Hybrid Group Acceptance Sampling Plans for Life Tests Based On the New Weibull-Pareto Distribution

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Abstract When the lifetime of an object follows a new Weibull-Pareto distribution, a hybrid group acceptance sampling plan based on truncated lifetimes is built in this article. The minimum number of testers and approval number needed for a given group size are determined for a specified consumer risk and test termination period. The minimum ratios of the true average life to the stated life at a given producer's risk are determined using the values of the operating characteristic function for various quality levels. Examples are used to demonstrate the findings.

Key words and phrases --- ***new Weibull-Pareto distribution, hybrid group acceptance sampling plans, consumer's risk, operating characteristic (OC) function, producer's risk, truncated life test***

I. INTRODUCTION

Acceptance or rejection of a commodity is based on its suitability for use. There are various forms of quality checking processes used in quality management. Acceptance sampling plans are an example of such a technique. An acceptance sampling plan is a method for determining the minimum sample size for analysis. This is especially important if a product's quality is measured by how long it lasts. When developing a sampling strategy, it is often assumed that only one object will be placed in a tester. In practise, however, testers who can handle a large number of items at once are used because testing time and money can be saved by testing items at the same time. A group of items in a tester can be considered, and the number of items in a group is referred to as the group size. A group acceptance sampling plan is an acceptance sampling plan focused on certain groups of objects (GASP). The hybrid group acceptance sampling plan is a method of deciding the minimum number of items for a predetermined number of groups (HGASP). When the HGASP is combined with truncated life tests, it is referred to as an HGASP based on truncated life tests, which assumes that the product's lifespan follows a certain probability distribution.

Acceptance sampling plans, group acceptance sampling plans, and hybrid group acceptance sampling plans (HGASP) of truncated life tests have all been studied in the past by Epstein(1954) [8], Gupta and Groll (1961) [10], Gupta(1962) [11], Fertig and Mann(1980) [9], Kantam and Rosaiah(1998) [12], Kantam(2001)*et al* [13], Baklizi(2003) [6], Wu and Tsai (2005) [24], Rosaiah and Kantam(2005) [17], Tsai and Wu(2006) [23], Balakrishnan *et al* (2007) [7], Aslam(2007) [1], Srinivasa Rao *et al* (2008) [18],Aslam and Kantam(2008) [2], Aslam *et al* (2009) [3], Srinivasa Rao *et al* (2009) [19],Srinivasa Rao (2009) [20], Lio *et al* (2010) [14], Srinivasa Rao *et al* (2010) [21], Srinivasa Rao(2011) [22], Aslam *et al* (2011) [4], Aslam *et al* (2011a) [5], Ramaswamy and Anburajan (2012) [16].

In section 2, we define the proposed hybrid group acceptance sampling plan (HGASP) based on truncated life tests when a product's lifetime follows the new Weibull-Pareto distribution. Section 3 discusses operating characteristic (OC) and producer risk. Section 4 explains the findings with some examples, and section 5 concludes with a description and conclusions.

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II. THE HYBRID GROUP ACCEPTANCE SAMPLING PLANS (HGASP)

The Pareto distribution's cumulative distribution function (cdf) is given by

$$F_1(x;\theta,k) = 1-\left(\frac{\theta}{x}\right)^k \qquad (2.1)$$

Here the scale parameter is θ>0, and the shape parameter is k>0.

The probability density function (pdf) corresponding to (2.1) is $f_1(x;\theta,k) = \frac{k\theta^k}{x^{k+1}}$ (2.2)

The cdf of the new Weibull-Pareto distribution (NWPD) is as follows

$$F(x) = \int_0^{\frac{1}{R(x)}} f_2(x)dx \qquad (2.3)$$

where R(x) is the Pareto distribution's survival function and is given by

$R(x)=1- F_1(x;\theta,k)$ and $f_2(x)$ is the Weibull distribution's pdf is given by

$$f_2(x) = \alpha\lambda(\lambda x)^{\alpha-1}e^{-(\lambda x)^\alpha} \qquad (2.4)$$

where x>0, α >0 and λ >0 are all true.

