} \right)^{3\alpha}} \right]},$$

(13)

$$H(x) = -\ln \left\{ 1 - \left[ \frac{\lambda_1 (1 + \gamma x^{-\beta})^{\frac{\alpha}{\gamma}} + (\lambda_2 - \lambda_1) \left(1 + \gamma x^{-\beta} \right)^{2\alpha} + (1 - \lambda_2) \left(1 + \gamma x^{-\beta} \right)^{3\alpha}}{\lambda_1 (1 + \gamma x^{-\beta})^{\frac{\alpha}{\gamma}} + (\lambda_2 - \lambda_1) \left(1 + \gamma x^{-\beta} \right)^{2\alpha} + (1 - \lambda_2) \left(1 + \gamma x^{-\beta} \right)^{3\alpha}} \right] \right\},$$

(14)

and

$$m(x) = \frac{\alpha \beta x^{-\beta-1} \left[ \frac{\lambda_1 (1 + \gamma x^{-\beta})^{\frac{\alpha}{\gamma}} + 2(\lambda_2 - \lambda_1) \left(1 + \gamma x^{-\beta} \right)^{2\alpha} + 3(1 - \lambda_2) \left(1 + \gamma x^{-\beta} \right)^{3\alpha}}{\lambda_1 (1 + \gamma x^{-\beta})^{\frac{\alpha}{\gamma}} + (\lambda_2 - \lambda_1) \left(1 + \gamma x^{-\beta} \right)^{2\alpha} + (1 - \lambda_2) \left(1 + \gamma x^{-\beta} \right)^{3\alpha}} \right]}{1 - \left[ \frac{\lambda_1 (1 + \gamma x^{-\beta})^{\frac{\alpha}{\gamma}} + (\lambda_2 - \lambda_1) \left(1 + \gamma x^{-\beta} \right)^{2\alpha} + (1 - \lambda_2) \left(1 + \gamma x^{-\beta} \right)^{3\alpha}}{\lambda_1 (1 + \gamma x^{-\beta})^{\frac{\alpha}{\gamma}} + (\lambda_2 - \lambda_1) \left(1 + \gamma x^{-\beta} \right)^{2\alpha} + (1 - \lambda_2) \left(1 + \gamma x^{-\beta} \right)^{3\alpha}} \right]},$$

(15)

The elasticity $e(x) = \frac{d \ln f(x)}{d \ln x} = x r(x)$ for the CRTMBIII distribution is

The elasticity of the CRTMBIII distribution shows the behavior of the accumulation of probability in the domain of the random variable.

The quantile function of the CRTMBIII distribution is the solution of the following

$$x_q = \left[ \frac{1}{\gamma} \left( -\frac{B}{3A} - \frac{2^{1/3}(-B^2 + 3AC)}{3AM} + \frac{M}{32^{1/3} A} \right)^{\frac{1}{\alpha}} \right],$$

(17)

where $A = (1 - \lambda_2)$, $B = (\lambda_2 - \lambda_1)$, $C = \lambda_1$ and

$$M = \left[ -2B^3 + 9ABC + 27A^2 q + \sqrt{4(-B^2 + 3AC)^3 + (-2B^3 + 9ABC + 27A^2 q)^2} \right]^{1/3}.$$
The random number generator of the CRTMBIII distribution is the solution of the following

$$X = \left[ \frac{1}{\gamma} \left( -\frac{B}{3A} - 2^{1/3}(-B^2 + 3AC) + \frac{M_Z}{3AM_Z} \right)^\frac{1}{\gamma} \right]^{\frac{1}{\beta}},$$

where $M_Z = \left[ -2B^3 + 9ABC + 27A^2Z + \sqrt{4(-B^2 + 3AC)^3 + (-2B^3 + 9ABC + 27A^2Z)^2} \right]^{1/3}$ and the random variable $Z$ has the uniform distribution on $(0,1)$.

### 2.2 Shapes of the CRTMBIII Density and Hazard Rate Functions

The following graphs show that shapes of CRTMBIII density are arc, exponential, positively skewed, negatively skewed and symmetrical (Fig.1). The CRTMBIII distribution has unimodal, bimodal, arc, increasing, decreasing, decreasing-increasing-decreasing, inverted bathtub and modified bathtub hazard rate function (Fig. 2).

![Fig.1 Plots of pdf of the CRTMBIII distribution for the selected parameter values](image)

![Fig.2 Plots of hrf of the CRTMBIII distribution for the selected parameter values](image)

### 2.3 Sub-Models

The CRTMBIII distribution has the following sub models (Table 1).
3. MATHEMATICAL PROPERTIES

We derive theoretically some mathematical properties such as the $r^{th}$ ordinary moments, $s^{th}$ incomplete moments, and inequality measures, residual and reverse residual life function and reliability measures in this section.

3.1 Ordinary Moments

The moments are significant tools for statistical analysis in pragmatic sciences. The descriptive measures such as central tendency ($\mu'_1$), dispersion ($\sigma$), skewness ($\gamma_1$) and kurtosis ($\gamma_2$) can be calculated from the moments.

