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A Two Stage Group Sampling Plans based on truncated life tests for Type-II Generalized Log-Logistic distribution

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Abstract: This paper will illustrate the development of a two-stage group sampling plan based on the truncated life tests for the life time of the products follows type-II generalized log-logistic distribution (TGLLD). The decision to be made regarding the acceptance of lot is depends on the observed number of failures from each group either in first or second stage of sampling. At an accepted level of consumer's risk and at a predefined test termination time, the design parameters like number of groups required and the acceptance number for each group at two stages are derived for the underlying lifetime distribution. Single stage group sampling plans are also considered as special cases of the proposed plan and both plans are compared with each other with respect to the values of average sample number and the operating characteristics.

Keywords—Type-II generalized log-logistic distribution, average sample number, consumer's risk, producer's risk, operating characteristics.

I. INTRODUCTION

Introduction Acceptance sampling is the process of inspecting a random sample from a lot of products to decide whether to accept that lot or not. The main purpose of developing such plans is to make a decision on the quality of lot of products tested from a random sample. The lot is accepted if the observed number of failures does not exceed the acceptance number before the test termination time.

The acceptance sampling plans for truncated life test are frequently used to determine the sample size from a lot under consideration. For usual sampling plan it is assumed that only a single item is put in a tester. Testers accommodating multiple numbers of items at a time in order to save the time and cost. For this type of testing the number of items to be equipped in a tester is given by the specification. The acceptance sampling plan under this type of testers will be called group acceptance sampling plan (GASP). If GASP is used in conjunction with truncated life tests, it is called a GASP based on truncated life test assuming that the lifetime of product follows a certain probability distribution. For such a test the determination of sample size is equivalent to determine the number of groups.

Many authors have put their efforts to develop the acceptance sampling plans based on truncated life tests, referring to few of such plans are Gupta and Groll [8], Kantam and Rosaiah. [9], Kantam et al. [10], Rosaiah et al. [15], [16], Aslam and Shabaz [1], Rao [19], Aslam and Jun [2], [3] & [4], Aslam et al. [5], Rao et al. [20], [21], Rosaiah et al. [17], [18].

The theme to present this paper is to develop a two-stage group sampling plans based on the truncated life tests when the life time of a product follows type-II generalized log-logistic distribution (TGLLD).As far as sample size is concerned, a two-stage group sampling plans may throw better results than a single sampling plan. Some of the authors have drawn their attention in developing such plans viz. Razzaque et al. [13], Aslam et al. [6], Rao et al. [22], Ramaswamy et al. [11], [12]. The subsequent part of this paper is organized in the following way. Introduction of TGLLD is given in section 2. Section 3 describes the design of the two-stage sampling plan. Summarized analysis with real data example and conclusions are presented in section 5 and 6 respectively.

II. TYPE-II GENERALIZED LOG-LOGISTIC DISTRIBUTION

Log-logistic distribution (LLD) has proven its importance in quality control. Different authors developed properties and types of acceptance sampling plans for LLD. The cumulative distribution function (CDF) of the log-logistic distribution (LLD) is

$$F\left(t;\sigma,\theta\right)=\frac{\left(t/\sigma\right)^{\lambda}}{\left[1+\left(t/\sigma\right)^{\lambda}\right]};t>0,\sigma>0,\lambda>1$$

(1)

Since the practical pertinence of generalized log-logistic distribution (GLLD) in diverse sectors, various authors have paid their attention in developing some extensions for effective and wide use of log-logistic distribution. One such extension to this distribution named as Type-II generalized log-logistic distribution (TGLLD) introduced by Rosaiah *et al.* [16], its cumulative distribution function (CDF) is

$$F(t;\lambda,\theta,\sigma)=1-\left[1+\left(t/\sigma\right)^{\lambda}\right]^{-\theta};t>0,\lambda>1,\theta>0,\sigma>0$$

(2)

It may be noted that the distribution given in (2) is defined through the reliability oriented generalization of log-logistic distribution. In short, we call this as the Type-II generalized log-logistic distribution [Type-I generalized (exponentiated) log-logistic distribution is dealt with by Rosaiah *et al.* [14]]. The corresponding probability density function (PDF) is given by

$$f(t;\lambda,\theta,\sigma)=\frac{\lambda\theta}{\sigma}\frac{\left(t/\sigma\right)^{\lambda-1}}{\left[1+\left(t/\sigma\right)^{\lambda}\right]^{\theta+1}};t>0,\lambda>1,\theta>0,\sigma>0$$

(3)

where σ is the scale parameter, λ and θ are shape parameters.

Rao *et al.* [20] & [21] developed the reliability test plans for this distribution. The reliability function and hazard (failure rate) function of type-II generalized log-logistic distribution are respectively given by

$$R\left(t\right)=\left[1+\left(t/\sigma\right)^{\lambda}\right]^{-\theta}$$

(4)

$$h\left(t\right)=\frac{\lambda\theta\left(t/\sigma\right)^{\lambda-1}}{\left[1+\left(t/\sigma\right)^{\lambda}\right]};t>0,\lambda>1,\theta>0,\sigma>0$$

(5)

The three-parameter TGLLD will be denoted by TGLLD$\left(\lambda,\theta,\sigma\right)$.

The 100_q^{th} percentile of the TGLLD is given by

$$t_q=\sigma\eta_q\quad,\quad\text{where}\quad\eta_q=\left[\left(1-q\right)^{-1/\theta}-1\right]^{1/\lambda}$$

(6)

Hence, for fixed values of $\theta=\theta_0$ and $\lambda=\lambda_0$, the quantile t_q in equation (6) is the function of scale parameter $\sigma=\sigma_0$ *i.e.*, $t_q\geq t_q^0\Leftrightarrow\sigma\geq\sigma_0$, where $\sigma_0=t_q^0/\eta_q$.

It may be noted that σ_0 depends on θ_0 and λ_0 to draw the acceptance sampling plans for TGLLD.

III. Design of Two–Stage Group Sampling Plan

We prefer to use the percentile point as the quality parameter instead of mean and it is denoted by tq. According to the acceptance sampling plans the hypothesis $H_0:t_q\geq t_q^0$ is tested based on the number of observed failures from a sample in a pre-fixed time. The number of products in the lot to be tested and is divided into equal sized groups subject to the availability of the number of testers. It is assumed that the experimental time and number of products in each group are fixed in advance. Since the number of products is a multiple of number of groups, determining the number of products is equivalent to determining number of groups. The operating procedure of the proposed two stage sampling plan is described below when fixed sizes of *r* items in a group are assumed to be tested.

