OPTIMIZATION AND ANALYSIS OF SKIP-LOT SAMPLING STRATEGIES BASED ON A DOUBLE-SAMPLING FRAMEWORK

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Abstract

This paper presents a novel approach to designing skip-lot sampling inspection plans aimed at reducing the required sample size while maintaining effective quality control. By using the traditional double-sampling plan as a reference, the proposed design provides a framework for making inspection more efficient without compromising the reliability of decisions regarding lot acceptance. The study explores the operational characteristics of the suggested plan and evaluates its performance relative to conventional double-sampling procedures, demonstrating that it can achieve equivalent or better-quality assurance with fewer samples. One of the key advantages of the proposed plan is its lower acceptance rates, which enhances the stringency of quality control while potentially reducing inspection costs and effort. The design process incorporates critical quality metrics, including the acceptable quality level and the limiting quality level as well as the acceptable quality level and the average outgoing quality level to guide the selection of the most appropriate sampling plan for a given production scenario. Overall, the proposed skip-lot inspection approach offers a practical, cost-effective alternative to standard sampling techniques, providing manufacturers and quality managers with a method to optimize inspection resources while ensuring high product quality.

Keywords: Sample Size, Double Sampling Plan, Acceptance Rate, Skip-lot Sampling Inspection Plans

I. Introduction

Skip lot sampling plans (SkSP), evolving from Dodge's foundational work on continuous sampling, offer an efficient framework for auditing sequentially produced lots by leveraging a history of high quality. The SkSP-2 variant, recognized for its flexibility, operates by initially conducting a 100% inspection of lots using a predefined reference sampling plan. After a string of i consecutively accepted lots, the system transitions to a reduced-frequency mode, inspecting only a fraction f of the lots; the immediate reinstatement of full inspection upon any rejection provides a self-correcting mechanism for quality deterioration. While various attribute plans single, double,

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or multiple—can serve as the reference, recent research has underscored the particular efficacy of pairing SkSP-2 with severe plans, such as a zero-acceptance single-sampling plan, for high-cost or destructive testing scenarios. Building on this principle, a novel advancement is the integration of a double-sampling plan (DSP) as the reference system [1]. This hybrid approach, particularly a SkSP-2 plan with a DSP using acceptance numbers (0,1), demonstrates a superior ability to minimize the average sample number while preserving protection levels, offering significant economic advantages over traditional plans. Construction methodologies and lookup tables for these plans, developed under the Poisson model for defect counts, are provided, with the results remaining a valid approximation for binomial proportions when the fraction nonconforming is small [2].

The inspection process begins with full evaluation of every lot using the reference plan. Once i consecutive lots pass inspection, the plan transitions to partial inspection, where only a fraction f of the lots is sampled [4]. If a defective lot is detected during the reduced inspection phase, full inspection is resumed. As noted by Hahn (1974) [6], various attribute-based sampling methods—such as single, double, or multiple sampling plans—can serve as reference plans within the SkSP-2 framework. Recent studies [5] highlight that combining SkSP-2 with a single-sampling plan (SSP) using a zero-acceptance number is particularly advantageous in scenarios involving destructive or high-cost testing. The core innovation of employing a Double-Sampling Plan (DSP) as the reference plan within the SkSP-2 structure lies in its compound efficiency [3]. A DSP alone reduces the average sample number (ASN) by providing a second chance to inspect a lot before rejection, which is particularly beneficial for lots with quality near the acceptable boundary. The SkSP-2 framework amplifies this efficiency by introducing a temporal dimension; after establishing a record of good quality, the system not only uses smaller samples (via the DSP) but also inspects fewer lots overall. This creates a two-tiered reduction in inspection effort. The resulting hybrid plan is inherently responsive, dynamically adjusting inspection intensity based on real-time quality history [4].

