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Economic Design of Single Sampling Plan and Quick Switching System Under Zero Inflated Poisson Distribution

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Abstract

Objectives: This article focuses on designing a plan and system based on the Zero-Inflated Poisson (ZIP) distribution, aiming to determine the optimal sample size, acceptance number, and economic cost. **Methods:** The study employs the ZIP distribution as the baseline due to its suitability for scenarios with excessive zero defects during inspection. Sampling plans are developed using the ZIP distribution for both single sampling and the Quick Switching System (QSS). The economic cost function is derived and optimized for each system, with numerical examples provided to illustrate the optimal total cost. **Findings:** The QSS designed under the ZIP distribution is found to be more cost-efficient compared to the single sampling plan based on the Poisson distribution. The proposed system achieves an optimal total cost, effectively managing zero-inflated defect scenarios in modern production processes. **Novelty:** This work applies the ZIP distribution to address zero defects in high-quality manufacturing and introduces a cost-optimized framework for sampling plans and systems. Thus, in shop-floor situations, both producers and consumers can benefit from this model, making decisions with minimal total cost.

Keywords: Acceptance Sampling Plan; Economic Cost; Operating Ratio; Quick Switching Single Sampling System; Zero-Inflated Poisson Distribution

1 Introduction

An acceptance sampling plan is a quality control method used in engineering to determine whether a batch of materials, components, or products meets specified standards and should be accepted or rejected, based on the evaluation of a sample. Acceptance sampling plans are generally classified into two categories: attributes and variables. Various types of sampling plans exist, including Single Sampling Plans, Double Sampling Plans, and Sequential Sampling Plans. A single sampling plan is defined by two key parameters: the sample size (n) and the acceptance number (c). In contrast, a double sampling plan is characterized by four parameters: the first sample size (n_1), the second sample size (n_2), the first acceptance number (c_1), and the second acceptance number (c_2).

In later years, special-purpose plans such as the Quick Switching System (QSS) have been adopted in inspection as a simple and efficient method to minimize the number of samples inspected. In this scheme, the procedure begins with normal inspection, and if a rejection occurs, it immediately switches to tightened inspection. This immediate switching between the normal and tightened plans is known as the Quick Switching System (QSS).

In the modern era, technological advancements have significantly improved product quality, leading to minimal defects during inspection. However, due to random fluctuations, occasional defects may still occur. Under such circumstances, the Zero-Inflated Poisson Distribution (ZIPD) provides a more suitable model. ZIPD is a special type of mixture distribution that combines a Poisson component with a zero-inflated component. It has wide applications in fields such as agriculture, epidemiology, medicine, econometrics, public health, process control, and manufacturing.

The total number of risks can be reduced by using the Hurdle-Poisson distribution compared to the modified QSS sampling plan based on the weighted Poisson distribution[1]. A new sampling system, named the Bayesian Quick Switching Single Sampling System, has been proposed, and its performance measures have been studied along with other plan parameters[2]. Another procedure has been developed under the Bayesian Quick Switching System with a Repetitive Group Sampling plan, indexed through various quality levels[3]. A Tightened-Normal-Tightened (TNT) sampling scheme by attributes has also been designed, specifically for cases where the number of defects follows a Zero-Inflated Poisson (ZIP) distribution[4]. Furthermore, single sampling plans have been studied in the presence of fuzzy number non-conformities, modelled using the ZIP distribution structure[5]. The Operating Characteristic (OC) and Average Sample Number (ASN) curves of these plans resemble a band-shaped lower boundary; under this approach, the Fixed Average Sample Number (FASN) attains a lower value depending on the adequacy of process quality[6]. Additionally, sampling plans have been designed using ZIP distribution with fuzzy logic theory, and their efficiency has been highlighted when compared with existing plans[7].

