

## **Selection of mixed sampling plan with double sampling plan as attribute plan indexed through MAPD and AQL using IRPD**

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### **ABSTRACT**

*This paper presents the procedure for the construction and selection of mixed sampling plan (MSP) using Intervened Random effect Poisson Distribution (IRPD) as a baseline distribution. Having the double sampling plan as attribute plan, the plans are constructed through acceptable quality level (AQL) and maximum allowable percent defective (MAPD). Tables are constructed for easy selection of the plan.*

**Key words and phrases:** *acceptable quality level, intervention, mixed sampling plan, maximum allowable percent defective, operating characteristic, intervened random effect poisson distribution.*

**AMS (2000) Subject Classification Number:** *Primary: 62P30 Secondary: 62D05*

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### **INTRODUCTION**

Mixed sampling plans consist of two stages of rather different nature. During the first stage the given lot is considered as a sample from the respective production process and a criterion by variables is used to check process quality. If process quality is judged to be sufficiently good, the lot is accepted. Otherwise the second stage of the sampling plan is entered and lot quality is checked directly by means of an attribute sampling plan.

There are two types of mixed sampling plans called independent and dependent plans. If the first stage sample results are not utilized in the second stage, then the plan is said to be independent otherwise dependent. The principal advantage of mixed sampling plan over pure attribute sampling plan is a reduction in sample size for a similar amount of protection.

Reference [2] have considered Double sampling plans as an extension of single sampling plan. A detailed comparison of various attributes sampling plans and the merits of the double sampling plan can be seen in [3] and [14]. [13] proposed a method for determining the operating characteristics of mixed variables – attributes sampling plans, single sided specification and standard deviation known using the normal approximation. The mixed sampling plans have been designed under two cases of significant interest. In the first case, the sample size  $n_1$  is fixed and a point on the OC curve is given. In the second case, plans are designed when two points on the OC curve are given.

Reference [1] has studied the mixed sampling plans and reliability based sampling plans. [5], [6] and [7] have constructed the mixed sampling plans using Poisson distribution as a baseline distribution. [12] has constructed

mixed variables – attributes sampling plans indexed through various parameters. [8] also made contributions to mixed sampling plans.

In the product control, the defective units are either rebuilt or replaced by new units during the sampling period. Quality engineers are always interested in improving the quality level of product to enhance the satisfaction of the customers and hence, they keep making changes in the production process. These actions trigger a change in the expected incidence of defective items in the remaining observational period. Any action for reducing the number of defectives during the sampling period is called an intervention and such intervention parameter ranges from 0 to 1.

In Intervened Random effect Poisson Distribution (IRPD), Poisson parameter is modified in two ways: one method is multiplying an intervention parameter  $\rho$  (a constant) and secondly, multiplying an unobserved random effect which follows Gamma probability distribution. The IRPD can be very useful to the quality and reliability engineers, who always make changes in the production system in the observational period of quality checking to ensure reliability of the system, because, the failure rate of the components may vary in different time intervals. The other areas of application of IRPD are queuing, demographic studies, process control and so on.

Reference [15] has used Intervened Poisson Distribution (IPD) in the place of Zero Truncated Poisson Distribution (ZTPD) for the study on cholera cases. [9], [10] and [11] introduced Intervened Random effect Poisson Distribution in the place of Poisson distribution for the construction of attribute sampling plans.

In this paper, using the operating procedure of mixed sampling plan (independent case) with double sampling plan as attribute plan, tables are constructed using IRPD as a baseline distribution. The tables are constructed for mixed sampling plan (MSP) indexed through i) AQL ii) MAPD. The plan indexed through MAPD is compared with the plan indexed through AQL.

## 2. Conditions for Applications of IRPD - Mixed sampling plan

- Production process is modified during the sampling inspection by an intervention.
- Lots are submitted substantially in the order of their production.
- Inspection is by variable in the first stage and attribute in the second stage with quality defined as the fraction defective.
- Lot quality variation exists.