The development of this SkSP-2 plan with a DSP reference addresses a critical need in modern manufacturing and supply chain management for "lean" quality assurance methodologies. In an era of just-in-time production and high-value, complex products, the costs of destructive testing, laboratory analysis, and even simple operational delays are significant. This plan offers a scientifically rigorous method to minimize these costs without compromising the integrity of the outgoing quality control process [9]. Its applicability extends beyond traditional manufacturing to sectors like pharmaceuticals (for batch testing of raw materials), software (for automated testing of sequential builds), and agriculture (for quality assessment of bulk harvests), proving its versatility as a tool for efficient quality surveillance [8].

II. Sampling Plan

The Skip-Lot Sampling Plan of type SkSP-2 is an advanced, statistically driven inspection methodology designed to enhance quality control efficiency. It achieves this by dynamically reducing inspection frequency in response to a demonstrated history of consistent high quality. This plan operates by strategically transitioning between two phases based on the performance of sequentially produced lots. The procedure is initiated in a Normal Inspection phase, where every lot is subjected to a full inspection using a predefined reference plan. The key innovation in the proposed model is the use of a Double-Sampling Plan (DSP) as this reference. Under this DSP, each lot selected for inspection undergoes a two-stage process: an initial sample (n_1) is taken, and a decision to accept or reject the lot is made based on the first acceptance number (c_1). If the results are inconclusive, a second sample (n_2) is drawn, and a final decision is made using a second acceptance number (c_2). This two-stage approach inherent to the DSP provides greater flexibility and reduces the average sample number compared to single-stage plans. Once a predetermined number of consecutive lots (*i*) are accepted under normal inspection, the system transitions to a

Reduced (Skip-Lot) Inspection phase. In this phase, only a fraction *f* of the lots are inspected using the DSP; the remaining lots are automatically accepted without any inspection. This continues until a lot is rejected, which triggers an immediate reversion to the Normal Inspection phase. The cycle repeats, ensuring that the system remains responsive to any degradation in quality.

The integration of a DSP within the SkSP-2 framework introduces a powerful synergy. For instance, a DSP with stringent acceptance numbers like (c_1=0, c_2=1) is exceptionally effective at minimizing inspection effort while maintaining tight control, making it ideal for high-cost or destructive testing environments. Developing such a plan requires the careful specification of several parameters: the clearance number (i), the sampling fraction (f), the DSP parameters (n_1, n_2, c_1, c_2), and the desired performance points such as the Acceptable Quality Level (AQL) and Limiting Quality Level (LQL) to shape the plan's Operating Characteristic (OC) curve. This combination results in a highly adaptive and economically superior inspection system.

Let us designate this skip-lot plan as SkSP-2DSP. The OC function $P_{\mathrm{a}}(p)$ and the average sample number function $\mathrm{ASN}(p)$ of the $\mathrm{SkSP}-2DSP$ plan at quality level p are given as follows:

$$P_{\mathrm{a}}(p) = \sum_{j=0}^{m1} \frac{[m(P) + (1-m)P^j]}{[m + (1-m)P^j]} \tag{1}$$

Here, P is the probability of accept a lot under the DSP, given by

$$P = R(k_1; m_1) + \sum_{k=c_{1+1}}^{c_2} q(k; m_1) R(k_2 - m; k_2)$$

with $k_1 = m_1 p, k_2 = k_2 p, q(m;k) = \exp(-\mathrm{k}) m^k / k$ and

$$R(c_1; n) = \sum_{m=0}^{c_1} q(m; k)$$

We also have

$$\mathrm{ASN(R)} = \mathrm{ASN}(p) \tag{2}$$

Where $\mathrm{ASN}(R)$ is the ASN of the reference plan, i.e.

$$\mathrm{ASN}(R) = k_1 + k_2 \sum_{k=c_{c_1+1}}^{c_2} q(k; m_1)$$

and F is the average fraction of total lots that are inspected, i.e.