First stage: Draw the first random sample of size n1 from a lot, allocate *r* items to each of the g_1 groups (or testers) so that $n_1=rg_1$ and put them on test for the test time t_0. Accept the lot if the number of failures from each group is c_1 or less.

Truncate the test and reject the lot as soon as the number of failures in any group is larger than c_2 before t_0. Otherwise, go to the second stage.

Second stage: Draw the second random sample of size n_2 from a lot, allocate r items to each of g_2 groups, so that $n_2 = rg_2$ and put them on test for t_0. Accept the lot if the number of failures in each group is c_1 or less. Truncate the test and reject the lot if the number of failures in any group is larger than c_1 before t_0.

The other sampling plans can be obtained as particular cases of two stage sampling plan namely

i. IF $R=1$; IT BECOMES A DOUBLE SAMPLING PLAN

ii. IF $C_1=C_2$; IT TURNS TO A SINGLE STAGE GROUP SAMPLING PLAN.

As per the plan, it is necessitated that the design parameters g_1, g_2, c_1 & c_2 are to be derived for the specified values of group size r, consumer's risk and producer's risk. Also keeping in view of customers preference, it is desirable to design the plan with c_1=0 and c_2= 1.

The lot acceptance probability from the first stage in the two-stage group sampling plan is given by

$$P_a^{(1)} = \sum_{i=0}^{c_1} \binom{rg_1}{i} p^i (1-p)^{rg_1-i}$$

(7)

where g_1 is number of groups, c_1 is the acceptance number, r is the group size and p is the probability of getting a failure within the test termination time t_0. If the life time of the product t follows TGLLD then $p = F(t_0)$ given in (2). Since it is convenient to set the termination time as multiple of the targeted $100q^{th}$ lifetime percentile, t_q^0 and a constant δ_q. Let t_q be the true $100q^{th}$ lifetime percentile. Then p can be rewritten as

$$p = 1 - \left[1 + \left(t_0/\sigma\right)^{\lambda}\right]^{-\theta} = 1 - \left[1 + \left\{\left(\frac{\eta_q \delta_q^0}{\left(t_q/t_q^0\right)}\right)^{\lambda}\right\}\right]^{-\theta}$$

(8)

The probability of lot rejection at the first stage is given by,

$$P_r^{(1)} = 1 - \left[\sum_{i=0}^{c_2} \binom{rg_1}{i} p^i (1-p)^{rg_1-i}\right]$$

(9)

Probability of lot acceptance in the second stage will be

$$P_a^{(2)} = \left[1 - \left(p_a^{1} + p_r^{1}\right)\right]\left[\sum_{i=0}^{c_1} \binom{rg_2}{i} p^i (1-p)^{rg_2-i}\right]$$

(10)

Therefore, the probability of lot acceptance for the proposed two-stage economic reliability group sampling plan is given by

$$L(p) = P_a^{(1)} + P_a^{(2)}$$

(11)

In case of c_1 = 0 and c_2 =1, then the acceptance probability $L(p)$ in equation (11) becomes

$$L(p) = (1-p)^{rg_1} + rg_1 p (1-p)^{rg_1 - 1} (1-p)^{rg_2}$$

(12)

The design parameters i.e., the minimum number of groups g_1, g_2 can be obtained using two-point approach method, subject to satisfying the following two inequalities.

$$L\left(p\left(t_q/t_q^0\right) = \delta_1\right) \le \beta$$

(13)

$$L\left(p\left(t_q/t_q^0\right) = \delta_2\right) \ge 1-\alpha$$

(14)

where δ_1 is the percentile ratio at the consumer's risk and δ_2 is the percentile ratio at the producer's risk. Here we take the value of δ_1 as 1. Let p_1 and p_2 are the failure probabilities corresponding to consumer's and producer's risks respectively and are given by

$$p_1 = 1 - \left[1 + \left(\eta_q \delta_q^0\right)^{\lambda}\right]^{-\theta} \text{ and } p_2 = 1 - \left[1 + \left\{\left(\frac{\eta_q \delta_q^0}{\left(t_q / t_q^0\right)}\right)^{\lambda}\right\}\right]^{-\theta} \quad (15)$$

It may be possible to get multiple solutions for the design parameters subject to satisfying the equations (13) and (14). Hence one may choose the solution which minimizes the ASN of the plan.

The ASN for the two-stage sampling plan is obtained by

$$ASN = rg_1 + rg_2 + \left(1 - P_a^{(1)} - P_r^{(1)}\right) \quad (16)$$

where $P_a^{(1)}$ and $P_r^{(1)}$ are evaluated at $p = p_2$.

Therefore the design parameters for the proposed two-stage group sampling plan can be obtained by the solution from the following optimization problem.

Minimize $ASN(p_2) = rg_1 + rg_2 + \left(1 - P_a^{(1)} - P_r^{(1)}\right)$ (17a)

Subject to

$L(p_1) \le \beta$ (17b)

$L(p_2) \ge 1 - \alpha$ (17c)

$1 \le g_2 \le g_1$ (17d)

$0 \le c_1 \le c_2$ (17e)

g_1, g_2, c_1 and c_2 are integers (17f)

As it is not ideal to have more number of groups in the second stage than in the first stage, hence the constraint (17d) is brought in.

The design parameters g_1 and g_2 of the proposed plan are derived for a specified α, β, δ_1 and δ_2 in such a fashion that minimize *ASN* (p_2) subject to the inequalities (17b) and (17c) for specified values of shape parameters λ and θ, test termination ratio t_q / t_q^0 and the number of testers r. The minimum number of groups required for the two-stage group sampling plan for parametric combinations $(\theta = 2, \lambda = 2)$ and $(\theta = 1.5, \lambda = 2)$ according to values of percentile ratios $t_q / t_q^0 = 5, 5.5, 6, 6.5, 7$ for a specified consumer's risk β =0.25, 0.10, 0.05, 0.01 when *r* =3, 5 are estimated for 25th and 50th percentiles and are presented in Tables 1-4. For the data under consideration given in section 5, the plan parameters obtained for the estimated values of θ and λ i.e., $\hat{\theta} = 1.18$ and $\hat{\lambda} = 2.66$ are presented in tables 5 and 6.

