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Reliability Test Plans for Marshall-Olkin Extended Exponential Distribution

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Abstract

In this paper we develop a reliability test plan for acceptance/rejection of a lot of products submitted for inspection with lifetimes governed by the Marshall-Olkin extended exponential distribution. The results are illustrated by a numerical example.

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1 Introduction

Marshall and Olkin (1997) introduced an interesting method of adding a new parameter to an existing distribution. The resulting new distribution, known as the Marshall-Olkin extended distribution. Suppose we have a given distribution with survival function (SF) $\bar{F}(x),\ -\infty < x < \infty$. The Marshall-Olkin extended distribution is defined in the form of SF is given by

$$\bar{G}(x) = \frac{\alpha \bar{F}(x)}{1 - \bar{\alpha}\bar{F}(x)}, \qquad -\infty < x < \infty, \quad \alpha > 0, \quad \bar{\alpha} = 1 - \alpha. \tag{1.1}$$

If we take the SF of the exponential distribution, i.e. $\bar{F}(x) = e^{-x/\sigma}$, where $x > 0,\ \sigma > 0$, in equation (1.1), we obtain the SF as

$$\bar{G}(x) = \frac{\alpha e^{-x/\sigma}}{1 - \bar{\alpha} e^{-x/\sigma}}, \qquad x > 0, \quad \sigma, \alpha > 0, \quad \bar{\alpha} = 1 - \alpha. \tag{1.2}$$

The distribution with SF (1.2) is called Marshall-Olkin extended exponential distribution with parameters α and σ. The probability density function (p.d.f.) and cumulative distribution function (c.d.f) of the Marshall-Olkin extended exponential distribution with SF (1.2), respectively, are given by

$$g(x; \alpha, \sigma) = \frac{\frac{\alpha}{\sigma} e^{-x/\sigma}}{(1 - \bar{\alpha} e^{-x/\sigma})^2}, \qquad x > 0, \quad \alpha, \sigma > 0, \quad \bar{\alpha} = 1 - \alpha, \tag{1.3}$$

and

$$G(x; \alpha, \sigma) = \frac{1 - e^{-x/\sigma}}{1 - \bar{\alpha} e^{-x/\sigma}}, \qquad x > 0, \quad \alpha, \sigma > 0, \quad \bar{\alpha} = 1 - \alpha. \tag{1.4}$$

When $\alpha = 1$, the SF (1.2) and p.d.f. (1.3) reduce to those of the exponential distribution. In this aper we present a reliability test plan for the extended exponential model.

Acceptance sampling plans in statistical quality control concern with accepting or rejecting a submitted lot of a large size of products on the basis of the quality of products inspected in a sample taken from the lot. If the quality of the product that is inspected is the lifetime of the product that is put for testing, after the completion of sampling inspection what we have is a sample of life times of the sampled products. If a decision to accept or reject the lot subject to the risks associated with the two types of errors (rejecting a good lot/accepting a bad lot) is possible, such a procedure may be termed as '*Acceptance sampling based on life tests*' or '*Reliability test plans*'. Such a procedure obviously requires the specification of the probability model governing the life of the products.

In this paper we develop a reliability test plans to decide whether to accept or reject a submitted lot of products whose lifetime is governed by a Marshall-Olkin extended exponential distribution, derive its operating characteristic function and give the corresponding decision rule. Similar plans were developed by Gupta and Groll (1961), Goode and Kao (1961), Kantam and Rosaiah (1998), Kantam *et al.* (2001), Rosaiah and Kantam (2005) and Rosaiah *et al.* (2006). The proposed sampling plan, along with the operating characteristic, is given in Section 2. The description of tables is given in Section 3. The results are explained by an example in Section 4.

2 Reliability Test Plan

We assume that the lifetime of a product follows a Marshall-Olkin extended exponential distribution with scale parameter σ, defined by (1.3). A common practice in life testing is to terminate the life test by a pre-determined time't' and note the number of failures (assuming that a failure is well defined). One of the objectives of these experiments is to set a lower confidence limit on the average life. It is then to establish a specified average life with a given probability of at least p^*. The decision to accept the specified average life occurs if and only if the number of observed failures at the end of the fixed time 't' does not exceed a given number 'c'- called the acceptance number. The test may get terminated before the time 't' is reached when the number of failures exceeds 'c' in which case the decision is to reject the lot. For such a truncated life test and the associated decision rule; we are interested in obtaining the smallest sample size to arrive at a decision.

