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Cost Optimization Using Acceptance Sampling Plan: A Statistical Analysis with Single Sample

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A B S T R A C T

Economic plan play an important role for every product. The priority of every sampling plan is the reduction in time and cost, which totally depends on the sampling plan, a decision regarding rejection and acceptance of the lot is taken on the basis of a single sample. The purpose of this paper is to design an economic model to obtain optimal total cost on the basis of average total inspection (ATI).In a single sampling plan, one sample of items is selected at random from a lot and the disposition of the lot is determined from the resulting information. These plans are usually denoted as (n, c) plans for a sample size n, where the lot is rejected if there are more than c defectives. The present study deals with the development of a mathematical model that can help a producer to find a single sampling plan that minimizes the producers total cost (inspection and failure costs and post-sale failure cost) and satisfies both the producers and consumers quality risk requirements.

Introduction

Statistical quality control may be categorized into two parts process control and product control. The quality of the product can be control through the product and process control in any manufacturing industry and the product control has to perform when the product is in finished mode. Product control is equally important technique as process control in the field of statistical quality control to maintain the quality of the product. However, in product control, sampling plan for attributes and variables are available but sampling plan for attribute is easy to perform in any industry or manufacturing unit.

The acceptance sampling plan helps us to identify the sample size and types of sample so that we make a decision about acceptance or rejection of the lot. However, total inspection is error proof method to improve the quality of the product in product control. In single sampling plan, a sample is selected randomly from a lot is taken on the basis of resulting information. This plan is known as (n, c; d) plans, if d > c, do not accept the lot otherwise lot may be accept. However, this is simple and easy to understand while performing single sampling plan but also depends on the various given conditions.

An important traditional approach such as, the classical Dodge Romig (1998) rectifying attributes sampling plan provide an idea to help lot tolerance percent defective (LTPD) on each lot or the average outgoing quality limit (AOQL) protection for the lots. One of the most common ways to set the sampling plan parameters is to use what are often referred to as quality control tables.

The whole study touches through every activity on economic points, and both producer and consumer are always aware about the product's sampling plan so that they satisfy and agree with the plan. Wetherill, G.B. and Chiu, W.K. (1975) reviewed some major principles of acceptance schemes with emphasis on the economic aspect, their research include, the Bayesian approach, the minimize approach, Semi-economic approach. Tagaras (1994) developed an economic model to assist in the selection of minimum cost acceptance sampling plan by variables. The quadratic Taguchi loss function is adopted to model the cost of accepting items with quality characteristics deviating from the target value. Ferrell and Chhoker (2002) presented a sequence of models that addressed total inspection and single sampling with and without inspection error when a Taguchi - like loss function is used to describe the cost associated with any deviation between the actual value of product's quality characteristics and its target value. In recent years more emphasis was placed on process control and off - line quality control methods, but acceptance sampling plan still remained important functions in many practical quality control systems. Many situations assured in which screening inspection are feasible. Also there are many cases where sampling is inevitable, either because inspection is destructive, or because lot sizes are large and inspection is expensive, time consuming and has high error rate.

Montgomery (2005) pointed out that variables sampling plans usually involve smaller sample size than attributes sampling plans for the same levels of protection. The traditional method of conformance to specifications is that items achieved the specification limits. Taguchi (1986) highlighted the quality of product and presented the quadratic quality loss function for minimizing total losses to the society. The losses of quadratic function are explained in monetary terms and are easy to understand and to apply in the analysis of product or process improvement. Rahim and Tuffaha (2004) introduced the different problems of unbalanced tolerance design and optimum manufacturing target with the above mentioned quadratic quality loss functions.

Kapur and Wang (1987) addressed the problems of quality loss function and later Kapur, K.C. (1988) separately met an approach for development of specifications for quality improvement applied in the economic design of specification limits. This research highlighted that a methodology to reduce variance of the units shipped to the customer, using truncated distribution with specification limits.

Kapur, K. C. and Wang, C. J. (1994, 1996) have also discussed various approaches of Acceptance Sampling Plan. It is noticed, a few available research in the above literature emphasizing on the economic design of acceptance sampling plans has been developed to fulfill the Producer's and Consumer’s specifications. An attempt has been made in the present paper to develop an economical model so that it may help a producer to find an optimal single sampling plan that minimize the producer's total cost and satisfies both the parties.