It is observed form the tables 1 to 6 that when other parameters are fixed and the group size is increase from *r*=3 to 5, then the number of groups required are come down sharply. It is also indicates that larger group size requires smaller sample and helps to have quick decisions with minimum operational cost. When the percentile ratio raised to 50th percentile the number of groups required becomes lesser than in the 25th percentile.

IV. Comparison with Single-Stage Sampling Plan

In order to find out the worthiness of this plan, we considered a single-stage group sampling plan with *r* as the group size and tables are prepared accordingly. As we stated in this paper, the two-stage sampling plan becomes single-stage when $c_1 = c_2 = c$ .Then the probability of accepting the lot is

$$P_a = \sum_{i=0}^{c} \binom{rg}{i} p^i (1-p)^{rg-i}$$

where g is the number of groups required. Hence ASN is the number obtained as multiplying r with g.

In a similar fashion having specified level of unreliability at a given consumer's risk a table can be prepared for determining the number of groups and acceptance number required in the two-stage group sampling plan. It can be seen from tables 7 and 8, increase in the groups when the acceptance number turns from $c_1 = 0$ to 1, also number of groups required becomes lesser when group size raises from 3 to 5. If we consider ASN alone, single stage group sampling plan with $c_1 = 0$ provides smaller values than the two-stage sampling plan. If the group size grows, ASN and OC values are together to be considered, then two-stage sampling plan provides better results than single-stage sampling plan.

V. Description of the Proposed Methodology with Real Data Example

In this section, we use a real data set to show that the type-II generalized log-logistic distribution can be a suitable model. Folks & Chhikara [7] presented several sets of data to describe the Birnbaum-Saunders distribution. One of thedata set gives the runoff amounts at Jug Bridge, Maryland. For ready reference this data set is reproduced as follows:

0.17, 0.23, 0.33, 0.39, 0.39, 0.40, 0.45, 0.52, 0.56, 0.59, 0.64, 0.66, 0.70, 0.76, 0.77, 0.78, 0.95, 0.97, 1.02, 1.12, 1.19, 1.24, 1.59, 1.74 and 2.92.

We show a rough indication of the goodness of fit for our model by plotting the superimposed for the data shows that the TGLLD is a good fit in Figure 1 and also goodness of fit is emphasized with QQ plot, displayed in Figure 1. The maximum likelihood estimates of the three parameter TGLLD for the runoff amounts are $\hat{\sigma}$ =0.7616, $\hat{\lambda}$ =2.6602 and $\hat{\theta}$ =1.1772 and the Kolmogorov-Smirnov test and found that the maximum distance between the data and the fitted of the TGLLD is 0.0657 with p-value is 0.9999. Meanwhile, the maximum likelihood estimates of the two-parameter TGLLD for the runoff amounts are $\hat{\lambda}$ =2.6602 and $\hat{\theta}$ =1.772 and the Kolmogorov-Smirnov test and found that the maximum distance between the data and the fitted of the TGLLD is 0.2526 with p-value is 0.1891. Therefore, the two-parameter TGLLD is also provides reasonable good fit for the runoff amounts.

Suppose that an experimenter would like to use the proposed two-stage sampling plan to establish the true unknown 25th percentile lifetime for the product is 5 runoff amounts and experiment will be stopped after 5 runoff amounts. The producer's risk γ is 0.05 when the true 25th percentile is 5 times t_{q_0} and consumer's risk β is 0.25 when the true 25th percentile lifetime is t_{q_0}. Further, suppose that in the laboratory the experimenter has facility to install five items on a tester. This information leads to δ_q^0 =1.0. For *r*= 5, $\hat{\lambda}$ =2.6602 and $\hat{\theta}$ =1.772, the design parameters can be obtain from Table 5 as g_1 =2, g_2 =1, c_1=0 and c_2=1 since δ_q^0 =1.0 and t_q / t_q^0 =5. The sampling plan could be implemented as follows: select a first sample of size 10 randomly and distribute 5 items into each of 2 testers. Accept the lot if no failure from each tester. Reject the lot if more than 1 failure from any tester and terminate the test. If one failure is observed from any tester then go to the second stage, then select a second sample of size 5 from lot and allot to one tester. Accept the lot if there are no failures observed from the second sample. Reject the lot when first failure is identified from any tester and terminate the test. The probability of acceptance for this plan is 0.9982 and ASN is 10.12.

VI. Conclusions

In this article, a two-stage sampling plan to ensure the specified product lifetime percentile has been developed for the type-II generalized log-logistic distribution. The design parameters g_1 and g_2 of the proposed sampling plan are derived by the two-point method. Extensive tables have been provided for the industrial use according to various parameters and percentile values. It was observed that the number of groups required increases as the consumer's confidence increases, true quality decreases and as r increases the number of groups reduces for all the parameters. A comparison between the proposed group sampling plan and the ordinary group sampling plan has also been discussed. It has been noticed that the proposed plan requires a smaller sample size than the ordinary group sampling plan does. The methodology illustrated with real data example.

Table1: Minimum number of groups required and ASN in the two-stage sampling plan for θ=2 and λ =2 of TGLLD to ensure25th percentile of TGLLD.

