Sains Malaysiana 54(2)(2025): 611-620
http://doi.org/10.17576/jsm-2025-5402-25

Constructing Bayesian New Group Chain Acceptance Sampling Plans (BNGChSP-1) using Tangent Angle for Probabilistic Quality Region (PQR) and Limiting Quality Region (LQR)

(Membina Pelan Persampelan Rangkaian Kumpulan Baharu Bayesian (BNGChSP-1) menggunakan Sudut Tangen untuk Wilayah Kualiti Kebarangkalian (PQR) dan Wilayah Kualiti Had (LQR))

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Received: 15 April 2024/Accepted: 22 November 2024

ABSTRACT

This article develops Bayesian new group chain acceptance sampling plans (BNGChSP-1) using the tangent angle for two distinct regions, namely the probabilistic quality region (PQR) and the limiting quality region (LQR). The BNGChSP-1, which makes use of past knowledge about the process variation, can be used as an alternative to traditional plans for evaluating the processes that generate the lots. The angle for both regions is calculated by using the tangent, and the region with a smaller angle resembles the ideal operating characteristics (OC) curve better than the region with a bigger angle. The finding shows that the PQR generates a smaller angle than the LQR, suggesting that the PQR more closely resembles the ideal OC curve compared to the LQR. The smaller angle indicates that the PQR offers greater protection to both producers and consumers than the LQR.

Keywords: Bayesian new group chain acceptance sampling plans (BGChSP-1); limiting quality region (LQR); probabilistic quality region (PQR); tangent angle

ABSTRAK

Artikel ini membincangkan pelan persampelan Bayesian baharu penerimaan kumpulan berantai (BGChSP-1) menggunakan sudut tangen untuk dua wilayah berbeza, iaitu wilayah kualiti kebarangkalian (PQR) dan wilayah kualiti terbatas (LQR). BGChSP-1 ini, yang menggunakan pengetahuan terdahulu tentang proses variasi, boleh digunakan sebagai satu alternatif kepada pelan tradisi untuk menentukan proses yang menjana lot. Sudut untuk kedua-dua wilayah dihitung menggunakan tangen dan wilayah dengan sudut yang lebih kecil menyerupai lengkung cirian pengoperasian (OC) yang ideal dengan lebih baik berbanding wilayah dengan sudut yang lebih besar. Penemuan ini menunjukkan bahawa PQR menjana sudut yang lebih kecil berbanding LQR, mencadangkan bahawa PQR lebih menyerupai OC yang ideal berbanding LQR. Sudut yang lebih kecil menunjukkan bahawa PQR menawarkan perlindungan yang lebih baik kepada kedua-dua pengeluar dan pengguna berbanding LQR.

Kata kunci: Pelan persampelan Bayesian baharu penerimaan kumpulan berantai (BGChSP-1); sudut tangen; wilayah kualiti kebarangkalian (PQR); wilayah kualiti terbatas (LQR)

INTRODUCTION

Acceptance sampling is a quality control statistical technique that sampling specific quantities of products and decide whether to accept or reject a batch (Pardo 2023). It consists of the evaluation of an indicated number of pieces from the lot and making a verification that they agree with certain preset criteria. Bayesian sampling plans are a type of acceptance sampling that incorporates Bayesian decision theory (Casaca & Gomes 2006). These plans can be optimal, as they allow for the formal posing and answering of the question: "How many should I test?" (Gimlin & Breipohl 1972). Bayesian sampling plans

considered the quality level of the lots and using the Bayes risk as the criterion which is in the form of expected loss for consumers and producers. However, this technique has mainly a decisive advantage in case of indefiniteness in the parameters' values (Li & Li 2015).

Tangent angle is a geometric concept, which has its trigonometric representation. It is a trigonometric function that gives their length ratio of the opposite and adjacent sides of a right triangle with that angle. With regards to quality control, the tangent angle could be utilized in numerous ways. As an illustration, the Gaussian weighting based tangent angle (GWBTA) feature tensor is used for signatures differentiation in offline signature verification that is based on shape (Bonde, Narwade & Bonde 2022). As further use case, the tangential angles of a dam are found by the adaptive complementary filter which uses the shape of the rubber dam as its reference (Hu et al. 2021).

