NIPES

Journal of Science and Technology Research

Journal homepage: www.nipesjournals.org.ng

Sampling Plan for Process Average Based on the Modeling of the Process Output in a Local Manufacturing Enterprise

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Article Info

***Keywords*:**
Sampling plan, Average Quantity System, Probability distribution models, Statistical Quality Control, Control Charts.

Received 25 September 2023
Revised 11 December 2023
Accepted 22 December 2023
Available online 23 Dec. 23

https://doi.org/10.5281/zenodo.10426444

Abstract

In today's competitive market and to ensure manufactured goods meet the internationally recognized average quantity system, manufacturers must begin to put in place sampling plans to monitor the average net weight of goods in lots released into the market. In this study, we deployed the use of the X bar-S chart to investigate process stability and the continuous probability distribution plots to model the process output and obtain process parameters useful in the design of an economic process average sampling plan. The UCL and LSL are deployed as two key locations in the design process. This plan gives a lot-by-lot average net weight sampling plan requiring a sample size of 16 per lot, and an average acceptance limit of 70.2g. This paper demonstrates how the design of a process average sampling plan can be hinged on the existing process parameters, especially when the process is found to be stable, however slightly off-centered the process might be, as no manufacturing process can be entirely free from errors. This is an easy-to-use sampling plan that does not require much training to be implemented on the factory floor by artisans and foremen.

1.Introduction

Delivering high-quality products and services to customers remains the bedrock of the total quality management philosophy; therefore, organizations constantly look for ways to enhance their production and management procedures in order to stay competitive in the market[1][2]. As a result, among other things, productivity, product quality, and customer satisfaction must all be improved[3]. Consumers who are unable to confirm the net quantity of the contents of packages they buy are protected by the net content inspection of packaged goods, which uses sample plans for market surveillance. This guarantees ethical business operations and maintains market competition. Additionally, it encourages makers, distributors, and retailers to use ethical production and distribution practices [4], [5]. The average net weight of the packaged content must match or exceed the labelled net quantity stated on the package in order for a lot to be considered acceptable [4], and this is consistent with the Average Quantity System (AQS), which is widely used to identify net weight flaws in products intended for general use [6][7].

Acceptance sampling plans are a statistical quality control approach used to measure random samples of populations known as "lots" of materials or products against established standards [8], [9]. When evaluating a product is harmful, expensive, time-consuming, or there is a high risk of product liability, a sampling plan is most helpful to implement [10]. Acceptance sampling plans can be classified into two categories, which are the attribute sampling plans where lots are accepted when the number of defective items in the sample from the lot is less than or equal to an acceptability constant while a variable sampling plan are quality characteristics which can be measured on a numerical scale and when compared to a pre-specified value, lot sentencing is carried out [11]. These sampling techniques have been extensively utilized in businesses for the inspection and testing of both the end products and the raw materials after production, prior to their release onto the open market [12]. Plans for acceptance sampling are created to offer some assurance to both producers and customers that the items in a lot conform to the specified requirements. Plans for acceptance sampling also assist manufacturers ship their goods into the market on schedule by reducing the time and expense of product examination. The chance of preventing a type I error, which is the rejection of a good lot, and a type II error, which is the approval of an unsuitable lot, is typically used to assess the statistical dependability of a sampling method.

The National Agency for Food and Drug Administration and Control (NAFDAC) made it necessary for produced items, such as bar soaps in this case, to have a declared net weight that is explicitly stated on the pack and that is also adhered to in the interest of the general public [13]. This highlights the need for local firms to start improving their manufacturing processes in order to get their products to satisfy the generally accepted average quantity norms if they want to compete on the global market. As a result, sampling for acceptance, which give criteria and decision rules for deciding whether to accept or decline a batch/lot based on randomly tested samples, play a crucial part in quality assurance approaches. They are frequently employed by producers, suppliers, contractors, and service providers across numerous industries. It is commonly recognized that probability distribution plays a key role in constructing an effective plan when designing sampling plans, notably single sampling schemes [14]. Therefore, it is necessary to understand the distribution and parameters of the relevant quality feature [9].