## 3. Glossary of symbols:

The symbols used in this paper are as follows:

$p$  : submitted quality of lot or process

$P_a(p)$ : probability of acceptance for given quality '  $p$  '

$p_1$  : submitted quality such that  $P_a(p_1) = 0.95$  (also called AQL)

$p_*$  : maximum allowable percent defective (MAPD)

$n_{1,1}$  : sample size for variable sampling plan

$n_{1,2}$  : first sample size for attribute sampling plan

$n_{2,2}$  : second sample size for attribute sampling plan

$c_1$  : first attributes acceptance number

$c_2$  : second attributes acceptance number

$d_j$  : number of defectives in the  $j^{\text{th}}$  sample ( $j=1,2,3,\dots$ )

$\beta_j$  : probability of acceptance for the lot quality '  $p_j$  '

$\beta'_j$  : probability of acceptance assigned to first stage for percent defective '  $p_j$  '

$\beta''_j$  : probability of acceptance assigned to second stage for percent defective '  $p_j$  '

$z(j)$  : 'z' value for the  $j^{\text{th}}$  ordered observation

$k$  : variable factor such that a lot is accepted if  $\bar{X} \leq A = U - k\sigma$

**4. Operating procedure of Mixed Sampling Plan having Double Sampling Plan as attribute plan**

Reference [13] has given following procedure for the independent mixed sampling plan with upper specification limit (U) and standard deviation ( $\sigma$ ).

- Determine the parameters of the mixed sampling plan  $n_{1,1}$ ,  $n_{1,2}$ ,  $n_{2,2}$ ,  $k$ ,  $c_1$  and  $c_2$
- Take a random sample of size  $n_{1,1}$  from the lot
- If a sample average  $\bar{X} \leq A = U - k\sigma$ , accept the lot
- If a sample average  $\bar{X} > A = U - k\sigma$  take a second sample of size  $n_{1,2}$
- Inspect all the articles included in the sample. Let 'd<sub>1</sub>' be the number of defectives in the sample
- If  $d_1 \leq c_1$ , accept the lot
- If  $d_1 > c_2$ , reject the lot
- If  $c_1 + 1 \leq d_1 \leq c_2$ , take a second sample of size ' $n_{2,2}$ ' from the remaining lot and find the number of defectives 'd<sub>2</sub>'
- If  $d_1 + d_2 \leq c_2$ , accept the lot
- If  $d_1 + d_2 > c_2$ , reject the lot

**5. Construction of Mixed Sampling Plan having Double Sampling Plan as attribute plan using IRPD.**

Reference [13] has given the OC function of mixed sampling plan as

$$L(p) = P_{n_1}(\bar{X} \leq A) + P_{n_1}(\bar{X} > A) \sum_{j=0}^c p(j; n_2) \quad (1)$$

The above expression is given as

$$\beta_j = \beta'_j + (1 - \beta'_j) \beta''_j \quad (2)$$

The operation of mixed sampling plans can be properly assessed by the OC curve for given values of the fraction defective. The development of mixed sampling plans and the subsequent discussions are limited only to the upper specification limit 'U'. By symmetry, a parallel discussion can be made for lower specification limits.

The procedure for the construction of mixed variables – attributes sampling plans is provided by [13] for a given ' $n_{1,1}$ ' and a point ' $p_j$ ' on the OC curve is given below.

- Assume that the mixed sampling plans are independent
- Split the probability of acceptance ( $\beta$ ) determining the probability of acceptance that will be assigned to the first stage. Let it be  $\beta'_j$

- Decide the sample size  $n_{1,1}$  (for variable sampling plan) to be used
- Calculate the acceptance limit for the variable sampling plan as

$A = U - k\sigma = U - [z(p_j) + \{z(\beta'_j)/\sqrt{n_{1,1}}\}]\sigma$ , where U is the upper specification limit and  $z(t)$  is the

standard normal variate corresponding to 't' such that  $t = \int_{z(t)}^{\infty} \left( \frac{1}{\sqrt{2\pi}} \right) e^{-u^2/2} du$

- Determine the sample average  $\bar{X}$ . If a sample average  $\bar{X} > A = U - k\sigma$ , take a second stage sample size ' $n_{2,2}$ ' using attribute sampling plan.

