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AN ECONOMIC RELIABILITY TEST PLAN BASED ON TRUNCATED LIFE TESTS FOR MARSHALL-OLKIN POWER LOMAX DISTRIBUTION WITH APPLICATIONS

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Abstract. In every competitive enterprise, there has been a resurgence of interest in increasing the quality of products. In this paper, we create new acceptance sampling plans based on truncated life tests for the Marshall-Olkin power Lomax distribution. The minimum sample sizes needed to declare the specified mean life with respect to the newly developed sampling plans are obtained for different values of the model parameters. Besides, the operating characteristic function values, minimum ratios of the true value and the required value of the parameter with a given producer risk are discussed. Moreover, the results are illustrated using numerical examples, and a real data set is considered to illustrate the functioning of the recommended acceptance sampling plans. The result shows that the proposed plan is more adequate compared with other acceptance sampling plans available in the open literature. So, it can be used for industry applications.

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1. Introduction

Nowadays, acceptance sampling plans (ASP) have been considered an essential requirement for improving the quality of commodities in the global business market. Therefore, they have been developed into notable tools for competitive enterprises. An ASP is related to the judgement of the consumer about whether to accept or reject a lot or material delivered by the

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manufacturer, depending on the outcome of a random sample acquired from that lot. The technique behind the *ASP* first starts by describing the minimum sample size required to maintain a specific mean life when the life test time is stopped at a predetermined time. These particular kinds of experiments are called truncated lifetime tests (*TLT*). *ASP* in accordance with *TLT* with a single-item set is broadly studied by many investigators. For example, see, [1–18], etc. In practice, statistical distributions are worthwhile representations for distingushing variability in real data sets. In particular, the Lomax distribution was introduced by [19], and has been broadly applied for modelling business, economics, and actuarial data. In fact, the statistics literature is filled with hundreds of papers on the Lomax distribution and their successful applications due to its simple characterization. Examples include [20–26], among many others. It is important to highlight that, the Lomax distribution has been recommended as a heavy-tailed substitute for the exponential, Weibull, and gamma distributions. In addition, it affiliates with the family of decreasing failure rate distributions. Recently, [27] introduced a notable generalisation of the Lomax distribution called the power Lomax (*PL*) distribution. They proved that the *PL* model gives more adequacy in the treatment of bladder cancer than the Lomax model. More recently, [28] introduced a new model, namely Marshall-Olkin power Lomax (*MOPL*) distribution. This model retains desirable properties from its parent distribution. The cumulative distribution function of the *MOPL* distribution is specified by

$$G(x,\gamma,\beta,\theta,\lambda) = 1 - \frac{\gamma}{\left[1+(x/\lambda)^{\beta}\right]^{\theta} - (1-\gamma)}; \quad x,\gamma,\beta,\theta,\lambda > 0. \tag{1}$$

The corresponding probability density function is specified by

$$g(x,\gamma,\beta,\theta,\lambda) = \frac{\gamma\beta\theta\lambda^{-\beta}x^{\beta-1}\left[1+(x/\lambda)^{\beta}\right]^{-\theta-1}}{\left(\gamma+(1-\gamma)\left\{1-\left[1+(x/\lambda)^{\beta}\right]^{-\theta}\right\}\right)^{2}};$$

$$x,\gamma,\beta,\theta,\lambda > 0.$$

This paper proposes a *ASP* when the lifetime of a product adopts the *MOPL* distribution, with a particular emphasis on numerical illustrations. It aims to provide a substantial sampling economy with regard to diminishing the minimum sample sizes (*MSS*). For various acceptance numbers, confidence levels, and values of the ratio of the fixed experimental time to the specified mean life, the minimum sample size necessary to assure a specified mean lifetime worked out. The results are illustrated by a numerical example. The operating characteristic functions of the sampling plans and producer's risk, and the ratio of true mean life to a specified mean life that ensures acceptance with a pre-assigned probability are tabulated. Based on this study, the optimal number of testers demanded decreases as test termination time increases. Moreover, the operating characteristic values increase as the mean life ratio increases, which indicates that items with an increased mean life will be accepted with a higher probability compared with items with a lower mean life ratio. Hence, it is prescribed for researchers working in industrial statistics, as well as for practitioners working in double and group *ASP*. These reasons motivate the development of an *ASP* of the *MOPL* distribution under a truncated life test.

