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A Modified Single Sampling Plan for the Inspection of Attribute Quality Characteristics

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ABSTRACT

In this manuscript, a modified single sampling plan is proposed for the inspection of products in which the non-conforming items can be classified in to two categories namely critical and non-critical; and explained with the help of industrial example. The operating procedure of this plan is also proposed and the performance measures such as the probability of acceptance, average sample number, average total inspection and average out going quality are also derived. The optimal parameters are determined which will have minimum sample size. The efficiency of the proposed plan is also discussed over the conventional single sampling plan. The extensive tables for selecting a modified single sampling plan based on AQL and LQL are provided for both Binomial and Poisson distributions and explained with the help of industrial data.

Keywords: Critical Defects, Non-Critical Defects, Lot Sentencing, Acceptable Quality Level, Limiting Quality Level, Average Sample Number; Average Total Inspection

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1. INTRODUCTION

Acceptance sampling plans are used by the consumer for disposition of produced items in lots as suitable to be consumed. A lot is a group of products, produced in a similar environment is assessed either as acceptable or reject able based on the inspection of a sample of items drawn from the lot. Acceptance sampling plans provide assurance to the consumers on the quality and safety of accepted products. One of the main aims of implementation of the acceptance sampling plans is to reduce the inspection cost, directly proportional to the sample size with the desired protection of the producer and the consumer. The application of the acceptance sampling plans has been increasingly recognized by many industries. For example, the application of acceptance sampling is discussed by Bray and Lyon (1973) in food industry; Baker *et al*. (1993) in drug testing; Bhaumik and Bhargava (2005) in testing fiber optical; Deros *et al*. (2008) in electrical and electronic manufacturing industries; Santos-Fernandez *et al*. (2015) in food processing industries. In general, the acceptance sampling plans are classified into two major categories namely attribute sampling plans and variables sampling plans. The first one will be used for the inspection of attribute quality characteristics, in which the items are just classified as conforming or non-conforming. The later one can be used for inspection of measurable quality characteristics, in which the quality characteristics are measured on a continuous scale. For more details on the recent developments on acceptance sampling plans, the readers are referred to Bebbington *et al*. (2000), Clements (1979, 1980), Cassady and Nachlas (2003), Dahms and Hildebrandt (1998), Legan *et al*. (2001), Liu and Cui (2013), Palcat (2006) and the references cited there in.

In the literature of acceptance sampling, several sampling plans are available. Some of the basic sampling plans are single sampling plan, double sampling plan, multiple sampling plan and sequential sampling plan. In single sampling plan (SSP), the decision on the disposition of lots will be decided based on the inspection of only one sample drawn from the lot. The SSP is specified by two parameters namely n, the sample size and c, the acceptance number. The operation of this plan is simple as follows;

Step 1: Draw a random sample of size n from the lot of size N and observe the number of non-conforming items (d) in the sample.

Step 2: If $d \leq c$, then accept the lot; otherwise reject it.

Use of SSP sometimes leads to a great loss to the producer, since the whole lot may be rejected based on the results of single sample. To overcome this drawback, double and multiple sampling plans were developed. In the double sampling plan, two samples are used to make decision on the disposition of the lot and in multiple sampling plans more than two samples will be used. For more details about the basic sampling plans readers may refer to Schilling (1982), Duncan (1986) and Montgomery (2009).

In this paper, we propose a modified SSP in which the non-conforming items are classified into critical and non-critical. This modified SSP will provide minimum average sample number compared to the conventional single sampling plan. This paper is organized as follows. The modified SSP is explained in section 2. The designing methodology of the proposed plan is explained in section 3. Advantages of the proposed plan are given in sections 4 and 5 whereas some concluding remarks are given in section 6.

2. MODIFIED SINGLE SAMPLING PLAN (MSSP)

The conventional SSP given above will consider only one type of non-conforming items, in fact that it is assumed as critical defectives. The defective items found by the consumer while inspection, which would be replaced by the producer. That is the defective items are considered here as critical defectives even though the defectives belong to non-critical defectives. For example, in regular manufacturing industries the defects are classified into several categories. As stated by Borror (2009: 190), A typical seriousness classification includes four levels of defect seriousness:

- Critical defect may lead directly to severe injury or catastrophic economic loss.
- Serious defect may lead to injury or significant economic loss.
- Major defect may cause major problems during normal use. A major defect will likely result in reducing the usability of the product.
- Minor defect may cause minor problems during normal use.

