

# MULTI REFERENCE SKIP-LOT SAMPLING PLAN

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## Abstract

*Skip-lot sampling plans have become significant in modern quality control due to rising production volumes and the demand for cost-effective inspection methods that will yield high-quality outputs. When inspecting a submitted lot, a skip-lot plan is economically favourable and guarantees high quality. Thus, this approach benefits both producers and consumers. The skip-lot sampling plan generally utilizes the same sampling plan as the reference plans for both skipping and normal inspection. However, using the same plan in both phase favours either the producer or the consumer in the most essential situations. This article introduces a novel approach, the Multi Reference Skip-Lot Sampling Plan with the provision of having two different reference plans in the normal and skipping phases of the skip-lot plan. The paper explores the efficacy of this approach by deriving performance measures using a power series approach. To evaluate the proposed plan, a comparison is made with existing skip-lot sampling plans that use single sampling plans or double sampling plans as reference plans. This comparison is based on operational characteristics and average sample number values, accompanied by graphical representations. The comparative analysis demonstrates that the new plan effectively balances the satisfaction of both producers and consumers. Additionally, the study offers a strategy for selecting the plan parameters using the unity value approach, supported by a table providing unity values.*

**Keywords:** Quality control, acceptance sampling plan, skip-lot sampling plan, operational characteristic function, average sample number

## 1. INTRODUCTION

Quality plays a crucial role in determining a positive brand image and reputation. Enhancing the quality is directly equal to the improvement of the level of satisfaction among customers. As industries navigate the complex production process, the significance of Statistical Quality Control (SQC) becomes concrete. SQC serves as a guiding compass to ensure consistency of quality through various statistical analyses. An important part of SQC is acceptance sampling, where quality is assessed on the basis of sample quality or statistical characteristics. Accordingly, it can be categorized into two types: attribute sampling plans, which are based on the number of defectives, and variable sampling plans, which are based on sample averages and deviations. A detailed study has been conducted by [15] about the acceptance sampling. These acceptance sampling plans are extensively used in businesses to maintain high product quality with minimal inspection costs. Various types of plans have emerged for this purpose, such as single sampling plans (SSP), double sampling plans (DSP), multiple sampling plans, chain sampling plans, etc. Numerous modifications have been developed in plans to achieve new heights in quality control. However, the quest for a plan which can maintain consistent top quality with low inspection costs in all kind of situations remains.

The basic methodology of the lot-by-lot sampling plan involves inspecting samples from individual lots and deciding whether to accept or reject the lot based on these samples. In contrast, cumulative results plans, which include continuous sampling plans, skip lot sampling plans, chain sampling plans, etc. rely on the acceptance results from the previous lots to make decisions about the current lot being inspected. The skip-lot sampling plan (SkSP-1) was designed by [8], incorporating the concepts of a continuous sampling plan of type CSP-1 into a continuous series of product lots from the same trusted source. Later, [14] introduced the SkSP-2, utilizing reference plans for lot inspection and derived performance measures for the plan through the power series approach and the Markov chain method. The introduction of skip-lot sampling plans significantly reduces inspection costs, making them economically advantageous. Then, [13] demonstrated that single sampling, double sampling, and multiple sampling plans could serve as reference plans for SkSP-2. Also, [9] highlighted that the most efficient plan for situations requiring expensive or detrimental inspections is SkSP-2 with a single sampling plan (SSP) as the reference plan, specifically one with an acceptance level of zero. Further development of the SkSP-2 using SSP with a zero-acceptance limit as the reference plan was designed by [20]. Later, [22] developed SkSP-2 with reference plan as double sampling plan (DSP) to reduce the sample size required for inspection. Introduction of an SkSP-2 with reference plan as the two-stage group sampling and constructed tables for parameter selection was done by [1]. Later on, [2] considered the Intervened Poisson distribution (IPD) in SSP as the reference plan and presented a corresponding design for SkSP-2.