- Split the probability of acceptance  $\beta_j$  as  $\beta'_j$  and  $\beta''_j$ , such that  $\beta_j = \beta'_j + (1 - \beta'_j) \beta''_j$ . Fix the value of  $\beta'_j$ .

- Now determine  $\beta''_j$ , the probability of acceptance assigned to the attributes plan associated with the second stage sample as  $\beta''_j = (\beta_j - \beta'_j)/(1 - \beta'_j)$

- Determine the appropriate second stage sample size ' $n_{2,2}$ ' from  $P_a(p) = \beta''_j$  for  $p = p_j$

Using the above procedure, tables can be constructed to facilitate easy selection of mixed sampling plan with double sampling plan as attribute plan using IRPD as a baseline distribution indexed through AQL and MAPD.

Reference [9], [10], [11] suggested the probability mass function of the DSP using IRPD as a baseline distribution for  $n_{1,2}=n_{2,2}=n$  is

$$P_a(p) = \sum_{i=0}^{c_1} p_i + \sum_{j=c_1+1}^{c_2} p_j \left( \sum_{i=0}^{c_2-j} q_i \right) \quad (3)$$

where

$$p_i = \left[ \frac{e^{-k\theta} (k\theta)^x}{(1+\rho k\theta)^\alpha} \sum_{l=0}^x \left( \frac{\rho}{1+\rho k\theta} \right)^l \frac{(\alpha+l-1)!}{l!(x-l)!(\alpha-1)!} \right]$$

$$q_i = \left[ \frac{e^{-\theta} \theta^i}{(1+\rho\theta)^\alpha} \sum_{l=0}^i \left( \frac{\rho}{1+\rho\theta} \right)^l \frac{(\alpha+l-1)!}{l!(i-l)!(\alpha-1)!} \right] \text{ and } \theta = \frac{\rho p}{1+\rho p}$$

Using the above procedure, tables can be constructed to facilitate easy selection of MSP using IRPD as a baseline distribution. The tables furnished in this paper are for the case when  $\alpha=1$ ,  $k=1$  and  $n_{1,2}=n_{2,2}=n$ .

## 6. Construction of Mixed Sampling Plans indexed through MAPD and MAAOQ

MAPD, introduced by [4] and studied by [16] is the quality level corresponding to the inflection point of the OC curve. The degree of sharpness of inspection about this quality level ' $p_*$ ' is measured by ' $p_t$ ', the point at which the tangent to the OC curve at the inflection point cuts the proportion defective axis. For designing, [16] proposed a selection procedure for single sampling plan indexed with MAPD and  $K = \frac{p_t}{p_*}$

Using the probability mass function of the IRPD, given in expression (1), the inflection point ( $p_*$ ) is obtained by using  $\frac{d^2 P_a(p)}{dp^2} = 0$  and  $\frac{d^3 P_a(p)}{dp^3} \neq 0$ . The  $n_{2,2}$ MAPD values are calculated

for different values of  $c_1$ ,  $c_2$  and  $\rho=0.7$  for  $\beta'_* = 0.30$  using c++ program and presented in Table 1.

The MAAOQ (Maximum Allowable Average Outgoing Quality) of a sampling plan is defined as the Average Outgoing Quality (AOQ) at the MAPD.

By definition  $AOQ = p P_a(p)$  and  $MAAOQ = p_* P_a(p_*)$

The values of MAPD and MAAOQ are calculated for different values of  $c_1$ ,  $c_2$  and  $\rho=0.7$  for  $\beta'_* = 0.30$  and the ratio  $R = \frac{MAAOQ}{MAPD}$  is presented in Table 1.