The rest of the article proceeds as follows: The *ASP* of the *MOPL* distribution is introduced in Section 2. Numerical examples and illustrations are explored in Section 3. Section 4 ends the paper with some conclusions.

2. Design of *ASP* for Submitted Lots

Here, we develop a reliability test plan with a lifetime governed by the *MOPL* distribution described in the introduction. The plan concentrates on deciding the number of items to be tested, denoted by n, and the highest allowable number of defective items among the tested items for acceptance of the item. That is the acceptance number, denoted by c. The test is stopped at a pre-specified time t and the entry of the number of defective items is denoted by d. The selection procedure is to accept the lot if and only if at the end of the fixed time t, d does not exceed c, with a specified probability of $p^{\star}$. The test may be stopped before the time t is gained when d exceeds c. In that case, we reject the lot. Here, we try to obtain the lowest sample size needed to gain agreement. Besides, we assume that the model parameters γ, β, θ are known, when λ is unknown. Therefore, the average lifetime depends only on λ. Let λ_0 be the needed lowest mean lifetime. Then we have

$$G(t,\gamma,\beta,\theta,\lambda) \leq G(t,\gamma,\beta,\theta,\lambda_0) \quad \Longleftrightarrow \quad \lambda \geq \lambda_0. \tag{2}$$

The most commonly used single sampling plan involves the following terms:

(1) The number of testers n put on the test.
(2) The maximum test period t.
(3) The acceptance number c.
(4) The quantity t/λ_0 , where λ_0 is the specified mean life and t is the highest test period.

The consumer's risk (δ) is the probability of accepting a bad lot (while the true mean life η is smaller than the specified mean life λ_0). Here, δ is fixed and it is not greater than $1 - p^*$. The probability of p^* is a minimum confidence level. That is, the probability of rejecting a lot with $\lambda < \lambda_0$ exceeds p^*. This kind of sampling plan is represented as $(n, c, t/\lambda_0)$. If n is adequately large, then the well-known theory of binomial probability can be used. Hence, we have to find the minimum positive integer n (for given values of p^*, $(0 < p^* < 1)$, λ_0 and c), which satisfies the following expression:

$$\sum_{i=0}^{c} \binom{n}{i} p^i (1-p)^{n-i} \leq 1 - p^*, \tag{3}$$

where $p = G(t, \gamma, \beta, \theta, \lambda_0)$, given in Equation (1) with appropriate parameters, represents the failure probabilities prior time t which based on the quantity t/λ_0. This ratio is important for designing the experiment.

The smallest values of n which hold in Equation (3) are for $p^* = 0.75, 0.90, 0.95, 0.99$ and $t/\lambda_0 = 0.4, 0.6, 0.8, 1, 1.2, 1.4, 1.6, 1.8$ and $\gamma = \beta = \theta = 2$ gained and displayed in Table 1.

If $p = G(t, \gamma, \beta, \theta, \lambda_0)$ is negligible and n is high (as is true in various instances of our current study), we can use a Poisson probability having parameter $\mu = np$, so that Equation (3) could be inscribed as

$$\sum_{i=0}^{c} \frac{e^{-\mu} \mu^i}{i} \leq 1 - p^*, \tag{4}$$

where $p = G(t, \gamma, \beta, \theta, \lambda_0)$. The values of n will be the smallest positive integer that satisfies Equation (4) are calculated for the similar sets of p values as those used for Equation (2). The outcomes are depicted in Table 2.

