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Minimum ATI Sampling Plan Indexed Through MAAOQ

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Abstract: This paper is a practical application of designing accurate sampling plan in acceptance sampling replacing AOQL by MAAOQ, eliminating the setbacks of Dodge-Romig (1952) plan. The need of using MAAOQ instead of AOQL is illustrated and the accuracy and direct applicability of the method is explained. The efficiency of the plan compared to Dodge plan is depicted using ATI Table, OC curve and AOQ curve. Also the sampling plans and minimum ATI for many pairs of process average and MAAOQ is developed. The paper is an initiative to reduce the error occurred in the Dodge Sampling plan due to the graphic errors and approximation errors. Exact sampling plans at any MAAOQ can be determined using computer algorithm so that there is no need of tables or graphs. Also the process average is accounted showing the consistency with control chart. The efficiency of this plan over Dodge sampling plan in terms of sample size, minimum ATI and probability of acceptance at better quality levels were shown. A chance for shifting the outgoing quality from MAAOQ to an extreme point AOQL is also mentioned in the study.

Introduction

This is an analogue to the fundamental study of designing sampling plan by Dodge-Romig (1952) fixing outgoing quality and minimizing the cost of inspection. If the process is under control and observed by a control chart, then process average is also taken as additional information to fix the sampling plan as in Dodge-Romig study. Even though AOQL is the utmost outgoing quality, it could not be practically attained by a lot, (Anascombe 1958) as it is only mathematically but not logically developed. MAAOQ is the ordinate of MAPD which is the maximum tolerable incoming quality and incorporating more defective incoming quality as to reduce the outgoing quality is not logically acceptable. Thus AOQL is only a mathematical optimum which could not be practically achieved in a lot inspection process. MAPD suggested by Mandelson (1962) and established by Mayer (1967) is highly consumer protective, fulfilling the quality aspirations of engineers and inspection technicians. Pandey (1988) has studied the three-decision ASR plan with an outgoing quality measure - Inflection Average Outgoing Quality- IAOQ. Ramkumar (1996) pointed out the scope of an outgoing tolerance quality -MAAOQ- instead of AOQL and developed sampling plans. Maximum Allowable Average Outgoing Quality (MAAOQ) is the average

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Key words and phrases: Min-ATI; MAAOQ; Sampling Plan; OC curve; AOQ Curve.

outgoing quality at the inflection point of OC curve say MAPD = c/n. There are many sampling designs developed using MAAOQ in Single, Double, Conditional, Skiplot , Continuous, Link, Chain sampling plans and in switching systems. R Radhakrishnan, R.Sampath Kumar, K.K. Suresh, Mallika, Jayalakshmi were significantly contributed sampling plan designs on MAAOQ during the period 1996-2015. Ramkumar and Erick (2017) had presented a new single sampling plan on MAPD with minimum ATI in line with Dodge Romig LTPD sampling plan minimizing Average total inspection. Even though Dodge-Romig's MAAOQ-Min ATI sampling plan holds the consumer's and producer's interests ,still there is a need to extend the Dodge plan due to some misuse of this plan as mentioned by Avik Ganguly (2009) in his research paper explaining the misuse, frivolous use, and need of expansion for usefulness of Dodge-Romig sampling plan.

MAAOQ is the worst average outgoing percent of defectives practically attained by a product under sampling inspection with replacement of defectives by non-defectives. It is the outgoing product quality at MAPD so that the consumer is convinced of its incoming quality level, declining trend of quality and uniqueness of the sampling plan. Also it provides a provision for improvement of quality to an ultimate limit. MAAOQ plotted in the OC curve directly implies the acceptable area on OC curve with which the customer reliably accepts a product. Thus MAAOQ is the practical maximum percent defectives allowed and attained. Due to the accountability of MAAOQ as an outgoing measure, based on incoming inflection point on OC curve, it is considered here as the first parameter to design the sampling plan. It will protect the consumer's interest especially on in-plant inspections and in the case of semi-finished products. Fixing the producer's interest in terms of minimum ATI, it will minimize the cost of inspection.