### Selection of the plan

For the given values of  $\rho$ ,  $\beta'_*$ , MAPD and MAAOQ, the ratio  $R = \frac{MAAOQ}{MAPD}$  is found and the nearest value of R is located in Table 1. The corresponding value of  $c_1$ ,  $c_2$  and  $n_{2,2}$ MAPD values are noted and the value of  $n_{2,2}$  is obtained using  $n_{2,2} = \frac{n_{2,2}MAPD}{MAPD}$ .

**Example 1:** Given  $\rho=0.7$ ,  $\beta'_* = 0.30$ , MAPD=0.0330 and MAAOQ=0.0190, the ratio  $R = \frac{MAAOQ}{MAPD} = 0.5754$  is computed. In Table 1 the nearest R value is 0.5747 which is corresponding to  $c_1=3$  and  $c_2=6$ . The value of

$n_{2,2}$ MAPD=3.9200 is found and hence the value of  $n_{2,2}$  is determined as  $n_{2,2} = \frac{n_{2,2}MAPD}{MAPD} = \frac{3.9200}{0.033} = 119$ . Thus  $n_{1,2}=n_{2,2}=119$ ,  $c_1=3$  and  $c_2=6$  are the parameters of the mixed sampling plan having DSP as attribute plan using IRPD as a baseline distribution for the given values of  $\rho=0.7$ , MAPD=0.0330 and MAAOQ=0.0190.

Table 1:  $n_{2,2}$ MAPD and  $n_{2,2}$ MAAOQ values for a specified values of  $c_1$ ,  $c_2$  and  $\rho=0.7$  of mixed sampling plan when  $\beta'_* = 0.30$

$c_1$	$c_2$	$\beta_*$	$\beta'_*$	$n_{2,2}$ MAPD	$n_{2,2}$ MAAOQ	$R = \frac{MAAOQ}{MAPD}$
0	1	0.7887	0.6981	0.6710	0.4648	0.6981
	2	0.7322	0.6174	1.2200	0.7532	0.6174
	3	0.7036	0.5765	1.7600	1.0146	0.5765
	4	0.6866	0.5523	2.3000	1.2702	0.5523
	5	0.6751	0.5359	2.8400	1.5219	0.5359
	6	0.6669	0.5241	3.3900	1.7766	0.5241
1	2	0.7586	0.6551	1.4400	0.9433	0.6551
	3	0.7236	0.6051	1.9100	1.1557	0.6051
	4	0.6987	0.5695	2.4200	1.3781	0.5695
	5	0.6817	0.5453	2.9400	1.6031	0.5453
	6	0.6700	0.5286	3.4620	1.8300	0.5286
	7	0.6616	0.5166	4.0000	2.0664	0.5166
2	3	0.7384	0.6263	2.3600	1.4780	0.6263
	4	0.7217	0.6024	2.6810	1.6729	0.6024
	5	0.6997	0.5708	3.1400	1.7923	0.5708
	6	0.6821	0.5459	3.6210	1.9767	0.5459
	7	0.6689	0.5270	4.1300	2.1765	0.5270
	8	0.6593	0.5133	4.6500	2.3868	0.5133
3	4	0.7312	0.6160	3.3000	2.0320	0.6160
	5	0.7200	0.6000	3.5400	2.1240	0.6000
	6	0.7023	0.5747	3.9200	2.2528	0.5747*
	7	0.6853	0.5504	4.3600	2.3997	0.5504
	8	0.6710	0.5300	4.8400	2.5652	0.5300
	9	0.6600	0.5143	5.3400	2.7463	0.5143
4	5	0.7194	0.5991	4.3500	2.6060	0.5991
	6	0.7166	0.5951	4.4700	2.6600	0.5951

#### Practical problem:

Suppose the plan  $n_{1,1}=18$ ,  $k=1.5$  is to the lot by lot acceptance inspection of a calculator battery, the characteristic to be inspected is the “operating temperature” of the battery for which there is a specified upper limit of  $40^0\text{C}$  with known S.D ( $\sigma$ )= $0.5^0\text{C}$ .