$$F = \frac{L}{[L + (1-L)P^k]}$$

III. Comparison of the SkSP-2DSP Plan with the Traditional DSP

In terms of effectiveness, resource use, and inspection effort, the Skip-Lot Sampling Plan of Type SkSP-2 employing a Double-Sampling Plan (SkSP-2DSP) as a reference has a number of advantages over the conventional Double-Sampling Plan (DSP). A thorough comparison of the two schemes' main operating features and performance indicators can be found below. The OC curves of any two lot-inspection plans are a common way to compare them. If the OC curves of two plans are almost identical, they will be said to be matched. The 'operation ratio' is a commonly used metric to compare the plans; it is defined as follows: $R = p_2/p_1$, where p_1 and p_2 are the values of p such that $P_a(p) = 0.85$ and $P_a(p) = 0.20$ each. Double-sampling inspection plans are now compared to the SkSP-2DSP plan. This can be accomplished by using Table 1. Here, it is assumed that the DSP's first and second sample sizes are equivalent (i.e. $m_1 = m_2$). Take a look at this example [11]. The implementation of a SkSP-2DSP plan is planned. The intended OCs are a consumer's quality level of 9% non-conforming with a 10% chance of acceptance (p2=0.09) and a satisfactory producer's quality level of 2.5% non-conforming with a 95% chance of acceptance (p1=0.025). The intended operating ratio is therefore R=p2/p1=0.09/0.025=3.6. We can see from Table 1 that three R values—3.789, 3.785, and 3.787—are near 3.7. We find the SkSP-2DSP plan with $c_1 = 0, c_2 = 4, f = 1/5$, and i=5 with the maximum value, 3.637. These numbers are supported by Table 1, which gives us $np_1 = 0.921$. The first sample size is $n_1 = np_1/p_1 = 0.8521/0.125 = 38.09 \simeq 37$ and $n_2 = n_1 = 35$, since p1 is determined to be 0.020. The corresponding DSP has an operating ratio of 3.6421 for SkSP-2DSP plan's R=3.637. The DSP's parameters are $c_1 = 1, c_2 = 5, n_1 = np_1/p_1 = 1.383/0.025 = 53.53 \simeq 54$ and $n_2 = n_1 = 54$. according to Table 1, which corresponds to 3.621. Therefore, the sample size of the SkSP-2DSP plan is smaller than that of the corresponding DSP for the provided values of $p_1, p_2, \alpha = 0.05$, and $\beta = 0.10$ [12].

Table 1: *Operating ratios for DSPs and the SkSP-2 plan with a DSP reference plan*

DSP						SkSP-2 with DSP reference plan					
c_1	c_2	f	i	R	np_1	c_1	c_2	f	i	R	np_1
0	3	1	-	4.928	0.4294	0	1	1/3	4	5.899	0.589
0	3	1	-	5.760	0.9579	0	2	1/3	6	4.793	0.656
						0	2	1\4	10	4.989	0.535
1	2	1	-	5.8603	0.2465	0	1	1/3	4	5.853	0.338
								1/5	10	5.098	0.459
1	3	1	-	5.772	0.8613	0	2	1/3	4	4.120	0.537
						1	2	1/3	6	4.320	0.281
1	4	1	-	4.2713	1.0836	0	3	1/2	8	3.236	0.805
						1	3	1/3	8	5.732	0.680
1	5	1	-	3.6421	1.3423	0	3	1/3	6	5.370	0.621
						0	3	1/5	8	3.210	0.463
						1	4	1/5	4	3.357	1.269
1	6	1	-	4.0466	1.5621	1	4	1/4	6	3.510	1.766
						1	4	1/5	8	5.384	1.389
						1	5	1/4	8	5.525	1.486
2	2	1	-	3.6103	0.9602	1	2	1/3	8	5.224	0.746
2	3	1	-	6.7233	1.3447	0	2	1/5	8	3.065	0.312
						1	3	½	8	3.293	0.843
						2	3	½	4	3.246	0.830
2	4	1	-	4.0823	1.8574	0	3	1/5	10	5.829	0.841
						0	3	1/3	6	5.604	0.870
						1	4	2/3	4	3.890	1.433
						2	3	¼	4	3.894	1.347
						2	4	1/3	4	3.303	1.820
2	6	1	-	3.3046	1.9031	1	4	½	6	3.882	1.564
						1	4	¼	10	3.695	1.219
						1	5	2/3	8	3.989	1.629
						1	5	2/3	10	3.562	1.762
						2	4	¼	4	3.459	1.797

