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Determination of cumulative Poisson probabilities for double sampling plan

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Abstract
Acceptance Sampling is a Statistical tool of Quality Control. Sampling plans are used to accept/reject the lots when inspecting a series of lots. In this paper an attempt is made to determine the cumulative probabilities of a Double sampling plan for various *np* values under the condition $n_1=n_2$ and acceptance number (c_1,c_2) with Poisson distribution as a base line distribution. Tables are constructed and numerical illustrations are given to describe the determination of cumulative Double Sampling Plan using Poisson distribution and its Operating Characteristic curve is drawn.

Keywords: Double Sampling Plan (DSP), size of the first sample and second sample (n_1, n_2), Acceptance numbers (c_1, c_2), Lot size *(N)*, Lot quality *(p)*, Average Outgoing Quality (AOQ).

1. Introduction and Review of Literature

Acceptance sampling is an inspection procedure used to determine whether to accept or reject a specific quantity of material. Acceptance Sampling is a form of testing that involves taking random samples of "lots," or batches, of finished products and measuring them against predetermined standards.

All sampling plans are devised to provide a specified producer's and consumer's risk. However, it is in the consumer's best interest to keep the average number of items inspected (ANI) to a minimum because that keeps the cost of inspection low. Sampling plans differ with respect to ANI. The most often used sampling plans are Single Sampling Plan and Double Sampling Plan.

Single Sampling Plan: Two numbers specify a single sampling plan. They are the number of items to be sampled *(n)* and a prespecified acceptable number of defects *(c)*. If there are fewer or equal defects in the lot than the acceptance number, *c*, and then the whole batch will be accepted. If there are more than *c* defects, the whole lot will be rejected or subjected to 100% screening.

Double Sampling Plan: Often a lot of items are so good or so bad that we can reach a conclusion about its quality by taking a smaller sample than would have been used in a single sampling plan. If the number of defects in this smaller sample (of size n_1) is less than or equal to some lower li it (c_1), the lot can be accepted. If the number of defects exceeds an upper limit (c_2), the whole lot can be rejected. But if the number of defects in the n_1 sample is between c_1 and c_2, a second sample (of size n_2) is drawn. The cumulative results determine whether to accept or reject the lot.

In Double Sampling Plan (DSP) by attributes, the lot acceptance procedure is characterized by the parameters N, n_1, n_2, c_1 and c_2. Dodge and Roming (1959) [1] have considered Double Sampling Plan as an extension of Single Sampling Plan (SSP). Guenther (1970) [3] developed trial and error procedure for constructing double sampling plan for a specified producer's and consumer's risk. A detailed comparison of various attribute sampling plans and the merits of the double sampling plan can be seen in Schilling (1982) [11] and Duncan (1986) [2]. Schilling and Johnson (1980) [12] have developed a table for the construction and evaluation of matched sets of double sampling plans. Hald (1981) [4] has constructed tables for double sampling plan with the fixed 5% producer's and 10% consumer's risks. Soundararajan and Arumainayagam (1990) [14] have provided tables for easy selection of double sampling plan indexed through Acceptable Quality Level (AQL) and Limiting Quality Level (LQ

Radhakrishnan (2002) [5] contributed to the construction of Double and Continuous Sampling Plans indexed through Maximum Allowable Average Outgoing Quality (MAAOQ). Radhakrishnan and Sampath kumar (2007) [6] have constructed mixed sampling plans indexed through MAPD and AQL with Double Sampling Plan as the attribute plan. Sekkizhar (2007) [13] constructed double sampling plan indexed through MAPD and MAAOQ using Intervened Random effect Poisson Distribution (IRPD) as the basic distribution. Radhakrishnan and Sivakumaran (2009) [7] constructed six sigma sampling plans indexed through Six Sigma Quality Level (SSQL) with Double Sampling Plans as reference plans.