The operating characteristic (OC) function of the plan $(n, c, t/\lambda_0)$ gives the probability of affirming the lot. The probability can be expressed as equation specified as

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

where $p = G(t, \gamma, \beta, \theta, \lambda_0)$ is considered as a function of the lot quality parameter λ. For given p^*, t/λ_0, the values of c and n are obtained based on OC. The values of OC considered as a function of λ/λ_0 for the number of sampling plans are displayed in Table 3.

The producer's risk (α) is the probability of ignoring a lot whenever $\lambda > \lambda_0$. The value of α can be computed by obtaining $p = G(t, \gamma, \beta, \theta, \lambda_0)$ and then applying the binomial probability. For a particular value of α say ϵ, one might think what the value of λ/λ_0 will guarantee that α

is at most ϵ. Besides, the probability p can be inscribed as a function of λ/λ_0. The value λ/λ_0 is the smallest positive number for which the following inequality holds:

$$\sum_{i=0}^{c} \binom{n}{i} p^i (1-p)^{n-i} \geq 1-\epsilon. \tag{5}$$

For a specified plan $(n, c, t/\lambda_0)$, $\epsilon = 0.05$ and p^*, the smallest values of λ/λ_0 coinciding with the expression mentioned in Equation (5) are displayed in Table 4. A detailed procedure for single *ASP* is previously discussed in [8,13,14].

3. Description of the Tables and Example

For a demonstration, assume that the lifetime model is the *MOPL* model defined with $\gamma = \beta = \theta = 2$. The investigator needs to establish that the true unknown mean life is at least 1000 hours (hrs) with confidence $p^\star = 0.75$. The test can be stopped at $t = 600$ hrs. Thus, from Table 1, the minimum sample size corresponding to $p^\star = 0.75$, $t/\lambda_0 = 0.6$ and $c = 2$ is 4. If, during 600 hrs, no more than 2 failures out of 4 occur, then the lot is ignored. If the Poisson approximation is used, the value of $n = 6$ is gained from Table 2 for the same set of values.

For the sampling plan $(n = 7, c = 2, t/\lambda_0 = 0.6)$ and confidence level $p^\star = 0.75$ under *MOPL* distribution with $\lambda = 2$, $\alpha = 2$, $c = 2$, the values of the *OC* function from Table 3 are as displayed below

λ/λ_0	2	4	6	8	10	12
OC	0.7101	0.9781	0.9972	0.9994	0.9998	0.9999

This shows that if the true average life is twice the required mean lifetime ($\lambda/\lambda_0 = 2$) the α is approximately 0.2899. That is, the *OC* values increase as the average life ratio increases, which means accepting lots of items when they have a higher probability. Thus, producers should increase the mean life of their products.

Table 4 gives the values of the quantity λ/λ_0 for the specified plan with the condition that the α less than ϵ. For example, when $p^\star = 0.75$, $t/\lambda_0 = 0.6$, $c = 2$, $\epsilon = 0.05$, Table 4 gives a value of 4.68. That is, the product must have a mean life of 4.68 times the specified average lifetime in order to be accepted under the above *ASP* with a probability of at least 0.95.

Figure 1 presents the *MSS* acquired in this paper for the considered *ASP* with the sampling plan $(n, c, t/\lambda_0 = 0.6)$ and $p^\star = 0.90$ for the *MOPL* model and its counterparts proposed by [17] when the lifetime adopts Gumbel-Uniform (*GU*) distribution, [2] when the lifetime adopts the Akash (*A*) distribution, [1] when lifetime adopts the two-parameter Quasi Shanker (TQS) distribution, and [31] when the lifetime adopts the Marshall-Olkin extended Lomax (*MOEL*) distribution. From this figure, we can say that the smallest *MSS* based on this proposed sampling plan is less than the *MSS* described in its counterparts considered.

