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* **Corresponding author**.

gopimalaisamy@gmail.com

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Designing of Skip Lot Sampling Plan using Single Sampling Plan by Attributes under the Situations of Borel Distribution as Reference Plan

S. Jayalakshmi[1], M. Gopinath[1,2]*

1 Department of Statistics, Bharathiar University, Coimbatore, Tamil Nadu, India
2 Department of Mathematics, Sri Krishna Arts and Science college, Coimbatore, Tamil Nadu, India

Abstract

Objectives: Skip-lot sampling plans (SkSPs) have long been valuable for enhancing inspection efficiency in quality control, particularly in large-scale production environments. This study aims to introduce a skip-lot sampling plan of type SkSP-2, designed to streamline inspection efforts while preserving high standards of quality assurance. **Methods:** The SkSP-2 plan is developed using single sampling plans (SSPs) by attributes under the framework of the Boral distribution. The Boral distribution, which is known for its ability to model rare or irregular events, provides an appropriate basis for simulating quality characteristics in such contexts. The plan's performance is analyzed using operating characteristic (OC) curves and average sample number (ASN) values to compare its effectiveness against equivalent SSPs. **Findings:** Key findings reveal that the SkSP-2 plan requires significantly fewer samples, particularly when dealing with lower defect levels, while still maintaining comparable OC curve behavior to other SSPs. This highlights the plan's capability to reduce sample sizes without compromising the accuracy of quality control assessments. **Novelty:** This study contributes a novel framework for the design of skip-lot sampling plans, specifically under the Boral distribution. By presenting an efficient methodology that reduces inspection costs while maintaining quality assurance, this research offers a valuable addition to the field of quality control practices.

Keywords: Skip-lot sampling plans; Single sampling plans; Boral distribution; Operating characteristic curves; Average sample number

1 Introduction

Acceptance sampling is a statistical quality control technique that uses a random sample from a batch to determine whether the entire lot meets quality standards. The objective is to reduce inspection costs while ensuring quality through parameters such as sample size and acceptance number. Recent studies have focused on developing sampling plans under various distributions, including the Borel distribution.

Wanas and Khuttar[1] surveyed the Borel distribution in analytic functions, while Daly and Shneer[2] applied Stein's technique to estimated it in queueing systems and stochastic processes. Their work has protracted the Borel distribution's applications in probabilistic models. Numerous studies have enhanced acceptance sampling plans under specific distributions. Facchinetti et al.[3] proposed a method by means of the generalized beta distribution, and Harsh Tripathi et al.[4] projected a SkSP-R plan under the Gompertz distribution. Alomani and Al-Omari[5] discovered acceptance plans built on the Xgamma distribution.

Fuzzy set theory has also been practiced to improve the dependability of acceptance sampling, as shown by Bhattacharyya[6]. Rami Reddy et al.[7] designed percentile-based plans using the Exponentiated Inverse Kumaraswamy Distribution to holder non-normal data. Suganya and Pradheepa Veerakumari[8] presented a Skip-Lot Sampling Plan (SkSP-T) under the Intervened Poisson Distribution. Lastly, Jayalakshmi and Gopinath[9] developed a single sampling plan under the Borel distribution, contributing to its practical applications in quality control.

2 Methodology

If a Galton-Watson branching process is governed by a Poisson offspring distribution with mean μ, then the total number of individuals in the process follows a Borel distribution characterized by the parameter μ. According to Daly and Shneer (2021), the total number of descendants, X, of the initial ancestor adheres to this specific distribution. This establishes a direct connection between the Borel distribution and the structure of the Galton-Watson process under Poissonian dynamics.

The random variable X is supposed to have a Borel distribution with parameter λ, gamble the mass function is

$$P(X=k) = \frac{e^{-(\lambda k)}(\lambda k)^{(k-1)}}{k!} \tag{1}$$

For $k \in N = \{1, 2...\}$.