Considering $R(x) = \left(\frac{\theta}{x}\right)^k$ and (2.3), (2.4) the cdf of the NWPD is as follows

$$F(X) = \int_0^{\frac{1}{\left(\frac{\theta}{x}\right)^k}} \alpha\lambda(\lambda x)^{\alpha-1}e^{-(\lambda x)^\alpha}dx \qquad (2.5)$$

$$F(x) = 1-e^{-\lambda^\alpha\left(\frac{x}{\theta}\right)^{\alpha k}} \qquad (2.6)$$

If we take $\delta = \lambda^\alpha$ and $\beta = \alpha k$, the new Weibull-Pareto distribution's cdf can be written as

$$F(x) = 1-e^{-\delta\left(\frac{x}{\theta}\right)^\beta} \qquad (2.7)$$

The pdf is given by

$$g(x) = \frac{\beta\delta}{\theta}\left(\frac{x}{\theta}\right)^{\beta-1} e^{-\delta\left(\frac{x}{\theta}\right)^\beta} \qquad (2.8)$$

Where $0<x<\infty$, $\beta>0$, $\theta>0$ and $\delta>0$.

The hazard function is given by

$$h(x) = \frac{\beta\delta}{\theta}\left(\frac{x}{\theta}\right)^{\beta-1} \qquad (2.9)$$

The following can be seen in the hazard function:

(1) if β = 1 , the failure rate is constant, making the NWPD valid for calculating the failure rate of devices or components.

(2) if β > 1 , the hazard is an increasing function, indicating that the NWPD is appropriate for making components that wears faster with time.

(3) if β < 1 , the hazard is a decreasing function, making the NWPD ideal for modelling components that wear out more slowly over time.

A few distributional properties of NWPD are:

$$E(x) = \theta\delta^{\frac{-1}{\beta}}\Gamma\left(\frac{\beta+1}{\beta}\right) \qquad (2.10)$$

$$median = \theta\left(\frac{1}{\delta}\ln(2)\right)^{\frac{1}{\beta}} \qquad (2.11)$$

$$\text{var}\,iance = \theta^2\delta^{\frac{-2}{\beta}}\Gamma\left(\frac{\beta+2}{\beta}\right)-\left[\theta\delta^{\frac{-1}{\beta}}\Gamma\left(\frac{\beta+1}{\beta}\right)\right]^2$$

(2.12)

The pdf the largest order statistic $X_{(n)}$ is given by

$$\alpha_{(n)} = \frac{n\beta\delta}{\theta}\left(\frac{x}{\theta}\right)^{n-1} e^{-\delta(\frac{x}{\theta})^\beta} \times \left[1-e^{-\delta(\frac{x}{\theta})^\beta}\right]^{n-1}$$

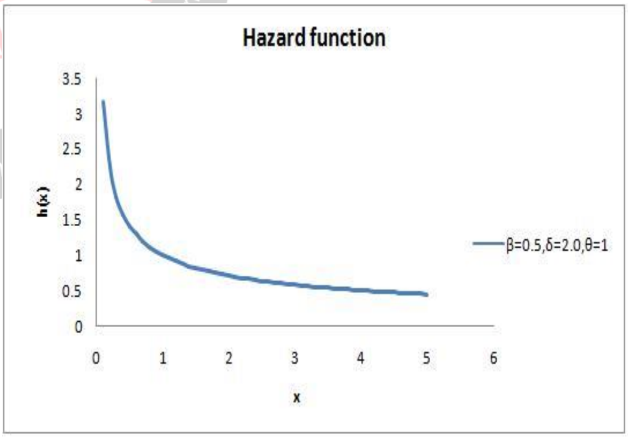
(2.13)

The pdf of the smallest order statistic $X_{(1)}$ is given by

$$\alpha_{(1)} = \frac{n\beta\delta}{\theta}\left(\frac{x}{\theta}\right)^{n-1} e^{-\delta(\frac{x}{\theta})^\beta} \times \left[e^{-\delta(\frac{x}{\theta})^\beta}\right]^{n-1}$$

(2.14)

The other distributional properties are thoroughly discussed by Nasiru and Lugu (2015) [15].



When β < 1 and δ =2, the new Weibull-Pareto distribution is a decreasing failure rate (DFR) model that is most useful in reliability studies when the components wear slower over time. We're interested in studying this distribution because of its DFR structure.