As stated in http://www.hkqcc.com/defect-classification.html, defects are classified into three categories. During inspection, all defects found are classified into 3 categories: Critical, Major and Minor. These classifications are made based on the following principles:

- Critical: A Defect that is likely to result in producing an unsafe condition or contravene mandatory regulation. In our normal practice, no Critical Defect is accepted; any of this kind of defect found will be subjected to an automatic rejection of inspection result.
- Major: A Defect that would reduce the usability of the product, or that shows an obvious appearance defect that would affect the sales of the product.
- Minor: A Defect that does not reduce the usability of the *product, but it is still beyond the defined quality standard.*

Defects could be counted as critical, major or minor according to your specifications and inspections criteria.

Jeya Chandra (2001) has explained the impact of the different defects discussed above in the examples 3.2 and 3.3. They relevant parts of the examples are given below:

"A manufacturer of a component requires that the tolerance on the outside diameter be 5 ± 0.006". Defective components that are oversized can be reworked at a cost of $5.00 per piece. Undersized components are scrapped at a cost of $10.00 per piece".
"The specifications for the thickness of a gauge block are $1^{n+0.002}_{-0.001}$. *Defective blocks that are undersized have to be scrapped at a cost of $12.00 a piece, and the blocks that are oversized can be reworked at a cost of $5.00 a piece."*

That is, if the quality characteristic is the outer diameter of the component (say a shaft), then the oversized components are classified as minor defectives, since these components can be reworked. However the undersize components are classified as Major/Critical defectives, since these components cannot be reworked and have to be scraped. On the other hand if the quality characteristic is the inner diameter of a component (say a shaft) then the undersize components are classified as minor defectives, since these components can be reworked. However the oversize components are classified as Major/Critical defectives, since these components cannot be reworked and have to be scraped. In some situations, it is necessary to classify the non-conforming items as critical and non-critical defectives. For such type of situations, there is no sampling plan is available in the literature. For this purpose, we propose this modified version of SSP and is designated as modified single sampling plan (MSSP). The operating procedure of the new plan is explained below.

Step 1: Draw a random sample of size n from the lot of size N and observe the number of non-conforming items which are to be classified as critical (d_1) and non-critical (d_2) defectives.

Step 2: If $d_1 \le c_1$ and $(d_1+d_2) \le c_2$ then accept the lot; otherwise reject the lot.

The newly proposed plan has three parameters namely, n, the sample size, and c_1 and c_2 are the acceptance numbers respectively for the critical and combined defectives.

2.1 Performance Measures

The following are the important measures of the proposed MSSP.
a. Probability of acceptance
b. Average sample number
c. Average outgoing quality
d. Average Total inspection

2.1.1 Probability of Acceptance

The probability of acceptance or the operating characteristic (OC) function is one of the most useful measures of sampling plans which can be used to assess the performance of a sampling plan. The OC function of the proposed MSSP, which gives the proportion of lots that are expected to be accepted for given product quality, (p', p''), $(p'' > p')$ is derived as

$$P_a(p',\ p'') = \sum_{d_1=0}^{c_1}\left[P(d_1)\sum_{d_2}^{c_2-d_1}P(d_2)\right] \tag{1}$$

Under binomial model, the above function becomes

$$P_a(p',\ p'') = \sum_{d_1=0}^{c_1}\left[\binom{n}{d_1}p'^{d_1}(1-p')^{n-d_1} \times \sum_{d_2=0}^{c_2-d_1}\binom{n}{d_2}p''^{d_2}(1-p'')^{n-d_2}\right] \tag{2}$$

Under Poisson model, the OC function becomes

$$P_a(p',p'') = \sum_{d_1=0}^{c_1}\left[\frac{e^{-np'}(np')^{d_1}}{d_1!}\sum_{d_2=0}^{c_2-d_1}\frac{e^{-np''}(np'')^{d_2}}{d_2!}\right] \tag{3}$$

2.1.2 Average Sample Number

The average sample number (ASN) is defined as the average number of sampled units per lot used for making decisions either acceptance or rejection of the lot. So the ASN of the proposed MSSP is same as that of the conventional single sampling plan. That is,

$$ASN(p',\ p'') = n \tag{4}$$

2.1.3 Average Total Inspection

The average total inspection (ATI) is defined as the average number of units inspected per lot based on the sample size for accepted lot and all inspected units in not-accepted lots.

$$ATI(p',\ p'') = n + \{1 - P_a(p',\ p'')\}(N-n) \tag{5}$$

Where $P_a(p',\ p'')$ is the probability of acceptance of MSSP, which is given in (1).