The mean and variance of the Borel Distribution with parameter λ stand by,

$$\mu = E(X) = (1-\lambda)^{-1} \tag{2}$$

and

$$\alpha^2 = Var(X) = \lambda(1-\lambda)^{-3} \tag{3}$$

respectively.

2.1 Skip Lot Sampling Plan of Type – 2 (SKSP – 2)

The SkSP-2, initially proposed by Dodge and Perry in 1971 and later enhanced by Perry in 1973a, includes a method to minimize examination activities when the submitted lots consistently maintain acceptable quality levels. This plan allows for skipping examination of certain lots, thereby optimizing resources while maintaining quality assurance. It uses an attribute-based lot-by-lot acceptance sampling plan, known as the location plan, to inspect individual lots.

The general operating procedure for the SkSP-2 plan is in this way:

1. Initiation with usual Examination: Begin with normal examination, following the reference plan.
2. Transition to Skipping Examination: When iii successive lots are accepted under usual examination, shift to skipping examination, where only a portion f of the lots is examined.
3. Reversion to Normal Examination: If a lot is disallowed throughout skipping examination, return to usual examination until situations for skipping are content again.

The SkSP-2 plan is defined by three parameters: the reference plan, the clearance interval i (the number of successive accepted lots required to transition to skipping examination), and the sampling frequency f (the fraction of lots inspected during skipping).

The performance of any sampling plan, including SkSP-2, is typically evaluated through its operating characteristic (OC) function and other key procedures for example the Average Sample Number (ASN) and the Average Fraction Inspected (AFI). These metrics provide insights into the plan's efficiency and its effectiveness in maintaining quality standards.

The OC and ASN function of SkSP-2 for the proportion value *p* are assumed by,

$$P_a(p) = \frac{fP + (1-f)P^i}{f + (1-f)P^i} \tag{4}$$

$$ASN(p) = ASN(R)F \tag{5}$$

Where ASN(R) represents the mean sample number function of the location plan, P denotes the likelihood of acceptance for the location plan, and F is the mean fraction of whole lots examined, articulated by the following relationship,

$$F = \frac{f}{f + (1-f)P^i} \tag{6}$$

3 Results and Discussion

3.1 Comparative Study

In comparison to the work of Tripathi et al. (2022)[4], which employed the skip-lot sampling plan, the primary distinction lies in the distribution used and the context of application. Tripathi et al. focused on reliability and life-cycle testing, whereas this research targets quality control in processes with sporadic defects using the Borel distribution. Both approaches share the objective of sample size reduction, but their applications cater to different industrial needs. While Tripathi et al.'s method is more relevant to sectors concerned with product reliability and lifetime testing, this study enhances operational efficiency in quality control settings, providing a practical solution for industries managing large-scale production with rare defects. Our findings demonstrate that using the Borel distribution can significantly reduce the sample size required to maintain quality, especially in contexts where defects occur sporadically, which is not addressed in Tripathi et al.'s work.

3.2 SSP in the Context of Borel Distribution

The Single Sampling Plan (SSP) for attributes is defined by parameters such as lot size (N), sample size (n), and acceptance number (c). When applying the SSP under the Borel distribution, we observe that for parameters $n = 113, c = 1, f = 1/5$, and $i = 4$, the probability of acceptance Pa(p) decreases as the proportion of defective items increases. This plan ensures that good quality lots with few defects are accepted, while lots with poorer quality are rejected. For example, the probability of acceptance at $p_1 = 0.001$ is 0.98, while at $p_2 = 0.03$, it drops to 0.05. This result highlights that the proposed plan protects consumers by not accepting low-quality lots, while also safeguarding producers from unnecessary rejection of good-quality lots, effectively balancing both parties' risks.

3.3 Analysis of Operating Characteristic Curves

The Operating Characteristic (OC) serves as one of the furthermost reliable routine indicators for assessing the efficiency of sampling plans. The OC function of SSP is described as,

$$P_a(p) = P[x \leq c] \tag{7}$$

where p is the lot quality, given as the proportion defective or fraction defective.