		δ =0.5, r=3				δ =1, r=3				δ =0.5, r=5				δ =1 ,r=5			
β	t_q / t_q^0	g_1	g_2	ASN	$L(P_2)$	g_1	g_2	ASN	$L(P_2)$	g_1	g_2	ASN	$L(P_2)$	g_1	g_2	ASN	$L(P_2)$
0.25	5	12	1	36.30	0.9935	3	1	9.30	0.9913	7	1	35.49	0.9932	2	1	10.55	0.9871
	5.5	12	1	36.25	0.9955	3	1	9.25	0.9939	7	1	35.41	0.9953	2	1	10.46	0.991
	6	12	1	36.21	0.9968	3	1	9.22	0.9957	7	1	35.35	0.9966	2	1	10.40	0.9935
	6.5	12	1	36.19	0.9976	3	1	9.19	0.9968	7	1	35.30	0.9975	2	1	10.34	0.9953
	7	12	1	36.16	0.9982	3	1	9.16	0.9976	7	1	35.26	0.9982	2	1	10.30	0.9964
0.1	5	17	1	51.40	0.9878	4	1	12.39	0.9862	10	1	50.66	0.9874	3	1	15.77	0.9765
	5.5	17	1	51.34	0.9915	4	1	12.33	0.9904	10	1	50.56	0.9912	3	1	15.66	0.9835
	6	17	1	51.29	0.9939	4	1	12.28	0.9931	10	1	50.48	0.9937	3	1	15.57	0.9881
	6.5	17	1	51.26	0.9955	4	1	12.24	0.9949	10	1	50.42	0.9954	3	1	15.49	0.9912
	7	17	1	51.22	0.9966	4	1	12.21	0.9962	10	1	50.36	0.9965	3	1	15.43	0.9934
0.05	5	21	1	63.48	0.9821	5	1	15.46	0.9802	12	1	60.77	0.9827	3	1	15.77	0.9765
	5.5	21	1	63.41	0.9875	5	1	15.40	0.9861	12	1	60.66	0.9879	3	1	15.66	0.9835
	6	21	1	63.35	0.991	5	1	15.34	0.99	12	1	60.57	0.9913	3	1	15.57	0.9881
	6.5	21	1	63.31	0.9934	5	1	15.30	0.9926	12	1	60.49	0.9936	3	1	15.49	0.9912
	7	21	1	63.27	0.995	5	1	15.26	0.9945	12	1	60.43	0.9952	3	1	15.43	0.9934
0.01	5	-	-	----	-------	7	1	21.60	0.9656	17	1	86.01	0.9682	4	1	20.97	0.9637
	5.5	-	-	----	-------	7	1	21.52	0.9757	17	1	85.88	0.9776	4	1	20.84	0.9743
	6	-	-	----	-------	7	1	21.45	0.9824	17	1	85.76	0.9838	4	1	20.73	0.9814
	6.5	-	-	----	-------	7	1	21.40	0.987	17	1	85.67	0.988	4	1	20.63	0.9862
	7	-	-	----	-------	7	1	21.35	0.9902	17	1	85.59	0.9909	4	1	20.56	0.9896

Table2: Minimum number of groups required and ASN in the two-stage sampling plan for θ=2 and λ =2 of TGLLD to ensure 50^{th} percentile of TGLLD.

β	t_q / t_q^0	δ =0.5, r=3				δ =1, r=3				δ =0.5, r=5				δ =1 ,r=5			
		g_1	g_2	ASN	$L(P_2)$	g_1	g_2	ASN	$L(P_2)$	g_1	g_2	ASN	$L(P_2)$	g_1	g_2	ASN	$L(P_2)$
0.25	5	4	1	12.27	0.9936	1	1	3.27	0.9884	3	1	15.55	0.9889	1	1	5.71	0.9687
	5.5	4	1	12.23	0.9955	1	1	3.23	0.9919	3	1	15.46	0.9923	1	1	5.60	0.9779
	6	4	1	12.19	0.9968	1	1	3.19	0.9942	3	1	15.40	0.9945	1	1	5.52	0.9840
	6.5	4	1	12.17	0.9977	1	1	3.17	0.9957	3	1	15.34	0.9959	1	1	5.45	0.9881
	7	4	1	12.14	0.9983	1	1	3.15	0.9968	3	1	15.30	0.9970	1	1	5.39	0.9910
0.1	5	6	1	18.39	0.9873	2	1	6.49	0.9702	4	1	20.70	0.9826	1	1	5.71	0.9687
	5.5	6	1	18.33	0.9912	2	1	6.42	0.9789	4	1	20.60	0.9879	1	1	5.60	0.9779
	6	6	1	18.28	0.9937	2	1	6.36	0.9847	4	1	20.51	0.9913	1	1	5.52	0.9840
	6.5	6	1	18.24	0.9954	2	1	6.32	0.9887	4	1	20.45	0.9936	1	1	5.45	0.9881
	7	6	1	18.21	0.9965	2	1	6.28	0.9915	4	1	20.39	0.9952	1	1	5.39	0.9910
0.05	5	8	1	24.49	0.9794	2	1	6.49	0.9702	5	1	25.84	0.9752	-	-	-	-
	5.5	8	1	24.42	0.9856	2	1	6.42	0.9789	5	1	25.72	0.9826	1	1	5.60	0.9779
	6	8	1	24.36	0.9896	2	1	6.36	0.9847	5	1	25.62	0.9874	1	1	5.52	0.9840
	6.5	8	1	24.31	0.9923	2	1	6.32	0.9887	5	1	25.54	0.9907	1	1	5.45	0.9881
	7	8	1	24.28	0.9942	2	1	6.28	0.9915	5	1	25.48	0.9930	1	1	5.39	0.9910
0.01	5	11	1	33.63	0.9647	-	-	-	-	6	1	30.97	0.9668	-	-	-	-
	5.5	11	1	33.54	0.9750	3	1	9.58	0.9619	6	1	30.84	0.9766	-	-	-	-
	6	11	1	33.47	0.9819	3	1	9.51	0.9722	6	1	30.73	0.9830	2	1	10.92	0.9597
	6.5	11	1	33.41	0.9866	3	1	9.45	0.9793	6	1	30.64	0.9875	2	1	10.81	0.9698
	7	11	1	33.36	0.9899	3	1	9.39	0.9843	6	1	30.56	0.9905	2	1	10.72	0.9769

Table3: Minimum number of groups required and ASN in the two-stage sampling plan for θ=1.5 and λ =2 of TGLLD to ensure 25^{th} percentile of TGLLD