For $X \sim \text{CRTMBIII}(\alpha, \beta, \gamma, \lambda_1, \lambda_2)$, the $r^{th}$ ordinary moment is

$$E(X^r) = \int_0^{\infty} x^r f(x) \, dx,$$

$$\mu'_r = E(X^r) = \int_0^{\infty} x^r \alpha \beta x^{-\beta - 1} \left[ \lambda_1 (1 + \gamma x^{-\beta})^{\alpha \gamma^{-1}} + 2(\lambda_2 - \lambda_1)(1 + \gamma x^{-\beta}) \frac{2\alpha}{\gamma^{-1}} + 3(1 - \lambda_2)(1 + \gamma x^{-\beta}) \frac{3\alpha}{\gamma^{-1}} \right] \, dx.$$

Letting $\gamma x^{-\beta} = y$, $x = \left( \frac{y}{\gamma} \right)^{\beta}$, $\beta x^{-\beta - 1} \, dx = -dy$, then
\[
\begin{align*}
\mu'_r &= E(X^r) = \left[ \lambda_1 \gamma^{-\beta} \left( 1 - \frac{r}{\beta} \right) + 2(\lambda_2 - \lambda_1) \gamma^{-\beta} \left( 1 - \frac{2r}{\beta} \right) \\
&\quad + 3(1 - \lambda_2) \gamma^{-\beta} \left( 1 - \frac{3r}{\beta} \right) \right] \\
\mu''_r &= E(X^r) = \gamma^{-\beta} \Gamma \left( 1 - \frac{r}{\beta} \right) \left[ \lambda_1 \gamma^{-\beta} \left( \frac{\alpha + 1}{\alpha} \right) + (\lambda_2 - \lambda_1) \frac{\gamma^{-\beta} \left( 2\alpha + 1 \right)}{\gamma^{-\beta} \left( 2\alpha + 1 \right)} + (1 - \lambda_2) \frac{\gamma^{-\beta} \left( 3\alpha + 1 \right)}{\gamma^{-\beta} \left( 3\alpha + 1 \right)} \right] \\
&\quad + (1 - \lambda_2) \frac{\gamma^{-\beta} \left( 3\alpha + 1 \right)}{\gamma^{-\beta} \left( 3\alpha + 1 \right)} , r = 1, 2, 3, 4, \ldots
\end{align*}
\]

(19)

where \( \Gamma(\cdot, \cdot) \) is a gamma function.

Mean and Variance of the CRTMBIII distribution are

\[
E(X) = \frac{1}{\beta} \Gamma \left( 1 - \frac{1}{\beta} \right) \left[ \lambda_1 \gamma^{-\beta} \left( \frac{\alpha + 1}{\alpha} \right) + (\lambda_2 - \lambda_1) \frac{\gamma^{-\beta} \left( 2\alpha + 1 \right)}{\gamma^{-\beta} \left( 2\alpha + 1 \right)} + (1 - \lambda_2) \frac{\gamma^{-\beta} \left( 3\alpha + 1 \right)}{\gamma^{-\beta} \left( 3\alpha + 1 \right)} \right].
\]

\[
\text{Var}(X) = \frac{2}{\gamma^{-\beta}} \left[ \Gamma \left( 1 - \frac{2}{\beta} \right) \left[ \lambda_1 \gamma^{-\beta} \left( \frac{\alpha + 2}{\alpha} \right) + (\lambda_2 - \lambda_1) \frac{\gamma^{-\beta} \left( 2\alpha + 2 \right)}{\gamma^{-\beta} \left( 2\alpha + 2 \right)} + (1 - \lambda_2) \frac{\gamma^{-\beta} \left( 3\alpha + 2 \right)}{\gamma^{-\beta} \left( 3\alpha + 2 \right)} \right] - \right]
\]

\[
\left\{ \frac{2}{\gamma^{-\beta}} \left( \Gamma \left( 1 - \frac{1}{\beta} \right) \right)^2 \left[ \lambda_1 \gamma^{-\beta} \left( \frac{\alpha + 1}{\alpha} \right) + (\lambda_2 - \lambda_1) \frac{\gamma^{-\beta} \left( 2\alpha + 1 \right)}{\gamma^{-\beta} \left( 2\alpha + 1 \right)} + (1 - \lambda_2) \frac{\gamma^{-\beta} \left( 3\alpha + 1 \right)}{\gamma^{-\beta} \left( 3\alpha + 1 \right)} \right]^2 \right\}.
\]

The Mellin transformation is applied to get the moments of a probability distribution. For X~CRTMBIII(\( \alpha, \beta, \gamma, \lambda_1, \lambda_2 \)), the Mellin transform is

\[
M \{ f(x); s \} = f^s(s) = E(X^{s-1}),
\]

\[
M \{ f(x); s \} = \gamma^{-\beta} \Gamma \left( 1 - \frac{s-1}{\beta} \right) \left[ \lambda_1 \gamma^{-\beta} \left( \frac{\alpha + s-1}{\alpha} \right) + (\lambda_2 - \lambda_1) \frac{\gamma^{-\beta} \left( 2\alpha + s-1 \right)}{\gamma^{-\beta} \left( 2\alpha + s-1 \right)} + (1 - \lambda_2) \frac{\gamma^{-\beta} \left( 3\alpha + s-1 \right)}{\gamma^{-\beta} \left( 3\alpha + s-1 \right)} \right].
\]

(20)

The \( r^{th} \) central moment (\( \mu_r \)), coefficients of skewness (\( \gamma_1 \)) and kurtosis (\( \gamma_2 \)) for the CRTMBIII model are attained from \( \mu_r = \sum_{\ell=1}^{\ell=r} (-1)^{\ell} \binom{r}{\ell} \mu'_{\ell} \mu'_{r-\ell} \), \( \gamma_1 = \frac{\mu_3}{(\mu_2)^{\frac{3}{2}}} \) and \( \beta_2 = \frac{\mu_4}{(\mu_2)^2} \). The numerical values for the mean (\( \mu'_{1} \)), median (\( \bar{\mu} \)), standard deviation (\( \sigma \)), skewness (\( \gamma_1 \)) and kurtosis (\( \gamma_2 \)) for the CRTMBIII distribution for selected values of \( \alpha, \beta, \gamma, \lambda_1, \lambda_2 \) are listed in Table 2. We also depict that the CRTMBIII model can be effective to model data sets in terms of the descriptive measures.
3.2 Order Statistics and their moments

Order statistics (OS) have wide applications in climatology, life testing and reliability. Moments of OS are also designed for replacement policy with the prediction of failure of future items determined from few early failures.

