Journal of Science and Technology Research

Journal homepage: www.nipesjournals.org.ng

Design of a Sampling Plan to Monitor the Net Weight Packaging of Semolina in a Production Plant

Kesiena Ezewu[a*], Friday Erhimudia Ukrakporb, Preye Henry Donyabi [c]

[a,b,c]Department of Mechanical Engineering, Delta State University, Abraka, Nigeria

Article Info

Keywords:
Sampling plan, Operating Characteristic Curve, Average Quantity System, Statistical Quality Control, Control Charts.

Received 10 October 2024
Revised 6 November 2024
Accepted 7 November 2024
Available online 8 December 2024

https://doi.org/10.5281/zenodo.14303270

Abstract

Given the global regulations on the net content of packaged goods, manufacturers need to make sure that the items they provide to consumers adhere to international norms and standards in order to be competitive in the modern global market. The purpose of this research is to design a variable sampling procedure for the release of packaged semolina flour into the market in fulfilment of regulatory standards in the interest of consumers. Using the Minitab 2021 statistical software, the process capability chart, operational characteristic curves, average outgoing quality (AOQ), and average total inspection (ATI) were generated and helpful in assessing the suitability of the sampling plan for lot-by-lot inspection. The packing process was found to be normally distributed with a p-value of 0.525 and an observed standard deviation of 2.030. the AOQ, and ATI in line with best practice suggests a sample size of 24 packs per lot for lot sentencing. The applicability of the plan was also demonstrated. Considering international regulatory requirements, this sampling plan enhances and improves the net content of the packaged products released into the market.

1.Introduction

A method of inspection used in statistical quality control is called acceptance sampling[1]. It is a technique for comparing preset standards to random sampling of populations known as "lots" of items or goods. Acceptance sampling is a component of service quality control, financial auditing, and operations management. It is crucial for corporate and industrial applications, supporting the decision-making process for quality control[2], [3]. Plans for sampling involve testing assumptions about products that have been submitted for evaluation and possible acceptance or rejection. A statistical technique is used in acceptance sampling to decide whether to accept or reject a large number of manufactured goods. It has long been a standard method of quality control in business environments[4]. Usually, it happens as the products are being shipped from the factory, however occasionally it happens within. A producer would often supply a customer with a number of things, and the consumer decides whether to accept or reject the lot based on how many items in a sample from the lot are defective. The lot is accepted if the quantity of nonconforming items is less than the acceptance threshold; if not, it is rejected[5].

To stay competitive and retain customer satisfaction in today's global marketplace, businesses need to use quality as a marketing tool to attract new clients. The net content examination of packaged goods provides protection to consumers who cannot verify the net quantity of the contents of the packages they purchase. This process makes use of sample plans for market monitoring. This ensures moral corporate practices and sustains competition in the market. It also promotes the employment of ethical manufacturing and distribution methods by vendors, retailers, and manufacturers[4],[6]. For a lot to be deemed acceptable, the average net weight of the packaged content must equal or surpass the labeled net quantity mentioned on the package[4]. This is in line with the Average Quantity System (AQS), which is frequently employed to detect net weight defects in goods meant for general consumption [6].

In recent times, some researchers have created lot inspection systems by assuming that the quality attributes of interest follow a normal distribution model[7],[8]. Ezewu et al. [9] used process characteristics derived from the product output modeling to create a sample strategy to track a product's net weight average. Sheu et al.[10] created a sampling strategy that accounts for process loss by utilizing the capability index. A regression estimator was used by Muhammad Aslam and Raza. [11] to create a sampling strategy appropriate for ambiguous and uncertain settings. Additionally, a variety of distributions and case studies have been the subject of diverse sample designs[12]–[16]. For lifetime performance index failure censoring reliability testing, Rasay et al. [17] developed two entirely new variable reliability approval sampling schemes. Wu & Wang[18] combined the benefits of the yield-based index and the loss-based index to construct a variable multi-dependent state sample strategy for lot sentencing centered on the advanced process capacity index. Based on Bayesian modeling, Fallahnezhad et al.[19] created a new acceptance sampling approach for accepting or rejecting a lot in order to update the distribution function of the likelihood of the nonconforming fraction.

The lot sentencing method in Liu S. W. et al. [20] was based on a one-sided process capability index, and the sample design in this study is based on the standard deviation of the net weight of the packing process. Therefore, the purpose of this work is to develop a sampling plan for lot inspection and the release of packaged semolina flour into the international and local markets, while taking into account the net weight limits set forth in line with global regulatory standards.