β	t_q / t_q^0	*δ =0.5, r=3*				*δ =1, r=3*				*δ =0.5 ,r=5*				*δ =1 ,r=5*			
		g_1	g_2	ASN	$L(P_2)$	g_1	g_2	ASN	$L(P_2)$	g_1	g_2	ASN	$L(P_2)$	g_1	g_2	ASN	$L(P_2)$
0.25	5	11	1	33.28	0.9942	3	1	9.31	0.9909	7	1	35.50	0.9929	2	1	10.56	0.9865
	5.5	11	1	33.24	0.9960	3	1	9.26	0.9936	7	1	35.42	0.9951	2	1	10.47	0.9906
	6	11	1	33.20	0.9971	3	1	9.22	0.9954	7	1	35.36	0.9965	2	1	10.40	0.9932
	6.5	11	1	33.17	0.9979	3	1	9.19	0.9967	7	1	35.31	0.9974	2	1	10.35	0.9950
	7	11	1	33.15	0.9984	3	1	9.17	0.9975	7	1	35.27	0.9981	2	1	10.30	0.9963
0.1	5	16	1	48.39	0.9885	4	1	12.39	0.9856	10	1	50.68	0.9868	3	1	15.79	0.9755
	5.5	16	1	48.33	0.9920	4	1	12.33	0.9899	10	1	50.58	0.9908	3	1	15.67	0.9828
	6	16	1	48.29	0.9943	4	1	12.29	0.9928	10	1	50.49	0.9934	3	1	15.58	0.9876
	6.5	16	1	48.25	0.9958	4	1	12.25	0.9947	10	1	50.43	0.9952	3	1	15.50	0.9908
	7	16	1	48.22	0.9968	4	1	12.22	0.9960	10	1	50.37	0.9964	3	1	15.44	0.9931
0.05	5	20	1	60.47	0.9828	5	1	15.47	0.9793	12	1	60.79	0.9818	3	1	15.79	0.9755
	5.5	20	1	60.40	0.9880	5	1	15.40	0.9855	12	1	60.67	0.9873	3	1	15.67	0.9828
	6	20	1	60.35	0.9914	5	1	15.35	0.9895	12	1	60.58	0.9909	3	1	15.58	0.9876
	6.5	20	1	60.30	0.9937	5	1	15.30	0.9923	12	1	60.50	0.9933	3	1	15.50	0.9908
	7	20	1	60.26	0.9952	5	1	15.26	0.9942	12	1	60.44	0.9949	3	1	15.44	0.9931
0.01	5	-	-	-	-	7	1	21.61	0.9641	-	-	-	-	4	1	20.99	0.9621
	5.5	-	-	-	-	7	1	21.53	0.9746	17	1	85.89	0.9765	4	1	20.85	0.9732
	6	-	-	-	-	7	1	21.46	0.9816	17	1	85.78	0.9830	4	1	20.74	0.9806
	6.5	-	-	-	-	7	1	21.40	0.9864	17	1	85.68	0.9874	4	1	20.65	0.9856
	7	-	-	-	-	7	1	21.36	0.9897	17	1	85.60	0.9905	4	1	20.57	0.9891

Table4: Minimum number of groups required and ASN in the two-stage sampling plan for θ=1.5 and λ =2 of TGLLD to ensure50th percentile of TGLLD.

		δ =0.5, r=3				δ =1, r=3				δ =0.5 ,r=5				δ =1 ,r=5			
β	t_q / t_q^0	g_1	g_2	ASN	$L(P_2)$	g_1	g_2	ASN	$L(P_2)$	g_1	g_2	ASN	$L(P_2)$	g_1	g_2	ASN	$L(P_2)$
0.25	5	4	1	12.29	0.9928	1	1	3.29	0.9871	2	1	10.40	0.9932	1	1	5.74	0.9653
	5.5	4	1	12.24	0.9950	1	1	3.24	0.9909	2	1	10.34	0.9953	1	1	5.63	0.9753
	6	4	1	12.20	0.9964	1	1	3.21	0.9935	2	1	10.29	0.9967	1	1	5.54	0.9821
	6.5	4	1	12.18	0.9974	1	1	3.18	0.9952	2	1	10.25	0.9975	1	1	5.47	0.9867
	7	4	1	12.15	0.9980	1	1	3.15	0.9964	2	1	10.22	0.9982	1	1	5.41	0.9899
0.1	5	6	1	18.41	0.9858	2	1	6.52	0.9668	4	1	20.74	0.9805	1	1	5.74	0.9653
	5.5	6	1	18.35	0.9901	2	1	6.44	0.9765	4	1	20.63	0.9864	1	1	5.63	0.9753
	6	6	1	18.30	0.9929	2	1	6.38	0.9830	4	1	20.54	0.9902	1	1	5.54	0.9821
	6.5	6	1	18.26	0.9948	2	1	6.33	0.9874	4	1	20.47	0.9928	1	1	5.47	0.9867
	7	6	1	18.22	0.9961	2	1	6.29	0.9904	4	1	20.41	0.9946	1	1	5.41	0.9899
0.05	5	7	1	21.46	0.9816	2	1	6.52	0.9668	4	1	20.74	0.9805	1	1	5.74	0.9653
	5.5	7	1	21.39	0.9871	2	1	6.44	0.9765	4	1	20.63	0.9864	1	1	5.63	0.9753
	6	7	1	21.34	0.9907	2	1	6.38	0.9830	4	1	20.54	0.9902	1	1	5.54	0.9821
	6.5	7	1	21.29	0.9932	2	1	6.33	0.9874	4	1	20.47	0.9928	1	1	5.47	0.9867
	7	7	1	21.26	0.9949	2	1	6.29	0.9904	4	1	20.41	0.9946	1	1	5.41	0.9899
0.01	5	10	1	30.61	0.9664	-	-	-	-	6	1	31.02	0.9630	-	-	-	-
	5.5	10	1	30.53	0.9763	3	1	9.61	0.9577	6	1	30.88	0.9738	-	-	-	-
	6	10	1	30.46	0.9828	3	1	9.53	0.9690	6	1	30.77	0.9810	2	1	10.96	0.9552
	6.5	10	1	30.40	0.9873	3	1	9.47	0.9768	6	1	30.67	0.9859	2	1	10.85	0.9663
	7	10	1	30.35	0.9904	3	1	9.41	0.9824	6	1	30.59	0.9894	2	1	10.75	0.9743

Table5: Minimum number of groups required and ASN in the two-stage sampling plan for θ=1.18 and λ =2.66 of TGLLD to ensure 25th percentile of TGLLD.