The plans studied under several authors are under the assumption that the samples are selected from an infinite lot, which is not practicable. So, a sampling plan is required which depends on the lot size *(N)*. Radhakrishnan and Vasanthamani (2009a, 2009b) [8, 9] determined the lot sizes for single sampling plans, double sampling plans of the type DSP (0, 1). Further Radhakrishnan and Vasanthamani (2009c) [10] determined the lot size for single and double sampling plans of the type DSP (0, 1) based on six sigma quality levels.

2. Conditions for application

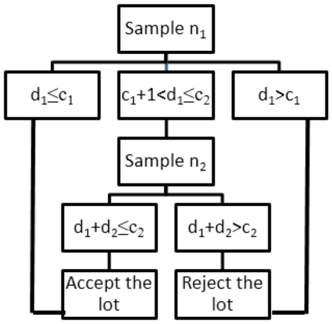
1. The sample units are selected from a finite lot and production is continuous.
2. Production is steady, so that results of past, present and future lots are broadly indicative of a continuous process.
3. Lots are submitted sequentially in the order of their production.
4. Inspection is by attributes, with the lot quality defined as the proportion defective.

3. Operating Procedure of DSP Plan

In Double sampling plan by attributes the lot acceptance procedure is characterized by the parameters N, n_1, n_2, c_1 *and* c_2. The operating procedure for double sampling plan is given below:

1. Select a random sample of size 'n_1' from a lot of size 'N'
2. Inspect all the items in the sample. Let 'd_1' be the number of non – conformities in the sample.
3. If $d_1 \leq c_1$, accept the lot.
4. If $d_1 > c_2$, reject the lot.
5. If $c_1+1 \leq d_1 \leq c_2$, take a second sample of size 'n_2' from the remaining lot and find the number of non– conformities 'd_2'.
6. If $d_1 + d_2 \leq c_2$, accept the lot.
7. If $d_1 + d_2 > c_2$, reject the lot.

The figure shows the way of decision making in a double sampling plan.



4. Operating Characteristic function

Under Poisson model, the OC function of the Double sampling plan as given by Dodge (1959) [1] is

$$P_a(p) = \sum_{r=0}^{c_1} \frac{e^{-n_1 p}(n_1 p)^r}{r!} + \left[\sum_{k=c_1+1}^{c_2} \frac{e^{-n_1 p}(n_1 p)^k}{k!} \left\{\sum_{r=0}^{c_2-k} \frac{e^{-n_2 p}(n_2 p)^r}{r!}\right\}\right]$$

4.1 Operating Characteristic Curve

The Operating Characteristic (OC) curve describes how well an acceptance plan discriminates between good and bad lots. A curve pertains to a specific plan, that is, a combination of *n* (sample size) and *c* (acceptance level). It is intended to show the probability that the plan will accept lots of various quality levels. Undoubtedly, every manager wants a plan that accepts lots with a quality level better than the AQL 100 percent of the time and accepts lots with a quality level worse than the AQL 0 percent of the time. However, such performance can be achieved only with 100 percent inspection. Consequently, managers are left with choosing a sample size *n* and an acceptance number *c* to achieve the level of performance specified by the AQL, α, LTPD and β.

The sampling distribution for the Double Sampling Plan is the binomial distribution because each item inspected is either defective (a failure) or not (a success). The probability of accepting the lot equals the probability of taking a sample of size *n* from a lot with a proportion defective of *p* and finding c or fewer defective items. However, if *n* is greater than 20 and *p* is less than 0.05, the Poisson distribution can be used as an approximation to the binomial to take advantage of tables prepared for the purpose of drawing OC curves (Table 1). To draw the OC curve, look up the probability of accepting the lot for a range of values of *p*. For each value of *p*,

1. Multiply *p* by the sample size *n*.
2. Find the value of *np* in the left column of the table.
3. Move to the right until you find the column for (c_1, c_2).
4. Record the value for the probability of acceptance, P_a.