The probabilistic quality region (PQR) stands for a quality concept that uses a probability function to show its quality of the product or service (Lange & Schnor 2023). For instance, a PQR (i.e., quality evaluation of blind images) is used to train deep networks in blind image quality assessment (Zeng, Zhang & Bovik 2018). The PQR performs for a more robust loss function and helps to converge the deep model training to be fast, as well as to greatly improve quality score prediction accuracy compared to quality score regression method (Zeng, Zhang & Bovik 2018).

Limiting quality region (LQR) is a control theory terminology. For example, an LQR-type controller that is specifically developed to suppress milling chatter can be incorporated in the control strategy. Most remarkably, the straightforward LQR controller significantly expands the stability limit of the milling procedure and can prevent the milling chatter vibration through excellent suppression ability (Li et al. 2020). Currently, there is a lack of research focused on demonstrating how to represent Bayesian new group chain acceptance sampling plans (BGChSP-1) using the tangent angle for PQR and LQR. The objective of the study was to develop a unified framework for BGChSP-1 that incorporates both PQR and LQR regions. This work utilizes Bayesian sampling plans, the benefits of the tangent angle in addressing product quality concerns, and the concept bridging PQR and LQR to improve the effectiveness and efficiency of acceptance sampling plans.

LITERATURE REVIEW

There are upsurges of the application of Bayesian group sampling plans on production processes, as authored in the recent literature. Kaviyarasu and Sivakumar (2022) studied a Bayesian perspective of repetitive group sampling for quality discrimination in a destructive progress discipline. Hafeez and Aziz (2019) developed Bayesian group chains for sampling plan in beta binomial distribution that involved both the consumer's and producer's risks. Also, Hafeez and Aziz (2022a) proposed a Bayesian two side complete group chain sampling plan for the binomial distribution, comparing it with the existing Bayesian group chain sampling plan.

Teh, Aziz and Zain (2021a) proposed application of the group chain acceptance sampling plans (GChSP-1) using the minimal angle method for the truncated life testing with respect to the risks faced by consumers and producers. Aziz, Teh and Zain (2021) developed new two-sided group chain acceptance sampling plans (NTSGChSP-1) for the generalized exponential distribution by using the minimum angle method. Teh, Aziz and Zain (2021b) suggested the new group chain acceptance sampling planning (NGChSP-1) that was developed by four acceptance criteria for the generalized exponential distribution. The results demonstrate the necessity of designing the sampling plans that include the consumer's and producer's risks, as well as the mean proportion of defects. The employment of Bayesian methods and the minimum angle of a clothed surface is a manifestation of the progress in quality control. Future study might be directed to fine-tuning these approaches and implementing them at different distribution and industries as this can improve the control procedure in this sector and others.

Bayesian modified group chain acceptance sampling plans (BMGChSP) for the binomial distribution with a beta prior and in the regions of quality was constructed by Hafeez and Aziz (2022b). Moreover, Aslam, Srinivasa Rao and Khan (2021) studied the unified group sampling plans which are one stage and two stage total expected failure-based sampling procedures for Weibull distribution under neutrosophic statistics together with their asymptotic variances and comparing the efficiency with the group sampling plan under classical statistics. Kaviyarasu and Sivakumar (2022) studied about the Bayesian repetitive group sampling plans in order to do quality assessment of the pharmaceutical products and the materials related to it. The main objective of the study was to assess the zero inflated Poisson distribution. Also, Kaviyarasu and Sivakumar (2022) studied Bayesian new group chain sampling plans to ensure quality of regions together with Bayesian group chain sampling plans for Poisson distribution with gamma prior.