In the following it is assumed that the distribution parameter α is known, while σ is unknown. In this case the average lifetime of the product depends only on σ and it is easily seen that the average lifetime is monotonically increasing in σ. Let σ_0 represent the required minimum average lifetime, then, for given value of α, the following holds:

$$G(x;\alpha,\sigma) = G(x;\alpha,\sigma_0) \quad \Leftrightarrow \quad \sigma \geq \sigma_0. \tag{2.1}$$

A sampling plan consists of the following quantities:

- The number of units 'n' on test,
- The acceptance number 'c',
- The maximum test duration 't', and
- The ratio t/σ_0, where σ_0 is the specified average life.

The consumer's Risk, i.e., the probability of accepting a bad lot (the one for which the true average life is below the specified average life σ_0) not to exceed $1 - p^*$, so that p^* is a minimum confidence level with which a lot of true average life below σ_0 is rejected, by the sampling plan. For a fixed p^* our sampling plan is characterized by $(n, c, t/\sigma_0)$. Here we consider sufficiently large sized lots so that the binomial distribution can be applied. The problem is to determine for given values of p^* $(0 < p* < 1)$, σ_0 and c, the smallest positive integer $'n'$ such that

$$L(p_0) = \sum_{i=0}^{c} \binom{n}{i} p_0^i \, (1-p_0)^{n-i} \quad \leq \quad 1 - p^*, \tag{2.2}$$

where $p_0 = G(t;\alpha,\sigma_0)$ is given by (1.4) indicates the failure probability before time 't' which depends only on the ratio t/σ_0. The function $L(p)$ is the operating characteristic function of the sampling plan, i.e. the acceptance probability of the lot as function of the failure probability $p(\sigma) = G(t;\alpha,\sigma)$. The average lifetime of the products is increasing in σ and, therefore, the failure probability $p(\sigma) = G(t;\alpha,\sigma)$ is decreasing function in σ which implies that the operating characteristic function is increasing in σ.

The minimum values of n satisfying the inequality (2.2) are obtained and displayed in Table 1 for $p^* = 0.75$, 0.90, 0.95, 0.99 and $t/\sigma_0 = 0.241$, 0.361, 0.482, 0.602, 0.903, 1.204, 0.505, 1.806 for $\alpha = 2$.

If $p = G(t;\alpha,\sigma)$ is small and n is large, the binomial probability may be approximated by Poisson probability with parameter $\lambda = np$ so that the left side of (2.2) can be written as

$$L^*(p) = \sum_{i=0}^{c} \frac{\lambda^i}{i!}\, e^{-\lambda} \quad \leq \quad 1 - p^*, \tag{2.3}$$

where $\lambda = n\ G(t;\alpha,\sigma_0)$. The minimum values of 'n' satisfying (2.3) are obtained for the same combination of p^* and t/σ_0 values as those used for (2.1). The results are given in Table 2.

For a given value of p^* and t/σ_0, the values of n and c are determined by means of the operating characteristic function. For some sampling plans, the values of the operating characteristic function depending on σ/σ_0 are displayed in Table 3. The producer's risk is the probability of rejecting a lot although $\sigma \geq \sigma_0$ holds. It is obtained by the operating characteristic function:

$$L[p(\sigma)] = L[G(t;\alpha,\sigma)]. \tag{2.4}$$

For a specified value of the producer's risk, say 0.05, one may be interested in knowing what value of σ or σ/σ_0 will ensure a producer's risk less than or equal to 0.05 for a given sampling plan. The value of σ and, hence, the value of σ/σ_0, is the smallest positive number for which the following inequality holds:

$$\sum_{i=0}^{c} \binom{n}{i} p(\sigma)^i\ [1 - p(\sigma)]^{n-i} \quad \geq \quad 0.95. \tag{2.5}$$

For some sampling plan $(n, c, t/\sigma_0)$ and values of p^*, minimum values of σ/σ_0 satisfying (2.5) are given in Table 4.