Notations

AQL: Acceptance Quality Level

LTPD: Lot Tolerance Percent Defective

OC: Operating Characteristic Curve

ATI: Average Total Inspection

ASN: Average Sample Number

AOQ: Average Outgoing Quality

AOQL: Average Outgoing Quality Limit

α: Probability of Type-I Error or Producer's Risk

β: Probability of Type-II Error or Consumer's Risk

TC: Total Cost

C_i: Inspection Cost

C_f: Internal Failure Cost

C_o: Cost of an Outgoing Defective

D_d: Defective Items Detected

D_n: Defective items not detected

Proposed sampling plan

Design of a single sampling plan, to find the parameters (n, c) such that

$$P_a(p_1) = P(X \le c | n, p_1) = 1 - \alpha \quad (1)$$

$$P_a(p_2) = P(X \le c | n, p_2) = \beta \quad (2)$$

Where, $p_1 = AQL$, $p_2 = LTPD$ and X is the number of defective items found in sample size n and $P_a(p)$ is the probability of accepting the lot if the defect level is p.

We assume that the lot size is large enough to use the binomial distribution to find the probability of lot acceptance. So, we can write the expression as follows

$$P_a(p) = \sum_{x=0}^{c} \binom{n}{c} p^x (1-p)^{n-x} \quad (3)$$

$$AOQ = \frac{pP_a(p)(N-n)}{N} \quad (4)$$

$$ATI = n + (1 - p_a(p))(N-n) \quad (5)$$

Let D_d and D_n are the defective items detected and defective items not detected respectively.

Mathematically, these defective items are expressed as follows:-

$$D_d = np + (1 - P_a(p))(N-n)p \quad (6)$$

$$D_n = p_a(p)(N-n)p \quad (7)$$

Note that if the lot is rejected with probability $[1 - p_a(p)]$, it will be total inspection and the remaining $(N-n)p$ defective items will be detected. On the other hand, if the lot is accepted with probability $p_a(p)$, then $(N-n)p$ defective items will not be detected. To derive the total quality cost per lot for a given sampling plan, we define the following cost parameters:

Table.1 (a)

C = 4

TC	N	AOQ	ATI	D_d	D_n	1-p_a(AQL)	p_a(LTPD)	p_a(p)
717.19	150	0.0135	548.93	16.46	13.53	0.1830	0.0179	0.5306
757.37	160	0.0119	601.80	18.05	11.94	0.2179	0.0110	0.4740
794.91	170	0.0104	651.19	19.53	10.46	0.2546	0.0066	0.4202
829.48	180	0.0090	696.68	20.90	9.09	0.2927	0.0039	0.3698
860.91	190	0.0078	738.04	22.14	7.85	0.3317	0.0023	0.3234
889.16	200	0.0067	775.21	23.25	6.74	0.3711	0.0013	0.2809
914.29	210	0.0057	808.27	24.24	5.75	0.4105	0.0007	0.2426
936.42	220	0.0048	837.40	25.12	4.87	0.4495	0.0004	0.2084
955.76	230	0.0041	862.84	25.88	4.11	0.4879	0.0002	0.1781
972.51	240	0.0034	884.88	26.54	3.45	0.5252	0.0001	0.1514

Table.1 (b)

C = 8

TC	N	AOQ	ATI	D_d	D_n	1-p_a(AQL)	p_a(LTPD)	p_a(p)
438.42	150	0.0245	182.13	5.46	24.57	0.0034	0.2702	0.9621
455.45	160	0.0238	204.54	6.13	23.86	0.0051	0.2049	0.9469
474.46	170	0.0231	229.56	6.88	23.11	0.0076	0.1521	0.9282
495.46	180	0.0223	257.19	7.71	22.28	0.0162	0.1107	0.9058
518.35	190	0.0214	287.30	8.61	21.38	0.0149	0.0791	0.8798
542.95	200	0.0204	319.67	9.59	20.40	0.0201	0.0556	0.8504
569.05	210	0.0194	354.00	10.62	19.37	0.0265	0.0384	0.8177
596.32	220	0.0183	389.90	11.69	18.30	0.0342	0.0262	0.7821
624.48	230	0.0172	426.95	12.80	17.19	0.0433	0.0176	0.7442
653.18	240	0.0160	464.71	13.94	16.05	0.0539	0.0117	0.7043