Minimizing average total inspection subject to a prefixed maximum allowable average outgoing quality, a single sampling plan could be developed similar to Dodge –Romig AOQL-Min.ATI plan. It is a more logical, incoming quality –MAPD- based, and outgoing quality-MAAOQ- protected sampling plan. The parameters of the sampling plan satisfy all properties of Dodge's method. Also this plan is based on process average under process control upon which modification of the plan is automatically carried out.

Efficiency of MAAOQ- Min.ATI Sampling Plan

Compared to Dodge's Single Sampling Plan with AOQL protection this sampling plan is more efficient due to the following reasons: The OC curve associated with this plan is more efficient in protecting producer's interest. i.e The probability of acceptance is a little more at all levels of incoming quality. (Fig:3 OC curves). Probability of acceptance at better quality and lower quality were equal in both sampling plans, while an additional acceptance is found at medium quality indicating the satisfaction of the consumers. Sample size required for the AOQL plan is high compared with MAAOQ plan. (Table:1 , Fig: 4). MAAOQ plan has a min. ATI compared to AOQL plan so that it is producer friendly.(Table:1) Dodge's result need graphs so that the approximate values of the parameter were only available, while algorithmic optimal solutions are obtained in this paper easily. Incoming product quality MAPD is the basis of fixing MAAOQ (Fig:1) , hence this plan is comparable with other MAPD plans. MAAOQ is logical, based on OC curve so that comparison is possible with other sampling plans based on OC curve. But AOQL has no direct influence on OC curve and its incoming quality had no any significance as an incoming quality. By taking AOQL instead of MAAOQ, barely a little more quality is attained (Fig:2), but cost incurred is very high due to increase in ATI(Tabe:1) and in practice AOQL is seldom attainable. If the lot satisfies MAAOQ consistently one can enhance the quality level to AOQL so that reduction –tightening process is possible. (Fig: 4). AOQ curve has inflection point at $p^*+2/n > p^*$, so it is not unreasonable to fix outgoing quality at p^* or nearby. nMAAOQ is a direct function of only c and it is more legible than nAOQL which is a function of complicated np_m where p_m is not a significant incoming quality (Fig:1). A computer program is prepared to evaluate n, c directly for any combination of MAAOQ and process average. As in Dodge plan there is no need of evaluating Z and comparing Z for various M to distinguish the minimum c and n.

Comparison of ATI

The following Table illustrates the need for minimizing Average Total Inspection. The probability of acceptance increases when the sample size increases but the required total inspection for termination of the lot by sample as well as the remaining of the lot is reduced to some extent. Though the sample size increases minimum ATI is realized ensuring a balanced sampling plan with sample and part of lots at a given process average and MAAOQ or AOQL for fixed lot size. From Table:1 it is found that the MAAOQ=4.5% can be attained with an inspection of minimum average of 69 units, comprised of 56 sample units and 13 remainder units. The min. ATI occurs at c=4, so that optimum sampling plan is (56,4). When the outgoing quality is fixed at AOQL=4.5% keeping the same process average, the min. ATI is 71 units, higher than MAAOQ sampling plan. Also the sampling plan requires one more unit in the sampling inspection (57, 4) instead of (56,4).

Table:1. Min.ATI for given N, P_M, P_L, $\bar{p}$

Process Average **1.35% k=0.30, N=10000,**					
MAAOQ **=4.5%**			AOQL=**4.5%**		
Samp. Size n	Accept No.c	ATI	Sam Size.n	Accept. No.c	ATI
17	1	259	19	1	316
31	2	130	31	2	130
44	3	81	44	3	81
56	**4**	**69**	**57**	**4**	**71**
69	5	74	71	5	77
81	6	83	85	6	87
94	7	95	100	7	101

Comparison of OC and ATI Curves

For N= 6000, MAAOQ=5% =AOQL, with process average =1.5% the OC curves are given in Fig: 3. From this one can see that probability of acceptance at good quality level is more assured in MAAOQ plans than in AOQL plan. Thus MAAOQ –Min.ATI Plan is also producer friendly. From the AOQ curve (Fig:4) it is found that keeping AOQL at MAAOQ for fixed c, the sample size is increased. Thus for producers requiring a certain level of AOQL, one can redefine the outgoing percent defective in terms of MAAOQ. Hence the required level is attained with smaller sample size.