Different sample techniques have been utilized by different authors to accept or reject products. Jun et al, [15] designed a recurring group sampling plan that, under failure-censored reliability testing, follows a Weibull distribution having known shape characteristics in order to reduce the frequency of failures experienced in spares. Rasay et al, [11] created two brand-new variable reliability approval sampling plans for lifetime performance index failure censoring reliability testing. The neutrosophic statistical interval method was suggested by Aslam, [16] to be used anytime there is uncertainty on the quality of a lot. By integrating the advantages of the yield-based index and loss-based index, Wu & Wang, [17] created a variable multi-dependent state sample plan for lot sentencing based on the advanced process capability index by combining the merits of the yield and loss-based index. In order to update the distribution function of the probability of the nonconforming fraction, Fallahnezhad et al, [18] developed a new acceptance sampling strategy for accepting or rejecting a lot based on Bayesian modeling. For the purpose of inspecting geographic data outputs depending on the acceptance quality level, Tong et al[19]presented a two-rank acceptance sampling scheme. Obeidat et al, [3] created a sampling strategy based on an algorithmic method to sample milling machine spare parts. Sheu et al[20] developed an acceptance sampling plan putting process loss into consideration, by basing the study on the incapability index. Lin et al [21] based the lot sentencing scheme on a one-sided process capability indices and the present study bases its sampling design on process parameters obtained from the modeling of the product net weight in the manufacturing enterprise.

The primary objective and contribution of this study is to develop a methodology for the construction of a process average sampling plan using process parameters obtained from the modeling of the manufacturing process in light of AQS. First we begin by modeling the product net weight using probability plots to determine the model which fits the data set for the study. Secondly, we investigate the stability of the manufacturing process using suitable control charts to identify the control limits within the specification limits based on the existing inherent product variation. Finally, vital parameters from the process model was required to determine the ideal sample size and average acceptance limit, using the lower control limit (LCL) and lower specification limit (LSL) as two key locations, which the probability of rejecting a good lot average ($\alpha = 0.05$) and the probability of accepting a poor lot average ($\beta = 0.10$) was based respectively. This is to ensure that the sampling plan for the process average does not admit poor lots with averages that may possibly fall below the LSL in view of AQS requirements. The rest of the paper is organized as follows. Section 2 describes the methodology deployed for the study. In section 3 we present the results and discussion and in section 4, concluding remarks are provided.

2. Methodology

A soap manufacturing industry in the Southern part of Nigeria was selected for this study due to the fast pace in sales of their antiseptic bar soaps manufactured. To satisfy International Regulatory bodies [4][6], it is desired that the products falling below the declared net weight should not be released into the market. The bar soap manufacturing process has an Upper Specification Limit (USL) of 73grams, and a Lower Specification Limit (LSL) of 70grams, and a target of 71.5grams. In the design of a variable sampling plan for this product, it is important that the distribution of the product quality characteristics of interest be known [8]. Also, the process/lot variability needs to be investigated for stability using the X bar- R or S charts, since the known distribution and variability known plans are the most economical[9].

In this study, an ISO certified digital laboratory weighing balance was used to weigh out random samples collected of ten bar soaps across 30 lots manufactured. Each lot/box of bar soaps weighing less than 20 kilograms, contains 20 rolls of bar soaps with each roll containing 12 pieces. A sample from a lot weighing 71.1grams is shown in Figure 1.

Figure 1: Net weight of a sample weighing 71.1grams

2.1 Continuous Probability Plots

Probability plots are extremely useful when we need to determine which probability distribution is most likely to provide a reasonable model for the data obtained for study[9]. These continuous distributions are important in statistical quality control and the dataset with a sample size of N=300 was tested against the exponential, normal, Weibull and Gamma distributions. These models also aid in determining the process yield of the manufacturing operation.

2.2 Mean and Standard Deviation Chart

To investigate the stability in the manufacturing process, ten bar soaps were randomly collected across 30 lots. Even if the manufacturing process were not perfectly controlled, the control chart will provide information leading to a conservative estimate of the standard deviation[9], for use in designing a sampling plan for the organization.

The X-chart expression is given thus;

$$UCL = \bar{\bar{x}} + A_3\bar{s}$$
$$CL = \bar{\bar{x}} \quad (1)$$
$$LCL = \bar{\bar{x}} + A_3\bar{s}$$

And the S-Chart is;

$$UCL = B_4\bar{s}$$
$$CL = \bar{s} \quad (2)$$
$$LCL = B_3\bar{s}$$

A_3, B_3 and B_4 were obtained from tables for constructing variables control charts[9]. $\bar{\bar{x}}$ = the mean across ten samples collected in a lot and finally, the mean from each lot across the thirty lots, and $\bar{s}$ = the mean of the standard deviation across thirty lots. A detailed procedure for constructing an X bar-S chart can be found in [9].