A modification on the skip-lot plan using the principles of CSP-2, introducing the SkSP-3 was done by [16]. They demonstrated that SkSP-3 with a single sampling plan (SSP) as the reference plan is much more efficient than the conventional SSP. More studies about the SkSP-3 can be referred in [21], [3], [17], [11], etc. Skip-lot sampling plans have been modified over time to meet specific requirements and situations because these plans can significantly reduce the expense of sample inspection while maintaining the necessary level of quality. Such a modification is done by [12] where a modified skip-lot sampling plan known as MSkSP-1 is developed, which will inspect at least one unit is from the lot, ensuring safety against "out of control" lots. Over the time, more such modifications were made in skip-lot sampling plans and one can refer to [4], [5], [18], [19], [6], [10], etc.

Historically, skip-lot sampling plans and their modifications have utilized the same reference plan for both normal and skipping inspections. When SkSP-2 uses a single sampling plan (SSP) as the reference for both inspections, it tends to favor consumer satisfaction. The acceptance probability for low proportion defective is minimum in the case of SkSP with SSP, which leads to rejection of some lots with acceptable quality level which in turn causes loss for the producers. Conversely, using a double sampling plan (DSP) as the reference for both inspections tends to favor the producer. The acceptance rate for the lots with high proportion is also high, this will result in the acceptance of lots with rejectable quality level making a loss for the customers who receive the defective products. This paper introduces a Multi Reference Skip-Lot Sampling Plan of type MR-SkSP-2, with two distinct reference plans for normal and skipping inspections. The introduction of separate reference plans aims to reduce the risk of missing defects while optimizing the risk for both producers and consumers. The content of the paper is structured as follows: Section 2 details the design and operation of the MR-SkSP plan, including its performance measures. Section 3 outlines the method for selecting the parameters of the plan, followed by a numerical example in Section 4. A comparative study has been performed in Section 5, between the MR-SkSP plan with conventional skip-lot plans using graphs and tables to illustrate performance metrics. In conclusion, Section 6 provides key takeaways and closing remarks. Additionally, a unity value table for selecting the parameters is included.

## 2. DESIGNING OF THE SKIP LOT SAMPLING PLAN WITH THE PROVISION OF HAVING TWO DIFFERENT REFERENCE PLANS

The skip-lot sampling plan of type SkSP-2 was derived from SkSP-1 by introducing a reference plan for both normal and skipping inspections. This modification allowed the plan to accommodate the preferences of both producers and consumers during lot inspections. The proposed MR-SkSP-2 plan employs different reference plans in the normal and skipping inspection. This multi-reference approach ensures a more balanced consideration of both producer and consumer interests. The operating steps for the MR-SkSP-2 are as given;

1. Inspect  $i$  consecutive lots submitted continuously for inspection without interruption (normal inspection), employing the SSP as the reference plan
2. If  $i$  consecutive lots are accepted, proceed to the skipping inspection. There, only a fraction  $f$  of the lots is inspected at random, using the DSP as the reference plan.
3. If no lot is rejected during the skipping inspection, continue with the skipping inspection. If any lot is rejected, switch back to normal inspection.
4. Examine the rejected lots and replace any defective products with intact ones.

The MR-SkSP-2 has the following parameters;

- The normal inspection reference plan SSP parameters  $c_1$  &  $n_1$  .
- The skipping inspection reference plan DSP parameters  $c_1, c_2, n_1$  &  $n_2$ .
- The sampling frequency,  $f$ .
- The clearance interval,  $i$ .

Performance measures are essential for evaluating the effectiveness and efficiency of the sampling plan in ensuring product quality and demonstrating superiority over conventional plans. These measures help to assess how effectively the sampling plan accomplishes its goals and maintains the expected standards of quality. Additionally, they guarantee a balance between quality assurance and operational efficiency. A vital performance measure for evaluating the effectiveness of a sampling plan is the Operating Characteristic (OC) function and the OC curve plotted from it.