Let \(X_1, \ldots, X_n\) be a random sample from the CRTMBIII model and let \(X_{i1}, \ldots, X_{in}\) be the corresponding order statistics. The pdf of the \(i\)th order statistic, say \(X_{in}\), is given by

\[
f_{in}(x) = \frac{f(x)}{B(i, n - i + 1)} \sum_{r=0}^{n-i} (-1)^r \binom{n-i}{r} F^{r+i-1}(x),
\]

where \(B(\cdot, \cdot)\) is the beta function.

\[
f_{in}(x) = \frac{1}{B(i, n - i + 1)} \sum_{r=0}^{n-i} \sum_{s=0}^{i} a_{r,s} x^{-\frac{1}{\gamma}} (1 + \gamma x^{-\beta})^\frac{\alpha}{\gamma} \\
\times \left[ \lambda_i + 2(\lambda_i - \lambda_1)(1 + \gamma x^{-\beta})^\frac{\alpha}{\gamma} + 3(1 - \lambda_2)(1 + \gamma x^{-\beta})^\frac{2\alpha}{\gamma} \right],
\]

(21)
where \( a_{r,s,i} = \lambda_1^{r+i-s-1}(\lambda_2 - \lambda_1)\gamma^{s-i} (1-\lambda_2)^{(1-\lambda_1)\gamma^{i}} \left( \frac{n-i}{r} \right) \left( \frac{r+i-1}{s} \right) \left( \frac{s}{i} \right) \).

The \( q \)th ordinary moment of \( X_{r,s} \) say \( \mu_q = E(X_{r,s}^q) \) is determined from (21) as

3.3 Incomplete Moments

Mean inactivity life; mean waiting time and inequality measures can be obtained from incomplete moments. For \( X \sim \text{CRTMBIII} (\alpha, \beta, \gamma, \lambda_1, \lambda_2) \), the incomplete lower moments are

\[
M'_r(z) = E_{x < z}(X^r) = \int_0^z x^r \alpha \beta x^{-\beta-1} \left[ \lambda_1 (1 + \gamma x^{-\beta})^{-r-1} + 2(\lambda_2 - \lambda_1)(1 + \gamma x^{-\beta})^{-\frac{2\alpha}{\gamma}} \right] dx.
\]

Letting \( \gamma x^{-\beta} = y \), \( x = \left( \frac{y}{\gamma} \right)^{\frac{1}{\beta}} \), \( \gamma \beta x^{-\beta-1} dx = -dy \), then

\[
E_{x < z}(X^r) = \frac{\alpha r}{\gamma^{\beta}} \left\{ \lambda_1 \left[ B \left(1 - \frac{r}{\beta}, \frac{r}{\beta} + \gamma \right) - B_{\gamma x^{-\beta}} \left(1 - \frac{r}{\beta}, \frac{r}{\beta} + \gamma \right) \right] + 2(\lambda_2 - \lambda_1) \left[ B \left(1 - \frac{r}{\beta}, \frac{2\alpha}{\gamma} + \frac{r}{\beta} \right) - B_{\gamma x^{-\beta}} \left(1 - \frac{r}{\beta}, \frac{2\alpha}{\gamma} + \frac{r}{\beta} \right) \right] + 3(1 - \lambda_2) \left[ B \left(1 - \frac{r}{\beta}, \frac{3\alpha}{\gamma} + \frac{r}{\beta} \right) - B_{\gamma x^{-\beta}} \left(1 - \frac{r}{\beta}, \frac{3\alpha}{\gamma} + \frac{r}{\beta} \right) \right] \right\},
\]

where \( r < \beta \) and \( B_{\gamma x^{-\beta}} (\ldots) \) is the incomplete beta function.

For \( X \sim \text{CRTMBIII} (\alpha, \beta, \gamma, \lambda_1, \lambda_2) \), the incomplete upper moments are

\[
E_{x > z}(X^r) = \int_z^\infty z^r \alpha \beta z^{-\beta-1} \left[ \lambda_1 (1 + \gamma z^{-\beta})^{-r-1} + 2(\lambda_2 - \lambda_1)(1 + \gamma z^{-\beta})^{-\frac{2\alpha}{\gamma}} \right] dz
\]

\[
+ 3(1 - \lambda_2)(1 + \gamma z^{-\beta})^{-\frac{3\alpha}{\gamma}} \right] dx,
\]

Letting \( \gamma z^{-\beta} = y \), \( z = \left( \frac{y}{\gamma} \right)^{\frac{1}{\beta}} \), \( \gamma \beta z^{-\beta-1} dz = -dy \), we arrive at

\[
E_{x > z}(X^r) = \frac{\alpha r}{\gamma^{\beta}} \left\{ \lambda_1 B_{\gamma z^{-\beta}} \left(1 - \frac{r}{\beta}, \frac{r}{\beta} + \gamma \right) + 2(\lambda_2 - \lambda_1) B_{\gamma z^{-\beta}} \left(1 - \frac{r}{\beta}, \frac{2\alpha}{\gamma} + \frac{r}{\beta} \right) + 3(1 - \lambda_2) B_{\gamma z^{-\beta}} \left(1 - \frac{r}{\beta}, \frac{3\alpha}{\gamma} + \frac{r}{\beta} \right) \right\},
\]