2.3 Sampling Plan for the Process Average

Variable sampling plans for a process parameter are used when either the average quality/quantity of the product or process is of concern to the manufacturer[8]. These plans are suitable for products packed in bins, drums, boxes etc. This is a single sampling plan which a single specification limit is of concern to the manufacturer and in this instance, the Lower Specification Limit (LSL). This plan has two parameters which are the sample size (n) and the average acceptance limit $\bar{X}_m$. This sampling plan requires that a random sample size (n) from the lot is selected and the average taken. If the sample average is less than the average acceptance limit $\bar{X}_m$, the lot is rejected and the entire lot reviewed, but if greater than $\bar{X}_m$, the lot is accepted and fit for the market.

In the design of this sampling plan, best practice [22], suggests that the probability of rejecting a good lot with average $\bar{X}_1$ be set at α = 0.05 which gives us the probability of accepting a good lot as (1-α= 0.95) and the acceptance of a lot with a poor average quality $\bar{X}_2$ with a probability of β be set at β = 0.10.. Let Z_α represent the standard normal value corresponding to the α, and Z_β denotes the standard normal value corresponding to β. In this situation, Z_α and Z_β are both negative and positive respectively [8]. Therefore, we have

$$Z_\sigma = \frac{\bar{X}_m - \bar{X}_1}{\sigma/\sqrt{n}} \quad (3)$$

And,

$$Z_\beta = \frac{\bar{X}_m - \bar{X}_2}{\sigma/\sqrt{n}} \quad (4)$$

Resolving equations (3) and (4) simultaneously[8] we obtain our desired parameters, which are the sample number (n) and the Average Acceptance Limit ($\bar{X}_m$) presented in equations (5) and (6).

$$n = \left[\frac{(Z_\beta - Z_\alpha)\sigma}{\bar{X}_1 - \bar{X}_2}\right]^2 \quad (5)$$

$$\bar{X}_m = \frac{Z_\beta \bar{X}_1 - Z_\alpha \bar{X}_2}{Z_\beta - Z_\alpha} \quad (6)$$

Using this sampling plan requires that n samples are taken from the lot, and we base our decision on; $\bar{x} = (\sum_1^n x_i/n) \geq \bar{X}_m$ accept; otherwise reject/review entire lot.

3. Results and Discussion

3.1 Model Selection and Process yield

The data on net weight for three hundred samples collected across thirty lots of manufactured product shown in the table 1 displayed at the appendix, was entered into the Minitab 20 software. To determine the probability distribution model best suited to model the process output, we deploy the use of probability plots. The lognormal and normal probability distribution plots with p-values of 0.918 and 0.905 respectively shown in Figure 2 and Figure 3 proved significant and superior to the plots from the Weibull, gamma and exponential probability distribution plots shown in the appendix.