2.1.4 Average Outgoing Quality

The average outgoing quality (AOQ) is defined as the expected quality of outgoing product following the use of an acceptance sampling plan for a given value of incoming product quality. The AOQ of the MSSP is determined as

$$AOQ(p',\ p') = p' P_a(p',\ p'')\frac{(N-n)}{N} \tag{6}$$

Where $P_a(p', p'')$ is the probability of acceptance of MSSP, which is given in (1).

The maximum of AOQ is called the average outgoing quality limit (AOQL).

3. DESIGNING METHODOLOGY OF MSSP

There are several designing methodologies available to design the acceptance sampling plans in the literature. One of most important methods is fixing two-points on the OC curve, in which the OC curve of the designed acceptance sampling plan passes through the two designated points. For protection of product quality both the producer and the consumer would focus on these two points on the OC curve to reflect their benchmarking risk. The producer usually desire to focus on a specific level of product quality, called the acceptable quality level (AQL) and denoted by p_1, which would yield a high probability for accepting a lot. The consumer would desire to focus on another specific level of product quality, called the limiting quality level (LQL) and denoted by p_2, which would give a low probability for accepting a lot. The probability of rejecting a lot at the quality level AQL is denoted by α, which is also called as the producer's risk and the probability of accepting a lot at the quality level LQL is denoted by β, which is called as the consumer's risk. Accordingly, a well-designed sampling plan must satisfy both the producer and consumer risks. That is, the sampling plan should pass through the two points on the OC curve namely (p_1, 1-α) and (p_2, β). So in order to find optimal sampling plan, we have used these two conditions as the constraints. Obviously, a sampling plan or sampling system having smaller sample size or ASN always would be more desirable. So, the ultimate aim is to find the optimal parameters of the proposed sampling plan which should minimize the sample size along with satisfying both the producer and consumer risks. In this paper, we have considered two different true quality levels for critical and non-critical defectives namely p' and p'' respectively, where ($p'' > p'$). Based on this, the optimal parameters of the proposed MSSP can be determined by solving the following non-linear optimization problem.

$$\begin{aligned} &\text{Minimize} \quad ASN(p', p'') = n \\ &\text{Subject to} \quad P_a(p_1', p_1'') \geq 1 - \alpha \\ &\qquad P_a(p_2', p_2'') \leq \beta \\ &\qquad n > 1,\ c_2 > c_1 \geq 0 \end{aligned} \tag{7}$$

Table 1. Optimal parameters of MSSP under binomial and poisson models with α = 5% and β = 10%