The operating characteristics function of SSP beneath the situation of Borel distribution is assumed by the following,

$$P_a(p) = \sum_{k=1}^{c} P(X = k \vee ¿\lambda)¿ = \sum_{k=1}^{c} \frac{e^{-(\lambda k)}(\lambda k)^{(k-1)}}{k!} \tag{8}$$

where $\lambda =$ np.

The act of any acceptance sampling plans is usually measured through its operating characteristic (OC) curve. A plot of P_a*(p)* in contradiction of *p* is called OC curve. It is observed from the Figure 1 the curve with parameters $n = 113, c = 1, f = 1/5$ and $i = 4$ the probability of acceptance $P_a(p)$ decreases as the amount of imperfect *p* increases. That is the plan accepts the good quality lots with low amount imperfect and rejects the lots through unfortunate quality. For instance, the probability of acceptance at $p_1 = 0.001$ is *0.98* and at $p_2 = 0.03$ is *0.05*. This ensures the plan protects the consumers by not accepting the low-quality lots and producers are safeguarded by not getting rejected the good quality lots. Hence, the projected plan favors both the consumer and producer by reducing their risks.

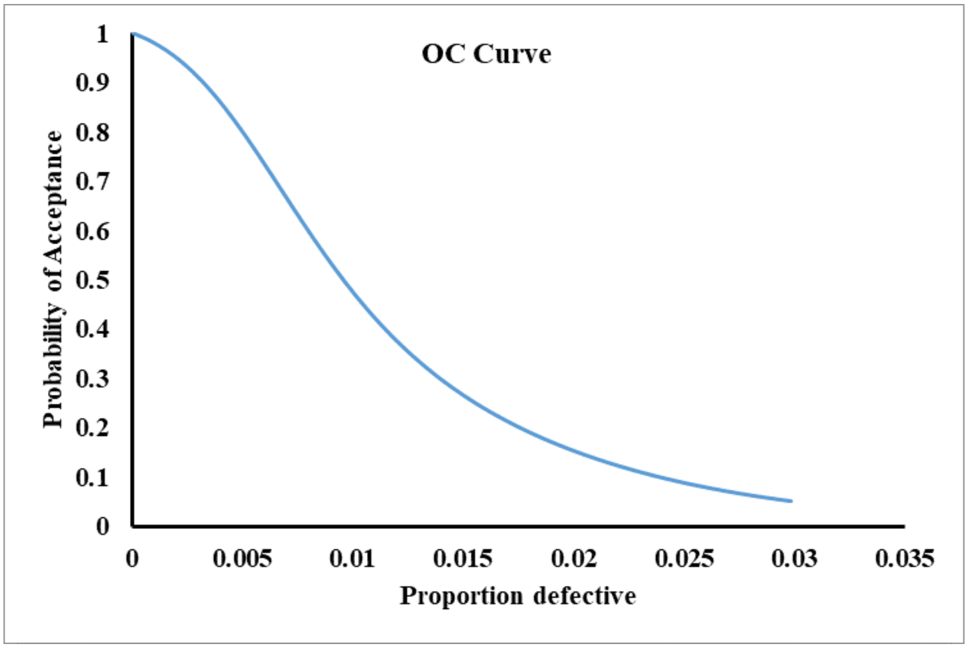

Fig 1. Operating Characteristic curve for SkSP -2 with SSP under the circumstances of Borel distribution ($n = 113, c = 1, f = 1/4, i\ = 4$)

3.4 Comparison of SKSP-2 with SSP in the Context of the Boral Distribution

An ordinary approach for associating two lot examination sampling plans is through analysing their Operating Characteristic (OC) curve. Additionally, A commonly employed performance metric is the operating ratio (OR), referred to as OR $= p_2/p_1$, where p_1 and $p_2$represent the acceptance quality limit (AQL) and the limiting quality limit (LQL), respectively. These parameters are defined such that $P_a(p_1) = 0.95$ and $P_a(p_2) = 0.10$. Here, the SkSP-2 plan utilizing SSP in accordance with the Boral distribution is compared to a lot-by-lot SSP under the same distribution.