The derivation of OC function for the SkSP-2 was done by [13], using the power series approach by finding the number of lots inspected during normal inspection and skipping inspection. Accordingly, for an MR-SkSP-2, the expected number of lots during the normal inspection is:

$$U = \frac{1 - P_{SSP}^i}{P_{SSP}^i(1 - P_{SSP})} \quad (1)$$

Similarly, during the normal inspection, the expected number of failure sequences before having  $i$  successive accepted lots is given as;

$$G = \frac{1 - P_{SSP}^i}{P_{SSP}^i} \quad (2)$$

Furthermore, the expected number of lots during skipping inspection is;

$$V = \frac{1}{f(1 - P_{DSP})} \quad (3)$$

Using these values, the probability of rejection,  $P_r$ , is defined as,

$$P_r = \frac{\text{expected number of lots rejected}}{\text{expected number of lots submitted}} = \frac{G + 1}{U + V} \quad (4)$$

Therefore, the probability of acceptance,  $P_a$ , is given by,

$$P_a = 1 - P_r = 1 - \frac{G + 1}{U + V} \quad (5)$$

where the  $P_{SSP}$  is the probability of acceptance of SSP and  $P_{DSP}$  is that of DSP.

Also, the average fraction of lots inspected (AFI) during the whole plan comprises of the lots from the normal phase and a fraction  $f$  of lots from the skipping inspection, and is given as;

$$F = AFI = \frac{U + fV}{U + V} \quad (6)$$

The average sample number for the proposed plan is given by;

$$ASN = \frac{ASN_{SSP} \cdot U + f \cdot ASN_{DSP} \cdot V}{U + V} \quad (7)$$

### 3. DETERMINATION OF OPTIMAL PARAMETERS FOR MR-SkSP-2

The selection of optimal parameters of the MR-SkSP-2 plan can be determined based on two defined points on the OC curve viz., acceptable quality level (AQL) and limiting quality level (LQL) and are denoted as  $p_1$  and  $p_2$  respectively. The risks associated with these points are known as producers risk ( $\alpha$ ) and consumer's risk ( $\beta$ ). The producer wants to avoid the rejection of acceptable lots and the consumers want to halt the acceptance of lots having poor quality. The optimal designing of the sampling plan should then address both the producer's and consumer's concern. This can be done by choosing the parameters for the plan while the OC curve pass through pre-determined points, say  $(p_1, 1 - \alpha)$  &  $(p_2, \beta)$ . Thus, the parameters of the MR-SkSP-2 plan can be determined when the following inequalities are satisfied;

$$P_a(p_1) \geq 1 - \alpha \quad (8)$$

$$P_a(p_2) \leq \beta \quad (9)$$

The plan parameters can be found using the unity value approach introduced by [7]. The resulting  $np$  values that satisfy the equations (8) & (9) are known as the unity values. The unity values for various combinations of  $f, i, c_1$  &  $c_2$  along with the  $P_a(p)$  are provided in the Table 1. The operating ratio ( $R = np_2/np_1$ ) for the values,  $\alpha = 0.05$  and  $\beta = 0.10$  which is used to distinguish the sampling plans are also given in the same table. An example illustrating the procedure for selecting the parameters is presented in detail in the next section.

**Table 1:** Unity values & operating ratio for the MR-SkSP-2.

$f$	$i$	$c_1$	$c_2$	$P_a$							$R = np_2 / np_1$ ( $\alpha = 0.05, \beta = 0.10$ )
				0.99	0.95	0.75	0.50	0.25	0.10	0.05	
0.25	5	1	5	0.9206	1.1836	1.5691	1.9425	2.7148	3.8792	4.7250	3.2774
0.33				0.8903	1.1381	1.5209	1.9046	2.7087	3.8786	4.7249	3.4080
0.50				0.8362	1.0764	1.4547	1.8551	2.7022	3.8780	4.7249	3.7517
0.67				0.8091	1.0336	1.4092	1.8229	2.6989	3.8777	4.7248	3.6027
0.75				0.7801	1.0149	1.3908	1.8104	2.6977	3.8776	4.7248	3.8207
0.25	4	1	5	0.9793	1.2535	1.6850	2.0713	2.7690	3.8837	4.7255	3.0983
	6			0.8987	1.1250	1.4805	1.8520	2.7690	3.8822	4.7253	3.4507
	8			0.8418	1.0384	1.3473	1.7449	2.6927	3.8893	4.7261	3.7453
	10			0.7942	0.9714	1.2551	1.6979	2.6922	3.8893	4.7261	4.0037
	12			0.7547	0.9182	1.1866	1.6819	2.6922	3.8893	4.7261	4.2359
0.25	5	0	1	0.1247	0.2470	0.4933	0.7886	1.3944	2.3004	2.9942	9.3142
			2	0.2406	0.3729	0.5974	0.8433	1.3990	2.3005	2.9942	6.1685
			3	0.3653	0.5019	0.7131	0.9234	1.4094	2.3007	2.9942	4.5843
			4	0.4930	0.6334	0.8357	1.0197	1.4296	2.3011	2.9942	3.6328
			5	0.6207	0.7648	0.9605	1.1264	1.4662	2.3019	2.9942	3.0099
0.25	5	0	6	0.7551	0.8955	1.0868	1.2405	1.5232	2.3031	2.9943	2.5718
			1	1.0930	1.3464	1.7028	2.0307	2.7257	3.8801	4.7251	2.8817
			2	1.3764	1.7500	2.3338	2.9008	3.9346	5.3155	6.2826	3.0375
			3	1.6359	2.1810	3.0475	3.8518	5.1232	6.6752	7.7447	3.0606
			4	1.9571	2.7057	3.8711	4.8538	6.2898	7.9890	9.1479	2.9527