Hafeez et al. (2022) presented Bayesian new group chain sampling plans (BNGChSP) to estimate the average probability of the acceptation. They employed binomial distribution to distinguish between the non-defective and defective products and the beta distribution was considered as a good prior distribution. The paper includes four quality regions namely (i) probabilistic quality region (PQR), (ii) quality decision region (QDR), (iii) limiting quality region (LQR), and (iv) indifference quality region (IQR). The numerical values of BNGChSP were calculated, and the inflection points values are derived based on different combinations of design parameters which consist of both the consumer's and producer's risks. The sensitivity

curves indicate the superiority of BNGChSP for industrial applications as a substitute.

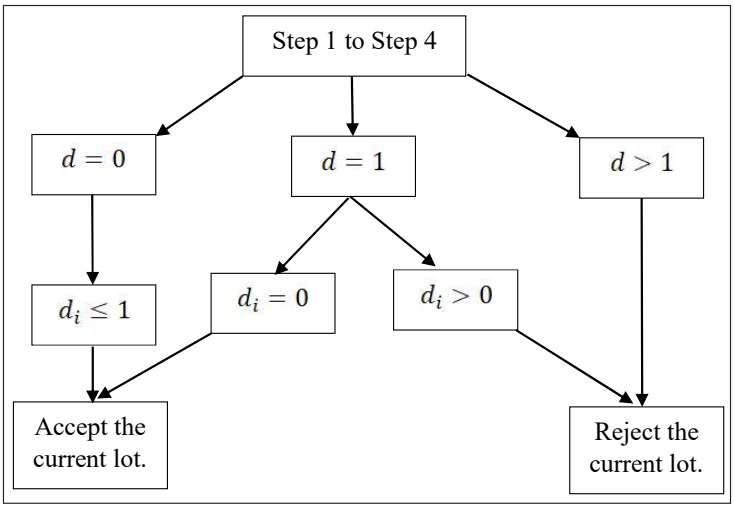
MATERIALS AND METHODS

The operating procedure for the NGChSP-1 is given as follows: Step 1: For each lot, the optimal number of groups, g is found, Step 2: The number of items, r is allocated to the g groups, Step 3: The test termination time, t_0 for the inspection activity is specified, Step 4: During the inspection activity, the number of defectives, d is counted. Decision: Accept the current lot if $d = 0$ given that the preceding lots have at most one defective. The current lot is also accepted if $d = 1$, given that there is no defective recorded in the preceding i lots. Reject the current lot if $d > 1$.

The current lot in the NGChSP-1 is accepted if $d = 0$ and the previous i lots have at most one defect. Assuming no defects were discovered in the previous i lots, the current lot is also accepted if $d = 1$. If not, the current lot is rejected. The probability of lot acceptance for the NGChSP-1 is derived using a tree diagram. The NGChSP-1 tree diagram is depicted in Figure 1, with *D* and $\overline{D}$ representing defectives and non-defectives, respectively.

There are four approved lots for the NGChSP-1 which are *DDD, DDD, DDD* and $\overline{D}\,\overline{D}\,\overline{D}$. The following represents the probability of lot acceptance, $L(p)$ for the NGChSP-1