Suppose desired quality levels are set, with a producer's quality level of 2.5% non-conforming and a 95% probability of acceptance $P_a(p_1) = 0.95$, and a consumer's quality level of 9% non-conforming by 10% probability of acceptance $P_a(p_2) = 0.10$. The calculated operating ratio is OR $= p_2/p_1 = 0.09/0.025 = 3.6$.

Since Table 1, the adjacent value of OR for SkSP-2 with SSP under the situations of the Boral distribution is 3.616. For this OR, the parameters $f = 2/5, i = 8$, and $c = 4$ is obtained. Using these values, np_1 is computed as 1.9179 from Table 2. The sample size is then determined as: $n = np_1/p_1 = 1.9179/0.025 = 76.71 \approx 77$. For the same OR=3.6, the closest value of OR for SSP under the situations of the Boral distribution is 3.632. For this OR, the acceptance number c is found to be 5 and $np_1$is 2.4293. The sample size is then computed as: $n = np_1/p_1 = 2.4293/0.025 = 97.172 \approx 98$.

Thus, for the given $p_1, p_2, \alpha,$ and β, the SkSP-2 plan with SSP under the situations of the Boral distribution requires a lesser sample size than the comparable SSP under the same distribution. For the matched sets of SkSP-2 with SSP lower than the situations of IPD plan and equivalent SSP under the circumstances of IPD plan, the points to draw the OC and ASN curves are given for the plan $f = 1/2, i\ = 4$ and $c = 4$ for SkSP-2 with SSP underneath the circumstances of IPD plan along with equivalent SSP underneath the circumstances of IPD with $c = 4$ in the Table 1.

Using these points, the OC and ASN curves are plotted and displayed in Figure 2 and 3. Figure 2 illustrates that the OC curves of SkSP-2 and SSP under the situations of the Boral distribution coincide at $p \leq AQL$ and $p \geq LQL$. Furthermore, the table indicates that the ASN values for matched plans highlight a significant reduction in sample size for SkSP-2 with SSP underneath the environments of the Boral distribution compared to SSP for low proportions of defectives. Further, when the proportion defective increases the ASN values are very close to the matched sampling plans. This feature is also demonstrated pictorially and displayed in Figure 3.

Table 1. Operating ratio values for a Skip-Lot Sampling Plan (SkSP-2) with SSP, using the Boral Distribution as the location plan

c	***i***	***f***	$\alpha = 0.05$ $\beta = 0.10$	$\alpha = 0.05$ $\beta = 0.05$	$\alpha = 0.05$ $\beta = 0.01$	$\alpha = 0.01$ $\beta = 0.10$	$\alpha = 0.01$ $\beta = 0.05$	$\alpha = 0.01$ $\beta = 0.01$