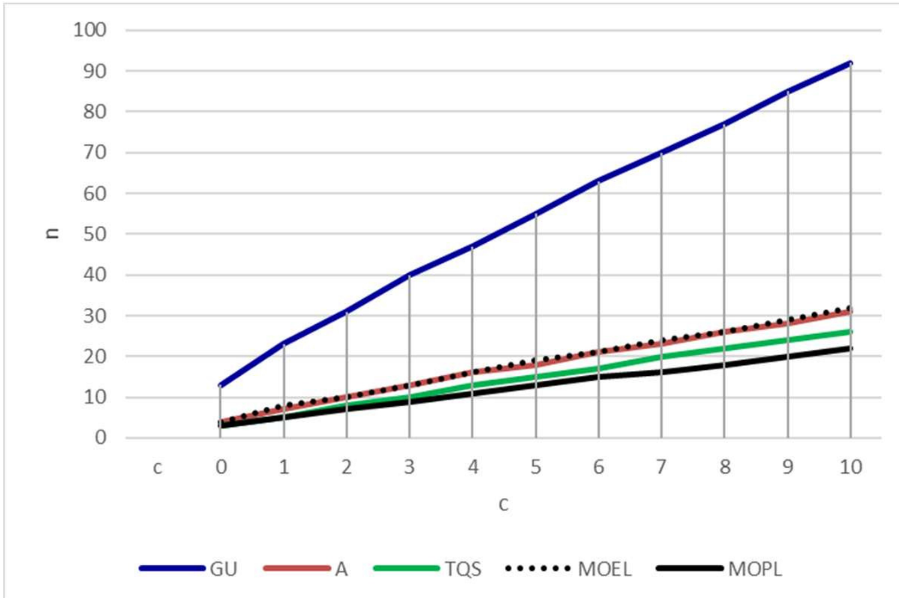

FIGURE 1. Comparisons of *MSS* obtained by *ASP* for various distributions.

Example: Consider the following ordered failure times of the release of a software given in terms of hrs from the start of the execution of the software, denoting the times at which the failure of the software is experienced. It was presented by [32]. These data can be regarded as an ordered sample of size 10 with observations $(t_i; i = 1, 2, \ldots, 10)$: 519, 968, 1430, 1893, 2490, 3058, 3625, 4422, 5218, 5823.

These data have been analyzed by [14] and [13]. Let the specified average life be 1000 hrs and the testing time be 600 hrs, this leads to a ratio of $t/\lambda_0 = 0.6$ with corresponding n and c as 5, 2 from Table 1 for $p^\star = 0.90$. Therefore, the sampling plan for the above sample data is $(n = 5$, $c = 2$,$t/\lambda_0 = 0.6)$. Based on the 5 observations, we have to decide whether to accept the product or reject it. We accept the product only, if the number of failures before 600 hrs is less than or equal to 2. However, the confidence level is assured by the sampling plan only if the given life times follow the *MOPL* distribution. In order to validate that the given sample is created by lifetimes adopting at least around the *MOPL* distribution, we associated the sample quantiles and the population quantiles and obtained an acceptable agreement. Thus, the assumption of the decision rule of the sampling plan needs to be confirmed. In the sample of 5 units, there is a 1 failure at 519 hrs before $t = 600$ hrs. Hence, the product can be accepted.

4. Conclusions

In this study, a reliability test plan is proposed based on the lifetime of the testers adopting the *MOPL* model. The optimal number of testers, *OC* functions, and the minimum ratio of the true average life to the given mean life are calculated for the *MOPL* model. Based on this study, the proposed *ASP* is an economical mechanism, since they suggested a small *MSS*. In summary, it can be used by industrial companies to decrease testing time, cost of investigation, energy, and labour. The results of this study may be used to create other types of *ASP*, such as, group and sequence *ASP* for the *MOPL* distribution.