Construction of sampling plan

Probability of acceptance of a lot at a proportion defective p is defined as

$$P_{a}(p)=\sum_0^c \frac{e^{-np}\, np^r}{r!}$$

when the no. of defectives of the lot follow Poisson distribution.

The point of inflection of OC curve is obtained from the equation $\frac{d^2\left(P_{a}(p)\right)}{dp^2} = 0$, which gives p*=c/n or np*=c. From Dodge's Equation

$ATI\ at\ p = \bar{p}$, I= $+(N-n)(1-P_{a}(\bar{p})\ ) = N-(N-n)P_{a}(\bar{p})$ ……………………(1)

IP_M =Z=NP_M - NP_M . $P_{a}(\bar{p})$ + nP_M . $P_{a}(\bar{p})$ where MAAOQ = P_M = p^*Pa(p^*)

Let M =N. P_M , Then Z=M - M. $\sum_0^c \frac{e^{-n\bar{p}}\,(n\bar{p})^r}{r!} + \sum_0^c \frac{e^{-np^*}\,(np^*)^{r+1}}{r!} . \sum_0^c \frac{e^{-n\bar{p}}\,(n\bar{p})^r}{r!}$

Let k=$\frac{\bar{p}}{P_M}$ then n$\bar{p} = n\frac{\bar{p}}{P_M} P_M$ =k.nP_M =$\sum_0^c \frac{e^{-np^*}\,(np^*)^{r+1}}{r!}$ =k. $\sum_0^c \frac{e^{-c}\,c^{r+1}}{r!}$=k. $\varphi(c)$

Where $\varphi(c) = \sum_0^c \frac{e^{-c}\,c^{r+1}}{r!}$ which is only a function of c.

Z=M - M. $\sum_0^c \frac{e^{-k.\varphi c}\,(k.\varphi(c))^r}{r!} + \varphi(c). \sum_0^c \frac{e^{-k.\varphi c}\,(k.\varphi(c))^r}{r!}$ ………………………..(2)

Also find Z=M - $M.\sum_0^{c+1} \frac{e^{-k.\varphi(c+1)}\,(k.\varphi(c+1))^r}{r!} + \varphi(c+1).\sum_0^{c+1} \frac{e^{-k.\varphi(c+1)}\,(k.\varphi(c+1))^r}{r!}$........(3)

For a fixed N, MAAOQ, and process average, determine M=N P_M and k=$\frac{\bar{p}}{P_M}$.

Put values of c =1,2,3,.......in the above equation(2), Z is a linear equation on M for fixed c, k. The value of c satisfying the above equations is the minimum acceptance number, which is used to determine minimum sample size. Since nMAAOQ is a monotonically increasing function in c, the minimum acceptance number provides minimum sample size. Putting c=1,2...40, the values of nMAAOQ are obtained in Table:2.

If there exists no solution for this equation within a reasonable successive values of c, here it is taken as maximum 30, equate c with c+2 and so on. Z is a linear function in M for fixed c so the common solution of equations will give Min. ATI. For example, when N=6000, P_M=0.05, $\bar{p}$=0.015 the equations (2) & (3) coincides at c=3 and for all other values, Z is different. (Fig: 2). From the Figure 2, it is seen that Z is minimum with c=3 upto the intersections of two straight lines (up to Z= 302) and then Z is minimum for c=4 in a range of M=250-350 considered. Also from the value of Z one can determine min. ATI, Z/P_M=2.83/0.05 =56.6=57.

Thus for given values of N, P_M, & $\bar{p}$ the optimum sampling plan with min. ATI can be fixed by observing minimum c. Then n can be determined indirectly using the formula P_M= p*.Pa(p*) as n= $\varphi(c)$/P_M. Also n can be calculated directly and exactly.