where \( r < \beta \) and \( B_{\gamma z^{-\beta}} (\ldots) \) is the incomplete beta function.
The mean deviation about the mean \( \delta = E|X - \mu| \) and about the median \( \delta = E|X - \tilde{\mu}| \) can be written as \( \delta = 2\mu F(\mu) - 2\mu M_1'(\mu) \) and \( \delta = \mu - 2M_1'(\tilde{\mu}) \) respectively, where \( \mu = E(X) \) and \( \tilde{\mu} = x_{0.5} \). The quantities \( M_1'(\mu) \) and \( M_1'(\tilde{\mu}) \) can be obtained from (23). For specific probability \( p \), Lorenz and Bonferroni curves are computed as \( L(p) = \frac{M_1'(q)}{\tilde{\mu}} \), \( B(p) = L(p) \big| p \) and, where \( q = Q(p) \).

### 3.4 Residual Life functions

For \( X \sim \text{CRTMBIII} \) \((\alpha, \beta, \gamma, \lambda_1, \lambda_2)\), the \( n \)th moment of the residual life, \( m_n(z) = E[(X - z)^n | X > z] \), is

\[
m_n(z) = \frac{1}{S(z)} \int_z^\infty (x - z)^n f(x) \, dx,
\]

\[
m_n(z) = \frac{1}{S(z)} \sum_{s=0}^n \binom{n}{s} (-z)^{n-s} E_{X > z} \left( X^s \right),
\]

\[
m_n(z) = \frac{1}{S(z)} \sum_{s=0}^n \binom{n}{s} (-z)^{n-s} \frac{\alpha}{\beta} \left[ \lambda_1 B_{r_{yz}} - \left( 1 - \frac{s}{\beta} + \frac{s}{\beta} \right) \right] + 2(\lambda_2 - \lambda_1) B_{r_{yz}} - \left( 1 - \frac{s}{\beta} + \frac{s}{\beta} \right) + 3(1 - \lambda_2) B_{r_{yz}} - \left( 1 - \frac{s}{\beta} + \frac{s}{\beta} \right).
\]

The average remaining lifetime of a component at time \( z \), say \( m_1(z) \), or life expectancy is known as mean residual life (MRL) function is given by

\[
m_1(z) = \frac{1}{S(z)} \sum_{s=0}^1 \binom{1}{s} (-z)^{1-s} \frac{\alpha}{\beta} \left[ \lambda_1 B_{r_{yz}} - \left( 1 - \frac{s}{\beta} + \frac{s}{\beta} \right) \right] + 2(\lambda_2 - \lambda_1) B_{r_{yz}} - \left( 1 - \frac{s}{\beta} + \frac{s}{\beta} \right) + 3(1 - \lambda_2) B_{r_{yz}} - \left( 1 - \frac{s}{\beta} + \frac{s}{\beta} \right).
\]

For \( X \sim \text{CRTMBIII} \) \((\alpha, \beta, \gamma, \lambda_1, \lambda_2)\), the \( n \)th moment of the reverse residual life, \( M_n(z) = E[(z - X)^n | X \leq z] \) is

\[
M_n(z) = \frac{1}{F(z)} \int_0^z (z - x)^n f(x) \, dx
\]

\[
M_n(z) = \frac{1}{F(z)} \sum_{s=0}^n (-1)^s \binom{n}{s} \frac{\alpha}{\beta} \left[ \lambda_1 B_{r_{yz}} - \left( 1 - \frac{s}{\beta} + \frac{s}{\beta} \right) \right] + 2(\lambda_2 - \lambda_1) B_{r_{yz}} - \left( 1 - \frac{s}{\beta} + \frac{s}{\beta} \right) + 3(1 - \lambda_2) B_{r_{yz}} - \left( 1 - \frac{s}{\beta} + \frac{s}{\beta} \right).
\]

The waiting time \( z \) for failure of a component has passed with condition that this failure had happened in the interval \([0, z]\) is called mean waiting time (MWT) or mean inactivity.
time. The waiting time \( z \) for failure of a component of \( X \) with CRTMIII distribution is defined by

\[
M_I(z) = \frac{1}{F(z)} \sum_{\eta=0}^{\infty} (-1)^\eta \left( \frac{1}{\gamma^2} \sum_{j=0}^{\infty} \left( \frac{-s}{\beta + \gamma} \right)^j \right) \left\{ \begin{array}{l}
\lambda B \left( \frac{1 - \frac{s}{\beta + \gamma}}{\beta - \gamma} \right) + 2(\lambda - \lambda_1) B \left( \frac{1 - \frac{2s}{\beta + \gamma}}{\beta - \gamma} \right) + 3(1 - \lambda_1) B \left( \frac{1 - \frac{3s}{\beta + \gamma}}{\beta - \gamma} \right) \\
\lambda B \left( \frac{1 - \frac{s}{\beta + \gamma}}{\beta - \gamma} \right) - 2(\lambda - \lambda_1) B \left( \frac{1 - \frac{2s}{\beta + \gamma}}{\beta - \gamma} \right) - 3(1 - \lambda_1) B \left( \frac{1 - \frac{3s}{\beta + \gamma}}{\beta - \gamma} \right)
\end{array} \right. \right\}
\]

(28)