		1/2	22.060	27.647	39.765	98.569	123.531	177.677
		1/3	16.459	20.618	29.653	75.283	94.303	135.632
	4	2/3	27.462	34.425	49.516	131.649	165.033	237.375
		2/5	18.661	23.381	33.628	88.824	111.292	160.070
		3/5	25.352	31.778	45.708	110.730	138.797	199.637
		1/2	24.741	31.022	44.622	98.514	123.525	177.677
		1/3	19.833	24.868	35.770	75.204	94.294	135.632
1	8	2/3	29.252	36.680	52.760	133.843	167.827	241.401
		2/5	21.594	27.076	38.946	88.752	111.284	160.070
		3/5	27.427	34.390	49.467	121.970	152.938	219.985
		1/2	26.815	33.623	48.364	98.511	123.525	177.677
		1/3	22.331	28.001	40.277	77.524	97.209	139.824
	12	2/3	30.740	38.546	55.444	135.925	170.439	245.159
		2/5	24.159	30.294	43.574	97.536	122.302	175.918
		3/5	29.189	36.601	52.646	124.556	156.183	224.653
		1/2	6.885	8.196	10.960	15.426	18.362	24.555
		1/3	5.871	6.987	9.343	13.067	15.550	20.793
	4	2/3	7.817	9.309	12.449	17.360	20.674	27.647
		2/5	6.298	7.495	10.023	13.876	16.514	22.083
		3/5	7.486	8.913	11.920	16.653	19.829	26.517
		1/2	7.307	8.706	11.643	15.646	18.642	24.931
		1/3	6.502	7.746	10.360	13.050	15.548	20.793
2	8	2/3	8.087	9.636	12.887	17.437	20.776	27.786
		2/5	6.816	8.121	10.861	14.190	16.906	22.610
		3/5	7.814	9.311	12.452	16.778	19.991	26.736
		1/2	7.689	9.162	12.253	15.852	18.888	25.261
		1/3	6.913	8.237	11.017	13.048	15.548	20.793
	12	2/3	8.296	9.885	13.220	17.517	20.873	27.915
		2/5	7.256	8.645	11.562	14.471	17.242	23.060
		3/5	8.066	9.611	12.853	16.901	20.138	26.932
		1/2	4.512	5.244	6.773	7.875	9.152	11.821
		1/3	4.009	4.659	6.017	7.011	8.146	10.521
	4	2/3	4.945	5.747	7.424	8.743	10.162	13.125
		2/5	4.245	4.933	6.372	7.481	8.693	11.228
		3/5	4.788	5.565	7.188	8.506	9.887	12.770
		1/2	4.723	5.490	7.091	8.161	9.487	12.254
		1/3	4.328	5.031	6.498	7.007	8.145	10.521
3	8	2/3	5.055	5.877	7.590	8.770	10.194	13.167
		2/5	4.518	5.251	6.783	7.593	8.827	11.401
		3/5	4.927	5.727	7.397	8.551	9.940	12.839
		1/2	4.908	5.705	7.369	8.234	9.571	12.363
		1/3	4.544	5.282	6.822	7.352	8.546	11.039
	12	2/3	5.144	5.979	7.723	8.796	10.225	13.207
		2/5	4.692	5.454	7.045	7.689	8.938	11.545
		3/5	5.071	5.895	7.615	8.592	9.987	12.900
		1/2	3.632	4.160	5.255	5.720	6.551	8.275
		1/3	3.305	3.785	4.780	5.154	5.902	7.455
	4	2/3	3.896	4.463	5.638	6.208	7.112	8.983
		2/5	3.445	3.946	4.984	5.428	6.216	7.852
		3/5	3.796	4.348	5.492	6.059	6.940	8.766
		1/2	3.763	4.310	5.445	5.719	6.551	8.275
		1/3	3.497	4.006	5.061	5.231	5.992	7.569
4	8	2/3	3.979	4.558	5.757	6.231	7.138	9.017

	2/5	3.616	4.143	5.233	5.662	6.486	8.193
	3/5	3.898	4.466	5.641	6.092	6.979	8.816
	1/2	3.860	4.422	5.586	5.776	6.617	8.359
	1/3	3.636	4.165	5.262	5.332	6.108	7.715
12	2/3	4.040	4.628	5.846	6.252	7.163	9.048
	2/5	3.740	4.285	5.413	5.719	6.551	8.275
	3/5	3.974	4.552	5.750	6.123	7.015	8.861

Table 2. Unity values for a Skip-Lot Sampling Plan (SkSP-2) with SSP, using the Boral Distribution as the location plan