By definition AOQ = p.(N-I /N) , then MAAOQ= AOQ at p=p^* where I is the ATI of sampling plan

MAAOQ=$p^* \frac{N-\{n+(N-n)\left(1-P_{a(p^*)}\right)\}}{N} = p^* \frac{N-\{n+(N-n)\left(1-P_{a(p^*)}\right)\}}{N} = p^* \frac{N-n\left(P_{a(p^*)}\right)}{N}$

ie $P_M = \left(\frac{1}{n} - \frac{1}{N}\right).\varphi(c).\quad P_M \approx \frac{1}{n}\varphi(c).$

Min ATI- direct method

Min .ATI can also be obtained directly as follows:

nMAAOQ = nP_M = $\varphi(c)$ implies n= $\frac{\varphi(c)}{\mathrm{P_M}}$

then ATI at p= $\bar{p}$ =I= n+(N-n)1-$P_{a(\bar{p})}$

substituting for n=$\frac{\varphi(c)}{\mathrm{P_M}}$ and n$\bar{p}$ =n. $\frac{\bar{p}}{\mathrm{P_M}}$. $\mathrm{P_M}$ =k .n$\mathrm{P_M}$ where k=$\frac{\bar{p}}{\mathrm{P_M}}$

I(c)= $\frac{\varphi(c)}{\mathrm{P_M}} + \left(N - \frac{\varphi(c)}{\mathrm{P_M}}\right) 1 - \sum_0^c \frac{e^{-k.\varphi(c)}\left(k.\varphi(c)\right)^r}{r!}$ ....(4)

For fixed N, $\mathrm{P_M}$, $\bar{p}$, k is found out and substitute c=1,2,3.. in the equation (4) .Then the values of ATI corresponding to each c say I(c) is obtained and minimum of it can be located by proper algorithm. Hence min ATI and optimum c is derived and then n=$\frac{\varphi(c)}{\mathrm{P_M}}$ is determined by extension of the algorithm.

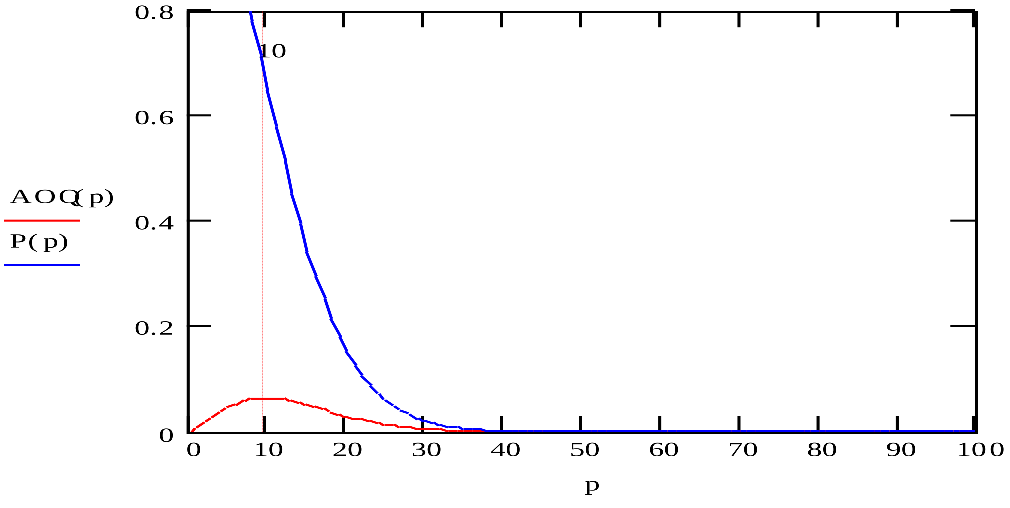
Construction of Figures and Tables

Fig(1) and Fig(2) display the OC curve and AOQ curve for a fixed plan showing the significance of MAAOQ and distinguishes it from AOQL. Fig:3 show straight lines for min. Z corresponding to different values of c, from which min. ATI can be obtained for M=250-350. It is obtained by substituting values of M in equation (2) &(3) , fixing k= $P_M/\bar{p}$, =0.015/0.05=0.3, for c=3. Fig:4 is obtained by plotting equation (3) for c=1,2,....20 giving optimum c and minimum ATI. Fig:5 give OC curves showing probability of acceptance of MAAOQ and AOQL- min ATI plans having same MAAOQ and AOQL with respective plan (56,5) and (58,5). .Fig:6 shows the AOQ curves for same MAAOQ & AOQL on the above plans.