3 Description of the Tables

Assume that the lifetime distribution is Marshall-Olkin extended exponential distribution with $\alpha = 2$ and that the experimenter is interested in establishing that the true unknown average life is at least 1000 hours with confidence $p* = 0.75$. It is desired to stop the experiment at $t = 241$ hours. Then, for an acceptance number $c = 2$, the required n in Table 1 is 32. If, during 241 hours, no more than 2 failures out of 32 are observed, then the experimenter can assert, with a confidence level of 0.75 that the average life is at least 1000 hours. If the Poisson approximation to binomial probability is used, the value of $n = 32$ is obtained from Table 2 for the same situation.

If the life distribution is assumed to be a gamma distribution with shape parameter 2 (an IFR model), the value of n from Table IB of Gupta and Groll (1961) is 63 using binomial probabilities and it is 64 using Poisson approximation. In general, all the values of n tabulated by us are found to be less than the corresponding values of n tabulated in Kantam and Rosaiah (1998) for a half logistic distribution, Rosaiah *et al.* (2006) for exponentiated log-logistic distribution, which in turn are less than those tabulated by Gupta and Groll (1961) with a gamma model as the lifetime distribution. For the sampling plan $(n = 32, c = 2, = 0.241)$ and confidence level $p^* = 0.75$ under Marshall-Olkin extended exponential distribution with $\alpha = 2$, the values of the operating characteristic function from Table 3 is as follows:

σ/σ_0	2	4	6	8	10	12
$L(p)$	0.6975	0.9291	0.9740	0.9878	0.9933	0.9960

The above values show that if the true mean lifetime is twice the required mean lifetime $(\sigma/\sigma_0 = 2)$ the producer's risk is approximately 0.3025.

From Table 4, we can get the values of the ratio σ/σ_0 for various choices of $(c, t/\sigma_0)$ in order that the producer's risk may not exceed 0.05. For example if $p^* = 0.75, t/\sigma_0 = 0.241, c = 2$, Table 4 gives a reading of 4.64. This means the product can have an average life of 4.64 times the required average lifetime in order that under the above acceptance sampling plan the product is accepted with probability of at least 0.95. The actual average lifetime necessary to accept 95 percent of the lots is provided in Table 4.

4 Numerical Example

Consider the following ordered failure times of the release of a software given in terms of hours from starting of the execution of the software up to the time at which a failure of the software is occurred (Wood, 1996). This data can be regarded as an ordered sample of size $n = 9$ with observations:

$$\{x_i : i = 1, 2, \ldots 9\} = \{254, 788, 1054, 1393, 2216, 2880, 3593, 4281, 5180\}.$$

Let the required average lifetime be 1000 hours and the testing time be $t = 602$ hours, this leads to ratio of $t/\sigma_0 = 0.602$ with a corresponding sample size $n = 9$ and an acceptance number $c = 1$, which are obtained from Table 1 for $p^* = 0.75$. Therefore, the sampling plan for the above sample data is $(n = 9, c = 1, t/\sigma_0 = 0.602)$. Based on the observations, we have to decide whether to accept the product or reject it. We accept the product only if the number of failures before 602 hours is less than or equal to 1. However, the confidence level is assured by the sampling plan only if the given life times follow Marshall-Olkin extended exponential distribution. In order to confirm that the given sample is generated by lifetimes following at least approximately the Marshall-Olkin extended exponential distribution, we have compared the sample quantiles and the corresponding population quantiles and found a satisfactory agreement. Thus, the adoption of the decision rule of the sampling plan seems to be justified. In the sample of 9 units, there is a 1 failure at 254 hours before $t = 602$ hours. Therefore we accept the product.

Table 1. Minimum sample size for the specified ratio t/σ_0, confidence level p^*, acceptance number c, $\alpha = 2$ using binomial approximation.

