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DESIGN AND PERFORMANCE EVALUATION OF A FUZZY CHAIN SAMPLING PLAN FOR TEXTILE QUALITY CONTROL

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Abstract:

In the textile sector, quality control is crucial since flaws in fabrics, yarns, dyeing, and finishing have a direct impact on customer satisfaction and production efficiency. In order to address the heterogeneity frequently present in textile processes, this study suggests a fuzzy chain sampling strategy. Single-sample acceptance probability are calculated using the Poisson distribution using inspection report data, and chain acceptance is based on successive acceptable samples. Fuzzy acceptance intervals are produced using α-cut decomposition, and the defect fraction is represented as a triangular fuzzy number. After applying an appropriate fuzzy decision rule, the plan is optimized by modifying the acceptance number and chain length to minimize inspection effort while balancing the risks for producers and consumers. The resulting plan offers a more flexible and reliable approach to quality assessment in textile manufacturing.

Keywords: Chain Sampling Plan, Fuzzy Probability Theory, Operating Characteristic Curve, Quality Control.

1. INTRODUCTION

Quality control in the textile industry is critical, because defects (in fabrics, yarns, dyeing, finishing etc.) can strongly affect downstream processes and end customer satisfaction. Combining chain sampling plan with fuzzy probability theory allows more realistic, flexible quality control, especially in textile manufacturing where materials and processes have inherent variability. In this paper a case study using chain sampling plan and fuzzy probability theory have been carried over a number of inspection reports.

For each sample, the defect proportion is then fuzzified by defining it as a triangular fuzzy number $\tilde{p} = (a_1, a_2, a_3)$. Using α-cut decomposition, the fuzzy parameter is converted into an interval for each α ε [0,1]

For each value of $p$in this interval, the single-sample acceptance probability is computed, producing for each α-level a fuzzy acceptance interval $[P_{a,\min}(\alpha), P_{a,\max}(\alpha)]$.

A decision rule is chosen by selecting an appropriate defuzzification or fuzzy decision method. One option is to require that the centroid (or modal) value of the chain acceptance probability exceeds a chosen threshold T (such as 0.5 or 0.9). A more conservative option is to require that the lower bound at a selected α-level (such as α = 0.5) meets the threshold.

2. METHODOLOGY

(a) Decide the sampling unit & acceptance rule for one sample

Sample size $n$and acceptance number c(you have $n = 125,\ c = 7$).

For one sample the *sample acceptance probability* is the Poisson CDF $P(\text{defects} \le c)$, for small p with $\lambda = np$:

$$P_{\text{sample}}(p) \approx \frac{e^{-\lambda}\lambda^x}{x!}, \lambda = np.$$

(b) Fuzzify p as a triangular fuzzy number $\tilde{p} = (a_1, a_2, a_3)$.

(c) α-cut decomposition is computed for each α∈[0,1] as α cut bounds

$$\tilde{p}[\alpha] = [a_1 + (a_2 - a_1)\alpha,\ a_3 - (a_3 - a_2)\alpha].$$

Poisson parameter: is $\lambda_{\text{low}}(\alpha) = n \cdot p_{\text{low}}(\alpha), \lambda_{\text{high}}(\alpha) = n \cdot p_{\text{high}}(\alpha)$.

The fuzzy acceptance probability band is:

$$P_a(i)[\alpha] = [P_{a,\text{low}}(i)[\alpha],\ Pa_{,\text{up}}(i)[\alpha]]$$

(d) Decision rule: A defuzzification/decision method, is used as follows

Centroid (defuzzified) p:

$$p_{\text{centroid}} = \frac{a_1 + a_2 + a_3}{3},$$

$$\lambda_{centroid} = n * p_{centroid}$$

Pa_centroid = POISSON.DIST(c, $\lambda_{\text{centroid}}$, TRUE).