$$L(p) = (P_0)^i[(i+1)P_1 + P_0], \qquad (1)$$



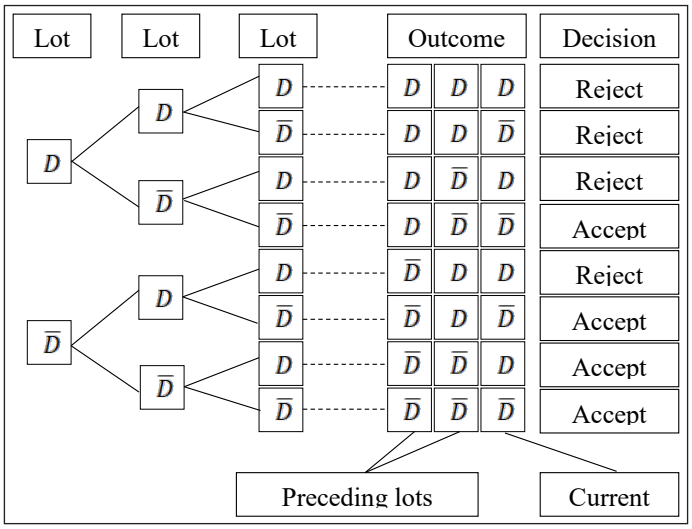


FIGURE 1. Tree diagram for the NGChSP-1

where P_0 is the probability of zero defective; i is the number of preceding lots; and P_1 is the probability of one defective.

The binomial distribution can be used to determine the probability of zero and one defective product based on the characteristics of a binomial experiment. Lots are made up of independent, identical trials, which make them valid. The inspection's output is based on two mutually exclusive possibilities: either it is defective, or it is not. Application of the binomial distribution is possible for large populations with sample fractions less than 0.10. The probability of acceptance for zero and one defective is given by

$$P_0(p) = (1-p)^{gr} \tag{2}$$

and

$$P_1(p) = (grp)(1-p)^{(gr)-1}, \tag{3}$$

where p is the fraction defective; g is the number of groups; and r is the number of products.

By substituting Equations (2) and (3) into Equation (1), the probability of lot acceptance for the NGChSP-1 can be simplified as

$$L(p) = (1-p)^{gr(i+1)}\left[\frac{(i+1)grp}{1-p} + 1\right]. \tag{4}$$

A suitable prior distribution is the beta distribution if the sample has a binomial distribution. This indicates that the fraction defective, p follows the beta distribution. The probability density function (PDF) for the beta distribution is given by

$$f(p) = \frac{1}{\beta(s,t)} p^{s-1}(1-p)^{t-1}. \tag{5}$$

where the mean for beta, μ is represented by $\frac{s}{s+t}$ and $s,t > 0$ are the shape parameters. The average probability of lot acceptance for the general expression of the Bayesian can be estimated by using

$$\bar{P} = \int_0^1 L(p) f(p)\, dp. \tag{6}$$

By substituting Equations (4) and (5) into Equation (6), the average probability of lot acceptance for the BNGChSP-1 can be simplified as

$$\begin{aligned}\bar{P} &= \int_0^1 \left((1-p)^{rg(i+1)} + (i+1)rgp(1-p)^{rg(i+1)-1}\right) * \frac{1}{\beta(s,t)} p^{s-1}(1-p)^{t-1}\, dp \\ &= \frac{1}{\beta(s,t)}[\beta(s, rg(i+1)+t) + (i+1)rg\beta(s+1, rg(i+1)+t-1)] \\ &= \frac{\Gamma(s+t)\Gamma(rg(i+1)+t)}{\Gamma(t)\Gamma(rg(i+1)+s+t)} + rg(i+1)\frac{s\,\Gamma(s+t)\Gamma(rg(i+1)+t-1)}{\Gamma(t)\Gamma(rg(i+1)+s+t)}.\end{aligned} \tag{7}$$

Equation (7) is a combination of binomial and beta distributions. When $s = 1$, then Equation (7) becomes

$$\bar{P} = \frac{1-\mu}{rg\mu(i+1)+1-\mu} + \frac{rg\mu(i+1)(1-\mu)}{(rg\mu(i+1)+1-\mu)(rg\mu(i+1)+1-2\mu)}. \tag{8}$$