		t/σ_0							
p^*	c	0.241	0.361	0.482	0.602	0.903	1.204	1.505	1.806
0.75	0	11	8	6	5	3	2	2	2
0.75	1	22	15	11	9	6	5	4	3
0.75	2	32	21	16	13	9	7	6	5
0.75	3	42	28	21	17	11	9	7	6
0.75	4	52	34	26	21	14	11	9	8
0.75	5	61	41	31	25	17	13	11	9
0.75	6	71	47	35	28	19	15	12	11
0.75	7	80	53	40	32	22	17	14	12
0.75	8	89	60	45	36	24	19	16	14
0.75	9	98	66	49	40	27	21	17	15
0.75	10	108	72	54	43	30	23	19	17
0.90	0	19	12	9	7	5	3	3	2
0.90	1	31	21	15	12	8	6	5	4
0.90	2	43	29	21	17	11	8	7	6
0.90	3	54	36	27	21	14	11	9	8
0.90	4	65	43	32	26	17	13	11	9
0.90	5	76	50	38	30	20	15	13	11
0.90	6	86	57	43	34	23	17	14	12
0.90	7	96	64	48	38	26	20	16	14
0.90	8	106	71	53	42	28	22	18	16
0.90	9	116	77	58	46	31	24	20	17
0.90	10	126	84	63	50	34	26	21	19
0.95	0	24	16	12	9	6	4	3	3
0.95	1	38	25	19	15	10	7	6	5
0.95	2	51	34	25	20	13	10	8	7
0.95	3	63	41	31	25	16	12	10	8
0.95	4	74	49	37	29	19	15	12	10
0.95	5	85	56	42	34	22	17	14	12
0.95	6	96	64	48	38	25	19	16	13
0.95	7	107	71	53	42	28	21	17	15
0.95	8	118	78	58	46	31	24	19	17
0.95	9	128	85	63	51	34	26	21	18
0.95	10	138	92	69	55	37	28	23	20
0.99	0	37	24	18	14	9	6	5	4
0.99	1	53	35	26	20	13	10	8	6
0.99	2	67	44	33	26	17	12	10	8
0.99	3	81	53	39	31	20	15	12	10
0.99	4	93	62	46	36	24	18	14	12
0.99	5	106	70	52	41	27	20	16	14
0.99	6	118	78	58	46	30	23	18	15
0.99	7	129	85	63	50	33	25	20	17
0.99	8	141	93	69	55	36	27	22	19
0.99	9	152	101	75	60	39	30	24	21
0.99	10	163	108	80	64	42	32	26	22

Table 2. Minimum sample size for the specified ratio t/σ_0, confidence level p^*, acceptance number c, $\alpha = 2$ using Poisson approximation.

		t/σ_0							
p^*	c	0.241	0.361	0.482	0.602	0.903	1.204	1.505	1.806
0.75	0	12	8	6	5	4	3	3	2
0.75	1	19	13	10	8	6	5	4	4
0.75	2	32	22	16	13	9	8	6	6
0.75	3	43	29	22	18	12	10	8	8
0.75	4	53	36	27	22	15	12	10	9
0.75	5	62	42	32	26	18	14	12	11
0.75	6	72	48	37	30	21	16	14	12
0.75	7	81	55	41	34	23	18	16	14
0.75	8	91	61	46	37	26	21	17	16
0.75	9	100	67	51	41	29	23	19	17
0.75	10	109	73	56	45	31	25	21	19
0.90	0	20	13	10	8	6	5	4	4
0.90	1	30	21	16	13	9	7	6	5
0.90	2	44	30	23	18	13	10	9	8
0.90	3	56	38	29	23	16	13	11	10
0.90	4	67	45	34	28	19	15	13	12
0.90	5	78	52	40	32	22	18	15	13
0.90	6	88	59	45	37	25	20	17	15
0.90	7	99	66	50	41	28	22	19	17
0.90	8	109	73	55	45	31	25	21	19
0.90	9	119	80	61	49	34	27	23	20
0.90	10	129	87	66	53	37	29	25	22
0.95	0	25	17	13	11	8	6	5	5
0.95	1	38	26	20	16	11	9	8	7
0.95	2	53	35	27	22	15	12	10	9
0.95	3	65	44	33	27	19	15	13	11
0.95	4	77	52	39	32	22	17	15	13
0.95	5	88	59	45	36	25	20	17	15
0.95	6	99	67	51	41	28	22	19	17
0.95	7	110	74	56	45	32	25	21	19
0.95	8	121	81	62	50	35	27	23	21
0.95	9	132	88	67	54	38	30	25	22
0.95	10	142	95	72	59	41	32	27	24
0.99	0	39	26	20	16	11	9	8	7
0.99	1	55	37	28	23	16	13	11	10
0.99	2	70	47	36	29	20	16	14	12
0.99	3	84	57	43	35	24	19	16	14
0.99	4	97	65	50	40	28	22	19	17
0.99	5	110	74	56	45	31	25	21	19
0.99	6	122	82	62	50	35	28	23	21
0.99	7	134	90	68	55	38	30	26	23
0.99	8	146	98	74	60	42	33	28	25
0.99	9	157	106	80	65	45	35	30	27
0.99	10	169	113	86	69	48	38	32	29

Table 3. Values of the operating characteristic function of the sampling plan $(n, c, t/\sigma_0)$ for given confidence level p^* with $\alpha = 2$.