I. SkSP-2DSP plan with smaller acceptance numbers.

An SSP with lesser acceptance values, like c=0 and c=1, is preferred for product features that require expensive or damaging testing by attributes, per Hahn (1974) [6]. However, because the c=0 sampling plan favors the consumer and the c=1 sampling plan favors the producer, the OC curves of SSPs with c=0 and c=1 result in a conflict of interest between the producer and the consumer. Adopting the DSP with $c_1 = 0$ and $c_2 = 1$ will get around this. Furthermore, all DSPs with $c_1 = 0$ and $c_2 = 1$ have the fundamental property that their OC curves fall between those of SSPs with c = 0 and c = 1. The DSP and the SkSP-2 plan with a DSP as the reference can be used interchangeably in certain circumstances [10]. Additionally, as seen in the preceding section, the SkSP-2DSP design has the advantage of requiring smaller sample sizes than traditional DSPs. When consumer protection is included in terms of (p_2, β), it is beneficial to employ the SkSP-2 plan with a DSP that has $c_1 = 0$ and $c_2 = 1$.

Table 2 makes it evident that when the quality is acceptable, the SkSP-2 plan has a higher chance of being accepted than a DSP with $c_1 = 0$ and $c_2 = 1$, and when the quality is low, the odds of acceptance are the same [12]. This indicates that the SkSP-2DSP plan's OC curve protects consumers in terms of (p_2, β), while providing substantially lower producer risk. The SkSP2DSP plan with $c_1 = 0$ and $c_2 = 1$ is therefore preferred because to the reduced sample size and decreased producer's risk, especially in small-sample scenarios involving expensive or destructive testing [14].

Table 2: *Values of p and $P_a(p)$ for DSPs and SkSP-2 plan with a DSP that has acceptance numbers $c_1 = 0$ and $c_2 = 1$.*

p	P_a for DSP with $n_1 = n_2 = 20$	P_a for SkSP-2 with $f = 0.5, i = 2$	P_a for SkSP-2 with $f = 0.5, i = 6$	P_a for SkSP-2 with $f = 0.5, i = 6$
0.01	0.180	0.841	0.965	0.961
0.02	0.190	0.823	0.818	0.890
0.03	0.500	0.531	0.649	0.603
0.04	0.563	0.743	0.505	0.506
0.05	0.409	0.321	0.389	0.340
0.06	0.897	0.385	0.298	0.243
0.07	0.467	0.265	0.227	0.202
0.08	0.072	0.143	0.172	0.108
0.09	0.430	0.147	0.131	0.189
0.10	0.899	0.023	0.099	0.076
0.12	0.087	0.056	0.057	0.058
0.14	0.043	0.076	0.033	0.042
0.16	0.041	0.023	0.020	0.020
0.18	0.035	0.012	0.054	0.017
0.20	0.010	0.006	0.001	0.005