c	*i*	*f*	***0.99***	***0.95***	***0.75***	***0.5***	***0.1***	***0.05***	***0.01***
		1/2	0.0304	0.1360	0.5461	1.0726	3.0007	3.7606	5.4089
		1/3	0.0399	0.1824	0.6213	1.1257	3.0022	3.7608	5.4089
	4	2/3	0.0228	0.1092	0.4957	1.0397	2.9998	3.7605	5.4089
		2/5	0.0338	0.1608	0.5867	1.1009	3.0015	3.7607	5.4089
		3/5	0.0271	0.1183	0.5141	1.0513	3.0001	3.7605	5.4089
		1/2	0.0304	0.1212	0.4714	1.0055	2.9990	3.7604	5.4089
		1/3	0.0399	0.1512	0.4989	1.0109	2.9991	3.7604	5.4089
1	8	2/3	0.0224	0.1025	0.4511	1.0026	2.9990	3.7604	5.4089
		2/5	0.0338	0.1389	0.4856	1.0083	2.9990	3.7604	5.4089
		3/5	0.0246	0.1093	0.4584	1.0036	2.9990	3.7604	5.4089
		1/2	0.0304	0.1118	0.4439	1.0003	2.9989	3.7604	5.4089
		1/3	0.0387	0.1343	0.4555	1.0007	2.9989	3.7604	5.4089
	12	2/3	0.0221	0.0976	0.4379	1.0001	2.9989	3.7604	5.4089
		2/5	0.0307	0.1241	0.4500	1.0005	2.9989	3.7604	5.4089
		3/5	0.0241	0.1027	0.4390	1.0001	2.9989	3.7604	5.4089
		1/2	0.2923	0.6548	1.4564	2.2155	4.5082	5.3664	7.1762
		1/3	0.3451	0.7681	1.5752	2.2852	4.5099	5.3666	7.1762
	4	2/3	0.2596	0.5764	1.3749	2.1722	4.5060	5.3661	7.1762
		2/5	0.3250	0.7160	1.5212	2.2526	4.5092	5.3665	7.1762
		3/5	0.2706	0.6021	1.4044	2.1875	4.5068	5.3662	7.1762
		1/2	0.2878	0.6163	1.3306	2.1260	4.5036	5.3659	7.1762
		1/3	0.3451	0.6927	1.3789	2.1323	4.5039	5.3659	7.1762
2	8	2/3	0.2583	0.5569	1.2993	2.1230	4.5034	5.3659	7.1762
		2/5	0.3174	0.6607	1.3566	2.1291	4.5037	5.3659	7.1762
		3/5	0.2684	0.5763	1.3104	2.1240	4.5035	5.3659	7.1762
		1/2	0.2841	0.5856	1.2879	2.1200	4.5033	5.3659	7.1762
		1/3	0.3451	0.6514	1.3076	2.1200	4.5033	5.3659	7.1762
	12	2/3	0.2571	0.5428	1.2759	2.1201	4.5033	5.3659	7.1762
		2/5	0.3112	0.6207	1.2983	2.1200	4.5033	5.3659	7.1762
		3/5	0.2665	0.5583	1.2802	2.1200	4.5033	5.3659	7.1762
		1/2	0.7326	1.2787	2.3124	3.2105	5.7693	6.7051	8.6604
		1/3	0.8232	1.4393	2.4562	3.2906	5.7708	6.7053	8.6604
	4	2/3	0.6598	1.1666	2.2116	3.1607	5.7686	6.7050	8.6604
		2/5	0.7713	1.3591	2.3916	3.2532	5.7700	6.7052	8.6604
		3/5	0.6782	1.2049	2.2482	3.1783	5.7688	6.7050	8.6604
		1/2	0.7067	1.2214	2.1600	3.1084	5.7679	6.7049	8.6604
		1/3	0.8232	1.3327	2.2187	3.1161	5.7680	6.7049	8.6604
3	8	2/3	0.6577	1.1410	2.1222	3.1045	5.7679	6.7049	8.6604
		2/5	0.7596	1.2768	2.1924	3.1122	5.7680	6.7049	8.6604
		3/5	0.6746	1.1708	2.1357	3.1058	5.7679	6.7049	8.6604
		1/2	0.7005	1.1753	2.1057	3.1010	5.7679	6.7049	8.6604
		1/3	0.7846	1.2694	2.1287	3.1013	5.7679	6.7049	8.6604
	12								