Compared with existing distributions, the Poisson distribution is the standard model for the analysis of count data. However, the Zero-Inflated Poisson (ZIP) distribution is proposed to address the issue of an “excessive” number of zero counts under inspection. When the data contain a larger proportion of zeros, the ZIP distribution is more appropriate for analysis. Hence, ZIP is considered a mixture of a distribution that degenerates at zero and a Poisson distribution. The total cost and sample size can be minimized while using QSS under ZIP distribution compared to QSS based on the Poisson distribution.

The major limitation of existing studies is that the use of the Poisson distribution leads to a higher sample size, acceptance number, and total cost. In contrast, the use of the ZIP distribution results in a lower sample size, acceptance number, and total cost. Therefore, the total cost of both the plan and the system under the ZIP distribution is more efficient compared to those based on the Poisson distribution.

The main objective of this article is designing optimal total cost for single sampling plan and Quick Switching System for attributes under the conditions of Zero Inflated Poisson (ZIP) distribution. Designing and illustrations were given to describe the total cost of sampling plan and system for specified strength.

2 Methodology

2.1 Optimal Design of Acceptance Sampling System

From the lot, a sample of ‘n’ units is chosen at random, and the disposition of the lot is determined depending on the basis of the information contained in that sample. A single sampling plan for attributes would be parameterized with three parameters, namely, sample size ‘n’, acceptance number ‘c’ and non-conformities in the sample ‘d’ for a lot size ‘N’.

The operating characteristic (OC) function for SSP under ZIPD is as follows:

$$P_{a(P)} = Z_i + (1 - Z_i)\, e^{-\lambda} + (1 - Z_i) \sum_{x_1=1}^{c} \frac{e^{-\lambda}.\ \lambda^{x}}{x_1!} \tag{1}$$

The designing Optimal Single Sampling Plan under the conditions of ZIPD is as follows,

1. Using Loganathan et al.,[8] for the given (p_1, p_2, α, and β) values, obtain SSP under ZIPD (n; c).
2. Compute AQL and LTPD.
3. Find Total Cost (TC).
4. The minimum cost will be the optimal single sampling plan under ZIPD.

The Total Cost (TC) is as follows:

$$TC = C_i.ATI + C_f.D_d + C_0.D_n \tag{2}$$

Where,

ATI – Average Total Inspection

$$ATI = n + (1 - P_a(p))(N - n) \tag{3}$$

AOQ – Average Outgoing Quality

$$AOQ = p.P_a(p)\left(\frac{N-n}{N}\right) \tag{4}$$

Let D_d denote the defective items detected and D_n denote the defective items not detected, then

$$D_d = np + (1 - P_a(p))(N - n)p \tag{5}$$

$$D_n = P_a(p)(N - n)p \tag{6}$$

Where,

C_i – Inspection cost per item, C_f – Internal failure cost, C_0 – Cost of an outgoing defective item.

Illustration: 1

In a washing machine manufacturing company, defects such as motor faults, drum imbalance, wiring issues, and leakage occur at a low rate due to advanced automation, and rigorous quality inspections. However, since a significant proportion of washing machines are defect-free, a Zero-Inflated Poisson (ZIP) distribution is used instead of a standard Poisson model to account for the excess zero-defect occurrences.

Fig 1. Washing Machine Manufacturing Company

To obtain the optimal sampling plan for the given set of input parameters. Suppose the manufacturer fixes the AQL as 0.02 (20 defective washing machine out of 1000), and the consumer fixes the LTPD as 0.07 (70 defective washing machine out of 1000). N = 1000, Z_i = 0.01, AQL=0.02, LTPD = 0.07, α = 0.05, β = 0.1, C_i = 1.0, C_f = 2.0, C_0 = 10, the procedure is as follows:

Step 1: Determine SSP under ZIPD for the given values of AQL = 0.02, LTPD = 0.07, α = 0.05, β = 0.1, p = 0.03.

1. (i)The operating ratio is R = 0.07/0.02 = 3.5 is computed.
2. (ii)From the Loganathan et al.,[8] table, the acceptance number is c = 6.
3. (iii)The sample size n = 154.
4. (iv)Hence the SSP under ZIPD (154; 6) is obtained.