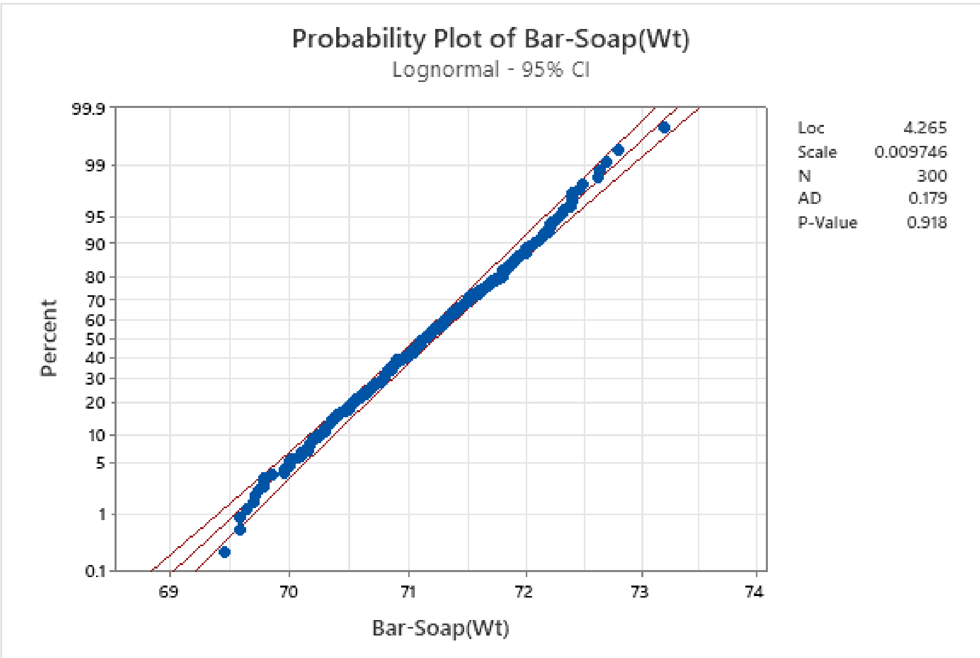

Figure 2: Lognormal probability plot of bar-soap net weights.

However, the sampling plan for the estimation of a process average requires that the quality characteristic of interest be normally distributed even though minor departures from normality may not affect the test results appreciably[8]. Therefore, from the probability distribution plot displayed in Figure 3, we can see that the manufacturing process is normally distributed with a mean of 71.14g and a standard deviation of 0.693.

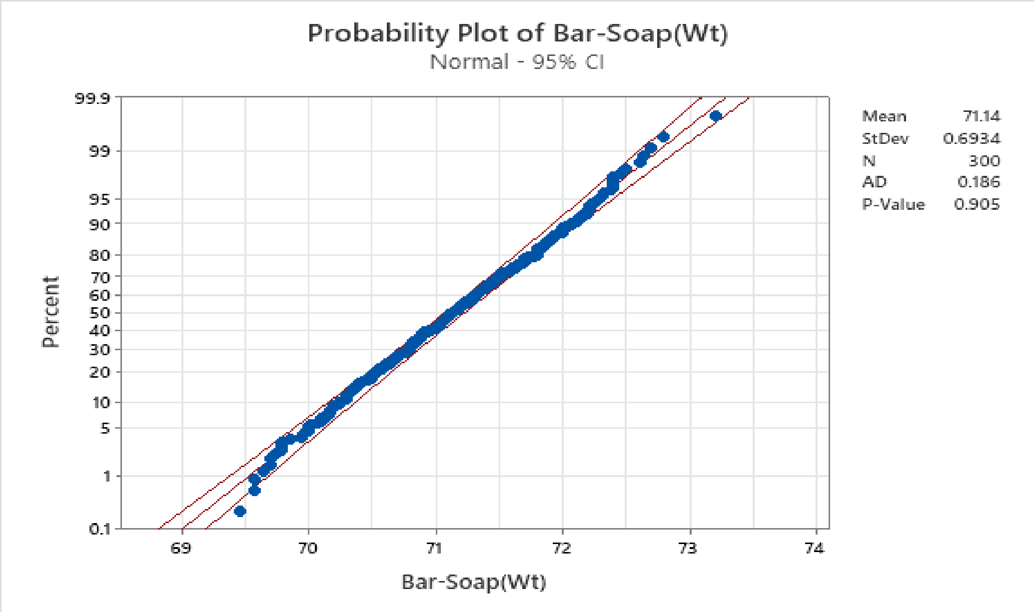

Figure 3: Normal probability plot of bar-soap net weights.

The cumulative normal distribution is defined as the probability that the normal random variable x, is equal to or less than a certain value, a, [9].

$$P\{x \leq a\} = F(a) = \int_{-\infty}^{a} \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)} dx \quad (7)$$

$$\text{Where } Z = \frac{X-\mu}{\sigma} \quad (8)$$

Evaluating further,

$$P\{x \leq a\} = P\left\{z \leq \frac{a-\mu}{\sigma}\right\} \equiv \Phi\left(\frac{a-\mu}{\sigma}\right) \quad (9)$$

Where Φ (·) stands for the cumulative distribution function of a standard normal distribution. "a" represents the LSL and USL as appropriate, μ represents the process mean and σ represents the process standard deviation. Therefore, from the quality characteristics of bar soap net-weights shown in Figure 4, with parameters obtained from the normal probability plot giving us a process mean of 71.14g and a process standard deviation of 0.693. The probability of the manufacturing process staying within specification limits may be determined.