Equation (7) becomes

$$\begin{aligned}\bar{P} = &\frac{(2-\mu)(2-2\mu)}{(rg\mu(i+1)+2-\mu)(rg\mu(i+1)+2-2\mu)} \\ &+ \frac{2rg\mu(i+1)(2-\mu)(2-2\mu)}{(rg\mu(i+1)+2-\mu)(rg\mu(i+1)+2-2\mu)(rg\mu(i+1)+2-3\mu)}\end{aligned} \tag{9}$$

when $s = 2$. Finally, when $s = 3$, then Equation (7) can be written as

$$\begin{aligned}\bar{P} = &\frac{(3-\mu)(3-2\mu)(3-3\mu)}{(rg\mu(i+1)+3-\mu)(rg\mu(i+1)+3-2\mu)(rg\mu(i+1)+3-3\mu)} + \\ &\frac{3rg\mu(i+1)(3-\mu)(3-2\mu)(3-3\mu)}{(rg\mu(i+1)+3-\mu)(rg\mu(i+1)+3-2\mu)(rg\mu(i+1)+3-3\mu)(rg\mu(i+1)+3-4\mu)}.\end{aligned} \tag{10}$$

The quality regions for the BNGChSP-1 are calculated by applying Newton's approximation where μ is used as the control point to reduce $\bar{P}$. This article focuses only on two quality regions namely probabilistic quality region (PQR) and limiting quality region (LQR). The PQR is defined as a region in which the product is accepted with a minimum probability of 0.05 and a maximum probability of 0.95 within $\mu_1 < \mu < \mu_2$. It is denoted by R_1 where $R_1 = \mu_2 - \mu_1$. Figure 2 shows the operating characteristics (OC) curve with the pair of coordinates for the PQR.

Based on Figure 2, the angle, θ is calculated by taking

$$\begin{aligned}\tan\theta &= \frac{\mu_2 - \mu_1}{0.95 - 0.05} \\ &= \frac{R_1}{0.90}.\end{aligned} \tag{11}$$

Upon simplification, the angle, θ is given by

$$\theta = \arctan\left(\frac{R_1}{0.90}\right). \tag{12}$$

The region $\mu_\alpha < \mu < \mu_2$ where a product is accepted with a maximum probability of 0.75 and a minimum probability of 0.05 is known as the LQR. It is represented by $R_2 = \mu_2 - \mu_\alpha$ and the OC curve with the two LQR coordinates is displayed in Figure 3.

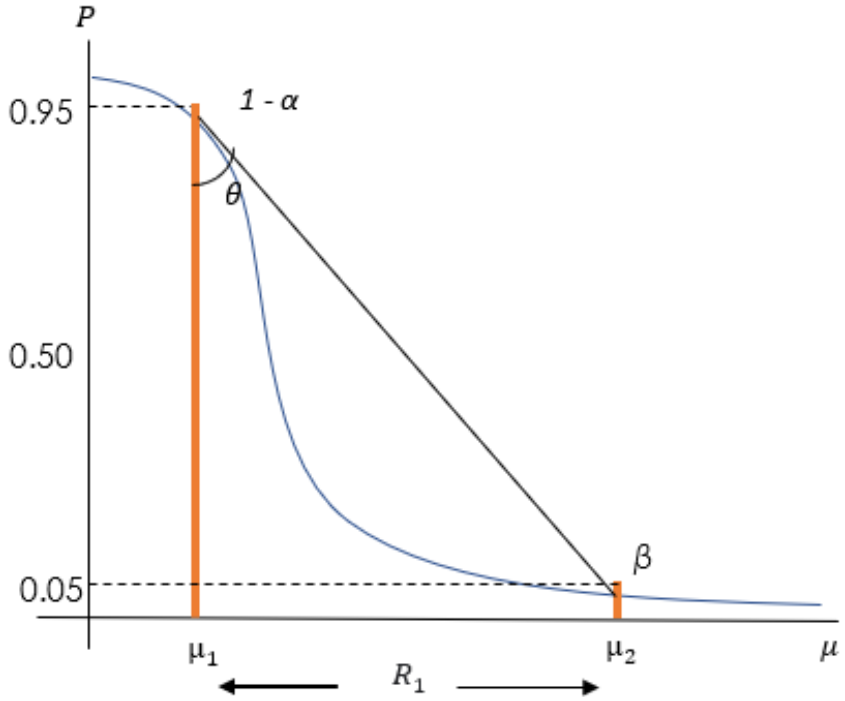


FIGURE 2. The PQR on the OC curve by Hafeez and Aziz (2022a)