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Appendix

Table 1. Minimum sample sizes using binomial probabilities.

		t/λ_0							
p^*	c	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8
0.75	0	2	1	1	1	1	1	1	1
	1	4	3	2	2	2	2	2	2
	2	6	4	4	3	3	3	3	3
	3	7	5	5	4	4	4	4	4
	4	9	7	6	6	5	5	5	5
	5	11	8	7	7	6	6	6	6
	6	13	9	8	8	7	7	7	7
	7	15	11	9	9	9	8	8	8
	8	16	12	11	10	10	9	9	9
	9	18	13	12	11	11	10	10	10
	10	19	15	13	12	12	11	11	11
0.90	0	3	2	2	1	1	1	1	1
	1	5	3	3	3	2	2	2	2
	2	7	5	4	4	4	3	3	3
	3	9	6	5	5	5	4	4	4
	4	11	8	7	6	6	6	5	5
	5	13	9	8	7	7	7	6	6
	6	15	11	9	8	8	8	8	7
	7	16	12	10	10	9	9	9	8
	8	18	13	12	11	10	10	10	10
	9	20	15	13	12	11	11	11	11
	10	22	16	14	13	12	12	12	12
0.95	0	3	2	2	2	1	1	1	1
	1	6	4	3	3	3	2	2	2
	2	8	6	5	4	4	4	3	3
	3	10	7	6	5	5	5	5	4
	4	12	8	7	6	6	6	6	6
	5	14	10	8	8	7	7	7	7
	6	16	11	10	9	8	8	8	8
	7	18	13	11	10	9	9	9	9
	8	19	14	12	11	11	10	10	10
	9	21	15	13	12	12	11	12	11
	10	23	17	15	13	13	12	13	12
0.99	0	5	3	3	2	5	2	2	2
	1	8	5	4	4	7	3	3	3
	2	10	7	6	5	5	4	4	4
	3	12	8	7	6	11	5	5	5
	4	14	10	8	7	13	6	6	6
	5	16	11	10	9	15	8	7	7
	6	18	13	11	10	17	9	8	8
	7	20	14	12	11	18	10	9	9
	8	22	16	13	12	20	11	11	10
	9	24	17	15	13	22	12	12	11
	10	26	19	16	14	24	13	13	12

TABLE 2. Minimum sample sizes using Poisson probabilities.

		t/λ_0							
p^*	c	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8
0.75	0	3	2	2	2	2	2	2	2
	1	5	4	4	3	3	3	3	3
	2	7	6	5	5	5	5	4	4
	3	9	7	6	6	6	6	6	6
	4	11	8	8	7	7	7	7	7
	5	12	10	9	8	9	8	8	8
	6	14	11	10	10	10	9	9	9
	7	16	12	11	11	11	10	10	10
	8	18	14	13	12	12	12	11	11
	9	19	15	14	13	13	13	13	13
	10	21	17	15	14	14	14	14	14
0.90	0	4	3	3	3	3	3	4	4
	1	7	5	5	5	5	4	5	5
	2	9	7	6	6	6	6	6	6
	3	11	9	8	8	7	7	7	7
	4	13	12	9	9	9	9	9	9
	5	15	13	12	10	10	10	10	10
	6	17	14	13	12	11	11	11	11
	7	18	15	14	13	13	13	12	12
	8	19	17	15	14	14	14	14	14
	9	23	18	16	16	15	15	15	15
	10	25	20	18	17	16	16	16	16
0.95	0	5	4	4	4	4	4	4	4
	1	8	6	6	6	5	5	5	5
	2	10	8	8	7	7	7	7	7
	3	12	10	9	9	9	8	8	8
	4	15	12	11	10	10	10	10	10
	5	17	13	12	12	11	11	11	11
	6	19	15	14	13	13	13	13	12
	7	21	17	15	15	14	14	14	14
	8	23	18	17	16	16	15	15	15
	9	25	20	18	17	17	17	16	16
	10	27	21	19	19	18	18	18	18
0.99	0	8	7	6	5	5	5	5	5
	1	11	9	8	8	7	7	7	7
	2	13	11	10	11	9	9	9	9
	3	16	13	12	12	11	11	11	11
	4	20	15	13	13	13	12	12	12
	5	21	17	15	14	14	14	14	14
	6	24	19	17	16	16	15	15	15
	7	26	20	18	18	17	17	17	17
	8	28	22	20	19	19	18	18	19
	9	30	24	22	21	20	21	20	20
	10	32	25	23	22	21	22	21	21