When $p = AQL$, the producer's risk, α, is 1 minus the probability of acceptance. When *(p=LTPD)*, the consumer's risk, β, equals the probability of acceptance.

5. Example 1

The Noise King Muffler Shop, a high-volume installer of replacement exhaust muffler systems, just received a shipment of 1,000 mufflers. The sampling plan for inspecting these mufflers calls for a sample size $n=n_1=n_2=60$ and acceptance numbers $c_1=1$ *and* $c_2=3$. The contract with the muffler manufacturer calls for an AQL of 1 defective muffler per 100 and an LTPD of 6 defective mufflers per 100. Calculate the OC curve for this plan, and determine the producer's risk and the consumer's risk for the plan.

5.1 Solution

Let $p=0.01$.Then multiply *n by p* to get 60(0.01) = 0.60. Locate 0.60 in Table 1. Move to the right until you reach the column for $c_1=1$ *and* $c_2=3$. Read the probability of acceptance: 0.982. Repeat this process for a range of *p* values. The following table contains the remaining values for the OC curve.

Values for the Operating Characteristic Curve with n_1=n_2= 60, c_1=1, c_2=3			
Proportion defective *(p)*	***np***	**P_a**	**Comments**
0.01	0.6	0.982	α=1.000-0.982=0.018
0.02	1.2	0.863	
0.03	1.8	0.661	
0.04	2.4	0.453	
0.05	3.0	0.288	
0.06	3.6	0.174	β=0.174
0.07	4.2	0.102	
0.08	4.8	0.059	
0.09	5.4	0.034	
0.10	6.0	0.019	

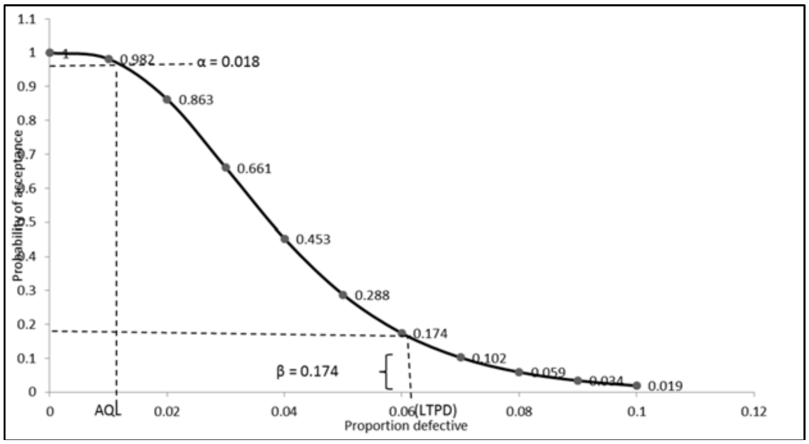


Fig 1: OC Curve for Double Sampling Plan

6. Average Outgoing Quality

To check whether the performance of the plan is what we want, we can calculate the plan's Average Outgoing Quality (AOQ), which is the expected proportion of defects that the plan will allow to pass. We assume that all defective items in the lot will be replaced with good items if the lot is rejected and that any defective items in the sample will be replaced if the lot is accepted. This approach is called rectified inspection. The equation for AOQ is

$$AOQ = (p/N)[(N - n_1)P_{a1} + (N - n_1 - n_2)P_{a2}]$$

where

$$P_{a1} = \sum_{r=0}^{c_1} \frac{e^{-n_1 p}(n_1 p)^r}{r!}$$

$$P_{a2} = \sum_{k=c_1+1}^{c_2} \frac{e^{-n_1 p}(n_1 p)^k}{k!} \left\{ \sum_{r=0}^{c_2-k} \frac{e^{-n_2 p}(n_2 p)^r}{r!} \right\}$$

The analyst can calculate AOQ to estimate the performance of the plan over a range of possible proportion defectives in order to judge whether the plan will provide an acceptable degree of protection. The maximum value of the average outgoing quality over all possible values of the proportion defective is called the Average Outgoing Quality Limit (AOQL). If the AOQL seems too high, the parameters of the plan must be modified until an acceptable AOQL is achieved.