Assume that a product's lifetime follows a new Weibull-Pareto distribution with θ as the scale parameter. F(.) is the cumulative distribution function of it and is given by

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$$F(t)=1-e^{-\delta\left(\frac{t}{\theta}\right)^{\beta}} \qquad (2.15)$$

Provided 0 < q < 1, the 100th percentile is expressed as

$$t_q=\theta\left(-\frac{1}{\delta}\log(1-q)\right)^{\frac{1}{\beta}} \qquad (2.16)$$

By substituting θ in the scaled form in equation 2.13 we get

$$F(t)=1-e^{-\delta\left(\frac{t}{t_q}\right)^{\beta}\left(\frac{-1}{\delta}\log(1-q)\right)} \qquad (2.17)$$

$$F(t)=1-e^{-\delta(\xi)^{\beta}\left(\frac{-1}{\delta}\log(1-q)\right)} \qquad (2.18)$$

where $\xi=\frac{t}{t_q}$. A standard procedure in life testing is to terminate the life test by a pre-determined time t, to require the probability of rejecting a bad lot be at least p^* and to have the maximum permissible number of bad items to accept the lot being equal to c. Under a truncated life test, the acceptance sampling plan for percentiles is to set the minimum sample size n for a given acceptance number c so that the consumer's risk, the probability of accepting a bad lot, does not exceed 1-p^*. A bad lot occurs when the true 100th percentile, t_q is below a specified percentile t_q^0. As a consequence, the probability p* is a confidence level in the sense that the probability of rejecting a bad lot with $t_q<t_q^0$ is at least p*. As a result, the proposed acceptance sampling plan can be defined by the triplet $(n,c,\xi)=\left(n,c,\frac{t}{t_q^0}\right)$ where $\xi=\frac{t}{t_q^0}$ for a given p*.

When a distribution is symmetric, the mean and median are clearly the same. If the distribution is skewed, that is, one side of the tail is longer than the other; the mean is expected to lean towards that side of the distribution. We may make the mean even bigger and bigger by increasing the amount of skewness, in which case the proportion of the population below the mean can be rendered excessively high. This is what is meant by saying that mean would not represent a center of the distribution since more than 80% of the population may be below the mean. However, if the median is used, there is still 50% of the population less than the median. We use q=0.50 since the median is a better estimate of the population mean for making decisions about quality of life in our current biased population. As a result, we can infer that NWPD's population median-based sampling plan is more cost-effective in terms of sample size than those based on population mean.

Let μ be the true value of the median of a product's lifetime distribution and μ_0 denote the given median, assuming that an item's lifetime follows new Weibull-Pareto distribution. We want to test the hypothesis $H_0:\mu\geq\mu_0$ against $H_1:\mu<\mu_0$ based on the failure results. If the sample information supports the hypothesis $\mu \geq \mu_0$ a lot is considered good and approved for consumer use; on the other hand if $\mu < \mu_0$, the lot of the product is rejected. This hypothesis is evaluated in acceptance sampling plans based on the number of failures from a sample in a pre-determined period. We reject the lot if the number of failures reaches the action limit c. If there is sufficient evidence that $\mu \geq \mu_0$ at a certain level of consumer risk, we will consider the lot. Otherwise, we would reject the whole batch. Based on the truncated life test, let us suggest the following HGASP:

1. Calculate the number of testers r and allocate the r items to each of the predefined groups g; the minimum sample for a lot is n = g.r.

2. Pre-fix the acceptance c and the experiment time t_0 for each group.

3. Accept the lot if there are at least c failures in each of the groups.

4. Stop the experiment if any group has more than c failures, and reject the whole lot.

We want to know how many testers r are required for a new Weibull-Pareto distribution with various values of acceptance number c, assuming that the group size g and the termination time t_0 are known. We will use $t_0 = \xi\mu_0$ for a given constant ξ (termination ratio) since it is more convenient to set the termination time as a multiple of the defined value μ_0 of the median. The producer's risk (α) is the probability of rejecting a good lot, while the consumer's risk (β) is the probability of accepting a bad lot. The proposed sampling plan's parameter value g is calculated to ensure the consumer's risk β. The consumer's risk β is often represented by the consumer's level of confidence. The consumer's risk will be $\beta = 1-p^*$ if the confidence level is p^*. We'll figure out how many groups g to include in the existing sampling plan so that the consumer's risk does not exceed a given value β. We may use the binomial distribution to develop the HGASP if the lot size is big enough. According to the HGASP, a lot of goods is only accepted if each of the g classes has at least c failures. As a consequence, the probability of a lot being accepted is given by

$$\left(\sum_{i=0}^{c}\binom{r}{i}p_0^i(1-p_0)^{r-i}\right)^g \leq \beta \qquad (2.19)$$

where $p_0 = F_t(\xi_0)$ is the probability of a failure during the time t = ξt_q^0. To save space, only the results of small sample sizes for β =0.25, 0.10, 0.05, 0.01; g=2(1)10;