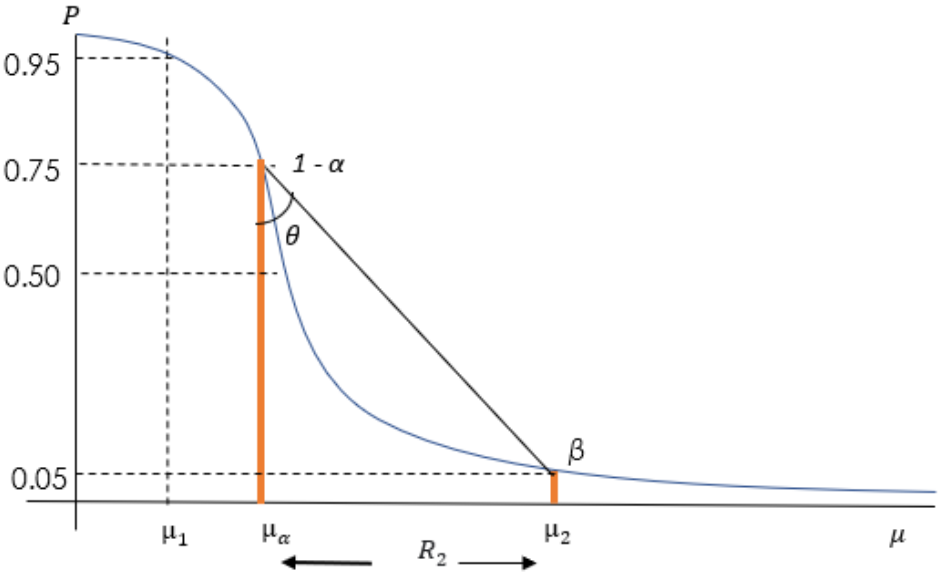


FIGURE 3. The LQR on the OC curve

The angle, θ in Figure 2 is found by using

$$\tan\theta = \frac{\mu_2 - \mu_\alpha}{0.75 - 0.05} = \frac{R_2}{0.70}. \quad (13)$$

When simplified, the angle, θ is provided by

$$\theta = \arctan\left(\frac{R_2}{0.70}\right) \quad (14)$$

RESULTS AND DISCUSSION

The following analysis delves into the effectiveness of the BNGChSP-1 under various design parameters. By examining these parameters, we can understand their impact on quality control. Table 1 shows the average probability of lot acceptance and the average fraction defective at different values of design parameters. Based on Table 1, the average fraction defective is 0.0045 when the design parameters are $(s, g, r, i, \bar{P}) = (1, 4, 4, 3, 0.95)$. The value indicates that when a lot consists of 10000 products, then the lot has on average 45 defective products after the inspection is done on the lot. The lot has a 95% acceptance rate on average, despite having an average of 45 defective products.

The average fraction defective depends on the values of the shape parameter of beta distribution, s. When the shape parameter of the beta distribution, s increases from 1 to 3, the average fraction defective also increases. For instance, the average fraction defective is 0.0045 when the design parameters are $(s, g, r, i, \bar{P}) = (1, 4, 4, 3, 0.95)$. The average fraction defective increases to 0.0051 when the design parameters are $(s, g, r, i, \bar{P}) = (3, 4, 4, 3, 0.95)$. If a producer has two different lots, the first lot consists of 10000 products which follow beta distribution with 1 as the shape parameter and the second lot also has 10000 products but the products follow the beta distribution with 3 as the shape parameter, then the producer should expect that on average, the first lot will have 45 defective products while the second lot will have 51 defective products.