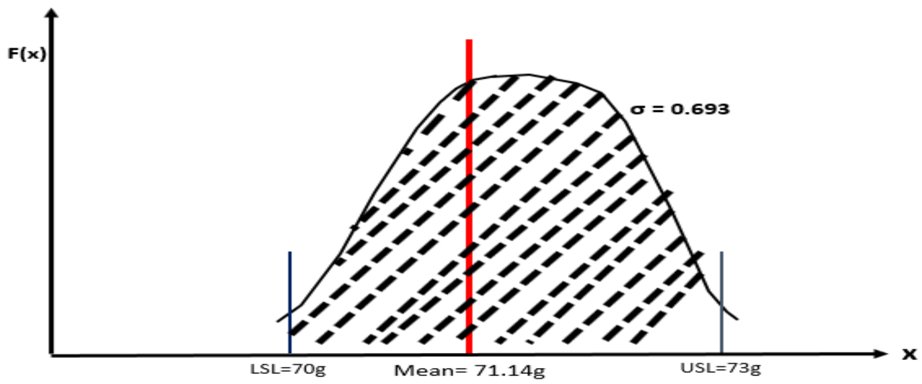

Figure 4: Normal distribution of bar-soap net-weights

The process yield is determined by factoring in the lower and upper specification limits thus;

$$P\{LSL \leq x \leq USL\} = P\{x \leq USL\} - P\{x \leq LSL\} \quad (10)$$

$$= \Phi\left(\frac{USL - \mu_{process}}{\sigma_{process}}\right) - \Phi\left(\frac{LSL - \mu_{process}}{\sigma_{process}}\right)$$

$$= \Phi\left(\frac{73 - 71.14}{0.693}\right) - \Phi\left(\frac{70 - 71.14}{0.693}\right)$$

$$= \Phi(2.68) - \Phi(-1.65) = 0.9468 \approx 95\%$$

This informs us that the manufacturing process has a potential process yield of 95% and process fall out of 5%. The process mean of 71.14g is below the centerline of 71.5g between the USL and LSL. Therefore, the fall outs are expected to fall below the LSL. The sampling plan designed, must therefore attempt to ensure that the 5% fall outs in specification does not get through the sampling process and into the market.

3.2 Process Stability

To determine how stable the manufacturing process is, in Figure5, the X bar-S chart was generated for the ten samples across the thirty lots. It can be observed that the manufacturing process is stable with all points within three standard deviations from the mean with an upper control limit of 71.8g and a lower control limit of 70.5g and these control limits are well within the upper and lower specification limits.

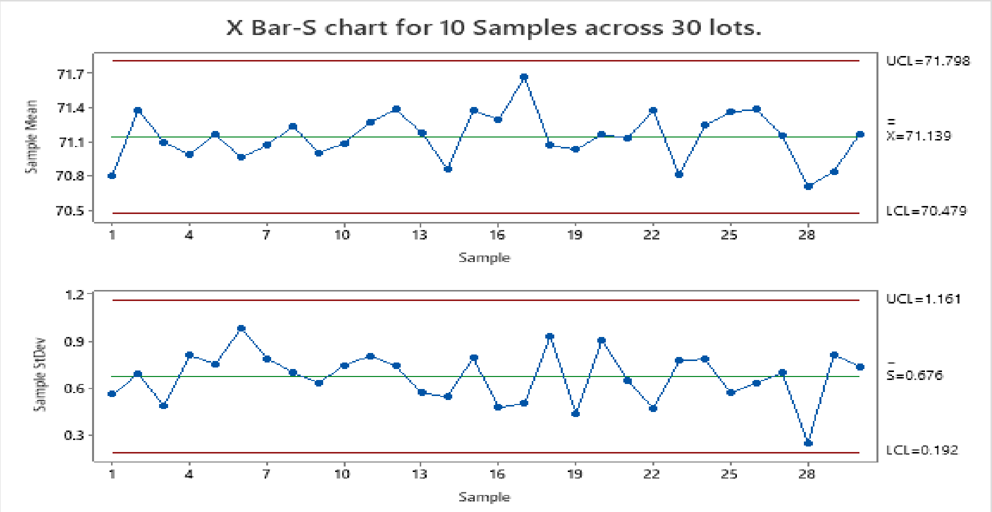

Figure 5: X Bar-S Chart of 10 samples across thirty lots of manufactured product.

3.3 Sampling Plan

In the design of a suitable sampling plan for this case study, and considering the x bar-Schart, we set the probability of rejecting a good lot average $\bar{X}_1$ at the LCL of 70.5g, set at $\alpha = 0.05$ and the acceptance of a poor lot average $\bar{X}_2$ with a probability of $\beta = 0.10$, set at the LSL of 70g which is outside the control limits.