In this example,  $U=40^0\text{C}$ ,  $\sigma=0.5^0\text{C}$  and  $k=1.5$

$$A = U - k\sigma = 40 - (1.5)(0.5) = 40 - 0.75 = 39.25^0\text{C}$$

Now, by applying the variable inspection first, take random sample of size  $n_{1,1}=18$  from the lot. Record the sample results and find  $\bar{X}$ . If  $\bar{X} \leq A = U - k\sigma = 39.25^0\text{C}$ , then accept the lot. If  $\bar{X} > A$ , take a random sample size  $n_{1,2}$  and apply the attribute inspection.

Under attributes inspection, by using double sampling plan as attribute plan using Intervened Random effect Poisson Distribution (IRPD) as a baseline distribution, if the manufacturer fixes the values MAPD=0.0330(330 non conformities out of 10000), MAAOQ=0.0190(190 non conformities out of 10000) and  $\beta'_* = 0.30$ , take a sample of size  $n_{1,2}=119$  and observe the number of defectives( $d_1$ ). If  $d_1 \leq 3$ , accept the lot and if  $d_1 > 6$ , reject the lot. If  $4 \leq d_1 \leq 6$ , take a second sample of size  $n_{2,2}=119$  from the remaining lot and find the number of defectives( $d_2$ ). If  $d_1 + d_2 \leq 6$ , accept the lot and if  $d_1 + d_2 > 6$ , reject the lot and inform the management for further action

## 7. Construction of Mixed Sampling Plans indexed through AQL

The procedure given in section 5 is used for constructing the mixed sampling plan indexed through AQL ( $p_1$ ). By assuming the probability of acceptance of the lot be  $\beta_1 = 0.95$  and  $\beta'_1 = 0.30$ , the  $n_{2,2}p_1$  values are calculated for different values of  $c_1$ ,  $c_2$  and 'p' using c++ program and is presented in Table 2.

Table 2:  $n_{2,2}$  AQL values for a specified values of  $c_1$ ,  $c_2$  and  $p$  of mixed sampling plan when  $\beta_1 = 0.95$  and  $\beta'_1 = 0.30$

$c_1$	$c_2$	$p$ values								
		0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0	1	0.2520	0.2550	0.2550	0.2550	0.2550	0.2550	0.2550	0.2550	0.2509
	2	0.5003	0.4950	0.4950	0.4950	0.4950	0.4880	0.4880	0.4880	0.4875
	3	0.7860	0.7850	0.7750	0.7750	0.7650	0.7580	0.7580	0.7490	0.7475
	4	1.0960	1.0950	1.0850	1.0750	1.0650	1.0490	1.0490	1.0390	1.0275
	5	1.4360	1.4250	1.4050	1.3850	1.3750	1.3590	1.3390	1.3290	1.3175
	6	1.7860	1.7650	1.7450	1.7150	1.6950	1.6690	1.6490	1.6290	1.6175
1	2	0.6160	0.6150	0.6080	0.6080	0.6080	0.5990	0.5990	0.5990	0.5975
	3	0.8580	0.8550	0.8580	0.8480	0.8480	0.8390	0.8390	0.8309	0.8275
	4	1.1480	1.1450	1.1380	1.1280	1.1180	1.1090	1.1090	1.1009	1.0975
	5	1.4680	1.4550	1.4380	1.4800	1.4180	1.3990	1.3890	1.3890	1.3675
	6	1.7980	1.7850	1.7680	1.7480	1.7280	1.7090	1.6890	1.6709	1.6575
	7	2.1580	2.1550	2.0980	2.0780	2.0480	2.0190	1.9990	1.9809	1.9575
2	3	1.0780	1.0650	1.0580	1.0480	1.0380	1.0390	1.0290	1.0209	1.0075
	4	1.2980	1.2850	1.2780	1.2680	1.2580	1.2490	1.2390	1.2309	1.2275
	5	1.5680	1.5550	1.5480	1.5280	1.5180	1.5090	1.4990	1.4909	1.4775
	6	1.8680	1.8550	1.8380	1.8180	1.8080	1.7790	1.7790	1.7609	1.7475
	7	2.1980	2.1850	2.1580	2.1280	2.1080	2.0890	2.0690	2.0509	2.0275
	8	2.5480	2.5250	2.4880	2.4580	2.4280	2.3990	2.3690	2.3409	2.3275
3	4	1.6180	1.6050	1.5580	1.5580	1.5380	1.5190	1.5090	1.4909	1.4775
	5	1.7980	1.7750	1.7580	1.7380	1.7280	1.7090	1.6890	1.6709	1.6575
	6	2.0380	2.0150	1.9980	1.9780	1.9580	1.9390	1.9190	1.9109	1.8975
	7	2.3180	2.2950	2.2780	2.2480	2.2280	2.2090	2.1890	2.1709	2.1475
	8	2.6280	2.6050	2.5780	2.5480	2.5180	2.4990	2.4690	2.4509	2.4275
	9	2.9680	2.9350	2.8980	2.8580	2.8280	2.7990	2.7690	2.7409	2.7075
4	5	2.2180	2.1950	2.1580	2.1180	2.0780	2.0490	2.0190	1.9909	1.9675
	6	2.3480	2.3250	2.2880	2.2580	2.2280	2.1990	2.1690	2.1509	2.1275