The average fraction defective is also influenced by the number of groups, g; a smaller number of groups will result in a greater average fraction defective. For example, if the design parameters are $(s, g, r, i, \bar{P}) = (1, 4, 4, 3, 0.95)$, the average fraction defective is 0.0045. At design parameters of $(s, g, r, i, \bar{P}) = (1, 1, 4, 3, 0.95)$, the average fraction defective rises to 0.0183. Besides that, the combination of the number of products, r and the number of preceding lots, i also determines the average fraction defective. When the number of products and the number of preceding lots of decrease, the average fraction defective increases. For example, the average fraction defective is 0.0045 when the design parameters are $(s, g, r, i, \bar{P}) = (1, 4, 4, 3, 0.95)$. The average fraction defective increases to 0.0183 when the design parameters are $(s, g, r, i, \bar{P}) = (1, 4, 2, 1, 0.95)$.

Table 2 shows the angle for PQR and LQR at different values of design parameters. The angle for both PQR and LQR reduces when the shape parameter, s of beta distribution rises. The angle for PQR is 22.511^o when the design parameters are $(s, g, r, i) = (1, 4, 4, 3)$. The angle is then reduced to 7.920^o when the design parameters change to $(s, g, r, i) = (3, 4, 4, 3)$. The result demonstrates that, in comparison to the beta distribution with a lower shape parameter, the beta distribution with a higher shape parameter more closely reflects the ideal OC curve. Stated differently, a product that displays a higher shape distribution of the beta distribution offers producers and consumers greater protection.

In addition to the shape parameter of beta distribution, the angle is also influenced by the number of groups. When the design parameters are $(s, g, r, i) = (1, 4, 4, 3)$, the PQR angle is 22.511^o. After that, the angle is increased to 37.668^o when the design parameters shift to $(s, g, r, i) = (1, 1, 4, 3)$. The result implies that an optimal OC curve is more closely resembled by a larger number of groups than by a smaller number of groups. Since inspecting more products will better protect producers and consumers than inspecting fewer, the findings will inadvertently direct the inspector to inspect more products.

In addition, the angle is determined by the number of products and the number of preceding lots. The angle rises as both the number of items and the number of preceding lots decline. In the scenario where the design parameters are $(s, g, r, i) = (1, 4, 4, 3)$, the PQR angle stands at 22.511^o. Next, when the design parameters change to $(s, g, r, i) = (1, 4, 2, 1)$, the angle increases to 37.668^o. The result demonstrates that a higher number of preceding lots than a lesser number of preceding lots is a better representation of the ideal OC curve. This result suggests that an inspector will undoubtedly protect producers and consumers more effectively if they are more knowledgeable about the prior inspections.

Considering all design parameters, the angle for PQR is always smaller than the LQR. When the design parameters are $(s, g, r, i) = (1, 4, 4, 3)$, the angle for PQR is 22.511^o. The angle for LQR with the identical design parameters is 27.345^o. In general, the results indicate that because the PQR has a smaller angle than the LQR, it offers greater protection to both producers and consumers.

TABLE 1. The average fraction defective for the specified probabilities in BNGChSP-1

s	g	r	i	0.95	0.75	0.05
1	4	4	3	0.0045	0.0155	0.3775
		3	2	0.0081	0.0274	0.5203
		2	1	0.0183	0.0607	0.7131
	3	4	3	0.0060	0.0206	0.4477
		3	2	0.0108	0.0364	0.5924
		2	1	0.0245	0.0801	0.7703
	2	4	3	0.0091	0.0308	0.5500
		3	2	0.0162	0.0541	0.6876
		2	1	0.0371	0.1180	0.8375
	1	4	3	0.0183	0.0607	0.7131
		3	2	0.0329	0.1055	0.8197
		2	1	0.0769	0.2249	0.9182
2	4	4	3	0.0049	0.0151	0.1746
		3	2	0.0088	0.0268	0.2824
		2	1	0.0199	0.0597	0.5021
	3	4	3	0.0065	0.0201	0.2233
		3	2	0.0117	0.0356	0.3520
		2	1	0.0267	0.0793	0.5923
	2	4	3	0.0099	0.0301	0.3096
		3	2	0.0177	0.0532	0.4662
		2	1	0.0406	0.1180	0.7175
	1	4	3	0.0199	0.0597	0.5021
		3	2	0.0359	0.1052	0.6821
		2	1	0.0847	0.2312	0.8859
3	4	4	3	0.0051	0.0150	0.1303
		3	2	0.0091	0.0267	0.2177
		2	1	0.0207	0.0597	0.4163
	3	4	3	0.0068	0.0200	0.1691
		3	2	0.0121	0.0355	0.2774
		2	1	0.0277	0.0794	0.5075
	2	4	3	0.0102	0.0300	0.2408
		3	2	0.0183	0.0531	0.3817
		2	1	0.0422	0.1185	0.6461
	1	4	3	0.0207	0.0597	0.4163
		3	2	0.0373	0.1055	0.6054
		2	1	0.0882	0.2343	0.8605