				σ/σ_0					
p^*	n	c	t/σ_0	2	4	6	8	10	12
0.75	22	2	0.241	0.6975	0.9291	0.9740	0.9878	0.9933	0.9960
0.75	11	2	0.361	0.7080	0.9335	0.9759	0.9887	0.9939	0.9963
0.75	7	2	0.482	0.7005	0.9322	0.9755	0.9886	0.9938	0.9963
0.75	6	2	0.602	0.6943	0.9314	0.9753	0.9885	0.9938	0.9963
0.75	4	2	0.903	0.6787	0.9291	0.9748	0.9884	0.9937	0.9962
0.75	3	2	1.204	0.6646	0.9270	0.9743	0.9882	0.9937	0.9962
0.75	3	2	1.505	0.6279	0.9176	0.9710	0.9867	0.9929	0.9957
0.75	3	2	1.806	0.6419	0.9238	0.9737	0.9881	0.9936	0.9962
0.90	30	2	0.241	0.5170	0.8608	0.9448	0.9730	0.9849	0.9907
0.90	15	2	0.361	0.5087	0.8591	0.9444	0.9729	0.9849	0.9907
0.90	10	2	0.482	0.5307	0.8707	0.9499	0.9758	0.9866	0.9918
0.90	7	2	0.602	0.5227	0.8691	0.9494	0.9756	0.9865	0.9918
0.90	5	2	0.903	0.5447	0.8823	0.9557	0.9790	0.9885	0.9930
0.90	4	2	1.204	0.5716	0.8958	0.9619	0.9822	0.9903	0.9942
0.90	4	2	1.505	0.5106	0.8753	0.9539	0.9784	0.9882	0.9929
0.90	3	2	1.806	0.4964	0.8723	0.9532	0.9782	0.9881	0.9929
0.95	35	2	0.241	0.4006	0.8016	0.9171	0.9583	0.9763	0.9853
0.95	17	2	0.361	0.3988	0.8033	0.9184	0.9591	0.9768	0.9856
0.95	11	2	0.482	0.4093	0.8118	0.9229	0.9617	0.9783	0.9866
0.95	8	2	0.602	0.4079	0.8134	0.9241	0.9624	0.9788	0.9869
0.95	5	2	0.903	0.4232	0.8271	0.9314	0.9665	0.9813	0.9885
0.95	4	2	1.204	0.4038	0.8218	0.9298	0.9659	0.9811	0.9884
0.95	4	2	1.505	0.4055	0.8270	0.9330	0.9678	0.9822	0.9892
0.95	4	2	1.806	0.3706	0.8122	0.9270	0.9649	0.9806	0.9882
0.99	46	2	0.241	0.2244	0.6718	0.8481	0.9194	0.9526	0.9699
0.99	22	2	0.361	0.2303	0.6811	0.8542	0.9232	0.9550	0.9715
0.99	14	2	0.482	0.2259	0.6807	0.8547	0.9237	0.9554	0.9718
0.99	10	2	0.602	0.2323	0.6901	0.8606	0.9273	0.9577	0.9733
0.99	7	2	0.903	0.2373	0.7026	0.8691	0.9326	0.9611	0.9756
0.99	5	2	1.204	0.2719	0.7380	0.8891	0.9442	0.9683	0.9803
0.99	5	2	1.505	0.2417	0.7198	0.8810	0.9401	0.9659	0.9789
0.99	4	2	1.806	0.2690	0.7467	0.8958	0.9485	0.9711	0.9822

Table 4. Minimum ratio of true σ and required σ_0 for the acceptability of a lot with producer's risk of 0.05 for $\alpha = 2$.