### Selection of the plan

Table 2 is used to construct the plans when  $p_1$ ,  $p$ ,  $c_1$  and  $c_2$  are given. For any given values of  $p_1$ ,  $p$ ,  $c_1$  and  $c_2$  one can

determine  $n_{2,2}$  value using  $n_{2,2} = \frac{n_{2,2}p_1}{p_1}$ .

**Example 2:** Given  $p=0.7$ ,  $p_1=0.0184$ ,  $c_1=0$ ,  $c_2=6$  and  $\beta'_1=0.30$ . Using Table 2, find

$n_{2,2} = \frac{n_{2,2}p_1}{p_1} = \frac{1.6490}{0.0184} = 90$ . For a fixed  $\beta'_1 = 0.30$ , the mixed sampling plan with DSP as attribute plan is  $n_{1,2} = n_{2,2} = 90$ ,  $p=0.7$ ,  $c_1=0$  and  $c_2=6$ .

## 8. Comparison of Mixed Sampling Plan indexed through MAPD and AQL

In this section MSP indexed through MAPD is compared with MSP indexed through AQL by fixing the parameters  $c_1$ ,  $c_2$  and  $\beta'_j$ .

For the specified values of  $p$ , MAPD and MAAOQ with the assumption for  $\beta'_1=0.30$  one can find the values of  $c_1$  and  $c_2$  indexed through MAPD. By fixing the values of  $c_1$  and  $c_2$  find the value of  $p_1$  by equating  $P_a(p) =$

$\beta_1=0.95$ . For  $\beta_1'=0.30$ ,  $c_1$  and  $c_2$  one can find the values of  $n_{2,2}$  using  $n_{2,2} = \frac{n_{2,2} p_1}{p_1}$  from Table 2. For different combinations of  $\rho$ , MAPD and MAAOQ the values of  $c_1$ ,  $c_2$  and  $n_{2,2}$  (indexed through MAPD) and  $c_1$ ,  $c_2$  and  $n_{2,2}$  (indexed through AQL) are calculated and presented in Table 3.

#### Construction of OC curve

The OC curves for the plan  $\rho=0.7$ ,  $n_{2,2}=119$ ,  $c_1=3$ ,  $c_2=6$  (indexed through MAPD) and  $n_{2,2}=133$ ,  $c_1=3$ ,  $c_2=6$  (indexed through AQL) based on the different values of ' $n_{2,2}p$ ' and  $P_a(p)$  are presented in Figure 1.