7. Example 2

Suppose that the Noise King is using rectified inspection for Double Sampling Plan. Calculate the average outgoing quality limit for a plan with n_1=n_2=120, c_1=1, c_2=2 *and N=1000*. Use Table 1 to estimate the probabilities of acceptance for values of the proportion defective from 0.01 to 0.08 in steps of 0.01.

7.1 Solution

Step 1: Determine the probabilities of acceptance for the desired values of p. These are shown in the following table.

Proportion defective *(p)*	**0.01**	**0.02**	**0.03**	**0.04**	**0.05**	**0.06**	**0.07**	**0.08**
np	1.2	2.4	3.6	4.8	6.0	7.2	8.4	9.6
P_a	0.727	0.332	0.130	0.048	0.017	0.006	0.002	0.001

Step 2: Calculate the AOQ for each value of p.

Proportion defective *(p)*	**0.01**	**0.02**	**0.03**	**0.04**	**0.05**	**0.06**	**0.07**	**0.08**
AOQ	0.0063	0.0057	0.0034	0.0017	0.0007	0.0003	0.0001	0.00005

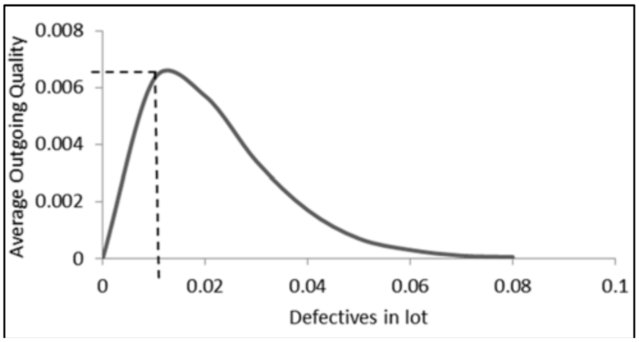


Fig 2: AOQ for Double Sampling Plan

Step 3: Identify the largest AOQ value, which is the estimate of the AOQL. In this example, the AOQL is 0.0063 at $p=0.01$.

8. Advantages of Cumulative Double Sampling Plan

There are several advantages for using Cumulative Double Sampling Plan.

- The plans tabulated are often encountered in practice.
- The cumulative Poisson tables are set up in accordance with sample size and acceptance numbers.
- When sample size and acceptance numbers are fixed, the probability of acceptance can be estimated by this table.
- The producer's risk and consumer's risk can be computed from the probability of acceptance to see if they were within the desired levels.
- The OC curve satisfies the quality and risk needs of the consumer and producer.

9. Conclusion

When *np* increases, the probability of acceptance decreases for the specified acceptance numbers. When the probability of acceptance reaches 1 at some acceptance numbers, then the procedure is stopped for the remaining acceptance numbers. Similarly, when the probability of acceptance attains 0 at certain acceptance numbers, then the remaining acceptance numbers for the same *np* value is also 0. Therefore, we can adopt this plan to predict the Cumulative Poisson Probabilities for Double Sampling Plan under the condition $n_1=n2$. Based on this plan, the better outcome can be achieved in the shop floor situations.