2.0 Methodology

In order to comply with the globally acknowledged standards for packaged product net weight[3],[4],[6], the manufacturer wishes to guarantee that the packaged semolina product never drops below the product's declared net weight of 1000 grams (1 kg). The declared net weight of the packaged semolina flour is 1000 grams, which is the lower specification limit (LSL), while the target net weight is 1010 grams and the upper specification limit (USL) is 1020 grams. Samples for the study were weighed using a certified digital electronic laboratory weighing balance (5000 g × 0.1 g).

2.1 Data Collection and Sample size

Twenty lots of packed semolina flour were used, and five samples were chosen at random to assess the production process' variability. The gross weights, which are the net weight plus the tare weight (weight of the empty pack), were determined using the electronic weighing balance. Moreover, the product net weight was calculated using the expression given in equation 1[4],[21]. The average tare weight was determined to be 8.5g based on NIST[4];

$$\text{Net-weight} = \text{Gross weight} - \text{Average tare weight} \tag{1}$$

Studies pertaining to the capabilities and features of manufacturing processes should use a sample size of $N \geq 100$[22]. In order to obtain a total of 100 individual samples, we take into account a sample size of 20 in subgroups of 5 [22], [23].

2.2 Investigation of the Process Stability

We use the Shewhart control chart for mean and range after testing the data set for normalcy in order to look into the stability of the process. For samples when there is a subgroup of four elements, the X-bar-R chart is appropriate[1], [2]. Equations (2) and (3) provide formulas for obtaining the control limits for the X-bar-R chart:

The Control Limits for the X bar are;

$$\begin{aligned} UCL &= \overline{\overline{x}} + A_2 \overline{R} \\ CL &= \overline{\overline{x}} \\ LCL &= \overline{\overline{x}} + A_2 \overline{R} \end{aligned} \tag{2}$$

Control limits for the R Chart are thus;

$$\begin{aligned} UCL &= D_4 \overline{R} \\ CL &= \overline{R} \\ LCL &= D_3 \overline{R} \end{aligned} \tag{3}$$

where x, which serves as both the center line and the average for all samples, R is the average range over all samples. The variables A2, D3, and D4 were derived from tables that took sample sizes into account[1], [2].

2.3 Sampling Plan

Acceptance sampling plans widely make use of Operating Characteristic (OC) curves and the designer of the plan must define a practicable Acceptable Quality Limit (AQL) and a Rejectable Quality Limit (RQL) as well as the producers and consumers risk which was applied in this study in line with best practice[24].We had to start by explaining to senior foremen and management that it is normal for a small number of items to occasionally fall short of the required specification in any manufacturing setting. However, our chosen performance assessment will be in Defective Parts per Million Opportunities (DPMO) since we are interested in extremely high-quality levels [25]. It was decided that 50 pieces in a million (50 DPMO) would be the acceptable quality level (AQL), which is the lowest quality level that is still deemed acceptable. A quality level that is deemed unacceptable and should be rejected we set at 500 pieces in a million, or 500 DPMO, which is the Rejectable Quality Level (RQL). According to Truett [24], there should be a high likelihood of accepting an AQL lot. This is because a probability of 0.95 indicates that producers have an alpha risk of rejecting a good lot ($\alpha = 0.05$) and a consumer risk of ($\beta = 0.10$) if they take a bad lot RQL.

2.4 Acceptance and Rejection Criteria

Sampling strategies are most inexpensive when the distribution and process parameters for the quality characteristic of interest are understood [1], [2]. We are interested in a sampling plan to regulate the lot or process fraction non-conforming using the lower specification limit (LSL). With a known standard deviation of the process of manufacturing, we can collect samples from a lot to assess whether the value of the mean is such that the fraction defective is acceptable, using the expression:

$$Z_{LSL} = \frac{\bar{x} - LSL}{\sigma_{process}} \geq k \quad (4)$$

It should be noted that k stands for the critical distance and ZLSL expresses, in standard deviation units, the distance between the average of the lot being tested and the lower specification limit. ZLSL ≥ k indicates that the lot is good; if it is less than k, it will be re-examined and deficient packs replaced.

2.5 Rectifying inspection

Acceptance sampling procedures usually require corrective action when lots are rejected. According to Montgomery[1] and Mitra[2], this usually entails a 100% inspection or screening of lots that are rejected, during which any defective items are replaced with better ones and the defective ones are either discarded or reconditioned. Equations (5) and (6) represent the two essential indicators for rectifying inspection: the average outgoing quality (AOQ) and the average total inspection (ATI) [1].

$$AOQ = \frac{P_a p(N - n)}{N} \quad (5)$$

$$ATI = n + (1 - P_a)(N - n) \quad (6)$$

Where N is the lot size, n is the sample size, Pa is the probability of accepting the lot at AQL or RQL, depending on the situation, and p is the fraction defective, which can be expressed as a percentage or as DPMO.