p_1'	p_2'	Binomial MSSP					Poisson MSSP				
		n	c_1	c_2	$P_a(p_1')$	$P_a(p_2')$	n	c_1	c_2	$P_a(p_1')$	$P_a(p_2')$
0.001	0.0020	4,701	9	21	0.95271	0.09098	4696	9	21	0.95274	0.09218
	0.0025	2,643	6	14	0.96342	0.09982	2644	6	14	0.96309	0.09995
	0.003	1,661	4	10	0.95433	0.09974	1662	4	10	0.95399	0.09981
	0.004	943	3	7	0.96202	0.09990	944	3	7	0.96168	0.09995
	0.005	578	2	5	0.95736	0.09940	579	2	5	0.95694	0.09936
	0.006	413	2	4	0.95202	0.09929	414	2	4	0.95153	0.09925
	0.007	335	1	4	0.95041	0.09886	335	1	4	0.95026	0.09979
	0.008	247	1	3	0.96069	0.09993	248	1	3	0.96017	0.09965
	0.009	220	1	3	0.96921	0.09902	221	1	3	0.96875	0.09871
	0.010	155	1	2	0.95062	0.09820	155	1	2	0.95039	0.09997
	0.012	129	1	2	0.96470	0.09827	130	1	2	0.96399	0.09787
	0.015	103	1	2	0.97679	0.09837	104	1	2	0.97619	0.09787
	0.020	77	1	2	0.98665	0.09853	78	1	2	0.98617	0.09787
	0.025	67	1	2	0.98979	0.07257	66	1	2	0.98995	0.08072
	0.030	67	1	2	0.98979	0.03335	66	1	2	0.98995	0.03890
	0.040	67	1	2	0.98979	0.06294	66	1	2	0.98995	0.00832
	0.050	45	0	1	0.95598	0.09944	47	0	1	0.95409	0.09537
	0.060	38	0	1	0.96269	0.09525	39	0	1	0.96175	0.09633
	0.07	32	0	1	0.96849	0.09805	33	0	1	0.96754	0.09926
	0.08	28	0	1	0.97238	0.09648	29	0	1	0.97142	0.09827
	0.09	25	0	1	0.97529	0.09463	26	0	1	0.97434	0.09633
	0.10	22	0	1	0.97822	0.09848	24	0	1	0.97629	0.09072
0.0025	0.005	1,871	9	21	0.95445	0.09469	1879	9	21	0.95263	0.09192
	0.006	1,101	6	14	0.95477	0.09942	1102	6	14	0.95416	0.09972
	0.0075	664	4	10	0.95461	0.09944	665	4	10	0.95393	0.09963
	0.010	377	3	7	0.96229	0.09927	378	3	7	0.96154	0.09939
	0.012	240	2	5	0.95296	0.09994	241	2	5	0.95192	0.09983
	0.015	165	2	4	0.95245	0.09834	166	2	4	0.95125	0.09825
	0.020	99	1	3	0.96079	0.09731	100	1	3	0.95949	0.09667
	0.025	62	1	2	0.95093	0.09553	62	1	2	0.95040	0.09997
	0.030	51	1	2	0.96574	0.09885	52	1	2	0.96399	0.09787
	0.035	44	1	2	0.97402	0.09581	45	1	2	0.97244	0.09479
	0.040	38	1	2	0.98033	0.09916	39	1	2	0.97891	0.09787
	0.050	31	1	2	0.98670	0.09099	31	1	2	0.98634	0.09997
	0.060	27	1	2	0.98984	0.07603	27	1	2	0.98951	0.08609
0.005	0.010	937	9	21	0.95432	0.09253	940	9	21	0.95244	0.09148
	0.012	550	6	14	0.95539	0.09912	551	6	14	0.95416	0.09972
	0.015	332	4	10	0.95503	0.09830	333	4	10	0.95366	0.09869
	0.020	188	3	7	0.96306	0.09913	189	3	7	0.96154	0.09939
	0.025	115	2	5	0.95871	0.09875	116	2	5	0.95674	0.09858
	0.030	82	2	4	0.95363	0.09839	83	2	4	0.95125	0.09825
	0.035	67	1	4	0.95094	0.09507	67	1	4	0.95056	0.09979
	0.04	49	1	3	0.96208	0.09792	50	1	3	0.95949	0.09667
	0.05	31	1	2	0.95146	0.09099	31	1	2	0.95039	0.09997
	0.06	25	1	2	0.96747	0.09974	26	1	2	0.96399	0.09787
	0.07	25	1	2	0.96747	0.05485	23	1	2	0.97129	0.08796