Table.1 (c)

C = 12

TC	N	AOQ	ATI	D_d	D_n	1-p_a (AQL)	p_a(LTPD)	p_a(p)
414.41	150	0.0254	150.54	4.51	25.48	0.00001	0.7477	0.9993
422.34	160	0.0251	160.97	4.82	25.17	0.00002	0.6699	0.9988
430.46	170	0.0248	171.65	5.14	24.85	0.00004	0.5878	0.9980
438.84	180	0.0245	182.69	5.48	24.51	0.00007	0.5052	0.9967
447.58	190	0.0241	194.18	5.82	24.17	0.0001	0.4254	0.9948
456.76	200	0.0238	206.26	6.18	23.81	0.0002	0.3517	0.9921
466.49	210	0.0234	219.07	6.57	23.42	0.0003	0.2845	0.9885
476.88	220	0.0230	232.73	6.98	23.01	0.0005	0.2264	0.9836
488.01	230	0.0225	247.39	7.42	22.57	0.0008	0.1770	0.9774
500.00	240	0.0221	263.16	7.89	22.10	0.0012	0.1362	0.9695

Table.2 (a)

C = 4, C_i = 1, C_f = 2, C_o = 10

P	TC	n	AOQ	ATI	D_d	D_n	1-p_a(AQL)	LTPD	p_a(p)
0.01	239.67	140	0.0084	151.81	1.51	8.48	0.1504	0.0290	0.9862
0.02	456.68	150	0.0138	305.57	6.11	13.88	0.1830	0.0179	0.8169
0.04	948.97	160	0.0077	807.31	32.29	7.70	0.2179	0.0110	0.2293
0.06	1110.24	170	0.0011	981.22	58.87	1.12	0.2546	0.0066	0.0226
0.08	1159.71	180	0.0000	999.20	79.93	0.06	0.2927	0.0039	0.0009
0.10	1200	190	0.0000	999.98	99.99	0.0016	0.3317	0.0023	0.0005
0.12	1240	200	0.0000	1000	120	0.0000	0.3711	0.0013	0.0000
0.14	1280	210	0.0000	1000	140	0.0000	0.4105	0.0007	0.0000
0.16	1320	220	0.0000	1000	160	0.0000	0.4495	0.0004	0.0000
0.18	1360	230	0.0000	1000	180	0.0000	0.4879	0.0002	0.0000
0.20	1400	240	0.0000	1000	200	0.0000	0.5252	0.0001	0.0000

Table.2 (b)

C = 8, C_i = 1, C_f = 2, C_o = 10

P	TC	N	AOQ	ATI	D_d	D_n	1-p_a(AQL)	LTPD	P_a (p)
0.01	228.81	140	0.0085	140.01	1.40	8.593	0.0021	0.3480	0.9999
0.02	328.43	150	0.0169	152.89	3.05	16.94	0.0034	0.2702	0.9965
0.04	618.95	160	0.0271	321.99	12.87	27.12	0.0052	0.2049	0.8071
0.06	989.97	170	0.0151	748.19	44.89	15.10	0.0076	0.1521	0.3033
0.08	1146.91	180	0.0029	963.63	77.09	2.90	0.0108	0.1107	0.0443
0.10	1199.56	190	0.0002	997.81	99.78	0.21	0.0149	0.0791	0.0287
0.12	1240	200	0.0000	999.94	119.99	0.007	0.0202	0.0556	0.0000
0.14	1280	210	0.0000	1000	140	0.000	0.0265	0.0385	0.0000
0.16	1320	220	0.0000	1000	160	0.000	0.0342	0.0262	0.0000
0.18	1360	230	0.0000	1000	180	0.0000	0.0433	0.0176	0.0000
0.20	1400	240	0.0000	1000	200	0.0000	0.0539	0.0117	0.0000

Table.2 (c)