Table: 1 give min. ATI for given N=10000, P_M & P_L =4.5 % at p=1.5% and it is obtained from the equation (1). Table: 2 the values of M up to which min. ATI exists at the specified c. The values are determined at certain k using the equation (2) and (3). Table:.3 gives parametric details of sampling plans and min .ATI at specified values of P_M ,and $\bar{p}$, and N= 500,1000,5000,10000. Conversion table to detect other parameters of the sampling plan obtained from authors paper (1994).

Fig:1 MAPD on OC curve and MAAOQ on AOQ curve for (30,3)

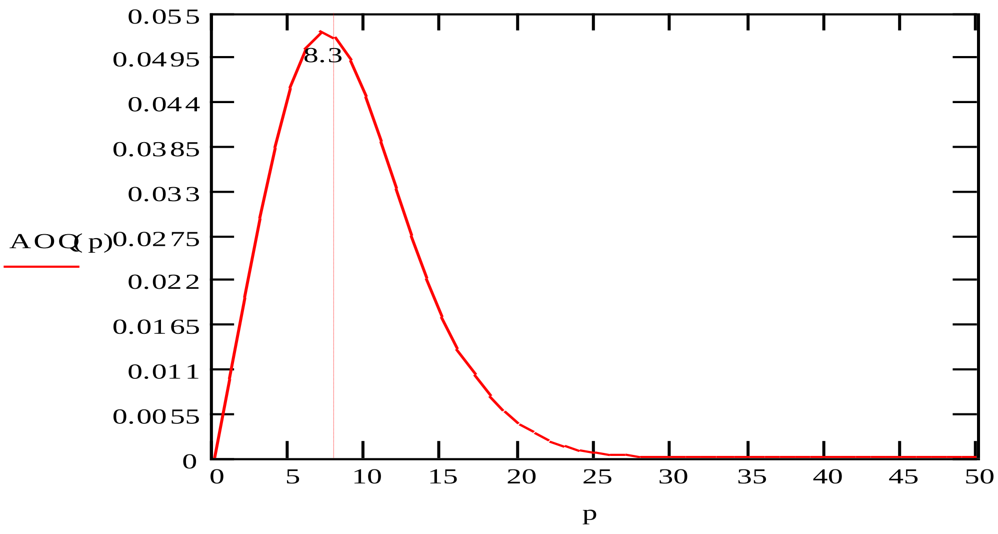
$n := 30$ $c := 3$



$\mathrm{MAPD} := .10$ $\mathrm{AOQL} := 0.065$ $\mathrm{MAAOQ} := .0647$

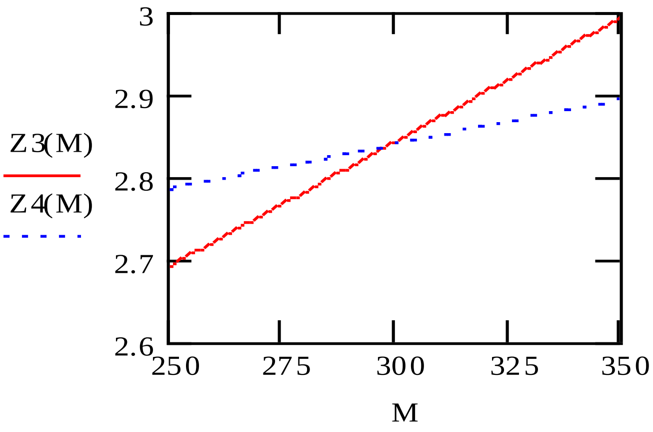
Fig:2 AOQ curve for a single sampling plan (100,3)