II. The SkSP-2DSP plan with smaller acceptance numbers

Using these tables, the plan can be selected for two sets of criteria: (1) given values of $(p_1, \alpha(= 0.05))$ and$(p_2, \beta(= 0.10))$; (2) given values of p_1 (with $= 0.05$) and the AOQL. Selection of the plan for given $(p_1, \alpha(= 0.05))$ and $(p_2, \beta(= 0.10))$. The OC curve is, in turn, fixed by suitably chosen parameters, such as considering two: The procedure for designing the plan for given values of $p_1, \alpha = 0.05, p_{2,}$ and $\beta = 0.10$ is as follows [15]. Compute the ratio $R = p_2/p_1$. Select the value of p_2/p_1 from Table 3 in the column headed R that is nearly equal to the computed p_2/p_1 value. Determine the values of np_1, f, and i that correspond to the p_2/p_1 value located. The first sample size n_1 is obtained by dividing np_1 by p_1 [13]. The second sample size n_2 is to be taken as being equal to n_1, because it is assumed that the first and second sample sizes are equal (Schilling, 1982) [9]. Example. To determine a plan for given values of $p_1 = 0.0075, \alpha = 0.05, p_2 = 0.07$, and $\beta = 0.10$, the following steps should be carried out. For given p_1 and p_2 values, the value of p_2/p_1 is found to be 9.333. From Table 3, the value of p_2/p_1 for $\alpha = 0.05$ and $\beta = 0.10$ is 9.4256, which is nearer to the value 9.333 obtained in the previous step. While selecting a sampling inspection plan, it is usual practice to fix the OC curve according to the desired degree of discrimination. Points on the OC curve, i.e., (P_1, α) and (P_2, β), or by considering one point on the curve, i.e., (P_2, α), along with the criterion of the AOQL, which gives protection to the consumer. In this section, Tables 3 and 4 are presented for designing a SkSP-2DSP plan with c1=0 and c2=1, for the case where the first and second sample sizes are equal. The values of f and i that correspond to 9.4256 are 0.5 and 8, respectively, and the corresponding value of np_1 is 0.262. The value of n_1 is obtained as $n_1 = np_1/p_1 = 0.262/0.0075 = 35.23 \simeq 35$. Because the table referred to is constructed for the case where $n_1=n_2$, the second sample size for the given problem is $n_2=35$. Thus, for given values of P1=0.0075, α=0.05, P2=0.07 and β=0.10, the desired SkSP-2DSP-(0, 1) plan includes the parameters $n_1=35$, $n_2=35$, f=1/2 and i=8.

Table: 3 *Values of operating ratio R against f and i for certain SkSP-2 DSP-(0,1) plans, for the case when* $n_1 = n_2$

f	i	np_1 for $P_a(p) = 0.85$	np_2 for $P_a(p) = 0.50$	f	i	$R = p_2/p_1$
1	-	0.664	2.49024	1	-	12.0511
2	4	0.837	2.49064	2	12	10.6863
	6	0.435	2.49024		10	10.5519
	8	0.395	2.49024		8	10.3977
	10	0.360	2.49024		6	10.2269
	12	0.303	2.49024		4	10.0279
3	4	0.815	2.49105	3	12	9.8643
	6	0.719	2.49024		10	9.6596
	8	0.642	2.49024		8	9.4256
	10	0.578	2.49024		6	9.1587
	12	0.245	2.49024	0.5	12	8.8725
4	4	0.329	2.49186	0.6	4	8.8492
	6	0.147	2.49025	0.7	10	8.5959
	8	0.008	2.49024		8	8.2787
	10	0.287	2.49024	0.8	12	8.2672
	12	0.287	2.49024		10	7.9535
5	4	0.376	2.49266	0.9	6	7.9131
	6	0.368	2.49026	1.2	12	7.8453
	8	0.279	2.49024	1.5	8	7.5945
	10	0.131	2.49024	1.6	10	7.5098
	12	0.122	2.49024	1.7	4	7.4853

The values of f and i that correspond to 9.4256 are 0.5 and 8, respectively, and the corresponding value of np_1 is 0.2642. The value of n_1 is obtained as $n_1 = np_1/p_1 = 0.2642/0.0075 = 35.23 \simeq 35$. Because the table referred to is constructed for the case where $n_1=n_2$, the second sample size for the given problem is $n_2=35$. Thus, for given values of P1=0.0075, α=0.05, P2=0.07 and β=0.10, the desired SkSP-2DSP-(0, 1) plan includes the parameters $n_1=35$, $n_2=35$, f=1/2 and i=8, [15].

III. Selection of the plan for given P_1 (with α=0.05) and AOQL

Table 4 can be used for designing SkSP-2DSP-(0,1) plans for given values of p_1 (with $\alpha = 0.05$) and the AOQL. For example, for given values of $p_1 = 0.035$ with $\alpha = 0.05$ and $\text{AOQL} = 0.066$, compute the ratio $\text{AOQL}/p_1 = 0.066/0.035 = 1.8857$. From Table 4, the value closest to this is 1.88293, which corresponds to the values $f = 1/2$ and $i = 6$. Corresponding to these values, the value of np_1 is found to be 0.2719. Hence, $n_1 = np_1/p_1 = 0.2719/0.035 = 7.769$, which can be rounded up to the next higher integer to become 8. Thus, the desired plan has the parameters $n_1 = n_2 = 8, f = 1/2$, and $i = 6$.