Step 2: Compute AQL and LTPD such that the conditions 1-P_a (AQL) $\leq \alpha$ and P_a (LTPD) $\leq \beta$ are to be satisfied.
Step 3: Calculated the Total Cost (TC) and identify the minimum total cost. To optimize the quality control plan, the sample size and acceptance number are adjusted, increasing up to n = 210, and c = 9.
Step 4: Hence the optimal single sampling plan under ZIPD is obtained as (171, 8) with TC = 477.93.

2.2 Designing Optimal QSSS under the conditions of ZIPD

The Operating Characteristics (OC) function of QSS is as follows:

$$P_a(p) = \frac{P_T}{1 - P_N + P_T} \tag{7}$$

Where,
P_N = Probability of acceptance under normal sampling plan
P_T = Probability of acceptance under tightened sampling plan

$$P_N = Z_i + (1 - Z_i)\, e^{-\lambda} + (1 - Z_i) \sum_{x_1=1}^{cN} \frac{e^{-\lambda}.\ \lambda^x}{x_1!} \tag{8}$$

$$P_T = Z_i + (1 - Z_i)\, e^{-\lambda} + (1 - Z_i) \sum_{x_1=1}^{cT} \frac{e^{-\lambda}.\ \lambda^x}{x_1!} \tag{9}$$

The designing of Optimal QSSS under the conditions of ZIPD is as follows,

1. Using Gunasekaran et al.,[9] for the given (p_1, p_2, α, β) values, obtain QSS (n; c_N, c_T).
2. Compute AQL, and LTPD.
3. Find Total Cost (TC).
4. Optimal QSS is obtained based on the minimum cost.

To obtain the optimal sampling system for the given set of input parameters. Suppose the manufacturer fixes the AQL as 0.02 (20 defective washing machine out of 1000), and the consumer fixes the LTPD as 0.07 (70 defective washing machine out of 1000). N = 1000, Z_i = 0.01, AQL=0.02, LTPD = 0.07, α = 0.05, β = 0.1, p = 0.03, C_i = 1.0, C_f = 2.0, C_0 = 10, the procedure is as follows:
Step 1: Determine QSS under ZIPD for the given values of AQL = 0.02, LTPD = 0.07, α = 0.05, β = 0.1, p = 0.03.

1. The operating ratio is R = 0.07/0.02 = 3.5 is computed.
2. From the Gunasekaran[9] table, the nearest value of R is 3.63219.
3. The acceptance numbers are c_N = 4, c_T = 3.
4. The sample size is determined as n = 1.9271/0.02 = 96.36 96.
5. Hence the QSS under ZIPD (96; 4,3) is obtained.

Step 2: Compute AQL and LTPD such that the conditions 1-P_a(AQL) $\leq \alpha$ and P_a(LTPD) $\leq \beta$ are to be satisfied.
Step 3: Calculated the Total Cost (TC) and identify the minimum total cost. To optimize the quality control plan, the sample size and acceptance number are adjusted, increasing up to n = 120, c_N = 7, and c_T = 2.
Step 4: Hence the optimal QSS under ZIPD is obtained as (100; 7,2) with TC = 394.29.

3 Result and Discussion

3.1 Comparison of Optimal Design for Plan and System using Poisson and ZIP Distribution

According to[10], in economic design of sampling plan, the optimal sampling plan using Poisson distribution is n=201, and c=9 with the minimum total cost TC = 504.98. But in this study, while using ZIP Distribution, the optimal sampling plan is n=171, and c=8 with the minimum total cost TC = 477.93. The optimal sampling system using ZIP distribution is n=100, c_N = 7, and c_T = 2 with the minimum total cost TC = 394.29. The efficiency of economic design of both plan and system using ZIP distribution is compared with the Poisson distribution.

The corresponding values of sample size, acceptance numbers and total cost are identified and presented in table 1. From this one can observe that, the total cost of both the plan and system under ZIPD is much lesser than Poisson distribution.