C = 12, C_i = 1, C_f = 2, C_o = 10

P	TC	n	AOQ	ATI	D_d	D_n	1-p_a(AQL)	LTPD	p_a(p)
0.01	228.81	140	0.0086	140	1.4	8.6	0.000005	0.8174	1.0
0.02	326.00	150	0.0169	150.01	3.00	16.99	0.00001	0.7477	0.9999
0.04	515.94	160	0.0331	170.50	6.82	33.17	0.00002	0.6699	0.9874
0.06	784.29	170	0.0387	354.41	21.26	38.73	0.00004	0.5878	0.7778
0.08	1068.21	180	0.0203	745.03	59.60	20.39	0.00007	0.5052	0.3109
0.10	1191.66	190	0.0041	958.31	95.83	4.16	0.0001	0.4254	0.2407
0.12	1239.89	200	0.0003	997.17	119.66	0.339	0.0002	0.3512	0.0035
0.14	1280	210	0.0000	999.96	139.99	0.0043	0.0003	0.2845	0.0001
0.16	1320	220	0.0000	999.99	160	0.0002	0.0005	0.2264	0.0000
0.18	1360	230	0.0000	1000	180	0.0000	0.0008	0.1770	0.0000
0.20	1400	240	0.0000	1000	200	0.0000	0.0012	0.1362	0.0000

Table.3

$C = 10$, $C_f = 0.2$, $C_o = 10$

C_i	TC	n	AOQ	ATI	D_d	D_n	1-p_a(AQL)	LTPD	p_a(p)
0.1	200	1000	0.00	1000	50	0.00	0.9999	0.0000	0.00005
0.2	300	1000	0.00	1000	50	0.00	0.9999	0.0000	0.00005
0.5	600	1000	0.00	1000	50	0.00	0.9999	0.0000	0.00005
1.0	1070.08	200	0.0024	950.12	47.50	47.50	0.2132	0.00024	0.0623
2.0	2020.20	200	0.0024	950.12	47.50	47.50	0.2132	0.0044	0.0623
3.0	2970.33	200	0.0024	950.12	47.50	47.50	0.2132	0.0044	0.0623
4.0	3920.45	200	0.0024	950.12	47.50	47.50	0.2132	0.0044	0.0623
5.0	4870.58	200	0.0024	950.12	47.50	47.50	0.2132	0.0044	0.0623
6.0	5820.71	200	0.0024	950.12	47.50	47.50	0.2132	0.0044	0.0623
7.0	6770.83	200	0.0024	950.12	47.50	47.50	0.2132	0.0044	0.0623
8.0	7720.96	200	0.0024	950.12	47.50	47.50	0.2132	0.0044	0.0623
9.0	8671.08	200	0.0024	950.12	47.50	47.50	0.2132	0.0044	0.0623
10.0	9621.21	200	0.0024	950.12	47.50	47.50	0.2132	0.0044	0.0623

Table.4 (a)

$C=10$, $C_i=1$, $C_o=10$

C_f	TC	n	AOQ	ATI	D_d	D_n	1-p_a(AQL)	P_a(LTPD)	p_a(p)
0.0	200	200	0.0233	533.54	26.67	23.32	0.0025	0.1616	0.5830
0.5	300	200	0.0233	533.54	26.67	23.32	0.0025	0.1616	0.5830
1.0	600	200	0.0233	533.54	26.67	23.32	0.0025	0.1616	0.5830
2.0	1770.08	200	0.0233	533.54	26.67	23.32	0.0025	0.1616	0.5830
3.0	2020.20	200	0.0233	533.54	26.67	23.32	0.0025	0.1616	0.5830
4.0	2970.33	200	0.0233	533.54	26.67	23.32	0.0025	0.1616	0.5830
5.0	3920.45	200	0.0233	533.54	26.67	23.32	0.0025	0.1616	0.5830
6.0	4870.58	200	0.0233	533.54	26.67	23.32	0.0025	0.1616	0.5830
7.0	5820.71	200	0.0233	533.54	26.67	23.32	0.0025	0.1616	0.5830
8.0	6770.83	200	0.0233	533.54	26.67	23.32	0.0025	0.1616	0.5830
9.0	7720.96	200	0.0233	533.54	26.67	23.32	0.0025	0.1616	0.5830
10.0	8671.08	200	0.0233	533.54	26.67	23.32	0.0025	0.1616	0.5830