#### 4. NUMERICAL EXAMPLE AND INTERPRETATION

Consider implementing an MR-SkSP-2 plan in an inspection process, with parameter thresholds set as  $p_1 = 0.004$  and  $p_2 = 0.02$ . These thresholds correspond to a producer's risk ( $\alpha$ ) of 0.05 and a consumer's risk ( $\beta$ ) of 0.10. Thus, the parameters of the plan are determined using the given steps,

Step 1 Using the given values of  $p_1$  and  $p_2$ , calculate the operating ratio,  $R$ , as;

$$R = \frac{p_2}{p_1} = \frac{0.02}{0.004} = 5 \tag{10}$$

Step 2 From the Table 1 of unity values and operating ratio, find the  $R$ -value closest to the calculated  $R$ -value (10) and it is found as 4.5843.

Step 3 The parameter values from the table corresponding to the  $R$ -value for the plan are:  
 $f = 1/4, i = 5, c_1 = 0$  &  $c_2 = 3$ .

Step 4 The  $np$  values corresponding to the obtained  $R$ -value is found as 0.5019 ( $np_1$ ) and 2.3007 ( $np_2$ ). From this, the sample size is calculated as largest of  $(np_1)/(p_1)$  or  $(np_2)/(p_2)$ . Thus,

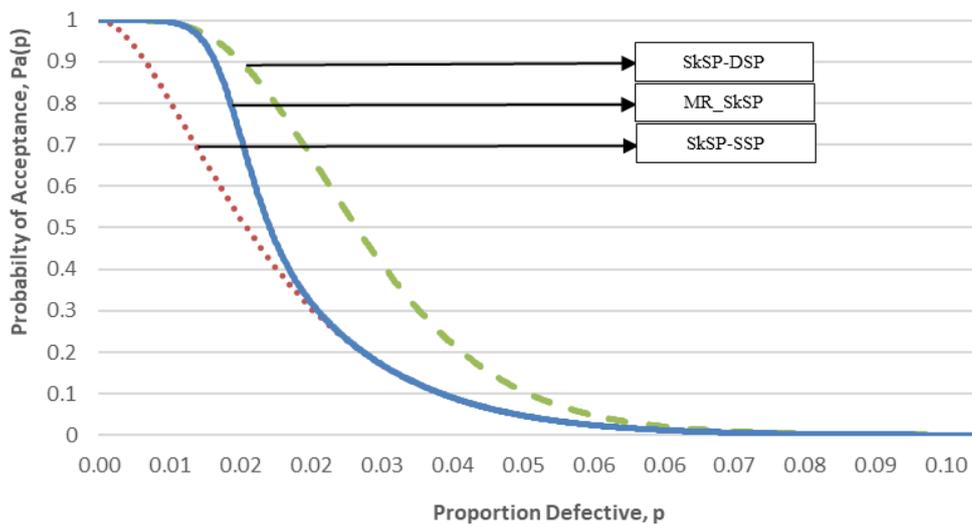
$$n = \frac{np_1}{p_1} \quad \text{or} \quad \frac{np_2}{p_2} = \frac{0.5019}{0.004} \quad \text{or} \quad \frac{2.3007}{0.02} = 125.475 \quad \text{or} \quad 115.035 \tag{11}$$