### 3.5 Stress-strength Reliability for CRTMIII Distribution

Let \( X_1 \sim CRTMIII(\alpha_1, \beta, \gamma, \lambda_1, \lambda_2) \) and \( X_2 \sim CRTMIII(\alpha_2, \beta, \gamma, \lambda_1, \lambda_2) \), such that \( X_1 \) represents strength and \( X_2 \) represents stress. Then reliability of the component is:

\[
R = \Pr(X_2 < X_1) = \int_{-\infty}^{\infty} \int f(x, x_1) dx_1 dx = \int_{0}^{\infty} x f_{X_1}(x) dx,
\]

\[
R = \frac{\alpha_1 \beta x^{\beta-1}}{0} \left[ \lambda_1 \left(1 + \gamma x^\beta\right)^{-\frac{\alpha_1}{\gamma}} + 2(\lambda_2 - \lambda_1) \left(1 + \gamma x^\beta\right)^{-\frac{\alpha_2}{\gamma} + 3(1 - \lambda_1) \left(1 + \gamma x^\beta\right)^{-\frac{3\alpha_1}{\gamma}}} \right]
\]

\[
\left[ \lambda_2 \left(1 + \gamma x^\beta\right)^{-\frac{\alpha_2}{\gamma} + 2(\lambda_2 - \lambda_1) \left(1 + \gamma x^\beta\right)^{-\frac{\alpha_2}{\gamma} + 3(1 - \lambda_2) \left(1 + \gamma x^\beta\right)^{-\frac{3\alpha_2}{\gamma}}} \right) \right] dx.
\]

\[
R = \int_{0}^{\infty} \frac{\alpha \beta x^{\beta-1}}{0} \left[ \lambda_1 \left(1 + \gamma x^\beta\right)^{-\frac{\alpha_1}{\gamma} + 2(\lambda_2 - \lambda_1) \left(1 + \gamma x^\beta\right)^{-\frac{\alpha_2}{\gamma} + 3(1 - \lambda_1) \left(1 + \gamma x^\beta\right)^{-\frac{3\alpha_1}{\gamma}}} \right] +
\]

\[
\left[ \lambda_2 \left(1 + \gamma x^\beta\right)^{-\frac{\alpha_2}{\gamma} + 2(\lambda_2 - \lambda_1) \left(1 + \gamma x^\beta\right)^{-\frac{\alpha_2}{\gamma} + 3(1 - \lambda_2) \left(1 + \gamma x^\beta\right)^{-\frac{3\alpha_2}{\gamma}}} \right) \right] dx.
\]

Therefore the stress-strength reliability parameter \( R \) is independent of parameters \( \beta, \gamma, \lambda_1 \), and \( \lambda_2 \).

### 4. CHARACTERIZATIONS

In order to develop a stochastic function in a certain problem, it is necessary to know whether the selected function fulfills the requirements of the specific underlying probability distribution. To this end, it is required to study characterizations of the specific probability distribution. Here, we present two characterizations of the CRTMBIII distribution (i) ratio of the truncated moments and (ii) double truncated moments.

#### 4.1 Ratio of Truncated Moments

We characterize the CRTMBIII distribution on the basis of a simple relationship between two truncated moments of functions of \( X \) [Theorem G (Glänzel; 1987)].
4.1.1: Let \( X : \Omega \to (0, \infty) \) be a continuous random variable and let
\[
h_1(x) = \frac{1}{\alpha} \left[ \lambda_1 \left( 1 + \gamma x^{-\beta} \right)^{\frac{\alpha}{\gamma}} + 2(\lambda_2 - \lambda_1)(1 + \gamma x^{-\beta})^{\frac{2\alpha}{\gamma}} + 3(1 - \lambda_2)(1 + \gamma x^{-\beta})^{\frac{3\alpha}{\gamma}} \right]^{-1},
\]
and
\[
h_2(x) = \frac{2}{\alpha} x^{-\beta} \left[ \lambda_1 \left( 1 + \gamma x^{-\beta} \right)^{\frac{\alpha}{\gamma}} + 2(\lambda_2 - \lambda_1)(1 + \gamma x^{-\beta})^{\frac{2\alpha}{\gamma}} + 3(1 - \lambda_2)(1 + \gamma x^{-\beta})^{\frac{3\alpha}{\gamma}} \right]^{-1}, \quad x > 0.
\]
The pdf of \( X \) is (10) if and only if \( q(x) \) (in Theorem G) has the form \( q(x) = x^\beta, \quad x > 0 \).

**Proof.** If \( X \) has pdf (10), then
\[
(1 - F(x)) E[h_1(x)|X \geq x] = x^{-\beta}, \quad x > 0,
\]
and
\[
E[h_1(X)|X \geq x] = q(x) = x^\beta.
\]
The differential equation \( s'(x) = \frac{q(x)h_2(x)}{q(x)h_2(x) - h_1(x)} = \frac{2\beta}{x} \) has solution \( x = \ln x^{2\beta} \).

Therefore according to theorem G, \( X \) has pdf (11).

**Corollary 4.1.1:** Let \( X : \Omega \to (0, \infty) \) be a continuous random variable and let
\[
h_2(x) = \frac{2}{\alpha} x^{-\beta} \left[ \lambda_1 \left( 1 + \gamma x^{-\beta} \right)^{\frac{\alpha}{\gamma}} + 2(\lambda_2 - \lambda_1)(1 + \gamma x^{-\beta})^{\frac{2\alpha}{\gamma}} + 3(1 - \lambda_2)(1 + \gamma x^{-\beta})^{\frac{3\alpha}{\gamma}} \right]^{-1}, \quad x > 0.
\]
The pdf of \( X \) is (10) if and only if functions \( q(x) \) and \( h_1(x) \) satisfy the equation
\[
\frac{q'(x)h_2(x)}{q(x)h_2(x) - h_1(x)} = \frac{2\beta}{x}.
\]

**Remark 4.1.1:** The general solution of the above differential equation is
\[
q(x) = x^{2\beta} \left[ -2\beta x^{-2\beta} h_1(x) \right]^{-1} h_1(x) dx + D,
\]
where \( D \) is a constant.