TABLE 2. The angle for PQR and LQR at different values of design parameters

s	g	r	i	Angle for PQR (^{o})	Angle for LQR (^{o})
1	4	4	3	22.511	27.345
		3	2	29.645	35.151
		2	1	37.668	42.984
	3	4	3	26.141	31.389
		3	2	32.871	38.46
		2	1	39.647	44.596
	2	4	3	31.006	36.565
		3	2	36.723	42.145
		2	1	41.648	45.787
	1	4	3	37.668	42.984
		3	2	41.161	45.575
		2	1	43.069	44.724
2	4	4	3	10.678	12.836
		3	2	16.909	20.059
		2	1	28.181	32.293
	3	4	3	13.544	16.187
		3	2	20.712	24.323
		2	1	32.147	36.236
	2	4	3	18.418	21.766
		3	2	26.489	30.541
		2	1	36.947	40.578
	1	4	3	28.181	32.293
		3	2	35.678	39.493
		2	1	41.676	43.085
3	4	4	3	7.920	9.353
		3	2	13.049	15.262
		2	1	23.728	26.996
	3	4	3	10.222	12.024
		3	2	16.424	19.064
		2	1	28.063	31.449
	2	4	3	14.371	16.759
		3	2	21.988	25.147
		2	1	33.862	37.006
	1	4	3	23.728	26.996
		3	2	32.261	35.532
		2	1	40.633	41.815

CONCLUSION

In this article, the tangent angle for the two separate regions—the limiting quality region (LQR) and the probabilistic quality region (PQR)—is used to build Bayesian new group chain acceptance sampling plans (BNGChSP-1). For sentencing the processes that generate the lots, the BNGChSP-1 can be utilized instead of standard plans because it utilizes historical knowledge about the process that generates the lots.

The average fraction defective depends on the values of the shape parameter of beta distribution, the number of groups, the number of products and the number of preceding lots. When the shape parameter of the beta distribution increases from 1 to 3, the average fraction defective also increases. The number of groups also affects the average fraction defective; a smaller number of groups will provide a higher average fraction defective. The average fraction defective is also determined by the number of products and the number of preceding lots. The average fraction defective increases as both the number of products and the number of preceding lots of decrease.

The angle for both PQR and LQR depends on the shape parameter of beta distribution, the number of groups, the number of products and the number of preceding lots. As the shape parameter for beta distribution increases, the angle for both PQR and LQR decreases. The angle increases as the number of groups decreases. The number of products and the number of preceding lots also affect the angle. As the number of products and the number of preceding lots of decrease, the angle increases. In general, the angle for PQR is always smaller compared to the angle created for LQR for all the design parameters. Future studies can investigate the BNGChSP-1 further by utilizing different prior distribution such as Poisson distribution, different region such as quality decision region (QDR), and different acceptance sampling such as Bayesian group chain acceptance sampling plans (BGChSP-1).

ACKNOWLEDGEMENTS

This research was supported by Ministry of Higher Education (MoHE), Malaysia, through The Fundamental Research Grant Scheme for Early Career (FRGS-EC/1/2024/STG06/UUM/02/3).

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