Table 1: Cumulative Poisson Probabilities for Double Sampling Plan

	(c_1,c_2)												
np	**(0,1)**	**(0,2)**	**(0,3)**	**(1,2)**	**(1,3)**	**(1,4)**	**(2,3)**	**(2,4)**	**(2,5)**	**(3,4)**	**(3,5)**	**(3,6)**	**(4,5)**
0.05	0.996	1.000											
0.1	0.986	0.999	0.999	0.999	1.000								
0.15	0.971	0.998	0.999	0.998	1.000								
0.2	0.952	0.995	0.999	0.995	1.000								
0.25	0.930	0.992	0.999	0.992	0.999	1.000							
0.3	0.905	0.986	0.998	0.987	0.99	1.000							
0.35	0.878	0.980	0.997	0.981	0.997	1.000							
0.4	0.850	0.972	0.996	0.974	0.995	0.999	0.996	0.999	1.000				
0.45	0.820	0.962	0.994	0.965	0.993	0.999	0.995	0.999	0.999	0.999	1.000		
0.5	0.790	0.951	0.992	0.955	0.990	0.998	0.993	0.998	0.999	0.999	1.000		
0.55	0.760	0.938	0.989	0.944	0.986	0.997	0.990	0.997	0.999	0.998	1.000		
0.6	0.729	0.924	0.986	0.932	0.982	0.996	0.987	0.996	0.999	0.998	1.000		
0.65	0.699	0.909	0.982	0.918	0.976	0.995	0.984	0.995	0.999	0.997	0.999	1.000	
0.7	0.669	0.892	0.977	0.904	0.970	0.993	0.979	0.994	0.998	0.996	0.999	1.000	
0.75	0.639	0.875	0.971	0.889	0.963	0.991	0.975	0.992	0.998	0.995	0.998	0.999	0.999
0.8	0.610	0.856	0.965	0.873	0.956	0.989	0.969	0.989	0.997	0.994	0.998	0.999	0.999
0.85	0.582	0.836	0.958	0.856	0.947	0.986	0.963	0.987	0.996	0.992	0.997	0.999	0.998
0.9	0.555	0.816	0.950	0.839	0.937	0.983	0.957	0.983	0.995	0.991	0.996	0.999	0.998
0.95	0.528	0.795	0.941	0.821	0.927	0.979	0.950	0.980	0.994	0.989	0.995	0.998	0.998
1	0.503	0.773	0.931	0.803	0.916	0.975	0.942	0.976	0.993	0.986	0.994	0.998	0.997
1.2	0.410	0.684	0.886	0.727	0.863	0.952	0.905	0.954	0.984	0.974	0.987	0.995	0.994
1.3	0.369	0.638	0.859	0.689	0.833	0.937	0.884	0.939	0.977	0.965	0.98	0.993	0.991
1.4	0.331	0.593	0.829	0.651	0.801	0.920	0.861	0.923	0.969	0.956	0.976	0.990	0.988
1.5	0.297	0.549	0.798	0.613	0.767	0.900	0.836	0.905	0.959	0.944	0.968	0.986	0.984
1.6	0.267	0.507	0.765	0.577	0.732	0.878	0.811	0.884	0.948	0.932	0.959	0.981	0.979
1.7	0.239	0.466	0.731	0.541	0.697	0.854	0.784	0.862	0.935	0.918	0.948	0.975	0.974
1.8	0.214	0.426	0.695	0.507	0.661	0.828	0.757	0.838	0.919	0.903	0.936	0.968	0.967
1.9	0.192	0.389	0.659	0.474	0.625	0.801	0.729	0.813	0.902	0.886	0.923	0.960	0.960
2	0.171	0.355	0.623	0.442	0.589	0.772	0.701	0.786	0.884	0.869	0.908	0.950	0.952
2.2	0.137	0.292	0.552	0.384	0.519	0.711	0.644	0.730	0.842	0.831	0.874	0.927	0.932
2.4	0.110	0.238	0.482	0.332	0.453	0.647	0.588	0.672	0.794	0.790	0.835	0.898	0.909
2.6	0.088	0.193	0.417	0.286	0.392	0.583	0.534	0.614	0.742	0.746	0.793	0.863	0.882
2.8	0.071	0.155	0.357	0.245	0.337	0.520	0.482	0.556	0.687	0.701	0.748	0.825	0.852
3	0.057	0.124	0.302	0.210	0.288	0.459	0.434	0.501	0.631	0.655	0.700	0.782	0.820
3.2	0.046	0.098	0.254	0.179	0.245	0.402	0.388	0.448	0.575	0.609	0.652	0.736	0.785
3.4	0.037	0.078	0.211	0.153	0.207	0.349	0.347	0.399	0.520	0.564	0.604	0.688	0.748
3.6	0.030	0.061	0.175	0.130	0.174	0.301	0.308	0.35	0.466	0.520	0.556	0.639	0.710
3.8	0.024	0.048	0.143	0.110	0.146	0.258	0.273	0.311	0.415	0.477	0.510	0.590	0.671
4	0.019	0.038	0.117	0.094	0.122	0.219	0.241	0.273	0.368	0.437	0.465	0.542	0.631