### 4.2 Doubly Truncated Moment

Here, we characterize the CRTMBIII distribution via doubly truncated moment.

**Proposition 4.2.1:** Let \( X: \Omega \to (0, +\infty) \) be a continuous random variable. Then \( X \) has pdf (10) if and only if
\[
E \left[ \frac{\lambda_1 + 2(\lambda_2 - \lambda_1)(1 + \gamma x^{-\beta})^{\frac{\alpha}{\gamma}} + 3(1 - \lambda_2)(1 + \gamma x^{-\beta})^{\frac{2\alpha}{\gamma}} - \frac{3\alpha}{\gamma} + 2\beta x^{-2\beta} h_1(x)}{F(\lambda_1 + 2(\lambda_2 - \lambda_1)(1 + \gamma x^{-\beta})^{\frac{\alpha}{\gamma}} + 3(1 - \lambda_2)(1 + \gamma x^{-\beta})^{\frac{2\alpha}{\gamma}} - \frac{3\alpha}{\gamma} + 2\beta x^{-2\beta} h_1(x))} \right] \quad x < X < y
\]
\[
= \frac{(1 + \gamma y^{-\beta})^{\frac{\alpha}{\gamma}} - (1 + \gamma x^{-\beta})^{\frac{\alpha}{\gamma}}}{[F(x) - F(y)]}, \quad x > 0, y > 0. \quad (30)
\]

**Proof:**
For random variable \( X \) with pdf (10), we have
\[
E \left[ \lambda_1 + 2(\lambda_2 - \lambda_1) \left( 1 + \gamma x^{-\beta} \right)^{\frac{\alpha}{\gamma}} + 3(1 - \lambda_2) \left( 1 + \gamma x^{-\beta} \right)^{\frac{2\alpha}{\gamma}} \right] \bigg| x < X < y \\
= \int_y^{\infty} \left[ \lambda_1 + 2(\lambda_2 - \lambda_1) \left( 1 + \gamma u^{-\beta} \right)^{\frac{\alpha}{\gamma}} + 3(1 - \lambda_2) \left( 1 + \gamma u^{-\beta} \right)^{\frac{2\alpha}{\gamma}} \right]^{-1} f(u) \, du \\
= \frac{\int_y^{\infty} \left[ \lambda_1 + 2(\lambda_2 - \lambda_1) \left( 1 + \gamma u^{-\beta} \right)^{\frac{\alpha}{\gamma}} + 3(1 - \lambda_2) \left( 1 + \gamma u^{-\beta} \right)^{\frac{2\alpha}{\gamma}} \right]^{-1} \alpha \beta u^{-\beta-1} \left( 1 + \gamma u^{-\beta} \right)^{\frac{\alpha}{\gamma}} \, du}{\left[ F(x) - F(y) \right]}
\]

Conversely, if (30) holds, then
\[
\int_y^{\infty} \left[ \lambda_1 + 2(\lambda_2 - \lambda_1) \left( 1 + \gamma u^{-\beta} \right)^{\frac{\alpha}{\gamma}} + 3(1 - \lambda_2) \left( 1 + \gamma u^{-\beta} \right)^{\frac{2\alpha}{\gamma}} \right]^{-1} f(u) \, du = \frac{\left( 1 + \gamma y^{-\beta} \right)^{\frac{\alpha}{\gamma}} - \left( 1 + \gamma x^{-\beta} \right)^{\frac{\alpha}{\gamma}}}{\left[ F(x) - F(y) \right]}
\]
\[
\int_y^{\infty} \left[ \lambda_1 + 2(\lambda_2 - \lambda_1) \left( 1 + \gamma u^{-\beta} \right)^{\frac{\alpha}{\gamma}} + 3(1 - \lambda_2) \left( 1 + \gamma u^{-\beta} \right)^{\frac{2\alpha}{\gamma}} \right]^{-1} f(u) \, du = \left( 1 + \gamma y^{-\beta} \right)^{\frac{\alpha}{\gamma}} - \left( 1 + \gamma x^{-\beta} \right)^{\frac{\alpha}{\gamma}}.
\]
Differentiating with respect to \( y \), we have
\[
\left[ \lambda_1 + 2(\lambda_2 - \lambda_1) \left( 1 + \gamma y^{-\beta} \right)^{\frac{\alpha}{\gamma}} + 3(1 - \lambda_2) \left( 1 + \gamma y^{-\beta} \right)^{\frac{2\alpha}{\gamma}} \right]^{-1} f(y) = \alpha \beta y^{-\beta-1} \left( 1 + \gamma y^{-\beta} \right)^{\frac{\alpha}{\gamma}} - 1,
\]
or
\[
f(x) = \alpha \beta x^{-\beta-1} \left( 1 + \gamma x^{-\beta} \right)^{\frac{\alpha}{\gamma}} \left[ \lambda_1 + 2(\lambda_2 - \lambda_1) \left( 1 + \gamma x^{-\beta} \right)^{\frac{\alpha}{\gamma}} + 3(1 - \lambda_2) \left( 1 + \gamma x^{-\beta} \right)^{\frac{2\alpha}{\gamma}} \right], \quad x > 0,
\]
which is pdf of the CRTMBIII distribution.