Among the  $n_1$  and  $n_2$ , we choose the largest one, thus the required sample size is approximately 126 products. Here, it's assumed that  $n_1 = n_2$ , thus both SSP and DSP is done using the same sample size. Hence the required sampling plan for the given specifications is  $f = 1/4, i = 5, c_1 = 0, c_2 = 3, n_1 = n_2 = 126$ .

### 5. COMPARATIVE ANALYSIS OF THE PLANS

The advantages of the proposed plan from the conventional SkSP-2 plans can be determined by comparing the performance measures of the plans such as  $P_a$ , ASN, and ATI. To analyze the characteristic of the proposed plan, OC curves are constructed with parameters ( $n = 100, c_1 = 2, c_2 = 5, i = 5, f = 0.25$ ) and it is evaluated against the conventional plans such as SkSP with SSP as the reference plan (SkSP-SSP) with parameters ( $n = 100, c_1 = 1, i = 5, f = 0.25$ ) and SkSP with DSP as the reference plan (SkSP-DSP) with parameters ( $n_1 = n_2 = 100, c_1 = 2, c_2 = 5, i = 5, f = 0.25$ ) and presented in Figure 1. It is noted that the proposed plan depicts the general behavior of the acceptance sampling plans, i.e., the probability of acceptance  $P_a$  decreases as the proportion defective increases. It is also noted that the proposed MR-SkSP plan lies between the conventional plans, indicating that it has the combined behavior of the conventional plans together. It is clear from the curves that when the proportion defective is high, the MR-SkSP-2 plan closely resembles the behavior of the SkSP-SSP plan. This arises because both plans highlight stricter screening and inspection, resulting in similar OC curve behavior under such conditions. Conversely, at lower levels of proportion defective, the MR-SkSP-2 plan mirrors the SkSP-DSP plan's behavior. This occurs because both plans allow for more tolerant inspection strategies or reduced sampling frequency, yielding comparable OC curves for lower defective proportions. Hence, the advantage of using the proposed plan over the conventional ones is its flexibility and adaptability in balancing inspection strictness and effectiveness.

Figure 2 gives an evaluation of the Average Sample Number (ASN) curves of the above-mentioned plans. It is seen that when the proportion defective is high, the ASN curve of the MR-SkSP plan matches closely with that of the SkSP-SSP plan. This indicates that the MR-SkSP procedure results in intensive analysis, requiring large sample sizes to detect and control higher defect rates effectively. This behavior reduces the risk of accepting defective items. It is also noted that for lower levels of  $p$ , the ASN curve of the MR-SkSP plan imitates the performance of the SkSP-DSP plan, needing fewer samples. This shows how the plan is able to relax inspection effort when defect levels are low, thereby saving resources and reducing inspection costs.



**Figure 1:** Operating Characteristic (OC) Curves

For further comparison, tables are provided with values of  $P_a$ , the ASN, and ATI for the aforementioned plans. Table 2 presents the performance measure values for varying proportions of defective,  $p$ . From the table, consider the case where the proportion defective is  $p = 0.01$ . The  $P_a$  value for the SkSP-SSP is 0.8395, i.e., 83.95%. This means that for the SkSP-SSP, the producer's risk for getting a good lot rejected is 16.05%. Again, when  $p = 0.01$ , the SkSP-DSP has an acceptance value of 99.6% ( $P_a = 0.9960$ ). Thus, the producer's risk is reduced to 0.4%. For the