n := 100 c := 3



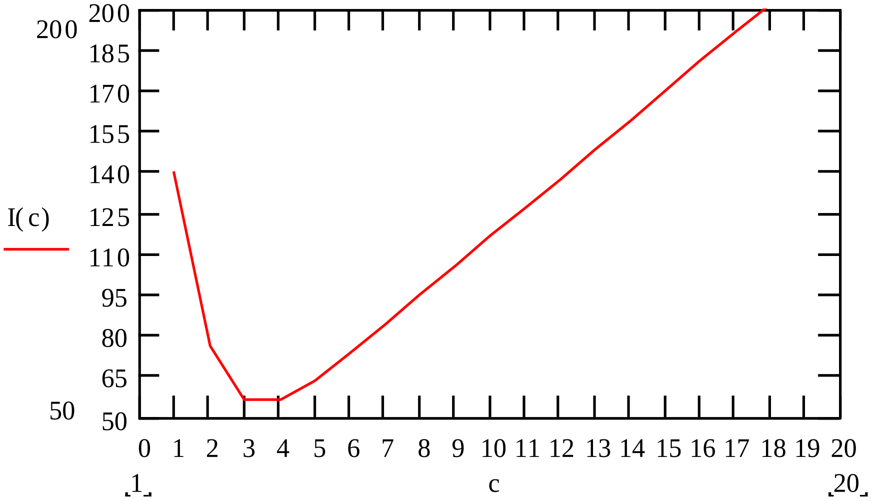
MAPD := .083 AOQL := 0.053 MAAOQ := .0517

Fig: 3: Value of Z for the range of M =250-350 for c=3 from equation (1) & (2)



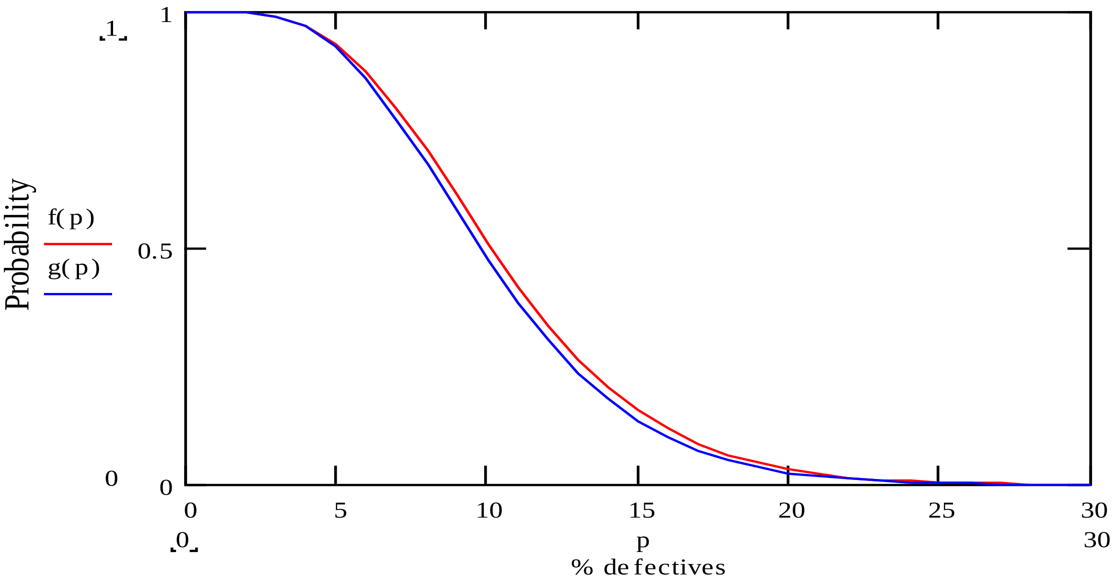
Z is minimum till M=302 (250<M<302) for c=3 and Z is minimum for c=4 when M>302 (302<M<350).