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c=0(1)8; ξ =0.7, 0.8, 1.0, 1.2, 1.5, 2.0 are displayed in table 1.

3. OPERATING CHARACTERISTIC OF THE SAMPLING PLAN

The probability of acceptance can be viewed as a function of the deviation of the specified value μ_0 of the median from its true value μ. This function is called operating characteristic (OC) function of the sampling plan. After obtaining the minimum number of groups g, one might be interested in determining the likelihood of a lot's acceptance when the output is considered good if $\mu \geq \mu_0$ or $\frac{\mu}{\mu_0}$. The OC is given by

$$L(p)=\left(\sum_{i=0}^{c}\binom{r}{i}p^i(1-p)^{r-i}\right)^g \qquad (3.1)$$

For any sampling plan, the OC values can be determined using equation 3.1. Table 2 indicates the OC values for sampling plans with $\frac{\mu}{\mu_0}$ = 2, 4, 6, 8, 10, 12; β=0.25, 0.10, 0.05, 0.01; δ=0.7, 0.8, 1.0, 1.2, 1.5, 2.0.

4. PRODUCER'S RISK

The producer may be interested in improving product's quality so that the acceptance probability exceeds a predetermined value. The minimum ratio can be obtained by satisfying the following inequality for a given value of the producer's risk, say α. $\left(\sum_{i=0}^{c}\binom{r}{i}p^i(1-p)^{r-i}\right)^g \geq 1-\alpha$

(3.2)

To save space, the minimum values of the ratio $\frac{\mu}{\mu_0}$=2 in case of new Weibull-Pareto distribution based on the values given in table 1 for the acceptability of a lot at the producer's risk of α = 0:05 are presented in table 3.

4. TABLES AND EXAMPLES

Table 1 shows the HGASP specification parameters for different values of the consumer's risk and the test termination time multiplier. It should be remembered that n = r × g can be used to determine the minimum sample size. Table 1 shows that as the test termination time multiplier ξ increases, the number of testers r decreases, implying that if the test termination time multiplier increases at a fixed group size, fewer testers are required. For an example, if β = 0.10, g = 7, c = 5 and ξ changes from 0.7 to 0.8, the necessary values of the design parameters of HGASP change from r=9 to r=7 as shown in Table 1. This pattern, however, is not constant because it is influenced by the acceptance rate. Table 2 shows the probability of acceptance for the lot at the median ratio that corresponds to the producer's risk. Finally, for given parameter values, table 3 shows the minimum ratios of true median to specified median for the acceptance of a lot with producer's risk α= 0.05.

If a product's lifetime follows the new Weibull-Pareto distribution, an HGASP should be designed to see if the median is greater than 1,000 hours, with a testing period of 700 hours and four groups. The values c = 2 and = 0.10 are presumed. As a result, the termination multiplier is equal to 0.700. The minimum number of testers available is calculated as r = 5 from Table 1. As a result, we'll choose a random sample of n = 20 items and assign 5 items to each of the four groups to test for 700 hours. This means that a total of 20 products are required, with 5 items assigned to each of the four groups. We will accept the lot if no more than two failures occurs in each of the four groups before 700 hours. We truncate the experiment as soon as the 3rd failure occurs before the 700th hours. For this proposed sampling plan the probability of acceptance is p = 0.6407 when the true value of the median is μ = 4,000 hours. This shows that, if the true value of the median is 4 times of the required value μ_0 = 1000 hours, the producer's risk is α = 0.3593.

If we need the ratio to assure a producer's risk of α = 0.05, we can obtain it from Table 3. For example, when β = 0.10, r = 6, g =4, c = 2 and δ = 0.700, the required ratio is $\frac{\mu}{\mu_0}$ =7.8659.