		δ =0.5, r=3				δ =1, r=3				δ =0.5 ,r=5				δ =1 ,r=5			
β	t_q / t_q^0	g_1	g_2	ASN	$L(P_2)$	g_1	g_2	ASN	$L(P_2)$	g_1	g_2	ASN	$L(P_2)$	g_1	g_2	ASN	$L(P_2)$
0.25	5	17	1	51.11	0.9993	3	1	9.12	0.9988	10	1	50.17	0.9993	2	1	10.12	0.9982
	5.5	17	1	51.08	0.9996	3	1	9.09	0.9993	10	1	50.13	0.9996	2	1	10.17	0.9989
	6	17	1	51.07	0.9997	3	1	9.07	0.9995	10	1	50.11	0.9997	2	1	10.13	0.9993
	6.5	17	1	51.05	0.9998	3	1	9.06	0.9997	10	1	50.09	0.9998	2	1	10.11	0.9995
	7	17	1	51.04	0.9999	3	1	9.05	0.9998	10	1	50.07	0.9999	2	1	10.09	0.9997
0.1	5	25	1	75.15	0.9985	4	1	12.15	0.9980	15	1	75.25	0.9985	3	1	15.32	0.9966
	5.5	25	1	75.12	0.9991	4	1	12.12	0.9988	15	1	75.20	0.9991	3	1	15.25	0.9979
	6	25	1	75.10	0.9994	4	1	12.10	0.9992	15	1	75.16	0.9994	3	1	15.20	0.9987
	6.5	25	1	75.08	0.9996	4	1	12.08	0.9995	15	1	75.13	0.9996	3	1	15.16	0.9991
	7	25	1	75.06	0.9997	4	1	12.06	0.9997	15	1	75.11	0.9997	3	1	15.13	0.9994
0.05	5	-	-	-	-	5	1	15.19	0.9971	18	1	90.30	0.9978	3	1	15.32	0.9966
	5.5	-	-	-	-	5	1	15.15	0.9982	18	1	90.24	0.9987	3	1	15.25	0.9979
	6	-	-	-	-	5	1	15.12	0.9989	18	1	90.19	0.9992	3	1	15.20	0.9987
	6.5	-	-	-	-	5	1	15.10	0.9993	18	1	90.15	0.9995	3	1	15.16	0.9991
	7	-	-	-	-	5	1	15.08	0.9995	18	1	90.13	0.9996	3	1	15.13	0.9994
0.01	5	-	-	-	-	7	1	21.26	0.9949	-	-	-	-	4	1	20.41	0.9945
	5.5	-	-	-	-	7	1	21.20	0.9968	-	-	-	-	4	1	20.33	0.9967
	6	-	-	-	-	7	1	21.16	0.9980	-	-	-	-	4	1	20.26	0.9979
	6.5	-	-	-	-	7	1	21.13	0.9987	-	-	-	-	4	1	20.21	0.9986
	7	-	-	-	-	7	1	21.11	0.9991	-	-	-	-	4	1	20.18	0.9990

Table 6: Minimum number of groups required and ASN in the two-stage sampling plan for θ=1.18 and λ =2.66 of TGLLD to ensure 50th percentile of TGLLD.

β	t_q / t_q^0	δ =0.5, r=3				δ =1, r=3				δ =0.5, r=5				δ =1 ,r=5			
		g_1	g_2	ASN	$L(P_2)$	g_1	g_2	ASN	$L(P_2)$	g_1	g_2	ASN	$L(P_2)$	g_1	g_2	ASN	$L(P_2)$
0.25	5	6	1	18.11	0.9991	1	1	3.11	0.9981	6	2	30.58	0.9970	1	1	5.31	0.9945
	5.5	6	1	18.08	0.9995	1	1	3.09	0.9988	4	1	20.16	0.9993	1	1	5.24	0.9966
	6	6	1	18.07	0.9997	1	1	3.07	0.9993	4	1	20.12	0.9995	1	1	5.19	0.9979
	6.5	6	1	18.05	0.9998	1	1	3.06	0.9995	4	1	20.10	0.9997	1	1	5.16	0.9986
	7	6	1	18.04	0.9999	1	1	3.05	0.9997	4	1	20.08	0.9998	1	1	5.13	0.9990
0.1	5	9	1	27.16	0.9982	2	1	6.22	0.9948	5	1	25.25	0.9983	1	1	5.31	0.9945
	5.5	9	1	27.12	0.9989	2	1	6.17	0.9968	5	1	25.19	0.9989	1	1	5.24	0.9966
	6	9	1	27.10	0.9993	2	1	6.14	0.998	5	1	25.15	0.9993	1	1	5.19	0.9979
	6.5	9	1	27.08	0.9996	2	1	6.11	0.9987	5	1	25.13	0.9996	1	1	5.16	0.9986
	7	9	1	27.07	0.9997	2	1	6.09	0.9991	5	1	25.10	0.9997	1	1	5.13	0.9990
0.05	5	11	1	33.19	0.9975	2	1	6.22	0.9948	6	1	30.29	0.9976	1	1	5.31	0.9945
	5.5	11	1	33.15	0.9985	2	1	6.17	0.9968	6	1	30.23	0.9986	1	1	5.24	0.9966
	6	11	1	33.12	0.999	2	1	6.14	0.998	6	1	30.18	0.9991	1	1	5.19	0.9979
	6.5	11	1	33.10	0.9994	2	1	6.11	0.9987	6	1	30.15	0.9994	1	1	5.16	0.9986
	7	11	1	33.08	0.9996	2	1	6.09	0.9991	6	1	30.12	0.9996	1	1	5.13	0.9990
0.01	5	15	1	45.25	0.9955	3	1	9.31	0.9904	9	1	45.42	0.9952	2	1	10.57	0.9858
	5.5	15	1	45.20	0.9973	3	1	9.25	0.9941	9	1	45.34	0.9970	2	1	10.46	0.9912
	6	15	1	45.16	0.9983	3	1	9.20	0.9962	9	1	45.27	0.9981	2	1	10.37	0.9943
	6.5	15	1	45.13	0.9989	3	1	9.17	0.9975	9	1	45.22	0.9988	2	1	10.30	0.9962
	7	15	1	45.11	0.9992	3	1	9.14	0.9983	9	1	45.18	0.9992	2	1	10.25	0.9974

Table7: The number of groups in the single-stage gasp for TGLLD at 25th percentile.