Fig:4 Min.ATI, Ic and min.c for given N, $\bar{p}$, P



From the figure c=3 and Min.ATI=53 for N=6000, $\bar{p}$ = 0.015, P_M=0.05, k=0.3

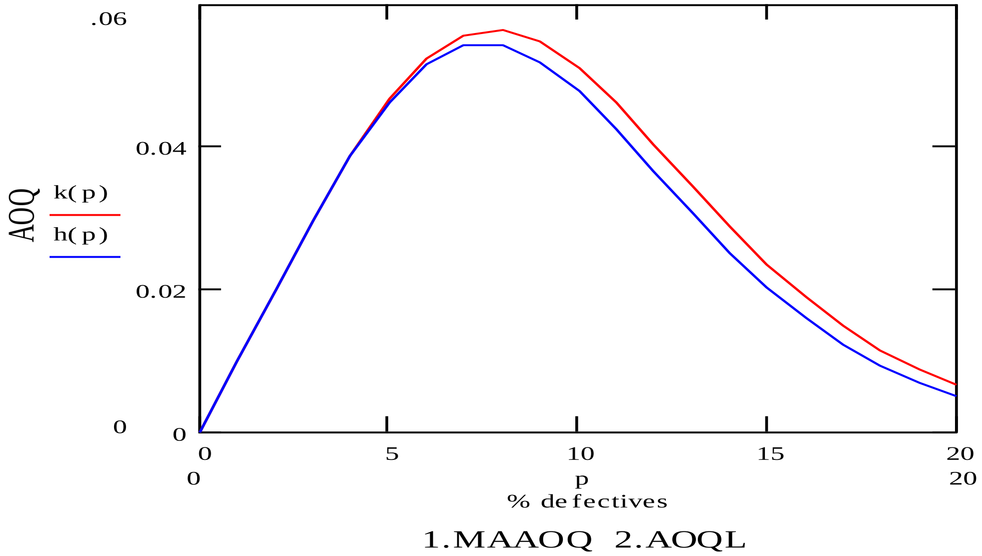
Fig: 5.OC curves for Min ATI plan keeping MAAOQ = AOQL , N=6000 , $\bar{p}$ =1.5%



1:MAAOQ 2.AOQL

1.f (p):MAAOQ =5.5%, (56,5). 2.g(p):AOQL =5.5%, (58,5)

Fig: 6.AOQ curves for fixed AOQL= MAAOQ.



1.k(p): MAAOQ =5.5%, AOQL=5.7%, (56,5). 2.h(p):AOQL =5.5%, (58,5)

Table:2 n MAAOQ **=** $\varphi(c)$ for c=1-40

c	$\varphi(c)$	c	$\varphi(c)$	c	$\varphi(c)$	c	$\varphi(c)$
1	0.736	11	6.372	21	11.711	31	16.975
2	1.353	12	6.912	22	12.24	32	17.499
3	1.942	13	7.45	23	12.768	33	18.022
4	2.515	14	7.986	24	13.296	34	18.545
5	3.08	15	8.521	25	13.823	35	19.068
6	3.638	16	9.055	26	14.35	36	19.59
7	4.191	17	9.588	27	14.875	37	20.112
8	4.74	18	10.12	28	15.401	38	20.634
9	5.287	19	10.652	29	15.926	39	21.155
10	5.83	20	11.182	30	16.451	40	21.677