4.2	0.015	0.030	0.094	0.079	0.102	0.185	0.213	0.239	0.324	0.398	0.423	0.494	0.592
4.4	0.012	0.023	0.076	0.067	0.085	0.156	0.187	0.209	0.284	0.361	0.383	0.449	0.553
4.6	0.010	0.018	0.061	0.057	0.071	0.130	0.164	0.182	0.247	0.327	0.345	0.405	0.514
4.8	0.008	0.014	0.048	0.048	0.059	0.108	0.143	0.158	0.215	0.295	0.311	0.365	0.477
5	0.006	0.011	0.038	0.040	0.049	0.090	0.125	0.137	0.185	0.266	0.279	0.326	0.441
5.2	0.005	0.009	0.030	0.034	0.041	0.074	0.109	0.118	0.160	0.238	0.249	0.291	0.407
5.4	0.004	0.007	0.024	0.029	0.034	0.061	0.095	0.102	0.137	0.214	0.222	0.259	0.374
5.6	0.003	0.005	0.019	0.024	0.028	0.050	0.082	0.088	0.117	0.191	0.198	0.230	0.342
5.8	0.003	0.004	0.014	0.020	0.023	0.041	0.071	0.076	0.100	0.170	0.176	0.203	0.313
6	0.002	0.003	0.011	0.017	0.019	0.033	0.062	0.065	0.085	0.151	0.156	0.179	0.285
6.2	0.002	0.002	0.009	0.014	0.016	0.027	0.053	0.056	0.072	0.134	0.138	0.157	0.259
6.4	0.001	0.002	0.007	0.012	0.013	0.022	0.046	0.048	0.061	0.119	0.122	0.138	0.235
6.6	0.001	0.001	0.005	0.010	0.011	0.018	0.040	0.041	0.052	0.105	0.107	0.121	0.212
6.8	0.001	0.001	0.004	0.008	0.009	0.015	0.034	0.035	0.044	0.092	0.094	0.106	0.192
7	0.001	0.001	0.003	0.007	0.007	0.01	0.029	0.030	0.037	0.081	0.083	0.092	0.173
7.2	0.001	0.001	0.002	0.006	0.006	0.009	0.025	0.026	0.031	0.071	0.073	0.080	0.155
7.4	0.001	0.001	0.001	0.001	0.005	0.008	0.021	0.022	0.026	0.063	0.064	0.070	0.139
7.6	0.001	0.001	0.001	0.004	0.004	0.006	0.018	0.019	0.022	0.055	0.056	0.061	0.124
7.8	0.000	0.000	0.001	0.003	0.003	0.005	0.016	0.016	0.019	0.048	0.049	0.053	0.111
8	0.000	0.000	0.001	0.003	0.003	0.004	0.01	0.014	0.016	0.042	0.042	0.046	0.099
8.2	0.000	0.000	0.001	0.002	0.002	0.003	0.011	0.011	0.013	0.037	0.037	0.039	0.088
8.4	0.000	0.000	0.001	0.002	0.002	0.002	0.010	0.010	0.011	0.032	0.032	0.034	0.078
8.6	0.000	0.000	0.000	0.001	0.001	0.002	0.001	0.008	0.009	0.028	0.028	0.029	0.070
8.8	0.000	0.000	0.000	0.001	0.001	0.001	0.001	0.007	0.008	0.024	0.024	0.025	0.062
9	0.000	0.000	0.000	0.001	0.001	0.001	0.001	0.006	0.006	0.021	0.021	0.022	0.054
9.2	0.000	0.000	0.000	0.001	0.001	0.001	0.001	0.005	0.005	0.018	0.018	0.019	0.048