Therefore, The Z score values are $Z_\beta = 1.282$; $Z_\alpha = -1.645, and\ \bar{X}_1 = 70.5g$; $\bar{X}_2 = 70g$; $\sigma = 0.693$. Substituting these values into equations (5) and (6) gives us the sample size (n) and the average acceptance limit ($\bar{X}_m$);

$$n = 16.45 \approx 16, \quad \text{And } \bar{X}_m = 70.2g \quad \text{respectively.}$$

This sampling plan requires that a random sample size of (n = 16) be selected from a lot and if the average net weight is below 70.2 g, the lot is rejected for review; otherwise, it is accepted and passed fit for the open market. The manufacturer agreed totally with this plan as he intends to monitor the process average and possibly improve process centering, by looking into the integrity of the soap molds and the filling process for better consistency in the product net weight. The enterprise uses a lot size of 240 pieces of bar soap (a roll containing 12pieces in 20 rolls packed in a carton). This sampling plan is seen to have a sampling ratio of 6.7%, which we consider sufficient for the manufacturing process having a process fall out of 5%. This methodology requires that a sampling ratio in percentage be greater or equal to the percentage process fallout obtained from the process output model. This should serve as a guide to establishing suitable lot sizes when the sample size is determined for lot sentencing, as it is expected, naturally, that a process having 100% process yield with 0% out of specification product, may also not require any sampling plan to be put in place.

4. Conclusion

This study shows how the sampling design of a manufactured product can be hinged on the output of the manufacturing process. Manufacturers of products for public consumption in view of AQS standards must begin to realize that they owe their customers a duty of care to ensure that the products they release into the market meet these AQS requirements in the interest of the customers as well as for the survival of their own business in today's competitive market. Though it was observed that the process mean appeared to be a little off-centered, leading to a predicted out of specification or process fall of 5%. It is understandable that no system is expected to be 100% efficient; hence, it was expedient to design the sampling plan on the basis of the existing manufacturing process parameters as observed. Therefore, the sampling plan requires a sample size of (n=16) and an average net weight limit of 70.2g. The X bar-S chart developed is found to be stable and may be used for lot monitoring along with the sampling plan to ensure AQS requirements are met and sustained. However, the manufacturer may still search for ways to further improve the process yield of his operations in an effort to reduce the process fallouts by improving the process mean of the manufacturing operation, as this can only improve the effectiveness of the sampling design put in place for lot sentencing. This is an easy-to-use sampling plan that does not require any special training to be implemented on the factory floor by artisans and foremen.