5. SUMMARY AND CONCLUSIONS

In the case of the new Weibull-Pareto distribution, a hybrid group acceptance sampling plan based on a truncated life test is proposed in this paper. When the consumer's risk (β) and other plan parameters are defined, the number of groups and acceptance number are calculated. As the test termination time multiplier increases, it is observed that the minimum number of groups needed decreases. Furthermore, as quality improves, the operating characteristic function increases disproportionately. When a large number of products are being checked at the same time, this HGASP may be used. Clearly, such a tester would save time and money during the testing process.

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TABLE 1. Minimum no.of testers(r) required for the proposed plan in the case of NWPD

β	g	c	δ					
			0.7	0.8	1.0	1.2	1.5	2.0
0.25	2	0	1	1	1	1	1	1
0.25	3	1	1	1	2	2	2	2
0.25	4	2	4	4	2	2	2	2
0.25	5	3	6	5	5	5	2	2
0.25	6	4	6	6	5	5	5	5
0.25	7	5	9	7	5	5	5	5
0.25	8	6	11	10	9	9	6	6
0.25	9	7	11	11	11	10	10	9
0.25	10	8	14	12	11	11	10	10
0.10	2	0	1	1	1	1	1	1
0.10	3	1	3	3	3	3	1	1
0.10	4	2	5	5	5	4	4	1
0.10	5	3	5	5	4	4	4	1
0.10	6	4	8	8	6	6	4	4
0.10	7	5	10	10	10	8	8	6
0.10	8	6	12	12	12	10	10	8
0.10	9	7	12	12	12	12	10	10
0.10	10	8	15	13	13	13	10	10
0.05	2	0	2	2	2	1	1	1
0.05	3	1	4	4	4	3	3	1
0.05	4	2	5	5	5	3	3	3
0.05	5	3	7	7	6	6	4	4
0.05	6	4	8	8	8	7	7	4
0.05	7	5	10	10	8	8	7	4
0.05	8	6	12	12	11	9	7	4
0.05	9	7	14	14	12	12	11	9
0.05	10	8	16	15	14	12	12	9
0.01	2	0	3	3	3	3	2	2
0.01	3	1	5	5	3	3	2	2
0.01	4	2	7	7	6	6	5	2
0.01	5	3	8	8	7	7	5	5
0.01	6	4	10	10	9	9	8	6
0.01	7	5	12	12	10	10	8	6
0.01	8	6	14	13	12	10	8	6
0.01	9	7	15	14	14	13	12	11
0.01	10	8	17	15	14	13	12	11

TABLE 2. OC values of the hybrid group acceptance sampling plan for NWPD with g=4 and c=2

β	r	δ	$\frac{\mu}{\mu_0}$					
			2	4	6	8	10	12
0.25	4	0.7	0.6166	0.8085	0.8961	0.9150	0.9357	0.9491
0.25	4	0.8	0.5696	0.7787	0.8592	0.8999	0.9240	0.9396

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0.25	2	1.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
0.25	2	1.2	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
0.25	2	1.5	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
0.25	2	2.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
0.10	5	0.7	0.3808	0.6407	0.7591	0.8237	0.8635	0.8901
0.10	5	0.8	0.3286	0.5950	0.7237	0.7957	0.8407	0.8711
0.10	5	1.0	0.2456	0.5127	0.6566	0.7142	0.7957	0.8332
0.10	4	1.2	0.4148	0.6671	0.7787	0.8388	0.8755	0.8999
0.10	4	1.5	0.3278	0.5926	0.7213	0.7935	0.8388	0.8694
0.10	1	2.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
0.05	5	0.7	0.3808	0.6407	0.7591	0.8237	0.8635	0.8901
0.05	5	0.8	0.3286	0.5950	0.7237	0.7957	0.8407	0.8711
0.05	5	1.0	0.2456	0.5127	0.6566	0.7142	0.7957	0.8332
0.05	3	1.2	0.7425	0.8797	0.9263	0.9488	0.9616	0.9698
0.05	3	1.5	0.6799	0.8444	0.9032	0.9320	0.9488	0.9595
0.05	3	2.0	0.5861	0.7868	0.8640	0.9032	0.9263	0.9414
0.01	7	0.7	0.1008	0.3212	0.4811	0.5893	0.6648	0.7196
0.01	7	0.8	0.0736	0.2707	0.4285	0.5403	0.6206	0.6801
0.01	6	1.0	0.1058	0.3290	0.4887	0.5960	0.6707	0.7247
0.01	6	1.2	0.0688	0.2603	0.4169	0.5292	0.6103	0.6707
0.01	5	1.5	0.1217	0.3537	0.5127	0.6174	0.6894	0.7412
0.01	2	2.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