Table:3a Sampling Plans ,Min ATI for specified MAAOQ, process average for N=500

	P_M							
$\bar{p}$	0.01	0.02	0.03	0.05	0.06	0.08	0.09	0.1
0.001	74,1,75	37,1,37	25,1,25	15,1,15	12,1,12	9,1,9	8,1,8	7,1,7
0.003	74,1,83	37,1,39	25,1,26	15,1,15	12,1,13	9,1,9	8,1,8	7,1,7
0.005	74,1,96	37,1,44	25,1,28	15,1,16	12,1,13	9,1,10	8,1,9	7,1,8
0.008	74,1,123	37,1,53	25,1,33	15,1,18	12,1,14	9,1,10	8,1,9	7,1,8
0.01	74,1,145	37,1,61	25,1,37	15,1,19	12,1,16	9,1,11	8,1,10	7,1,8
0.02	74,1,258	37,1,115	25,1,66	15,1,32	12,1,25	9,1,17	8,1,14	7,1,12
0.05		37,1,291	25,1,189	15,1,96	42,4,70	24,3,41	22,3,33	19,3,28
0.1			25,1,359	15,1,225		59,8,123	53,8,92	42,7,71

Table:3b Sampling Plans ,Min ATI for specified MAAOQ, process average for N=1000

	P_M							
$\bar{p}$	0.01	0.02	0.03	0.05	0.06	0.08	0.09	0.1
0.001	74,1,76	37,1,37	25,1,25	15,1,15	12,1,12	9,1,9	8,1,8	7,1,7
0.003	74,1,93	37,1,42	25,1,27	15,1,16	12,1,13	9,1,10	8,1,8	7,1,8
0.005	74,1,123	37,1,51	25,1,31	15,1,17	12,1,14	9,1,10	8,1,9	7,1,8
0.008	74,1,183	37,1,71	25,1,41	15,1,21	12,1,17	9,1,12	8,1,10	7,1,9
0.01	74,1,230	37,1,88	25,1,49	15,1,24	12,1,19	9,1,13	8,1,11	7,1,10
0.02	74,1,474	37,1,199	65,3,105	27,2,44	23,2,33	17,2,22	15,2,19	14,2,16
0.05				84,7,142	61,6,94	38,5,52	28,4,42	25,4,34
0.1						107,15,174	83,13,122	64,11,92

Table:3c Sampling Plans ,Min ATI for specified MAAOQ, process average for N=1000

	P_M							
$\bar{p}$	0.01	0.02	0.03	0.05	0.06	0.08	0.09	0.1
0.001	74,1,86	37,1,40	25,1,26	15,1,15	12,1,13	9,1,9	8,1,8	7,1,7
0.003	135,2,175	37,1,65	25,1,37	15,1,19	12,1,16	9,1,11	8,1,10	7,1,8
0.005	194,3,277	68,2,92	45,2,53	15,1,28	12,1,21	9,1,14	8,1,12	7,1,11
0.008	308,5,494	97,3.137	65,3,75	27,2,34	23,2,27	27,2,19	15,2,16	14,2,15
0.01	419,7,709	126,4,171	65,3,86	27,2,41	23,2,31	27,2,20	15,2,18	14,2,15
0.02		319,11,458	140,7,179	50,4,69	42,4,50	24,3,32	22,3,27	19,3,23
0.05				181,16,238	115,12,147	59,8,77	47,7,60	42,7,49
0.1					731,83,1226	225,33,294	154,25,193	112,20,139

Table:3d Sampling Plans ,Min ATI for specified MAAOQ, process average for N=10000

$\bar{p}$	P_M							
	0.01	0.02	0.03	0.05	0.06	0.08	0.09	0.1
0.001	74,1,99	37,1,43	25,1,27	15,1,16	12,1,13	9,1,10	8,1,9	7,1,8
0.003	135,2,217	68,2,80	45,2,49	15,1,24	12,1,19	9,1,13	8,1,11	7,1,10
0.005	251,4,343	97,3,113	45,2,61	27,2,31	23,2,24	17,2,18	15,2,16	7,1,14
0.008	474,8,625	126.4,163	65,3,84	27,2,41	23,2,31	17,2,21	15,2,18	14,2,15
0.01	637,11,917	154,5,204	84,4,101	39,3,46	32,3,36	17,2,24	15,2,20	14,2,17
0.02		426,15,561	158,8,210	62,5,79	51,5,58	31,4,36	27,4,31	19,3,26
0.05				224,20,278	133,14,169	73,10,87	59,9,68	47,8,55
0.1						271,40,345	183,30,223	133,24,159

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