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APPENDIX

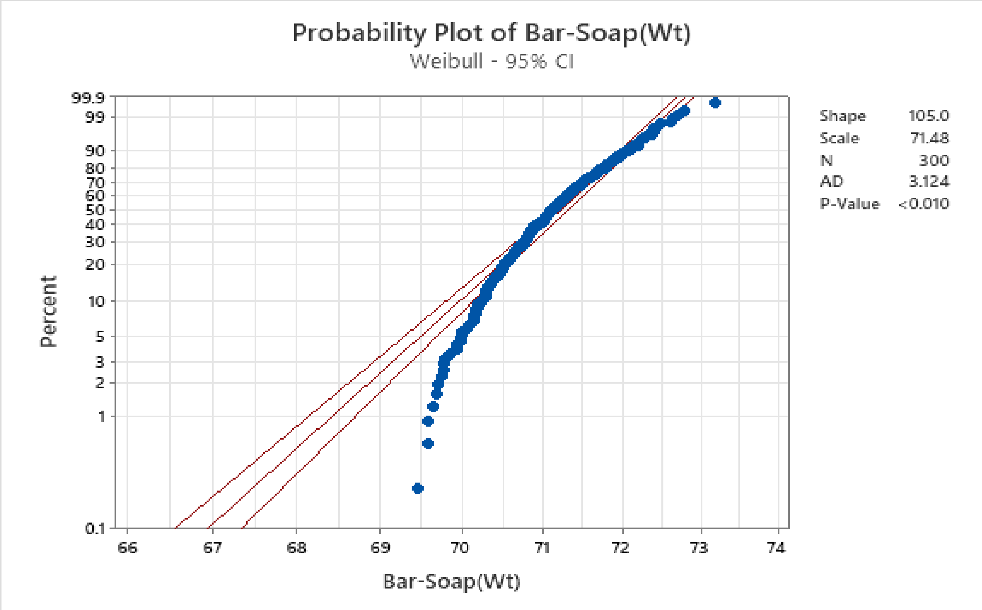

Figure 6: Weibull Probability plot of bar soap net weights

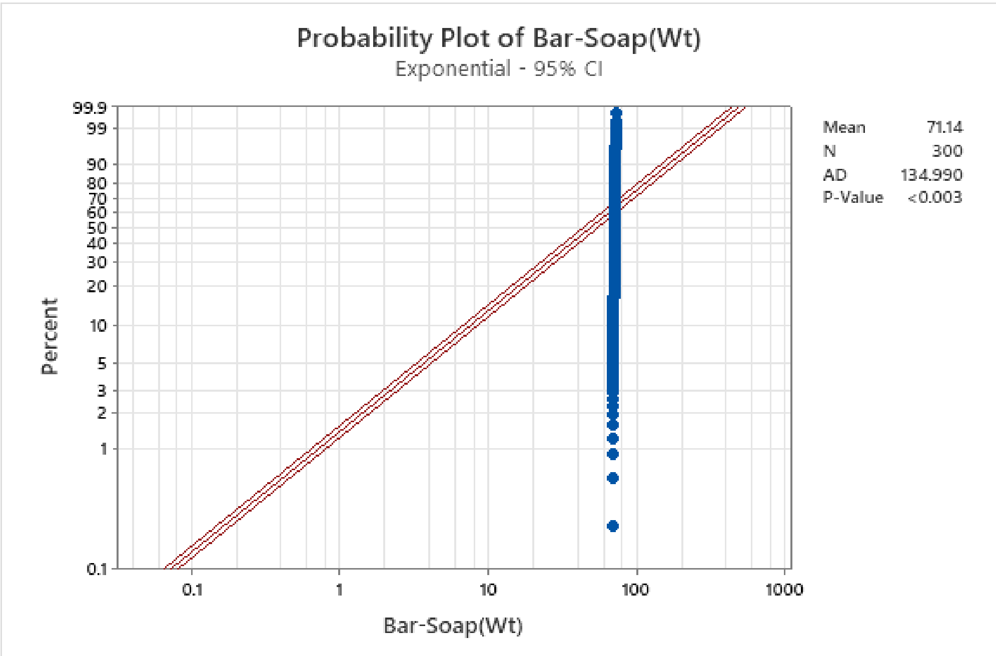

Figure 7: Exponential Probability plot of bar soap net weights

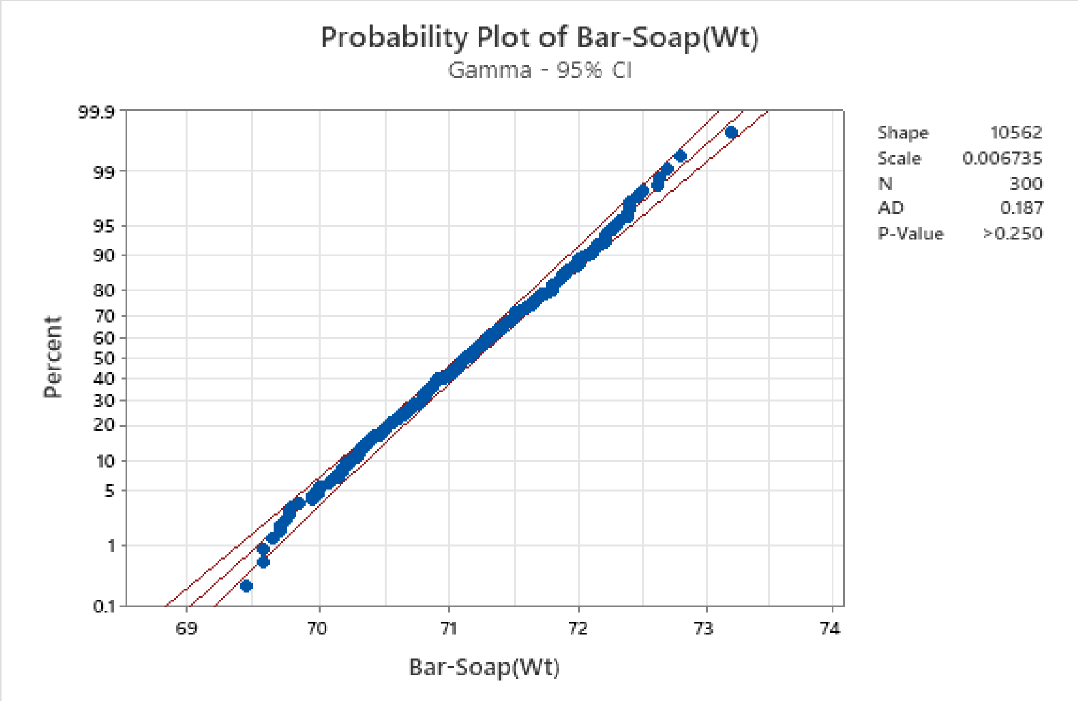

Figure 8: Gamma Probability plot of bar soap net weights

Table 1: 10 Random Samples collected and weighed out across 30 Lots

Lot 1	70.1	71.7	71.5	70.4	70.2	71.2	70.4	70.6	71.0	70.9
Lot 2	71.4	70.7	71.1	70.5	71.8	70.6	72.5	71.4	71.3	72.4
Lot 3	70.7	71.2	72.0	70.7	71.1	70.4	71.4	71.6	71.1	70.8
Lot 4	72.3	71.5	71.3	69.7	70.8	69.9	70.7	70.4	71.5	71.7
Lot 5	71.8	70.8	70.3	71.9	71.1	71.0	71.2	71.5	69.7	72.2
Lot 6	73.2	70.2	71.0	70.1	70.1	70.8	70.3	71.6	70.5	71.7
Lot 7	72.2	70.6	72.1	71.2	70.0	71.5	71.0	71.3	69.8	70.9
Lot 8	71.9	71.3	71.5	70.5	70.9	71.9	71.6	69.7	71.9	71.1
Lot 9	71.2	69.8	71.6	70.4	70.7	72.0	71.6	71.1	70.8	70.8
Lot 10	72.4	70.5	70.6	70.9	71.4	70.8	72.2	70.8	71.1	70.0
Lot 11	71.8	71.2	71.8	71.4	71.0	72.0	72.1	70.1	69.6	71.7