TABLE 3. Minimum ratio of the values of true median and the specified median for the producer's risk of α = 0.05 in the case of NWPD

β	g	c	δ					
			0.7	0.8	1.0	1.2	1.5	2.0
0.25	2	0	39.5788	33.7805	27.24526	25.4947	23.8683	22.2563
0.25	3	1	8.8201	8.7944	8.6600	8.3520	8.1709	8.0279
0.25	4	2	6.0661	5.7262	5.4892	5.1870	5.1053	5.0405
0.25	5	3	5.0842	4.9923	4.8955	4.8535	4.5668	4.2933
0.25	6	4	4.5844	4.4937	4.3266	3.7919	3.7766	3.6778
0.25	7	5	3.2807	3.1727	3.0519	2.7872	2.3206	2.3113
0.25	8	6	3.0755	2.9549	2.9112	1.9638	1.9447	1.8672
0.25	9	7	2.9269	2.8630	1.9974	1.8858	1.8170	1.8022
0.25	10	8	1.8139	1.7891	1.8065	1.6956	1.6630	1.5600
0.10	2	0	54.5564	50.3256	48.7458	46.1596	38.3547	32.5244
0.10	3	1	10.7541	10.1544	9.9430	9.3520	9.1425	9.0245
0.10	4	2	7.8659	7.6469	7.5577	6.9570	6.2388	5.9603
0.10	5	3	5.5470	5.4248	4.7403	4.6803	4.5668	4.2933
0.10	6	4	4.8897	4.7536	4.6380	4.0324	3.9766	3.6778
0.10	7	5	4.5119	4.5065	4.0309	3.9722	3.3206	3.3013
0.10	8	6	3.2564	3.1642	2.9794	2.7934	2.4547	2.0672
0.10	9	7	2.0741	2.0332	2.1144	2.0118	2.0043	1.9226
0.10	10	8	1.9371	1.9314	1.8761	1.7658	1.6683	1.2168

 DOI : 10.35291/2454-9150.2021.0317

0.05	2	0	68.9289	61.5640	58.2050	55.6708	53.3385	42.4911
0.05	3	1	12.6817	12.0046	11.9730	11.6915	11.4400	10.2279
0.05	4	2	9.6625	9.5610	8.8087	8.5893	7.2338	7.1404
0.05	5	3	7.2979	7.0537	6.9403	6.6803	5.5668	5.2933
0.05	6	4	6.2090	5.9536	5.2421	4.8456	4.7766	4.7021
0.05	7	5	4.7422	4.6065	4.5909	3.9022	3.8589	3.1940
0.05	8	6	3.4366	3.3720	3.3436	3.2934	3.0547	2.9995
0.05	9	7	3.1207	2.9022	2.7734	2.6768	2.5743	2.3226
0.05	10	8	2.2299	2.0730	2.0571	2.0311	1.9685	1.8773
0.01	2	0	95.2995	90.1305	86.1841	75.8460	64.3385	54.4513
0.01	3	1	17.6061	17.4069	16.5058	15.6915	14.6144	13.9200
0.01	4	2	10.4571	10.3714	9.9513	9.5704	8.9866	8.2384
0.01	5	3	7.4675	7.1805	6.9160	6.4884	5.9603	5.7558
0.01	6	4	5.9197	5.6675	5.2320	4.9656	4.4899	3.9021
0.01	7	5	4.2009	4.1340	3.9258	3.8091	3.7590	3.6942
0.01	8	6	3.7954	3.7847	3.7052	3.6152	2.8667	2.6993
0.01	9	7	2.9128	2.8380	2.7414	2.5372	2.5148	2.4226
0.01	10	8	2.5046	2.3542	2.2364	2.2113	2.0581	2.0173

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