Table 1. Continued

p_1'	p_2'	Binomial MSSP					Poisson MSSP				
		n	c_1	c_2	$P_a(p_1')$	$P_a(p_2')$	n	c_1	c_2	$P_a(p_1')$	$P_a(p_2')$
0.0075	0.015	628	9	21	0.95290	0.08734	627	9	21	0.95226	0.09104
	0.020	272	5	11	0.95021	0.09758	291	5	12	0.95549	0.09838
	0.025	184	4	9	0.96475	0.09924	185	4	9	0.96283	0.09999
	0.030	125	3	7	0.96381	0.09897	126	3	7	0.96154	0.09939
	0.035	82	2	5	0.95065	0.09799	94	2	6	0.95505	0.09515
	0.04	72	2	5	0.96590	0.09562	73	2	5	0.96319	0.09549
	0.05	50	2	4	0.96308	0.08845	50	2	4	0.96167	0.09659
0.010	0.020	472	9	21	0.95255	0.08483	470	9	21	0.95244	0.09148
	0.025	263	6	14	0.96552	0.09977	265	6	14	0.96265	0.09829
	0.030	165	4	10	0.95693	0.09977	167	4	10	0.95309	0.09686
	0.035	118	3	8	0.95324	0.09593	119	3	8	0.95011	0.09637
	0.040	94	3	7	0.96390	0.09594	95	3	7	0.96087	0.09661
	0.045	72	2	6	0.95399	0.09619	73	2	6	0.95050	0.09586
	0.05	57	2	5	0.96066	0.09885	58	2	5	0.95674	0.09858
	0.06	50	2	5	0.97311	0.07530	49	2	5	0.97315	0.09249
0.02	0.04	237	9	21	0.95264	0.07832	235	9	21	0.95244	0.09148
	0.045	166	7	16	0.95766	0.08546	165	7	16	0.95611	0.09739
	0.05	132	6	14	0.96620	0.09278	133	6	14	0.96189	0.09560
	0.06	76	4	9	0.95150	0.09864	84	4	10	0.95197	0.09328
	0.07	59	3	8	0.95495	0.09059	64	3	9	0.95131	0.09890
	0.08	50	3	7	0.95742	0.06101	48	3	7	0.95949	0.09125
0.03	0.05	311	15	38	0.95461	0.09378	335	16	41	0.95464	0.09388
	0.06	159	9	21	0.95200	0.07044	157	9	21	0.95169	0.08973
	0.07	93	6	14	0.95599	0.09942	110	7	16	0.95611	0.07224
	0.08	67	5	11	0.95716	0.09689	73	5	12	0.95478	0.09609
	0.09	51	4	9	0.95215	0.08936	56	4	10	0.95197	0.09328
	0.10	50	4	9	0.95574	0.04690	47	4	9	0.96053	0.09065
	0.20	50	4	9	0.95574	0.09754	13	2	4	0.95791	0.08136
0.04	0.06	357	22	54	0.95204	0.09247	416	24	64	0.95086	0.09847
	0.07	179	12	30	0.95204	0.09671	197	13	33	0.95035	0.09516
	0.08	105	8	19	0.95217	0.09954	118	9	21	0.95094	0.08802
	0.09	76	6	15	0.95038	0.09794	83	7	16	0.95449	0.09285
	0.10	57	5	12	0.95272	0.09588	67	6	14	0.96036	0.09039
	0.12	55	5	12	0.95872	0.09574	42	4	10	0.95197	0.09328
	0.15	55	5	12	0.96032	0.09217	28	3	8	0.95946	0.09119
0.05	0.08	220	17	44	0.95594	0.09702	249	19	49	0.95029	0.07928
	0.09	127	11	27	0.95467	0.09321	141	12	30	0.95239	0.09529
	0.10	84	8	19	0.95385	0.09577	94	9	21	0.95244	0.09148
	0.11	68	7	16	0.95608	0.07321	91	7	17	0.95061	0.09385
	0.12	55	6	14	0.96251	0.08029	56	6	14	0.95009	0.08837

Where $P_a(p_1', p_1'')$ and $P_a(p_2', p_2'')$ are the probability of acceptance of the MSSP at AQL and LQL respectively. In this paper, we have considered $p''=2p'$ in order to construct the tables. By solving the non-linear problem mentioned in (7), the optimal parameters (n, c_1 and c_2) can be determined and are tabulated in Table 1.

4. ILLUSTRATIVE EXAMPLES

4.1 Example 1 (Binomial Model)

Table 1 can be used to select the optimal parameters of the proposed MSSP for specified AQL and LQL under Binomial model. Suppose that a quality characteristic of interest under study follows a Binomial distribution. The quality auditor wishes to implement the proposed MSSP and wants to select an optimal MSSP for specified AQL with $\alpha = 0.05$ and LQL with $\beta = 0.1$. Suppose that the AQL and LQL are specified as $p_1' = 0.01$ and $p_2' = 0.05$, respectively. Then, Table 1 gives the optimal parameters of the MSSP as $n = 57$, $c_1 = 2$ and $c_2 = 5$. For this optimal MSSP, we get the probability of acceptance at AQL as 0.96066 and the probability of acceptance at LQL as 0.09885. The OC curves of the SSP and MSSP with above mentioned parameters are depicted in Figure 1.