Lot 12	72.4	70.9	70.3	70.6	71.9	70.9	72.1	70.8	71.8	72.0
Lot 13	71.3	71.5	70.4	71.5	70.3	71.0	71.9	71.8	70.7	71.4
Lot 14	71.6	71.2	70.3	70.8	70.6	70.9	71.3	71.4	69.8	70.7
Lot 15	70.2	71.5	72.6	72.3	70.9	71.3	71.1	71.7	70.3	71.8
Lot 16	71.7	70.8	70.4	71.4	71.7	70.9	71.3	71.9	71.4	71.7
Lot 17	71.4	72.3	71.5	72.0	72.5	71.5	71.3	70.8	71.9	71.4
Lot 18	72.2	72.4	71.1	70.0	71.4	70.5	72.1	69.9	70.9	70.2
Lot 19	70.8	70.9	72.0	71.2	70.3	71.3	71.1	70.9	70.9	71.0
Lot 20	72.8	71.2	70.2	69.6	71.6	71.8	70.8	71.0	70.7	71.8
Lot 21	72.2	71.1	71.3	70.7	71.2	71.1	70.8	70.1	72.2	70.7
Lot 22	71.3	71.4	71.1	70.7	71.1	71.4	72.0	72.3	71.5	71.0
Lot 23	72.1	71.2	70.8	69.5	71.5	70.5	71.3	70.0	70.3	71.0

Lot 24	71.9	72.4	70.3	70.8	70.5	71.8	72.1	71.3	71.1	70.2
Lot 25	71.9	71.7	71.6	71.4	71.6	70.5	71.3	70.2	71.5	71.9
Lot 26	71.2	72.1	71.5	72.0	70.6	72.3	70.7	70.9	70.8	71.7
Lot 27	71.8	70.5	71.1	72.2	70.8	71.2	71.8	69.8	71.3	71.1
Lot 28	70.9	71.1	70.3	70.5	71.0	70.6	70.6	70.8	70.4	70.9
Lot 29	72.7	71.0	71.0	71.0	70.5	71.3	70.3	70.6	70.5	69.6
Lot 30	70.2	71.2	70.5	72.6	71.5	71.2	70.2	71.3	71.1	71.7