Table.4 (b)

$C = 10$, $C_i = 0.2$, $C_o = 10$

C_f	TC	n	AOQ	ATI	D_d	D_n	1-p_a(AQL)	p_a(LTPD)	p_a(p)
0.0	200	1000	0.000	1000	50	0.00	0.9897	0.0000	0.00005
0.5	225	1000	0.000	1000	50	0.00	0.9897	0.0000	0.00005
1.0	250	1000	0.000	1000	50	0.00	0.9897	0.0000	0.00005
2.0	339.29	200	0.0233	533.54	26.67	23.32	0.0025	0.1661	0.5830
3.0	419.96	200	0.0233	533.54	26.67	23.32	0.0025	0.1661	0.5830
4.0	446.64	200	0.0233	533.54	26.67	23.32	0.0025	0.1661	0.5830
5.0	473.32	200	0.0233	533.54	26.67	23.32	0.0025	0.1661	0.5830
6.0	500	200	0.0233	533.54	26.67	23.32	0.0025	0.1661	0.5830
7.0	526.67	200	0.0233	533.54	26.67	23.32	0.0025	0.1661	0.5830
8.0	553.35	200	0.0233	533.54	26.67	23.32	0.0025	0.1661	0.5830
9.0	580.03	200	0.0233	533.54	26.67	23.32	0.0025	0.1661	0.5830
10.0	606.70	200	0.0233	533.54	26.67	23.32	0.0025	0.1661	0.5830

Table.5

$C_i = 1$, $C_f = 2$, $p = 0.05$

C_o	TC	N	AOQ	ATI	D_d	D_n	$1-p_a(AQL)$	$p_a(LTPD)$	$p_a(p)$
10	820.12	200	0.0233	533.54	26.67	23.32	0.0025	0.1661	0.5830
20	1053	200	0.0233	533.54	26.67	23.32	0.0025	0.1661	0.5830
30	1286	200	0.0233	533.54	26.67	23.32	0.0025	0.1661	0.5830
40	1519.81	200	0.0233	533.54	26.67	23.32	0.0025	0.1661	0.5830
50	1100	1000	0.0000	1000	50	0.00	0.9897	0.0000	0.00005
60	1100	1000	0.0000	1000	50	0.00	0.9897	0.0000	0.00005
70	1100	1000	0.0000	1000	50	0.00	0.9897	0.0000	0.00005
80	1100	1000	0.0000	1000	50	0.00	0.9897	0.0000	0.00005
90	1100	1000	0.0000	1000	50	0.00	0.9897	0.0000	0.00005
100	1100	1000	0.0000	1000	50	0.00	0.9897	0.0000	0.00005