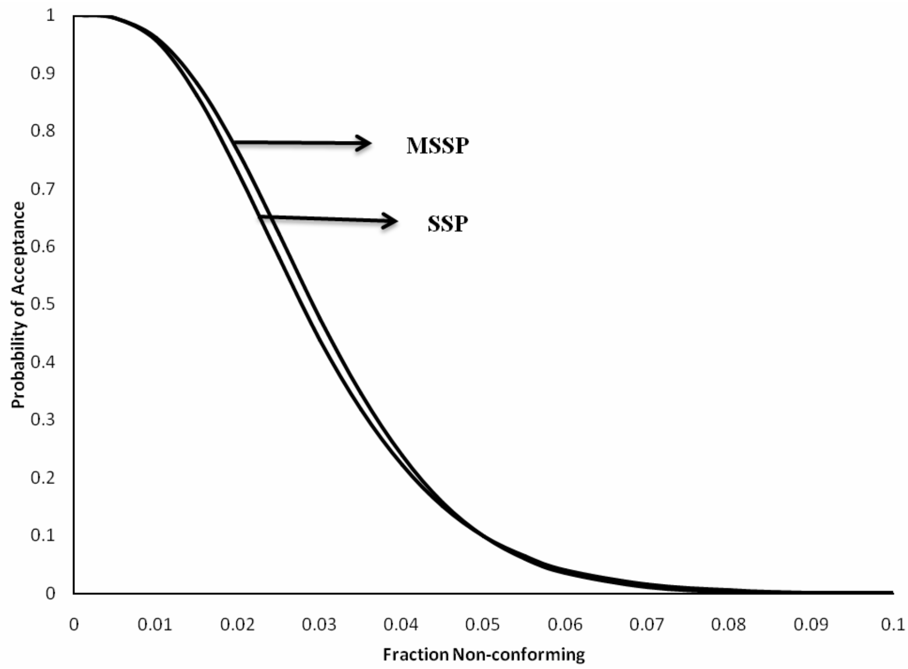

Figure 1. OC Curves of single sampling plan (n = 132, 3) and modified single sampling plan (n = 57, 2, 5) for specified $p_1 = 0.01$ and $p_2 = 0.05$ with $\alpha = 0.05$ and $\beta = 0.10$.

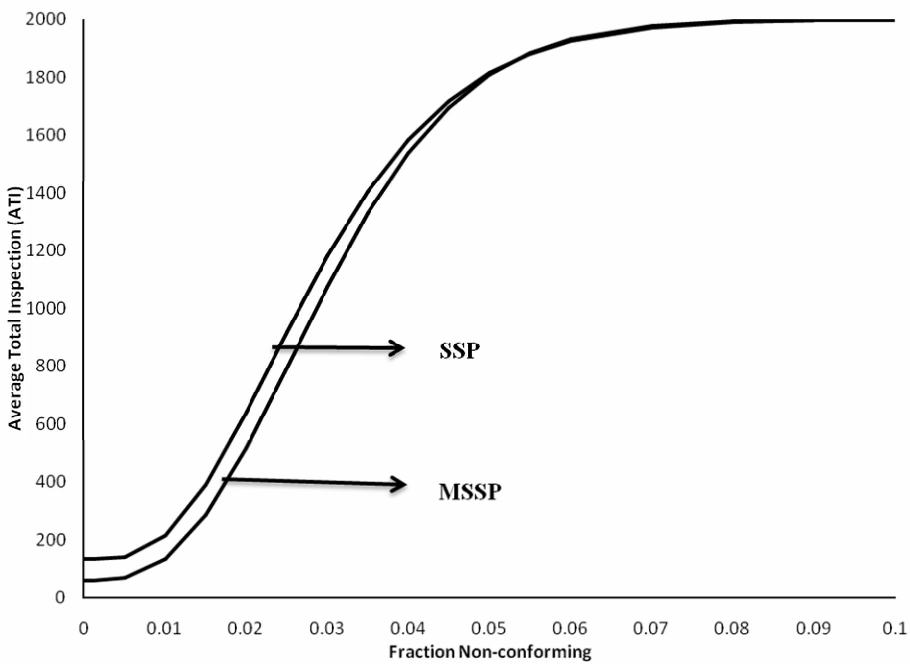

Figure 2. ATI curves of single sampling plan (N = 2,000, n = 132, 3) and modified single sampling plan (N = 2,000, n = 57, 2, 5).