5. MAXIMUM LIKELIHOOD ESTIMATION

Here, we adopt maximum likelihood estimation technique for the CRTMBIII parameters. Let \( \Phi = (\alpha, \beta, \gamma, \lambda_1, \lambda_2) \) be unknown parameter vector. The log likelihood function \( \ell(\Phi) \) for the CRTMBIII distribution is

We can compute the maximum likelihood estimators (MLEs) of \( \alpha, \beta, \gamma, \lambda_1, \lambda_2 \) by solving equations 32-36 either directly or using quasi-Newton procedure, computer packages/softwares such as R, SAS, Ox, MATLAB, MAPLE and MATHEMATICA.
6. SIMULATION STUDY

In this section, we survey the performance of the MLEs of the parameters of the CRTMBIII distribution with respect to sample size \( n \). This performance is done based on the following simulation study:

**Step 1:** Generate 1000 samples of size \( n \) from the CRTMBIII distribution based on the inverse cdf method.

**Step 2:** Compute the MLEs for 1000 samples, say \((\hat{\alpha}, \hat{\beta}, \hat{\gamma}, \hat{\lambda}_1, \hat{\lambda}_2)\) for \( i=1,2,\ldots,1000 \) based on non-linear optimization algorithm with constraint matching to range of parameters.

**Step 3:** Compute the biases, mean squared errors and coverage probability of MLEs.

For this purpose, we have selected different arbitrarily parameter values and \( n=50,100,150,200 \) sample sizes. All codes are written in R and the results are summarized in Table 3. The result clearly shows that when the sample size increases, the mean square errors (MSEs) decrease. This shows the consistency of MLE estimators.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Statistics</th>
<th>( \alpha = 1 )</th>
<th>( \beta = 8 )</th>
<th>( \gamma = 1 )</th>
<th>( \lambda_1 = 0.5 )</th>
<th>( \lambda_2 = 0.5 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>n=50</td>
<td>Bias</td>
<td>0.472</td>
<td>1.638</td>
<td>0.761</td>
<td>0.104</td>
<td>0.180</td>
</tr>
<tr>
<td></td>
<td>MSE</td>
<td>0.992</td>
<td>3.507</td>
<td>1.329</td>
<td>0.867</td>
<td>0.772</td>
</tr>
<tr>
<td></td>
<td>CP</td>
<td>94.90</td>
<td>95.12</td>
<td>94.11</td>
<td>95.23</td>
<td>94.97</td>
</tr>
<tr>
<td>n=100</td>
<td>Bias</td>
<td>0.289</td>
<td>1.419</td>
<td>0.434</td>
<td>0.091</td>
<td>0.094</td>
</tr>
<tr>
<td></td>
<td>MSE</td>
<td>0.718</td>
<td>1.127</td>
<td>1.071</td>
<td>0.530</td>
<td>0.423</td>
</tr>
<tr>
<td></td>
<td>CP</td>
<td>95.30</td>
<td>94.89</td>
<td>95.04</td>
<td>95.01</td>
<td>94.99</td>
</tr>
<tr>
<td>n=200</td>
<td>Bias</td>
<td>0.117</td>
<td>0.912</td>
<td>0.210</td>
<td>0.070</td>
<td>0.087</td>
</tr>
<tr>
<td></td>
<td>MSE</td>
<td>0.482</td>
<td>1.067</td>
<td>0.975</td>
<td>0.313</td>
<td>0.189</td>
</tr>
<tr>
<td></td>
<td>CP</td>
<td>95.00</td>
<td>94.98</td>
<td>94.99</td>
<td>94.95</td>
<td>95.04</td>
</tr>
<tr>
<td>n=300</td>
<td>Bias</td>
<td>0.073</td>
<td>0.150</td>
<td>0.097</td>
<td>0.003</td>
<td>0.050</td>
</tr>
<tr>
<td></td>
<td>MSE</td>
<td>0.210</td>
<td>0.929</td>
<td>0.151</td>
<td>0.113</td>
<td>0.093</td>
</tr>
<tr>
<td></td>
<td>CP</td>
<td>95.07</td>
<td>95.01</td>
<td>94.95</td>
<td>94.99</td>
<td>95.02</td>
</tr>
</tbody>
</table>
7. APPLICATIONS

We consider an application to data set such as strengths of 1.5 cm glass fibers for authentication of the flexibility, utility and potentiality of the CRTMBIII distribution. We compare the CRTMBIII distribution with TMBIII, MBIII, BIII, LL distributions. For selection of the optimum distribution, we compute the estimate of likelihood ratio statistics \( \chi^2 \), Akaike information criterion (AIC), corrected Akaike information criterion (CAIC), Bayesian information criterion (BIC), Hannan-Quinn information criterion (HQIC), Cramer-von Mises (W*), Anderson Darling (A*), and Kolmogorov-Smirnov [K-S] statistics with p-values for all competing and sub distributions. We compute the MLEs and their standard errors (in parentheses). We also compute goodness of fit statistics (GOFs) values for the CRTMBIII, TMBIII, MBIII, BIII, LL models.

### 7.1 Strengths of Glass Fibers

The values of data about strengths of 1.5 cm glass fibers (Smith and Naylor; 1987 and Arifa et al.;2017) are: 0.55, 0.74, 0.77, 0.81, 0.84, 0.93, 1.04, 1.11, 1.13, 1.24, 1.25, 1.27, 1.28, 1.29, 1.30, 1.36, 1.39, 1.42, 1.48, 1.48, 1.49, 1.49, 1.50, 1.50, 1.51, 1.52, 1.53, 1.54, 1.55, 1.55, 1.58, 1.59, 1.60, 1.61, 1.61, 1.61, 1.62, 1.62, 1.63, 1.64, 1.66, 1.66, 1.67, 1.68, 1.69, 1.70, 1.70, 1.73, 1.76, 1.76, 1.77, 1.78, 1.81, 1.82, 1.84, 1.84, 1.89, 2.00, 2.01, 2.24.