Fig.1 Optimal AOQ vs. p at C=4, AQL =0.02, LTPD=0.07, α=0.05, and β=0.10

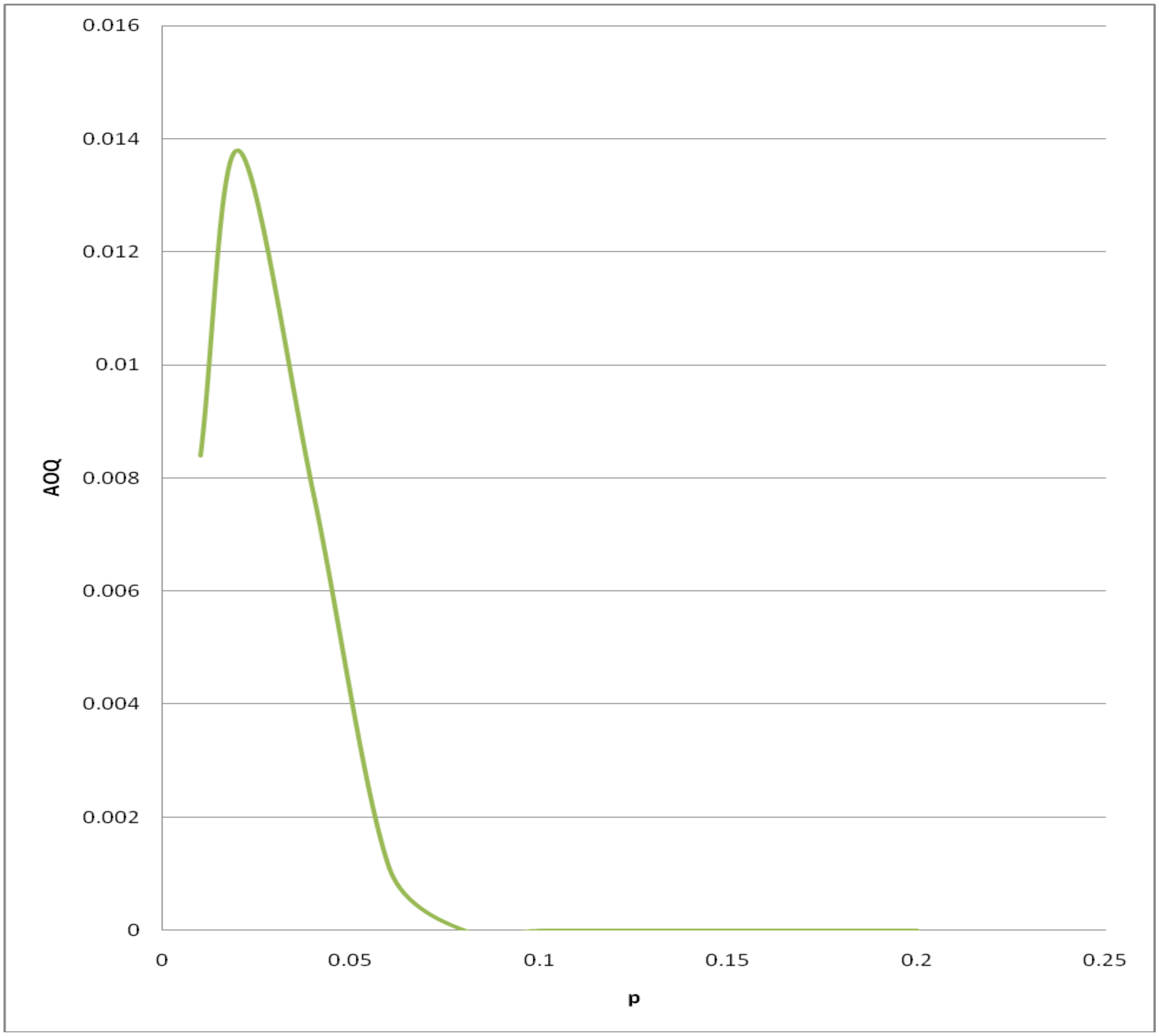