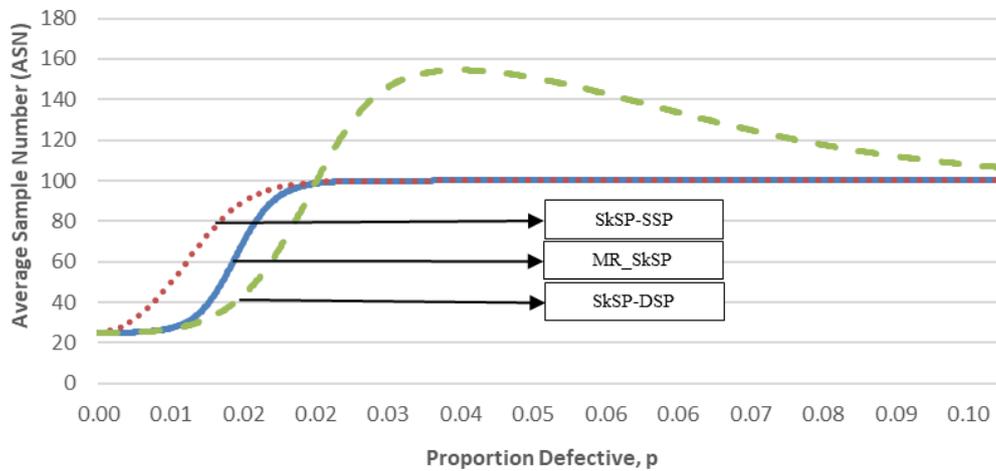


Figure 2: Average Sample Number (ASN) Curves

proposed plan, MR-SkSP-2, the acceptance value at  $p = 0.01$  is 98.35% ( $P_a = 0.983$ ). Similar to the SkSP-DSP plan, the MR-SkSP-2 also has a low producer's risk of 1.65% for a low proportion defective case. Meanwhile, when the proportion defective is elevated at  $p = 0.05$ , the SkSP-SSP has an acceptance of 4.04% ( $P_a = 0.0404$ ). Thus, the consumer's risk is only 4.04% for accepting a lot with a high fraction defective. However, the consumer's risk for the SkSP-DSP is at 8.85% ( $P_a = 0.0885$ ) for the same  $p = 0.05$ , leading to a higher acceptance of lots with defective products. Here, the proposed MR-SkSP-2 plan has a low acceptance of 4.04% ( $P_a = 0.0404$ ), similar to the SkSP-SSP. Thus, the consumer's risk is kept at a minimum level for the plan even when the defective proportion is high. This numerical illustration states that by integrating the strengths of the two different reference plans used in normal and skipping inspections, the MR-SkSP plan ensures a moderate approach that safeguards the interests of both parties involved. A similar behavior is observed in the case of ASN and ATI as well. Table 3 provides the same performance measure values for different parameter values such as sampling frequency ( $f$ ) and clearance interval ( $i$ ).

Table 2: Measures tabulated against  $p$  for SkSP-SSP, SkSP-DSP, MR-SkSP-2

p	$P_a$			ASN			ATI		
	SkSP-SSP	SkSP-DSP	MR-SkSP-2	SkSP-SSP	SkSP-DSP	MR-SkSP-2	SkSP-SSP	SkSP-DSP	MR-SkSP-2
0.01	0.8395	0.9960	0.9835	60.7222	28.5511	30.5765	0.0084	0.0100	0.0098
0.015	0.6195	0.9745	0.7982	86.0558	39.3873	60.0287	0.0093	0.0146	0.0120
0.02	0.4250	0.9005	0.4702	96.7964	65.5656	92.0643	0.0085	0.0180	0.0094
0.025	0.2915	0.7299	0.2969	99.4162	106.6065	99.0067	0.0073	0.0182	0.0074
0.03	0.1999	0.5137	0.2004	99.9061	138.9470	99.8798	0.0060	0.0154	0.0060
0.035	0.1360	0.3422	0.1361	99.9861	151.7832	99.9852	0.0048	0.0120	0.0048
0.04	0.0916	0.2236	0.0916	99.9981	154.4508	99.9982	0.0037	0.0089	0.0037
0.045	0.0611	0.1425	0.0611	99.9997	152.9084	99.9998	0.0027	0.0064	0.0027
0.05	0.0404	0.0885	0.0404	100.0000	149.1284	100.0000	0.0020	0.0044	0.0020
0.055	0.0266	0.0539	0.0266	100.0000	144.0540	100.0000	0.0015	0.0030	0.0015
0.06	0.0174	0.0323	0.0174	100.0000	138.3711	100.0000	0.0010	0.0019	0.0010
0.07	0.0073	0.0114	0.0073	100.0000	127.1072	100.0000	0.0005	0.0008	0.0005
0.08	0.0030	0.0041	0.0030	100.0000	117.7482	100.0000	0.0002	0.0003	0.0002
0.09	0.0012	0.0015	0.0012	100.0000	110.9458	100.0000	0.0001	0.0001	0.0001
0.10	0.0005	0.0006	0.0005	100.0000	106.4317	100.0000	0.0000	0.0001	0.0000