Require the centroid (or modal) chain acceptance probability ≥ threshold

3.1 SECONDARY DATA OBTAINED FROM INSPECTION REPORTS FOR CASE STUDY

TABLE 3.1

Report No.	Description	Inspection Date	Offer Quantity / /Order Quantity	Inspection Quantity	Final Inspection Plan Sample Size as per AQL Level II				Major Defects	Minor Defects	Inspection Result
					Sample Size	Critical	Major Pass	Minor Pass			
SS24-QLTY08F10000046932	T-Shirt	13.06.2024	1067/1265	125	125	0	5	5	22	0	Fail
01/POPPYS/24-25	Girls Top	09-12-2024	32400/27300	315	315	0	14	21	151	31	Fail
SS25-QLTY08F10000056945	T-Shirt	16.06.2025	3094/3093	125	125	0	5	5	80	10	Fail
AW25-QLTY08F10000058116	T-Shirt	23.07.2025	300/300	50	50	0	2	2	5	2	Fail
AW25-QLTY08F10000064245	T-Shirt	24.11.2025	396/400	50	50	0	2	2	9	0	Fail

Based on Fuzzy Decision Theory

Membership value	Meaning
0.0 – 0.4	*Rejection zone*
0.4 – 0.6	Uncertain / Marginal
≥0.6	acceptance zone

TABLE 3.1.1

p: a_1 =0.05, a_2 = 0.075, a_3 = 0.1,n =80, c=5-major defects, 6- minor defects-8

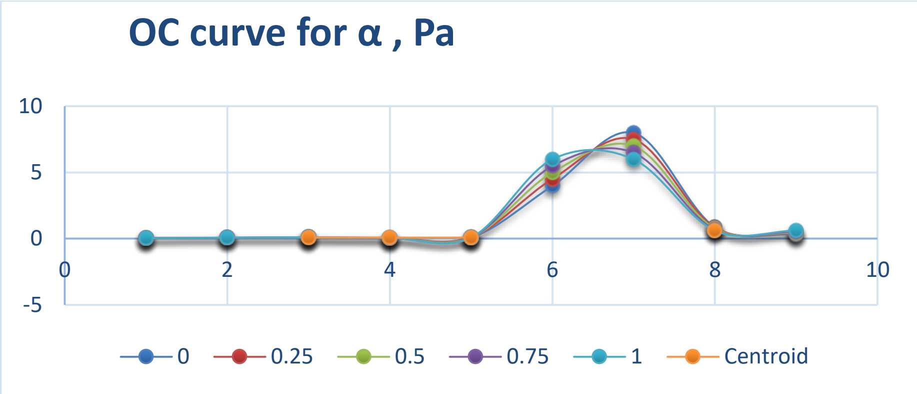
α	p low	P high	λ low	λhigh	Plow	$P_a$high	Acceptance Status
0	0.05	0.1	4	8	0.889326022	0.313374278	Marginal
0.25	0.05625	0.09375	4.5	7.5	0.831050579	0.378154694	Marginal
0.5	0.0625	0.0875	5	7	0.762183463	0.449711056	Borderline
0.75	0.06875	0.08125	5.5	6.5	0.68603598	0.526523623	Accept
1	0.075	0.075	6	6	0.606302782	0.606302782	Accept
Centroid	**0.075**	**0.075**			**0.606302782**		Accept

Interpretation of data from TABLE 3.1.1:

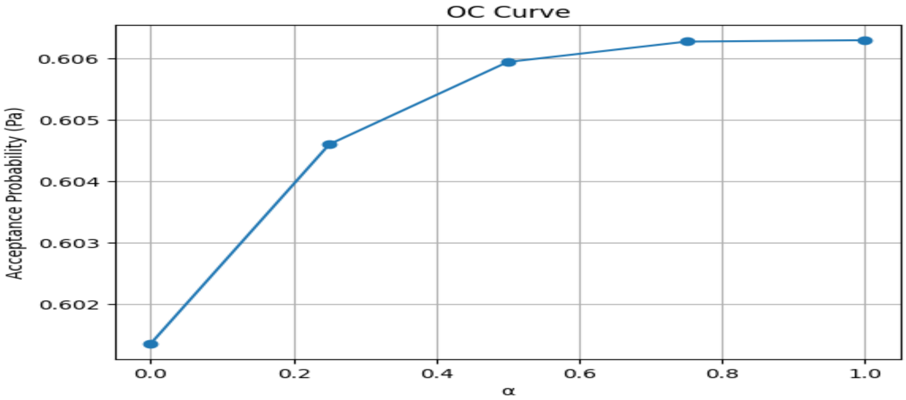
At low α values (0–0.5) → High uncertainty → Risky decisions.At high α values (0.75–1) → Low uncertainty → Reliable decisions. Centroid value 0.606302782givesthe most balanced and stable result.