Fig.2 Optimal AOQ vs. p at C=8, AQL =0.02, LTPD=0.07, α=0.05, and β=0.10

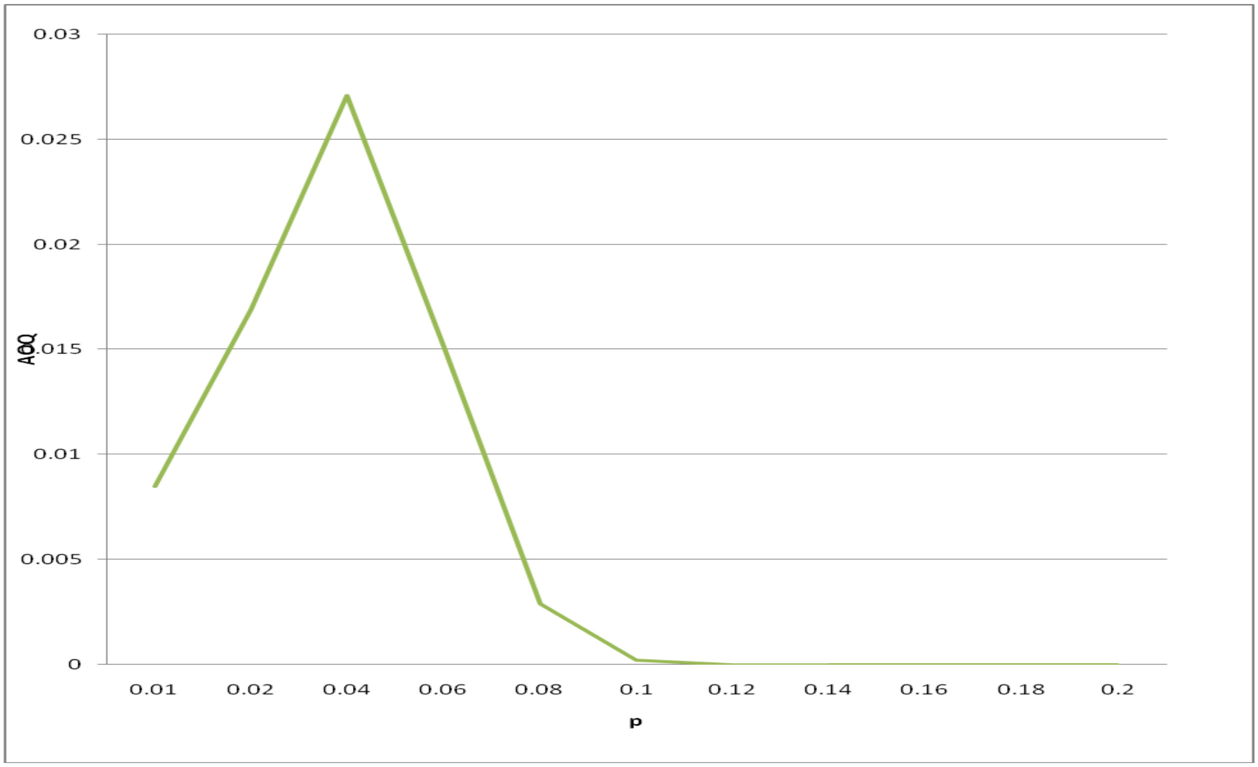
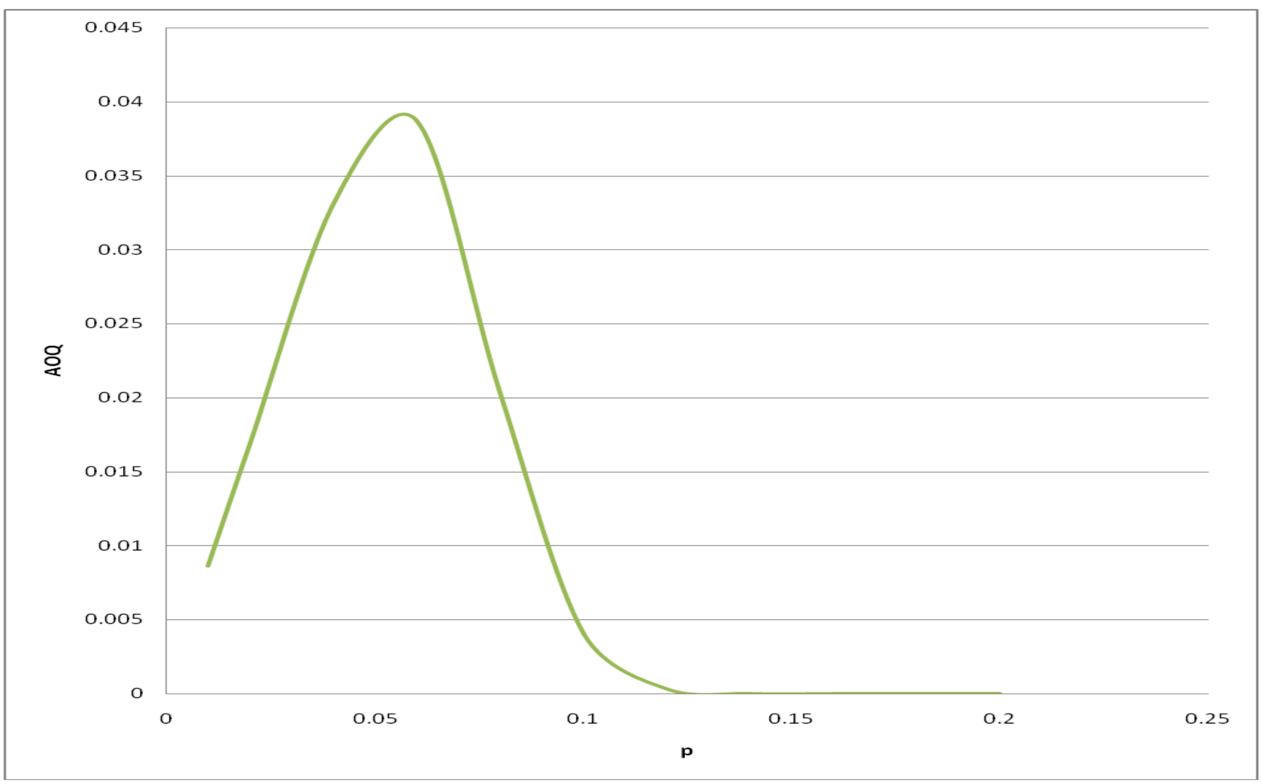