TABLE 3. *OC* values for the plan $(n, c, t/\lambda_0)$ for given confidence level $p^\star$, $c = 2$, $\gamma, \beta, \theta = 2$.

$p^\star$	n	t/λ_0	λ/λ_0					
			2	4	6	8	10	12
0.75	6	0.4	0.763	0.9877	0.9986	0.9997	0.9999	0.9999
	4	0.6	0.7101	0.9781	0.9972	0.9994	0.9998	0.9999
	4	0.8	0.4663	0.9238	0.9875	0.9972	0.9992	0.9997
	3	1	0.5985	0.9398	0.9894	0.9975	0.9992	0.9997
	3	1.2	0.4696	0.8861	0.9757	0.9936	0.998	0.9992
	3	1.4	0.3658	0.8194	0.9539	0.9867	0.9955	0.9982
	3	1.6	0.2851	0.7458	0.9237	0.9757	0.9913	0.9965
	3	1.8	0.2233	0.6709	0.8861	0.9601	0.9848	0.9936
0.90	7	0.4	0.6701	0.9799	0.9976	0.9995	0.9999	0.9999
	5	0.6	0.5287	0.9527	0.9934	0.9986	0.9996	0.9999
	4	0.8	0.4663	0.9238	0.9875	0.9972	0.9992	0.9997
	4	1	0.2826	0.83	0.9646	0.991	0.9972	0.9989
	4	1.2	0.1665	0.7101	0.9238	0.9781	0.9926	0.9972
	3	1.4	0.3658	0.8194	0.9539	0.9867	0.9955	0.9982
	3	1.6	0.2851	0.7458	0.9237	0.9757	0.9913	0.9965
	3	1.8	0.2233	0.6709	0.8861	0.9601	0.9848	0.9936
0.95	8	0.4	0.5778	0.97	0.9963	0.9993	0.9998	0.9999
	6	0.6	0.7101	0.9781	0.9972	0.9994	0.9998	0.9999
	5	0.8	0.2614	0.8502	0.9724	0.9934	0.998	0.9993
	4	1	0.2826	0.83	0.9646	0.991	0.9972	0.9989
	4	1.2	0.1665	0.7101	0.9238	0.9781	0.9926	0.9972
	4	1.4	0.0978	0.5839	0.8651	0.9561	0.9842	0.9936
	3	1.6	0.2851	0.7458	0.9237	0.9757	0.9913	0.9965
	3	1.8	0.2233	0.6709	0.8861	0.9601	0.9848	0.9936
0.99	10	0.4	0.4105	0.9439	0.9926	0.9985	0.9996	0.9998
	7	0.6	0.2525	0.8762	0.9799	0.9955	0.9987	0.9995
	6	0.8	0.1363	0.763	0.9509	0.9877	0.9962	0.9986
	5	1	0.1169	0.6964	0.9258	0.9797	0.9934	0.9975
	4	1.2	0.1665	0.7101	0.9238	0.9781	0.9926	0.9972
	4	1.4	0.0978	0.5839	0.8651	0.9561	0.9842	0.9936
	4	1.6	0.0581	0.4663	0.7919	0.9238	0.9705	0.9875
	4	1.8	0.0351	0.3653	0.7101	0.8813	0.9505	0.9781

TABLE 4. Minimum ratio of true mean life to specified mean life for the acceptability of a lot with $\alpha = 0.05$.