Table 3: Comparison of the plans

Given values			INDEXED THROUGH MAPD			INDEXED THROUGH AQL		
MAPD	MAAOQ	$\rho$	$c_1$	$c_2$	$n_{2,2}$	$c_1$	$c_2$	$n_{2,2}$
0.0420	0.0220	0.7	0	6	81	0	6	90
0.0170	0.0102	0.7	1	3	112	1	3	131
0.0480	0.0246	0.7	2	8	97	2	8	107
0.0330*	0.0190	0.7	3	6	119	3	6	133

\* Oc curves are drawn

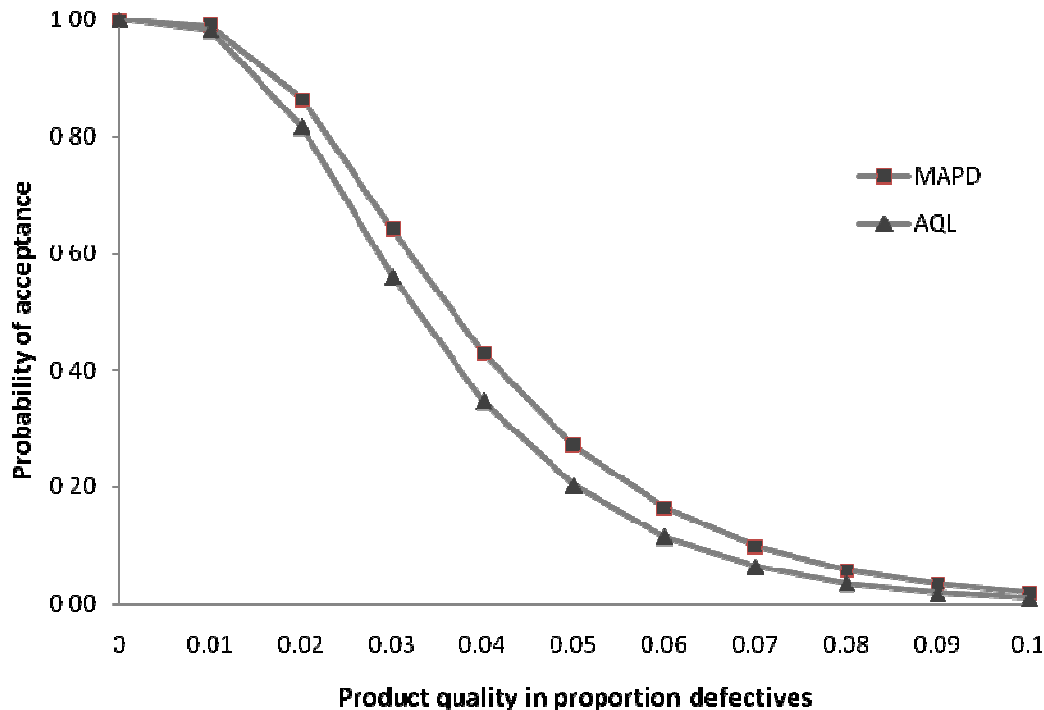


Fig 1: OC curves for the plans ( $\rho=0.7$ ,  $c_1=3$ ,  $c_2=6$ ,  $n_{1,2}=n_{2,2}=119$ ) and ( $\rho=0.7$ ,  $c_1=3$ ,  $c_2=6$ ,  $n_{1,2}=n_{2,2}=133$ )

#### CONCLUSION

In this paper the construction of mixed sampling plan with double sampling plan as attribute plan indexed through the parameters MAPD and AQL are presented by taking IRPD as a baseline distribution. Further the plan indexed through MAPD is compared with the plan indexed through AQL. It is concluded from the study that the second stage sample size required for double sampling plan indexed through MAPD is less than that of second stage sample size of the double sampling plan indexed through AQL. If the floor engineers know the levels of MAPD or AQL, they can have their sampling plans on the floor itself by referring to the tables. This provides the flexibility to the

floor engineers in deciding their sampling plans. Various plans can also be constructed to make the system user friendly by changing the first stage probabilities ( $\beta'_*$ ,  $\beta'_1$ ) and can also be compared for their efficiency.

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