Fig.3 Optimal AOQ vs. p at C=12, AQL =0.02, LTPD=0.07, α=0.05, and β=0.10



C_i = Cost of Inspection per item
C_f = Cost of failure before-sale of item
C_o = Cost of failure after sale of item

An economic sampling plan can be achieved with the help of this model as following

Minimize $TC = C_i.ATI + C_f.D_d + C_o.D_n$ (8)

Subject to

$1 - p_a(AQL) \leq \alpha$ (9)

$p_a(LTPD) \leq \beta$ (10)

Results and Discussion

To construct a single sampling plan with this economic model, we assume producer's risk (α) = 5%, consumer's risk (β) = 10%, p_1 = 2%, p_2 = 7% and p = 3%, lot size (N) = 1000 and various costs are cost of inspection (C_i) = 1.0, cost of internal failure (C_f) = 2.0 and cost of post-failure (C_o) = 1.0.

Discussion of single sampling plan about parameters from table 1(a), 1(b), 1(c) shows that sample size(n) varies from n = 150 to n = 240,it is clear that if n increases then (α, ATI) increase and β decreases while c remains fixed. On the other hand when c increases then (α, ATI) decrease while n remains fixed. On the basis of these records, a suitable optimal plan is n = 150, c = 12 and minimum (TC) = 414.41.On comparing if α =0, β = 1, n = 0, TC = 300 which is unfavorable to the consumer. With this discussion it is clear that we are bound to meet the required specifications for both producer and consumer.

Table 2(a), it is observed that on the part of sensitivity analysis to find optimal sampling plan when p varies. If p increases, then n and ATI also increases. It is observed that if p ≥ 0.12, c = 4 and n increases then ATI behave as constant (i.e. ATI = 1000) and AOQ = 0.On the other hand, from table 2(b), c = 8, p ≥ 0.14, n increases, but ATI behave as constant (i.e. ATI = 1000) and AOQ = 0.At the end, from table 2(c) c = 12, ATI increases as n and p increases but at p ≥ 0.14, AOQ = 0.

Table 3, C_i varies from 0.1 to 10.0 If $C_i \leq 0.5$, we have optimal total cost.On the other hand C_i increases the total cost also increases and all the other results remains constant.

Table 4(a), C_i is not sensitive about total cost as C_f increases then TC also increases at C_i =1.while table 4(b) shows that C_f is more sensitive about TC at C_i = 0.2.

Table 5, shows that $C_o \geq 40$ is sensitive towards TC, however $C_o \geq 50$, the optimal sampling plan tends to total inspection of the lot.

Finally, figure-1, 2, and 3 show the average outgoing quality (AOQ) of the corresponding optimal sampling plan as a function of the given producer's product quality p. One can see that the optimal AOQ curve is similar to the OC curve. When, p increases the optimal AOQ increases up to a certain point and then the optimal AOQ decreases. When p reaches a certain value, the optimal sampling plan is to have a 100% inspection of the entire lot and the optimal AOQ becomes zero.

We have been discussed an acceptance sampling plan with consideration of an economic criteria to meet the producer's and consumer's specifications. In this paper an economical model has been used to find an optimal single sampling plan that can minimize the producer's total cost and provide a protection for both producer as well as consumer. Here, from the discussion of tables and graphs analysis, we observe that the optimal sampling plan is very sensitive to the producer's product quality. The product inspection cost of internal and after sale failure also have effects on the choice of the economic sampling plan as discussed in this paper.

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