These tables offer a comprehensive insight into the performance of each plan under different conditions, aiding in the evaluation and comparison of their effectiveness and efficiency. In scenarios with a low proportion of defects, the MR-SkSP plan behaves similarly to the SkSP-DSP,

thereby reducing the rejection of quality lots and minimizing the cost for inspection by providing a lower sample size. Conversely, in conditions with a high proportion of defects, the MR-SkSP plan matches the performance of the conventional SkSP-SSP plan, thereby mitigating the risk of accepting low-quality lots while still using a moderately small sample size. Thus, within the same plan, the MR-SkSP balances the safety of manufacturers and customers under desirable conditions by carefully balancing lot acceptance and average sample number efficiently.

**Table 3:** Measures tabulated against parameter values for SkSP-SSP, SkSP-DSP, MR-SkSP-2

f	i	$P_a$			ASN			ATI		
		SkSP-SSP	SkSP-DSP	MR-SkSP-2	SkSP-SSP	SkSP-DSP	MR-SkSP-2	SkSP-SSP	SkSP-DSP	MR-SkSP-2
0.25	2	0.89930	0.99616	0.99316	38.10942	27.60917	27.86001	0.00899	0.00996	0.00993
	5	0.83955	0.99603	0.98346	60.72225	28.55108	30.57653	0.00840	0.00996	0.00983
	7	0.80429	0.99595	0.97099	74.06515	29.19033	34.07228	0.00804	0.00996	0.00971
0.25	5	0.83955	0.99603	0.98346	60.72225	28.55108	30.57653	0.00840	0.00996	0.00983
0.33		0.81537	0.99475	0.97831	69.87004	37.82546	40.11235	0.00815	0.00995	0.00978
0.50		0.78263	0.99222	0.96847	82.26293	56.02399	58.29159	0.00783	0.00992	0.00968
0.67		0.76147	0.98975	0.95924	90.26842	73.77007	75.37095	0.00761	0.00990	0.00959

## 6. CONCLUSION

The present research explores, a multi-reference skip-lot sampling plan, MR-SkSP, incorporating two different reference plans for normal and skipping inspections, has been designed and evaluated. The operational procedure and the unity value approach for parameter selection for the plan have been presented. The effectiveness of the MR-SkSP plan has been judged through comparative analyses with conventional skip-lot plans employing same reference plans in both phases. The Performance measures have been scrutinized using various graphs and tables. Findings reveal that the MR-SkSP plan demonstrates remarkable adaptability and effectiveness across varying proportions of defectiveness. In circumstances with a low proportion of defects, the MR-SkSP plan offers enhanced protection to producers by providing a high acceptance probability and lower ASN. Conversely, in situations with a higher proportion of defects, the plan prioritizes consumer satisfaction by offering a lower acceptance probability and higher ASN value. Notably, the MR-SkSP plan cleverly synthesizes the properties of conventional plans at the critical phases of inspection, ensuring optimal outcomes irrespective of the proportion of defects. Thus, the study underscores the significance of the MR-SkSP plan in achieving balanced and effective quality control, catering to the diverse needs of both producers and consumers alike. As the importance for the SkSP plans to maintain high quality along with low inspection time and cost is growing day by day, the proposed MR-SkSP has a significant role by enabling the suitable adaptation of the traditional SkSPs in the serious situations. While it is clear that using two different reference plan allows the adaptation of the traditional plans with a single reference plan, the method can be applied in the other skip-lot sampling plans like, SkSP-3, SkSP-V, SkSP-T etc.

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