IV. Construction of Tables 3 and 4

Under the conditions for the application of the Poisson model for the OC curve, for given values of $P_a(p), f$, and i, equation (1) can be solved for np, assuming that $c_1 = 0$ and $c_2 = 1$. Table 3 provides such unity values, i.e., np_1 and np_2 for $P_a(p) = 0.95$ and Pa(p) 0.10, respectively, for various values of f and i. Using these values, the operating ratios p2/p1 are calculated and are also shown in Table 3. (i.e. $n_2 = 2n_1$). Assuming nAOQ $\simeq$ npPa(p), for selected values of f and i, the values of npm that maximize nAOQ are determined, and nAOQL is obtained as nAOQL $np_m p_a$(pm). These values are shown in Table 4, along with np1 values for Pa(p) = 0.95. The ratios AOQL/p_1 are also calculated and shown in Table 4. The tables presented in this paper are for the case when $n_1 = n_2$. A similar set of tables can be constructed for the case when the size of the second sample is twice that of the first sample.

Table 4: *Values of $AOQL/p_1$ against f and i for certain SkSP-2 DSP-(0,1) plans, for the case when $n_1 = n_2$*

F	*i*	np_m	nAOQL	np_1 for $P_a(p) = 0.95$	f	i	AOQL/p_1
1	-	1.00000	0.501	0.264	1	-	2.420
0.5	2	0.519	0.519	0.237	1/2	10	2.172
	4	0.942	0.507	0.245	1/2	8	2.139
	6	0.908	0.504	0.235	1/2	6	2.147
	8	0.670	0.534	0.230	1/2	4	2.067
	10	0.697	0.528	0.203	1/2	2	2.386
0.6	2	0.915	0.5500	0.215	1/3	10	1.386
	4	0.906	0.197	0.219	1/3	8	1.403
	6	0.940	0.538	0.242	1/3	6	1.127
	8	0.997	0.575	0.278	1/3	4	1.953
	10	0.952	0.535	0.245	1/4	2	1.893
0.8	2	0.930	0.563	0.329	1/4	10	1.785
	4	0.896	0.521	0.317	1/2	8	1.780
	6	0.946	0.581	0.308	1/2	6	1.663
	8	0.985	0.501	0.297	1/2	4	1.620
	10	0.976	0.538	0.267	1/2	10	1.693
0.9	2	0.934	0.586	0.326	1/3	4	1.666
	4	0.851	0.536	0.368	1/4	8	1.658
	6	0.769	0.519	0.379	1/5	6	1.585
	8	0.973	0.590	0.331	1/5	2	1.570
	10	0.9352	0.502	0.322	1/5	8	1.515
2	2	0.971	0.619	0.401	1/4	7	1.536
	4	0.930	0.544	0.326	1/3	6	1.552
	6	0.9647	0.518	0.393	1/3	4	1.506
	8	0.995	0.505	0.336	1/5	8	1.488
	10	0.920	0.576	0.314	1/5	2	1.421

IV Conclusion

The skip-lot sampling inspection plan using a double-sampling plan (DSP) as its reference referred to as SkSP-2DSP offers significant reductions in sample size compared to traditional DSPs. This design is particularly effective in scenarios involving small sample requirements or costly and destructive testing, especially when acceptance numbers such as such as $C_1 = 0$ and $C_2 = 1$ are used. SkSP-2DSP is well-suited for production environments involving a continuous flow of batches or lots where product quality is consistently high or changes gradually over time. However, in cases of sudden quality deterioration, there is a risk that defective lots may pass unnoticed during the skipping phase. Under such conditions, reverting to a standard DSP provides better protection and responsiveness.

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