Table 1. Comparison of Optimal Design for Plan and System

	SSP_P (n; c)	SSP_ZIPD (n; c)	QSS_ZIPD (n; c_N, c_T)
Sample Size	201	171	100
Acceptance Number	9	8	7,2
Total Cost	504.98	477.93	394.29

Table 2. Single Sampling Plan satisfying AQL = 0.02, LTPD = 0.07, α = 0.05, β = 0.1, with n≤210

N	C	P_a(p)	AOQ	ATI	D_d	D_n	1-P_a(AQL)	P_a(LTPD)	TC
154	6	0.8172	0.0207	308.63	9.26	20.74	0.0373	0.0972	534.56
156	6	0.8093	0.0205	316.99	9.51	20.49	0.0395	0.0911	540.91
157	6	0.8052	0.0204	321.21	9.64	20.36	0.0407	0.0882	544.12
158	6	0.8011	0.0202	325.44	9.76	20.24	0.0418	0.0854	547.33
159	6	0.7970	0.0201	329.70	9.89	20.11	0.0430	0.0827	550.57
160	6	0.7929	0.0200	333.96	10.02	19.98	0.0442	0.0801	553.81
161	6	0.7887	0.0199	338.26	10.15	19.85	0.0454	0.0775	557.07
162	6	0.7845	0.0197	342.56	10.28	19.72	0.0466	0.0750	560.35
164	6	0.7761	0.0195	351.22	10.54	19.46	0.0492	0.0703	566.93
171	7	0.8542	0.0212	291.88	8.76	21.24	0.0235	0.0985	521.83
171	**8**	**0.9239**	**0.0230**	**234.12**	**7.02**	**22.98**	**0.0085**	**0.0999**	**477.93**
172	7	0.8509	0.0211	295.45	8.86	21.14	0.0243	0.0969	524.55
173	7	0.8476	0.0210	299.05	8.97	21.03	0.0250	0.0940	527.28
175	7	0.8409	0.0208	306.30	9.19	20.81	0.0265	0.0884	532.79
176	7	0.8374	0.0207	309.95	9.30	20.70	0.0272	0.0857	535.56
178	7	0.8305	0.0205	317.32	9.52	20.48	0.0288	0.0805	541.16
180	7	0.8234	0.0203	324.78	9.74	20.26	0.0305	0.0757	546.83
181	7	0.8199	0.0201	328.53	9.86	20.14	0.0313	0.0734	549.69
182	7	0.8163	0.0200	332.31	9.97	20.03	0.0322	0.0712	552.55
186	7	0.8015	0.0196	347.57	10.43	19.57	0.0358	0.0629	564.15
196	8	0.8608	0.0208	307.93	9.24	20.76	0.0189	0.0804	534.03
198	8	0.8548	0.0206	314.42	9.43	20.57	0.0200	0.0758	538.96
199	8	0.8518	0.0205	317.69	9.53	20.47	0.0206	0.0736	541.45
199	7	0.7506	0.0180	398.75	11.96	18.04	0.0495	0.0425	603.05
200	8	0.8488	0.0204	320.98	9.63	20.37	0.0212	0.0714	543.95
210	8	0.8166	0.0194	354.87	10.65	19.35	0.0277	0.0533	569.70
210	9	0.8949	0.0212	293.00	8.79	21.21	0.0110	0.0894	522.68

4 Conclusion

This study demonstrates the effectiveness of designing single sampling plans and Quick Switching Systems (QSS) under the Zero-Inflated Poisson (ZIP) distribution. By incorporating excess zero-defect cases during inspection, the ZIP-based approach provides a more realistic representation of modern manufacturing environments, where high-quality processes result in very low defect rates. A comparison with the traditional Poisson distribution clearly shows that the ZIP distribution yields smaller sample sizes, lower acceptance numbers, and reduced total costs, without compromising consumer or producer protection.