		t/σ_0							
p^*	c	0.241	0.361	0.482	0.602	0.903	1.204	1.505	1.806
0.75	0	25.91	28.25	28.34	29.53	26.67	23.81	29.73	35.68
0.75	1	7.40	7.46	7.28	7.34	7.23	7.92	7.72	6.64
0.75	2	4.64	4.50	4.55	4.57	4.62	4.67	4.89	4.71
0.75	3	3.64	3.60	3.55	3.55	3.33	3.54	3.28	3.25
0.75	4	3.13	3.02	3.05	3.04	2.93	2.98	2.93	3.04
0.75	5	2.76	2.75	2.74	2.73	2.69	2.64	2.71	2.51
0.75	6	2.55	2.51	2.46	2.43	2.38	2.43	2.31	2.48
0.75	7	2.37	2.33	2.32	2.29	2.28	2.26	2.23	2.19
0.75	8	2.24	2.24	2.21	2.19	2.11	2.15	2.18	2.19
0.75	9	2.13	2.13	2.09	2.10	2.05	2.05	1.97	2.00
0.75	10	2.07	2.04	2.03	1.99	2.01	1.97	1.95	2.02
0.9	0	44.82	42.32	42.52	41.36	44.39	35.54	44.39	35.68
0.9	1	10.47	10.59	10.01	9.90	9.79	9.59	9.90	9.29
0.9	2	6.28	6.28	6.03	6.03	5.72	5.42	5.83	5.87
0.9	3	4.69	4.67	4.62	4.44	4.33	4.44	4.42	4.64
0.9	4	3.92	3.86	3.79	3.81	3.64	3.61	3.73	3.53
0.9	5	3.46	3.37	3.39	3.31	3.21	3.13	3.31	3.25
0.9	6	3.10	3.05	3.05	2.98	2.94	2.80	2.79	2.77
0.9	7	2.86	2.83	2.81	2.75	2.75	2.73	2.64	2.68
0.9	8	2.68	2.67	2.63	2.58	2.50	2.54	2.51	2.61
0.9	9	2.54	2.50	2.49	2.44	2.39	2.39	2.42	2.37
0.9	10	2.43	2.40	2.38	2.33	2.31	2.28	2.21	2.34
0.95	0	56.53	56.53	56.53	53.22	53.22	47.39	44.39	53.53
0.95	1	12.84	12.66	12.84	12.48	12.32	11.39	11.99	11.83
0.95	2	7.46	7.40	7.23	7.17	6.84	6.90	6.79	7.00
0.95	3	5.48	5.32	5.32	5.32	5.00	4.89	5.00	4.64
0.95	4	4.48	4.40	4.40	4.27	4.10	4.23	4.12	4.01
0.95	5	3.87	3.79	3.76	3.78	3.57	3.60	3.61	3.61
0.95	6	3.47	3.45	3.42	3.34	3.23	3.18	3.27	3.06
0.95	7	3.19	3.15	3.12	3.05	2.97	2.89	2.83	2.92
0.95	8	2.99	2.93	2.89	2.83	2.79	2.81	2.68	2.82
0.95	9	2.81	2.76	2.72	2.72	2.65	2.63	2.56	2.55
0.95	10	2.66	2.64	2.61	2.58	2.53	2.48	2.47	2.50
0.99	0	87.57	85.11	85.11	82.78	79.87	71.12	74.02	71.12
0.99	1	17.89	17.89	17.54	16.89	16.29	16.58	16.29	14.47
0.99	2	9.79	9.59	9.59	9.39	9.11	8.43	8.67	8.13
0.99	3	7.11	6.90	6.74	6.64	6.32	6.23	6.11	5.99
0.99	4	5.65	5.62	5.52	5.35	5.26	5.17	4.89	4.95
0.99	5	4.84	4.76	4.69	4.60	4.44	4.29	4.19	4.33
0.99	6	4.29	4.21	4.15	4.08	3.92	3.92	3.74	3.64
0.99	7	3.87	3.79	3.73	3.67	3.55	3.51	3.42	3.39
0.99	8	3.58	3.51	3.46	3.42	3.28	3.20	3.18	3.21
0.99	9	3.34	3.31	3.25	3.23	3.07	3.08	2.99	3.07
0.99	10	3.15	3.10	3.04	3.02	2.91	2.88	2.85	2.81

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