		t/λ_0							
p^*	c	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8
0.75	0	10.91	12.69	11.65	13.96	15.66	17.68	19.08	15.65
	1	4.96	5.69	5.93	6.62	7.61	6.96	7.07	8.68
	2	3.96	4.68	4.91	4.92	4.7	5.67	5.94	5.98
	3	3.64	3.62	3.63	4.93	4.03	4.94	4.92	5.63
	4	2.79	2.97	3.92	3.93	3.92	3.98	4.91	4.74
	5	2.98	2.97	3.02	3.66	3.72	3.99	3.97	4.66
	6	2.67	2.7	2.96	3.02	3.03	3.61	3.99	4.63
	7	2.67	2.92	2.98	2.95	3.97	3.96	3.93	3.91
	8	2.69	2.65	2.75	2.92	3.09	3.69	3.93	3.99
	9	2.64	2.98	2.99	2.97	2.92	3.62	3.91	3.99
	10	2.64	2.92	2.92	2.76	2.93	3.02	3.6	3.9
0.90	0	12.96	15.63	15.99	18.94	21.69	17.67	19.08	22.9
	1	5.91	6.96	6.94	7.67	8.91	8.01	8.99	10.78
	2	4.65	4.98	4.91	5.6	5.95	5.91	5.94	6.99
	3	3.96	3.93	4.64	4.93	4.95	4.94	5.04	6.05
	4	3.93	3.97	3.92	3.98	4.92	3.97	4.9	5.98
	5	2.97	3.62	3.92	3.93	3.91	3.97	4.61	4.94
	6	2.92	2.97	3.62	3.63	3.72	3.98	4.03	4.95
	7	2.98	2.97	3.02	3.66	3.93	3.99	4.03	4.66
	8	2.67	2.78	2.96	3.09	3.62	3.68	3.92	4.66
	9	2.98	2.7	2.96	3.02	3.66	3.68	3.75	3.96
	10	2.98	2.92	2.98	2.95	3.66	3.69	3.67	4.03
0.95	0	15.9	16.9	17.91	20.6	19.76	22.62	24.98	22.9
	1	6.97	6.97	7.94	7.98	7.06	8.95	9.95	10.7
	2	3.95	3.92	4.66	4.94	5.66	6.79	6.65	7.94
	3	3.96	3.93	4.66	4.94	5.66	5.97	5.94	6.05
	4	3.97	3.91	3.97	4.93	4.92	4.96	5.04	5.97
	5	3.61	3.93	3.91	3.98	4.03	4.69	4.92	4.94
	6	2.92	3.66	3.98	3.72	3.96	4.07	4.66	4.933
	7	2.98	3.03	3.6	3.64	3.73	3.91	4.63	4.65
	8	2.73	2.92	3.62	3.91	3.92	3.79	3.97	4.65
	9	2.93	2.98	3.01	3.62	3.63	3.99	3.9	4.67
	10	2.66	2.78	2.99	3.03	3.62	3.92	3.73	4.67
0.99	0	16.9	17.9	18.91	21.6	21.76	23.62	25.98	23.9
	1	7.97	7.97	8.94	8.98	8.06	9.95	10.95	11.7
	2	4.95	4.92	4.66	4.94	5.66	6.79	6.65	7.94
	3	4.96	4.93	4.66	4.94	5.66	5.97	5.94	6.05
	4	4.97	4.91	4.97	4.93	4.92	4.96	5.04	5.97
	5	4.61	4.93	4.91	4.98	4.03	4.69	4.92	5.94
	6	3.92	4.66	4.98	4.72	4.96	4.07	4.66	5.933
	7	3.98	4.03	4.6	4.64	4.73	4.91	4.63	5.65
	8	3.73	3.92	4.62	4.91	4.92	4.79	4.97	5.65
	9	3.93	3.98	4.01	4.62	4.63	4.99	4.9	5.67
	10	3.66	3.78	3.99	4.03	4.62	4.92	4.73	5.67