		2/3	0.6558	1.1214	2.0916	3.1008	5.7679	6.7049	8.6604
		2/5	0.7501	1.2293	2.1192	3.1011	5.7679	6.7049	8.6604
		3/5	0.6713	1.1373	2.0965	3.1008	5.7679	6.7049	8.6604
		1/2	1.2128	1.9098	3.1324	4.1402	6.9372	7.9455	10.0362
		1/3	1.3462	2.0995	3.2949	4.2312	6.9388	7.9457	10.0362
	4	2/3	1.1173	1.7802	3.0149	4.0866	6.9364	7.9454	10.0362
		2/5	1.2781	2.0138	3.2214	4.1898	6.9380	7.9456	10.0362
		3/5	1.1449	1.8274	3.0603	4.1021	6.9367	7.9454	10.0362
		1/2	1.2128	1.8433	2.9577	4.0287	6.9357	7.9453	10.0362
		1/3	1.3260	1.9832	3.0251	4.0373	6.9357	7.9453	10.0362
4	8	2/3	1.1131	1.7432	2.9148	4.0242	6.9356	7.9453	10.0362
		2/5	1.2250	1.9179	2.9939	4.0331	6.9357	7.9453	10.0362
		3/5	1.1384	1.7791	2.9301	4.0257	6.9356	7.9453	10.0362
		1/2	1.2007	1.7966	2.8955	4.0202	6.9356	7.9452	10.0362
		1/3	1.3009	1.9075	2.9214	4.0208	6.9356	7.9453	10.0362
	12	2/3	1.1093	1.7167	2.8749	4.0199	6.9356	7.9452	10.0362
		2/5	1.2128	1.8542	2.9063	4.0205	6.9356	7.9452	10.0362
		3/5	1.1327	1.7455	2.8850	4.0200	6.9356	7.9452	10.0362

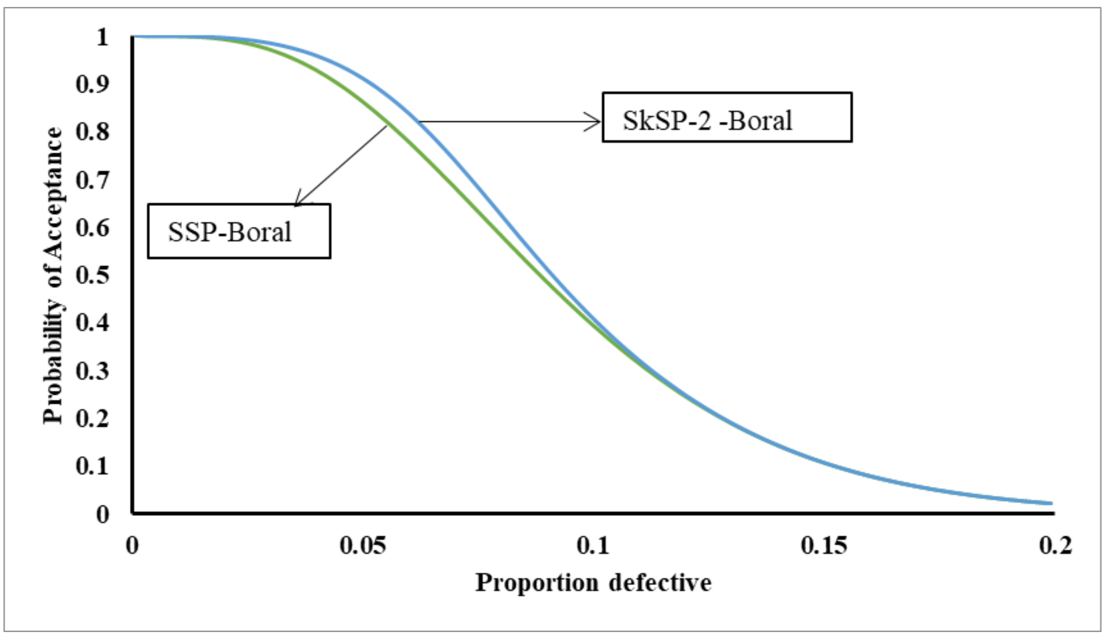

Fig 2. OC curves of matched SSP underneath the situations of Boral Distribution ($n = 50, c = 4$) and SkSP – 2 with SSP underneath the situations of Boral Distribution ($f = 1/2, i = 4, c = 4$)

3.5 Superiority of Current Research

This study not only builds upon previous research by applying the Borel distribution to sampling plans but also provides a more efficient solution for specific industrial needs. By demonstrating significant reductions in sample size while maintaining high levels of consumer and producer protection, the current research offers a practical advantage over previous methods, particularly in industries where defects are rare. While Tripathi et al.'s approach is valuable for sectors focused on reliability and life-cycle testing, our research addresses a gap in quality control for processes with sporadic defects, proving its superiority in these contexts.