β	t_q / t_q^0	$\lambda=2,\theta=2,r=3$						$\lambda=2,\theta=2,r=5$					
		Single with *c=0*			Single with *c=1*			Single with *c=0*			Single with *c=1*		
		g	ASN	OC	g	ASN	OC	g	ASN	OC	g	ASN	OC
0.25	5	-	-	-	4	12	0.9909	-	-	-	2	10	0.9937
	5.5	-	-	-	4	12	0.9936	1	5	0.9503	2	10	0.9956
	6	-	-	-	4	12	0.9955	1	5	0.9580	2	10	0.9969
	6.5	2	6	0.9571	4	12	0.9967	1	5	0.9641	2	10	0.9977
	7	2	6	0.9629	4	12	0.9975	1	5	0.9690	2	10	0.9983
0.1	5	-	-	-	5	15	0.9858	-	-	-	3	15	0.9858
	5.5	-	-	-	5	15	0.9901	-	-	-	3	15	0.9901
	6	-	-	-	5	15	0.9929	-	-	-	3	15	0.9929
	6.5	-	-	-	5	15	0.9948	-	-	-	3	15	0.9948
	7	-	-	-	5	15	0.9961	-	-	-	3	15	0.9961
0.05	5	-	-	-	6	18	0.9798	-	-	-	4	20	0.9753
	5.5	-	-	-	6	18	0.9858	-	-	-	4	20	0.9827
	6	-	-	-	6	18	0.9898	-	-	-	4	20	0.9875
	6.5	-	-	-	6	18	0.9925	-	-	-	4	20	0.9908
	7	-	-	-	6	18	0.9943	-	-	-	4	20	0.9930
0.01	5	-	-	-	8	24	0.9653	-	-	-	5	25	0.9626
	5.5	-	-	-	8	24	0.9755	-	-	-	5	25	0.9735
	6	-	-	-	8	24	0.9822	-	-	-	5	25	0.9808
	6.5	-	-	-	8	24	0.9868	-	-	-	5	25	0.9858
	7	-	-	-	8	24	0.9901	-	-	-	5	25	0.9892
		$\lambda=2,\theta=1.5,r=3$						$\lambda=2,\theta=1.5,r=5$					
0.25	5	-	-	-	4	12	0.9904	-	-	-	2	10	0.9934
	5.5	-	-	-	4	12	0.9933	-	-	-	2	10	0.9954
	6	-	-	-	4	12	0.9952	1	5	0.9570	2	10	0.9967
	6.5	2	6	0.9561	4	12	0.9965	1	5	0.9633	2	10	0.9976
	7	2	6	0.9620	4	12	0.9974	1	5	0.9682	2	10	0.9982
0.1	5	-	-	-	5	15	0.9852	-	-	-	3	15	0.9852
	5.5	-	-	-	5	15	0.9896	-	-	-	3	15	0.9896
	6	-	-	-	5	15	0.9926	-	-	-	3	15	0.9926
	6.5	-	-	-	5	15	0.9945	-	-	-	3	15	0.9945
	7	-	-	-	5	15	0.9959	-	-	-	3	15	0.9959
0.05	5	-	-	-	6	18	0.9789	-	-	-	4	20	0.9742
	5.5	-	-	-	6	18	0.9852	-	-	-	4	20	0.9819
	6	-	-	-	6	18	0.9893	-	-	-	4	20	0.9869
	6.5	-	-	-	6	18	0.9921	-	-	-	4	20	0.9903
	7	-	-	-	6	18	0.9941	-	-	-	4	20	0.9927
0.01	5	-	-	-	8	24	0.9638	-	-	-	5	25	0.9610
	5.5	-	-	-	8	24	0.9744	-	-	-	5	25	0.9723
	6	-	-	-	8	24	0.9814	-	-	-	5	25	0.9799
	6.5	-	-	-	8	24	0.9862	-	-	-	5	25	0.9851
	7	-	-	-	8	24	0.9896	-	-	-	5	25	0.9887

		$\lambda = 2.66, \theta = 1.18, r = 3$						$\lambda = 2.66, \theta = 1.18, r = 5$					
0.25	5	2	6	0.9734	4	12	0.9987	1	5	0.9778	2	10	0.9991
	5.5	2	6	0.9793	4	12	0.9992	1	5	0.9827	2	10	0.9995
	6	2	6	0.9835	4	12	0.9995	1	5	0.9862	2	10	0.9997
	6.5	2	6	0.9867	4	12	0.9997	1	5	0.9889	2	10	0.9998
	7	2	6	0.9890	4	12	0.9998	1	5	0.9908	2	10	0.9998
0.1	5	3	9	0.9603	5	15	0.9980	2	10	0.9560	3	15	0.9980
	5.5	3	9	0.9691	5	15	0.9988	2	10	0.9657	3	15	0.9988
	6	3	9	0.9754	5	15	0.9992	2	10	0.9727	3	15	0.9992
	6.5	3	9	0.9800	5	15	0.9995	2	10	0.9779	3	15	0.9995
	7	3	9	0.9836	5	15	0.9997	2	10	0.9818	3	15	0.9997
0.05	5	-	-	-	6	18	0.9971	-	-	-	4	20	0.9964
	5.5	4	12	0.9590	6	18	0.9982	-	-	-	4	20	0.9978
	6	4	12	0.9673	6	18	0.9989	3	15	0.9593	4	20	0.9986
	6.5	4	12	0.9735	6	18	0.9993	3	15	0.9670	4	20	0.9991
	7	4	12	0.9782	6	18	0.9995	3	15	0.9728	4	20	0.9994
0.01	5	-	-	-	8	24	0.9948	-	-	-	5	25	0.9944
	5.5	-	-	-	8	24	0.9968	-	-	-	5	25	0.9965
	6	6	18	0.9514	8	24	0.9980	-	-	-	5	25	0.9978
	6.5	6	18	0.9605	8	24	0.9987	4	20	0.9562	5	25	0.9985
	7	6	18	0.9674	8	24	0.9991	4	20	0.9639	5	25	0.9990

Table8: The number of groups in the single-stage gasp for TGLLD at 50th percentile.