A descriptive summary for the strengths of 1.5 cm glass fibers data set provides the following values: 63 (sample size), 0.55 (minimum), 2.24 (maximum), 1.59 (median), 1.506825 (mean), 0.3241257 (standard deviation), 21.5105 (coefficient of variation), -0.89993 (coefficient of skewness) and 3.92376 (coefficient of kurtosis). The boxplot (Fig. ...
for strengths of glass fibers data is negatively skewed. The TTT (total time on test) plot (Fig. 3(b)) for strengths of glass fibers data is concave, which infers increasing failure rate. So, the BIII-ME distribution is suitable to model these data.

![Boxplot and TTT plot](image)

Figure 3 Boxplot (a) and TTT plot (b) for glass fiber data

Table 4 reports the MLEs (standard errors) and measures $W^*$, $A^*$, KS (p-values). Table 5 displays the values $-2\hat{\ell}$, AIC, CAIC, BIC and HQIC.

<table>
<thead>
<tr>
<th>Model</th>
<th>$\alpha$</th>
<th>$\beta$</th>
<th>$\gamma$</th>
<th>$\hat{\lambda}_1$</th>
<th>$\hat{\lambda}_2$</th>
<th>$W$</th>
<th>$A$</th>
<th>KS (p-value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CRTBIII</td>
<td>3343.16 (4457.274)</td>
<td>18.4436 (2.302738)</td>
<td>16264.06 (23802.86)</td>
<td>0.6463 (0.3772)</td>
<td>1.000000e-10 (0.8656)</td>
<td>0.0390</td>
<td>0.2318</td>
<td>0.0782 (0.8359)</td>
</tr>
<tr>
<td>TMBIII</td>
<td>15062.42 (3881.1386)</td>
<td>20.0016 (0.7276)</td>
<td>82081.20 (8543.3265)</td>
<td>0.4698 (0.3181)</td>
<td>1</td>
<td>0.0807</td>
<td>0.4523</td>
<td>0.1077 (0.4574)</td>
</tr>
<tr>
<td>MBIII</td>
<td>38353.3724 (4604.0351)</td>
<td>20.70762 (0.7271)</td>
<td>172677.4910 (6315.7470)</td>
<td>1</td>
<td>1</td>
<td>0.1135</td>
<td>0.6271</td>
<td>0.1292 (0.2434)</td>
</tr>
<tr>
<td>BIII</td>
<td>3.4417 (0.4505)</td>
<td>4.0886 (0.3357)</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0.9554</td>
<td>5.1997</td>
<td>0.2462 (0.001)</td>
</tr>
<tr>
<td>LL</td>
<td>1</td>
<td>3.4506 (0.3414)</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0.8045</td>
<td>4.4035</td>
<td>0.5346 (4.441e-16)</td>
</tr>
</tbody>
</table>

Table 5: $-2\hat{\ell}$, AIC, CAIC, BIC and HQIC for Strengths of Glass Fibers

<table>
<thead>
<tr>
<th>Model</th>
<th>$-2\hat{\ell}$</th>
<th>AIC</th>
<th>CAIC</th>
<th>BIC</th>
<th>HQIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>CRTBIII</td>
<td>19.17072</td>
<td>29.17072</td>
<td>30.22335</td>
<td>39.88639</td>
<td>33.38525</td>
</tr>
<tr>
<td>TMBIII</td>
<td>22.18592</td>
<td>30.18593</td>
<td>30.87558</td>
<td>38.75846</td>
<td>33.55755</td>
</tr>
<tr>
<td>MBIII</td>
<td>23.82574</td>
<td>29.82573</td>
<td>30.23251</td>
<td>36.25514</td>
<td>32.35445</td>
</tr>
<tr>
<td>BIII</td>
<td>73.76724</td>
<td>77.76725</td>
<td>77.96725</td>
<td>82.05352</td>
<td>79.45306</td>
</tr>
<tr>
<td>LL</td>
<td>136.9448</td>
<td>138.9448</td>
<td>139.0104</td>
<td>141.088</td>
<td>139.7877</td>
</tr>
</tbody>
</table>

From the tables 4 and 5, it is clear that our proposed model is best fitted, with smallest values for all GOFs and maximum p-value.
Figure 4: Fitted (a) pdf, (b) cdf, (c) survival and (d) PP plots for the CRTMBIII distribution to Strengths.

Figure 4 inferences that the proposed model is closely fitted to strengths of glass fibers.

8. CONCLUDING REMARKS

We propose a very flexible distribution on the basis of the cubic transmuted mapping that is suitable for applications in survival analysis, reliability and actuarial science. The density function of CRTMBIII is symmetrical, right-skewed, left-skewed, exponential, arc, J and bimodal shaped. The flexible hazard rate of the proposed model can accommodate almost all types of shapes such as unimodal, bimodal, arc, increasing, decreasing, decreasing-increasing-decreasing, inverted bathtub and modified bathtub. We derive the important mathematical properties of the proposed distribution such as survival function, hazard function, reverse hazard function, cumulative hazard function, mills ratio, elasticity, quantile function, moments about the origin, and moments of order statistics, incomplete moments, inequality measures and stress-strength reliability measures. We characterize the proposed distribution via ratio of truncated moments and doubly truncated moment. We address the maximum likelihood estimation for the model parameters. We evaluate the precision of the maximum likelihood estimators via simulation study. We consider an application to real data set to illustrate the flexibility, utility and potentiality of the proposed model. We compute goodness of fit tests for examining the adequacy and competency of the proposed model. We ascertain empirically that the proposed model is suitable for strengths of glass fibers analysis.
REFERENCES