The analysis shows that as the confidence parameter α increases, uncertainty in probability and rate parameters decreases, leading to stable acceptance probability. At $\alpha = 1$ and at the centroid, the acceptance probability converges to **0.6063**, which satisfies the acceptance criterion. Hence, the final decision is **accept**, indicating a reliable and optimal outcome.

Graphical Interpretation :



OC curve for α, Pa



The OC curve illustrates the variation of acceptance probability with respect to the confidence parameter α. It is observed that the acceptance probability increases monotonically and converges to 0.6063 as α approaches unity. This convergence indicates stabilization of the decision process, validating the selection of 0.6 as the acceptance threshold. Hence, higher values of α ensure reliable and consistent decision-making.

TABLE3.1.2

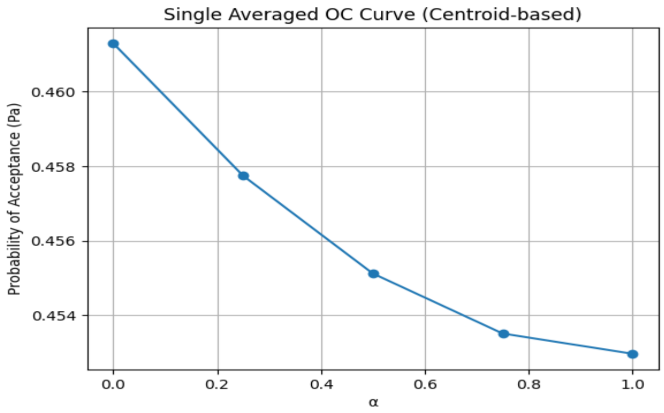
p: a_1 =0.048, a_2 = 0.064, a_3 = 0.0.08,n =125, c=7-major defects- 8, 11- minor defects

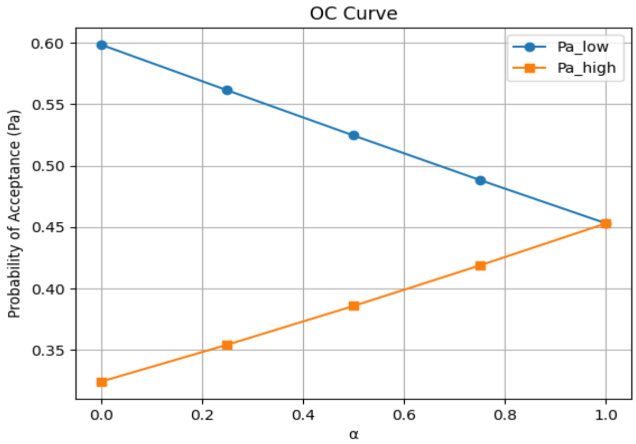
α	p_{low}	p_{high}	λ_{low}	λ_{high}	$P_{a\ low}$	$P_{a\ high}$	Acceptance Status
0	0.056	0.072	7	9	0.598713836	0.323896964	Marginal
0.25	0.058	0.07	7.25	8.75	0.561517533	0.353976728	Marginal
0.5	0.06	0.068	7.5	8.5	0.524638526	0.385597102	Marginal
0.75	0.062	0.066	7.75	8.25	0.488367119	0.418642006	Marginal
1	0.064	0.064	8	8	0.452960809	0.452960809	Marginal
Centroid					**0.452960809**		

Interpretation of data from TABLE 3.1.2:

Pa low = 0.5987 and Pa high = 0.3239 at α = 0: The Pa values lie within the Marginal region. Even though the lower bound is above 0.4, it's still considered marginal, and the lot isn't strongly rejected.Pa low = 0.4530 and Pa high = 0.4530 at α = 1**:** The Pa value is within the Marginal region. It's borderline, but it's not low enough to reject entirely. Therefore, we categorize it as Marginal**.** Pa∈[0,1] → can be interpreted as a membership degree in the fuzzy set "Acceptable lot"The system converges to:Pa=0.453.The lot belongs to the "acceptable" class with degree 0.453.It is not zero, so it is not rejected under fuzzy logic.All α-cuts fall in the Marginal region**,** meaning the lot isborderline acceptable**.** Fuzzy logic allows to accept the lot with moderate risk**,** rather than rejecting it outright**.**

Graphical Interpretation:





The Pa_low curve decreases as α increases. The Pa_high curve increases as α increases.Both curves meet at the centroid α = 1, where, Pa=0.452960809.This intersection represents the centroid operating point of the sampling plan. The curve smoothly decreases as α increases.Itconverges to the centroid Pa = 0.452960809 at α = 1**.**This single OC curve represents the central tendency of acceptance probability.