4.2 Example 2 (Poisson Model)

Table 1 can also be used to select the optimal parameters of the proposed MSSP for specified AQL and LQL under Poisson model. Suppose that one wants to find the optimal parameters of the proposed MSSP under Poisson model for specified AQL and LQL requirements. Suppose that the AQL and LQL are specified as $p_1' = 0.0025$ and $p_2' = 0.025$, respectively and the corresponding producer and consumer risks are $\alpha = 0.05$ and $\beta = 0.1$. Then, Table 1 gives the optimal parameters of the MSSP under Poisson model as $n = 62$, $c_1 = 1$ and $c_2 = 2$. For this optimal MSSP, the probability of acceptance at AQL is 0.95040 and the probability of acceptance at LQL as 0.09997.

5. COMPARISON

In this section, we compare the proposed MSSP with the conventional single sampling plan. For this purpose we provide Table 2, which gives the ASN of both MSSP and the conventional single sampling plan for some selected combination of AQL and LQL. From this table, it is observed that the proposed MSSP will have minimum ASN compared to the conventional SSP. For example, if $p_1 = 0.005$ with $\alpha = 0.05$ and $p_2 = 0.01$ with $\beta = 0.1$, then the ASN of MSSP under Binomial model is 1,389, whereas the ASN of SSP is 2,473. For the same requirements, the ASN of MSSP under Poisson model is 1,391 where as the ASN of SSP is 2,476.

Table 2. ASN of SSP and MSSP with α = 5% and β = 10%

p_1'	p_2'	ASN			
		Binomial		Poisson	
		SSP	MSSP	SSP	MSSP
0.001	0.002	12,376	4,701	12,379	4,696
	0.004	2,317	943	2,319	944
	0.006	1,112	413	1,114	414
	0.008	664	247	666	248
	0.010	531	155	533	155
0.005	0.010	2,473	937	2,476	940
	0.012	1,381	550	1,384	551
	0.015	783	332	785	333
	0.020	462	188	464	189
	0.025	266	115	268	116
0.01	0.02	1,235	472	1,238	470
	0.03	390	165	393	167
	0.04	198	94	232	95
	0.05	132	57	134	58
	0.06	110	50	112	49
0.02	0.04	616	237	619	235
	0.05	306	132	332	133
	0.06	194	76	197	84
	0.07	131	59	151	64
	0.08	98	50	116	48

In addition, we compare the proposed MSSP with the existing SSP in terms of OC and ATI. Figure 1 shows the probability of acceptance of SSP with parameters (n = 132, c = 3) and MSSP with parameters (n = 57, c_1 = 2, c_2 = 5) and Figure 2 provides the ATI curves of the above mentioned plans when the lot size is N = 2,000. From these, figures it is clearly understood that the proposed MSSP will give more probability acceptance when the fraction nonconforming is less at the same time the OC curve of MSSP coincide with SSP when fraction nonconforming is high. It indicates that the proposed MSSP protects both producer and the consumer with minimum sample size. Similarly, Figure 2 reveals that when fraction nonconforming is small, ATI of the MSSP is less and when the fraction nonconforming increases, it converges with the ATI of SSP. From these figures and Table 2, we conclude that the MSSP is more economical with desired protection.

6. CONCLUSIONS

In this paper, we have proposed a new sampling plan called modified single sampling plan for the application of attribute quality characteristics. This sampling plan is a new type in the sense that it considers two types of non-conforming items such as critical and non-critical. Further both Binomial and Poisson models are considered for designing the plans. Tables have been provided for easy application of the proposed plan. Through a comparative study, it is shown that the proposed plan requires minimum sample size under both the Binomial and Poisson models compared to the conventional single sampling plan. It is planned to take up the cases of more classification (Minor, Major and Critical) of defectives in the future studies.

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