9.4	0	0	0.000	0.001	0.001	0.001	0.000	0.004	0.004	0.015	0.016	0.016	0.042
9.6	0	0	0.000	0.001	0.001	0.001	0.000	0.003	0.004	0.013	0.013	0.014	0.037
9.8	0	0	0	0.001	0.001	0.001	0.000	0.003	0.003	0.011	0.011	0.012	0.033
10	0	0	0	0.001	0.001	0.001	0.000	0.002	0.002	0.010	0.010	0.010	0.029
10.2	0	0	0	0.000	0.000	0.000	0.000	0.002	0.002	0.008	0.008	0.009	0.025
10.4	0	0	0	0.000	0.000	0.000	0.000	0.002	0.002	0.007	0.007	0.007	0.022
10.6	0	0	0	0.000	0.000	0.000	0.000	0.001	0.001	0.006	0.006	0.006	0.019
10.8	0	0	0	0.000	0.000	0.000	0.000	0.001	0.000	0.005	0.005	0.005	0.017
11	0	0	0	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.004	0.005	0.015
11.2	0	0	0	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.004	0.004	0.013
11.4	0	0	0	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.003	0.003	0.011
11.6	0	0	0	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.003	0.003	0.010
11.8	0	0	0	0	0	0.000	0.000	0.001	0.000	0.000	0.002	0.002	0.008
12	0	0	0	0	0	0	0.000	0.001	0.000	0.000	0.002	0.002	0.007
12.2	0	0	0	0	0	0	0.000	0.000	0.000	0.000	0.001	0.001	0.006
12.4	0	0	0	0	0	0	0.000	0.000	0.000	0.000	0.001	0.001	0.005
12.6	0	0	0	0	0	0	0.000	0.000	0.000	0.000	0.001	0.001	0.004
12.8	0	0	0	0	0	0	0.000	0.000	0.000	0.000	0.001	0.001	0.004
13	0	0	0	0	0	0	0.000	0.000	0.000	0.000	0.001	0.001	0.003
13.2	0	0	0	0	0	0	0.000	0.000	0.000	0.000	0.001	0.001	0.003
13.4	0	0	0	0	0	0	0.000	0.000	0.000	0.000	0.001	0.001	0.002
13.6	0	0	0	0	0	0	0.000	0.000	0.000	0.000	0.001	0.001	0.002
13.8	0	0	0	0	0	0	0.000	0.000	0.000	0.000	0.001	0.001	0.002
14	0	0	0	0	0	0	0	0	0	0.000	0.000	0.000	0.001
14.2	0	0	0	0	0	0	0	0	0	0.000	0.000	0.000	0.001
14.4	0	0	0	0	0	0	0	0	0	0.000	0.000	0.000	0.001
14.6	0	0	0	0	0	0	0	0	0	0.000	0.000	0.000	0.001
14.8	0	0	0	0	0	0	0	0	0	0.000	0.000	0.000	0.001
15	0	0	0	0	0	0	0	0	0	0.000	0.000	0.000	0.001
15.2	0	0	0	0	0	0	0	0	0	0.000	0.000	0.000	0.001
15.4	0	0	0	0	0	0	0	0	0	0.000	0.000	0.000	0.001
15.6	0	0	0	0	0	0	0	0	0	0.000	0.000	0.000	0.001
15.8	0	0	0	0	0	0	0	0	0	0.000	0.000	0.000	0.000
16	0	0	0	0	0	0	0	0	0	0	0	0	0.000

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