The results confirm that QSS under ZIP is more cost-efficient than QSS under the Poisson distribution, offering an optimal balance between inspection effort and quality assurance. This ensures that producers can minimize inspection costs while consumers gain greater confidence in product reliability. Thus, the proposed ZIP-based economic design framework offers a practical, statistically sound, and economically viable solution for industries operating in zero-inflated defect scenarios, aligning quality control with both productivity and customer satisfaction.

Table 3. Quick Switching Single Sampling System satisfying AQL = 0.02, LTPD = 0.07, α = 0.05, β = 0.1, with n$\leq$120

N	C_N	C_T	P_a(p)	AOQ	ATI	D_d	D_n	1-P_a(AQL)	P_a(LTPD)	TC
98	6	2	0.9360	0.0253	155.76	4.67	25.33	0.0058	0.0752	418.38
100	5	2	0.8378	0.0226	246.03	7.38	22.62	0.0236	0.0538	486.98
100	6	2	0.9282	0.0251	164.60	4.94	25.06	0.0066	0.0674	425.10
100	**7**	**2**	**0.9733**	**0.0263**	**124.07**	**3.72**	**26.28**	**0.0016**	**0.0901**	**394.29**
101	5	2	0.8307	0.0224	253.25	7.60	22.40	0.0248	0.0512	492.47
101	6	2	0.9241	0.0249	169.24	5.08	24.92	0.0070	0.0638	428.62
101	7	2	0.9714	0.0262	126.72	3.80	26.20	0.0017	0.0849	396.31
102	5	2	0.8234	0.0222	260.59	7.82	22.18	0.0260	0.0488	498.05
102	6	2	0.9198	0.0248	174.03	5.22	24.78	0.0074	0.0605	432.26
102	7	2	0.9694	0.0261	129.47	3.88	26.12	0.0018	0.0801	398.40
105	5	2	0.8006	0.0215	283.51	8.51	21.49	0.0301	0.0424	515.47
105	6	2	0.9058	0.0243	189.29	5.68	24.32	0.0088	0.0518	443.86
105	7	2	0.9628	0.0259	138.30	4.15	25.85	0.0023	0.0675	405.11
106	5	2	0.7926	0.0213	291.41	8.74	21.26	0.0315	0.0405	521.47
106	6	2	0.9008	0.0242	194.69	5.84	24.16	0.0093	0.0493	447.97
106	7	2	0.9603	0.0258	141.46	4.24	25.76	0.0024	0.0639	407.51
110	5	2	0.7593	0.0203	324.20	9.73	20.27	0.0379	0.0340	546.39
110	6	2	0.8788	0.0235	217.87	6.54	23.46	0.0117	0.0406	465.58
110	7	2	0.9492	0.0253	155.21	4.66	25.34	0.0031	0.0516	417.96
112	5	2	0.7418	0.0198	341.25	10.24	19.76	0.0414	0.0313	559.35
112	6	2	0.8666	0.0231	230.42	6.91	23.09	0.0130	0.0371	475.12
112	7	2	0.9428	0.0251	162.83	4.88	25.12	0.0035	0.0467	423.75
113	5	2	0.7329	0.0195	349.91	10.50	19.50	0.0432	0.0301	565.93
113	6	2	0.8603	0.0229	236.95	7.11	22.89	0.0137	0.0355	480.08
113	7	2	0.9393	0.0250	166.83	5.00	25.00	0.0038	0.0444	426.79
115	5	2	0.7147	0.0190	367.50	11.02	18.98	0.0471	0.0279	579.30
115	6	2	0.8469	0.0225	250.47	7.51	22.49	0.0152	0.0326	490.35
115	7	2	0.9319	0.0247	175.25	5.26	24.74	0.0043	0.0404	433.19
120	6	2	0.8102	0.0214	287.00	8.61	21.39	0.0196	0.0268	518.12
120	7	2	0.9104	0.0240	198.85	5.97	24.03	0.0057	0.0324	451.12

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