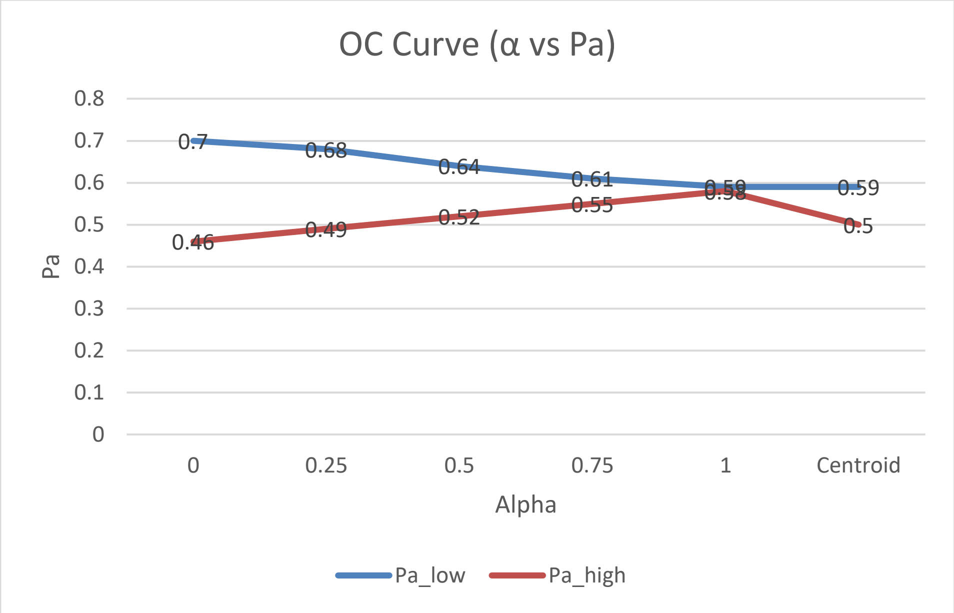
TABLE 3.1.3

p: a_1 =0.045, a_2 = 0.05, a_3 = 0.0.55,n =200, c=11-major defects- 11, 13- minor defects

α	**p low**	**p high**	**λ low**	**λhigh**	**P_a low**	**$P_a$high**	**Acceptance Status**
0	0.045	0.055	9	11	0.70598832	0.459888703	Accept
0.25	0.04625	0.05375	9.25	10.75	0.675966077	0.490048529	Accept
0.5	0.0475	0.0525	9.5	10.5	0.645328435	0.520738128	Accept
0.75	0.04875	0.05125	9.75	10.25	0.614284296	0.551794391	Accept
1	0.05	0.05	10	10	0.58303975	0.58303975	Accept
Centroid		**0.05**			**0.58303975**		

The analysis shows that as the confidence parameter α increases, uncertainty in probability and rate parameters decreases, leading to stable acceptance probability. At α = 1 and at the centroid, the acceptance probability converges to **0.58303975**, which satisfies the acceptance criterion. Hence, the final decision is **accept**, indicating a reliable and optimal outcome.

Graphical Interpretation:



The OC curve illustrates the variation of acceptance probability with respect to the confidence parameter α. It is observed that the acceptance probability increases monotonically and converges to **0.58303975** as α approaches unity. This convergence indicates stabilization of the decision process, validating the selection of 0.6 as the acceptance threshold. Hence, higher values of α ensure reliable and consistent decision-making.

Results and Conclusions:

Acceptance probabilities were computed using the Poisson distribution for the given sample size and acceptance number, showing a decrease in acceptance as the defect proportion increased.

Modeling the defect proportion as a triangular fuzzy number captured uncertainty in textile inspection data more effectively than a crisp probability.

α-cut decomposition produced fuzzy intervals of acceptance probabilities at different confidence levels, resulting in a banded fuzzy operating characteristic instead of a single curve.

Defuzzification using the centroid method provided a representative acceptance probability for decision-making.

Conservative decision rules based on lower α-cut bounds further reduced the risk of accepting poor-quality lots.

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