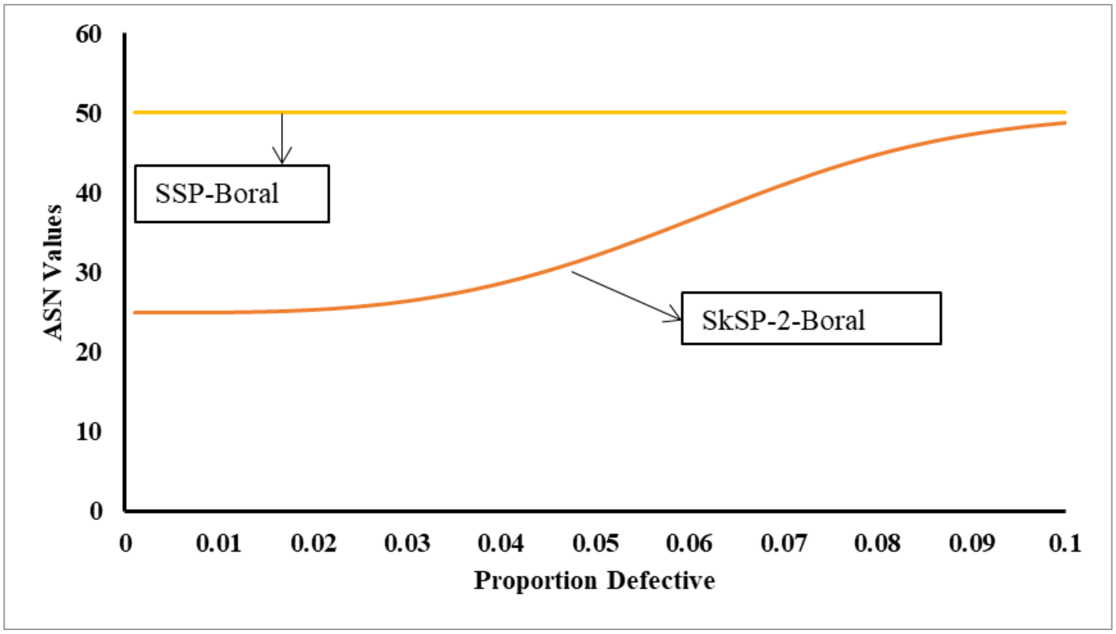

Fig 3. ASN curves of matched SSP underneath the situations of Boral Distribution ($n = 50, c = 4$) and SkSP – 2 with SSP underneath the situations of Boral Distribution ($f = 1/2, i = 4, c = 4$)

4 Conclusion

This study presents the design and evaluation of a SkSP-2, developed using single sampling plan principles underneath the situations of the Boral distribution. The analytical framework demonstrates the plan's efficiency in terms of reduced sample size requirements, making it highly effective for processes with sporadic or rare defects.

Comparison with equivalent SSPs under the Boral distribution reveals that the SkSP-2 plan exhibits comparable performance at critical quality levels (AQL and LQL) while significantly reducing examination efforts, as evidenced by the operating characteristic and average sample number curves. This reduction in sample size offers practical benefits for industries seeking to balance quality control with operational efficiency.

Future research may explore extensions of the SkSP-2 design for other complex probabilistic distributions or multi-stage sampling scenarios, broadening its applicability to diverse industrial settings. The integration of progressive statistical methods and computational utensils can further refine the strategy and analysis of sampling plans under non-standard situations.

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