β	t_q / t_q^0	$\lambda = 2, \theta = 2, r = 3$						$\lambda = 2, \theta = 2, r = 5$					
		Single with *c=0*			Single with *c=1*			Single with *c=0*			Single with *c=1*		
		g	ASN	OC	g	ASN	OC	g	ASN	OC	g	ASN	OC
0.25	5	-	-	-	2	6	0.9856	-	-	-	1	5	0.9902
	5.5	-	-	-	2	6	0.9899	-	-	-	1	5	0.9932
	6	-	-	-	2	6	0.9928	-	-	-	1	5	0.9951
	6.5	-	-	-	2	6	0.9947	-	-	-	1	5	0.9964
	7	1	3	0.9507	2	6	0.9960	-	-	-	1	5	0.9973
0.1	5	-	-	-	3	9	0.9677	-	-	-	2	10	0.9604
	5.5	-	-	-	3	9	0.9771	-	-	-	2	10	0.9719
	6	-	-	-	3	9	0.9834	-	-	-	2	10	0.9796
	6.5	-	-	-	3	9	0.9877	-	-	-	2	10	0.9848
	7	-	-	-	3	9	0.9907	-	-	-	2	10	0.9885
0.05	5	-	-	-	3	9	0.9677	-	-	-	2	10	0.9604
	5.5	-	-	-	3	9	0.9771	-	-	-	2	10	0.9719
	6	-	-	-	3	9	0.9834	-	-	-	2	10	0.9796
	6.5	-	-	-	3	9	0.9877	-	-	-	2	10	0.9848
	7	-	-	-	3	9	0.9907	-	-	-	2	10	0.9885
0.01	5	-	-	-	-	-	-	-	-	-	-	-	-
	5.5	-	-	-	4	12	0.9603	-	-	-	-	-	-
	6	-	-	-	4	12	0.9710	-	-	-	3	15	0.9558
	6.5	-	-	-	4	12	0.9783	-	-	-	3	15	0.9668
	7	-	-	-	4	12	0.9835	-	-	-	3	15	0.9747
		$\lambda = 2, \theta = 1.5, r = 3$						$\lambda = 2, \theta = 1.5, r = 5$					
0.25	5	-	-	-	2	6	0.9840	-	-	-	1	5	0.9891
	5.5	-	-	-	2	6	0.9888	-	-	-	1	5	0.9924
	6	-	-	-	2	6	0.9919	-	-	-	1	5	0.9945
	6.5	-	-	-	2	6	0.9940	-	-	-	1	5	0.9960
	7	-	-	-	2	6	0.9955	-	-	-	1	5	0.9970
0.1	5	-	-	-	3	9	0.9640	-	-	-	2	10	0.9561
	5.5	-	-	-	3	9	0.9745	-	-	-	2	10	0.9687
	6	-	-	-	3	9	0.9815	-	-	-	2	10	0.9772
	6.5	-	-	-	3	9	0.9863	-	-	-	2	10	0.9831
	7	-	-	-	3	9	0.9896	-	-	-	2	10	0.9872
0.05	5	-	-	-	3	9	0.9640	-	-	-	2	10	0.9561
	5.5	-	-	-	3	9	0.9745	-	-	-	2	10	0.9687
	6	-	-	-	3	9	0.9815	-	-	-	2	10	0.9772
	6.5	-	-	-	3	9	0.9863	-	-	-	2	10	0.9831
	7	-	-	-	3	9	0.9896	-	-	-	2	10	0.9872
0.01	5	-	-	-	-	-	-	-	-	-	-	-	-
	5.5	-	-	-	4	12	0.9558	-	-	-	-	-	-
	6	-	-	-	4	12	0.9676	-	-	-	3	15	0.9509
	6.5	-	-	-	4	12	0.9758	-	-	-	3	15	0.9630
	7	-	-	-	4	12	0.9816	-	-	-	3	15	0.9717

		$\lambda = 2.66, \theta = 1.18, r = 3$						$\lambda = 2.66, \theta = 1.18, r = 5$					
0.25	5	1	3	0.9618	2	6	0.9976	-	-	-	1	5	0.9984
	5.5	1	3	0.9702	2	6	0.9985	1	5	0.9508	1	5	0.9990
	6	1	3	0.9763	2	6	0.9991	1	5	0.9608	1	5	0.9994
	6.5	1	3	0.9808	2	6	0.9994	1	5	0.9681	1	5	0.9996
	7	1	3	0.9842	2	6	0.9996	1	5	0.9738	1	5	0.9997
0.1	5	-	-	-	3	9	0.9944	-	-	-	2	10	0.9930
	5.5	-	-	-	3	9	0.9965	1	5	0.9508	2	10	0.9957
	6	2	6	0.9531	3	9	0.9978	1	5	0.9608	2	10	0.9973
	6.5	2	6	0.9619	3	9	0.9985	1	5	0.9681	2	10	0.9982
	7	2	6	0.9686	3	9	0.9990	1	5	0.9738	2	10	0.9988
0.05	5	-	-	-	3	9	0.9944	-	-	-	2	10	0.9930
	5.5	-	-	-	3	9	0.9965	1	5	0.9508	2	10	0.9957
	6	2	6	0.9531	3	9	0.9978	1	5	0.9608	2	10	0.9973
	6.5	2	6	0.9619	3	9	0.9985	1	5	0.9681	2	10	0.9982
	7	2	6	0.9686	3	9	0.9990	1	5	0.9738	2	10	0.9988
0.01	5	-	-	-	4	12	0.9899	-	-	-	3	15	0.9844
	5.5	-	-	-	4	12	0.9938	-	-	-	3	15	0.9903
	6	-	-	-	4	12	0.9960	-	-	-	3	15	0.9938
	6.5	-	-	-	4	12	0.9974	-	-	-	3	15	0.9959
	7	3	9	0.9533	4	12	0.9982	-	-	-	3	15	0.9972

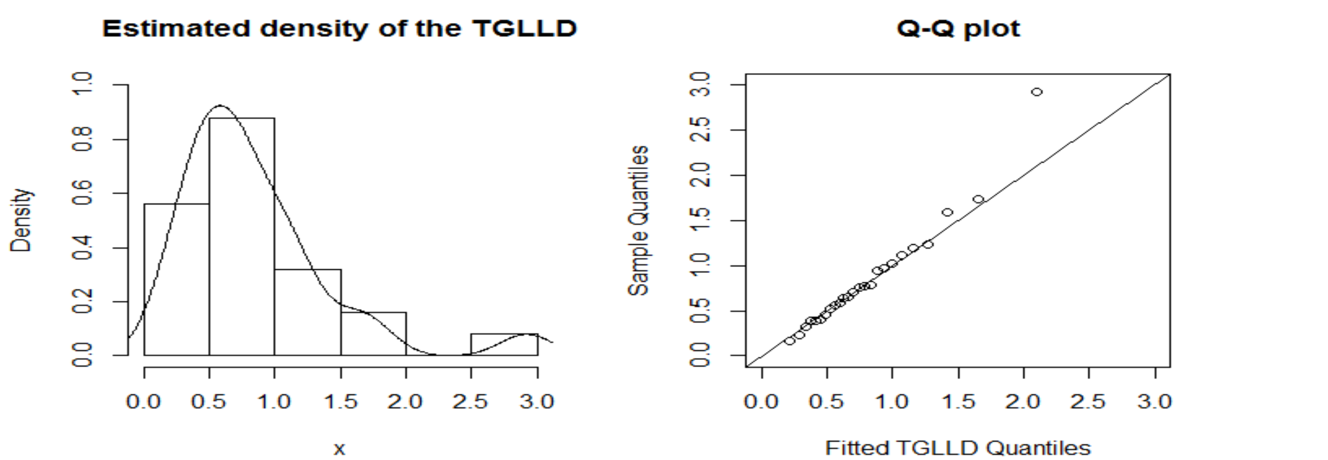

Figure 1. The density plot and Q-Q plot of the fitted type-II generalized log-logistic distribution for the runoff amounts data.

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