3.0 Results and Discussion

Twenty samples, each containing five packs of semolina flour, were weighed and recorded into a spreadsheet in order to look into process stability. Table 1 displays the net weight of each pack after the average tare weight of 8.5 grams was subtracted.

Table 1: Net-weight of Semolina packs in sub-groups of five.

Sample Number	OBSERVATIONS (NET-WEIGHT)				
1	1008.0	1011.5	1010.3	1012.5	1008.4
2	1008.7	1009.9	1011.5	1007.9	1007.4
3	1012.3	1009.3	1006.7	1010.4	1009.7
4	1006.9	1009.3	1009.3	1009.3	1008.0
5	1009.6	1004.4	1012.4	1006.7	1008.6
6	1008.6	1012.0	1011.4	1008.0	1007.2
7	1011.2	1008.1	1009.9	1008.0	1013.3
8	1006.4	1008.3	1013.2	1006.2	1014.3

9	1007.1	1010.0	1010.6	1008.8	1014.8
10	1011.0	1008.4	1008.7	1012.4	1011.2
11	1012.4	1008.9	1008.8	1013.2	1006.5
12	1011.8	1009.3	1007.6	1010.3	1011.3
13	1011.1	1006.9	1006.4	1008.3	1010.3
14	1010.8	1008.3	1010.7	1008.7	1010.7
15	1010.8	1009.5	1012.2	1009.1	1007.0
16	1009.6	1008.1	1009.2	1006.1	1007.9
17	1012.4	1008.5	1010.0	1006.5	1006.5
18	1009.1	1006.4	1009.9	1008.4	1010.7
19	1010.2	1011.0	1008.8	1010.4	1012.1
20	1010.9	1008.2	1010.8	1009.2	1008.9

Examining the case study dataset for normality in Figure 1 reveals that the product net weight has a normal distribution with a P-value of 0.525, exceeding the significance level of $\alpha = 0.05$, indicating that the dataset is normally distributed with a 2.03 process standard deviation. It is critical to understand the distribution of the quality feature of interest when creating a sampling plan[1], [3].

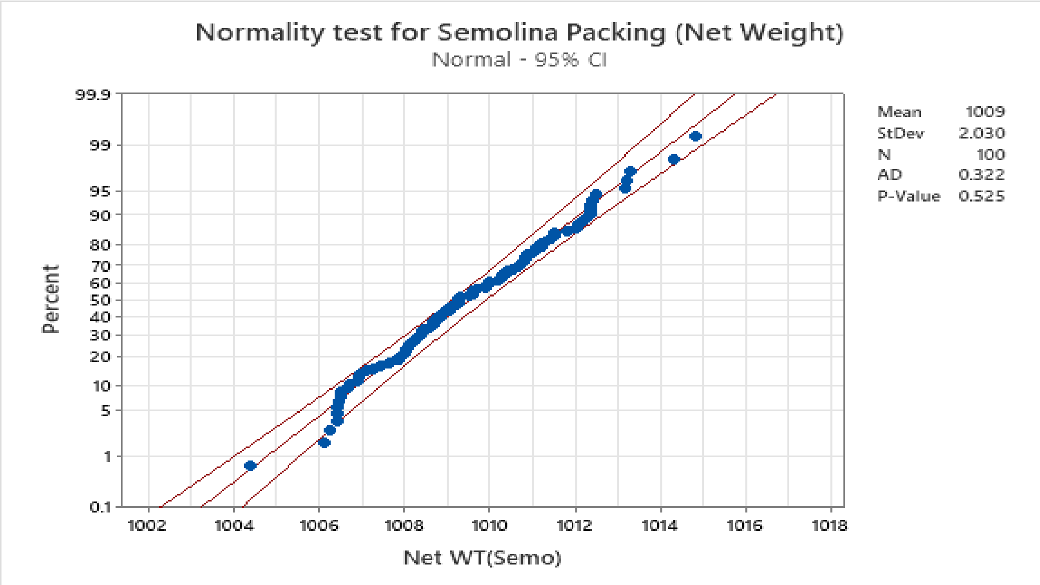

Figure 1. Normality test for Product net-weight.

Figure 2 displays the outcome of using the X bar-R chart to examine the process stability. The fact that all of the data points plot within three standard deviations of the mean indicates that the manufacturing process is stable. With an upper and lower net weight control limit of 1012.3g and 1006.6g, respectively, the process has a mean net weight of 1009.48g. The capability analysis shown in Figure 3 yielded a Cpk of 1.78 (excellent) and a Cp of 1.88 (satisfactory)[26], [27].

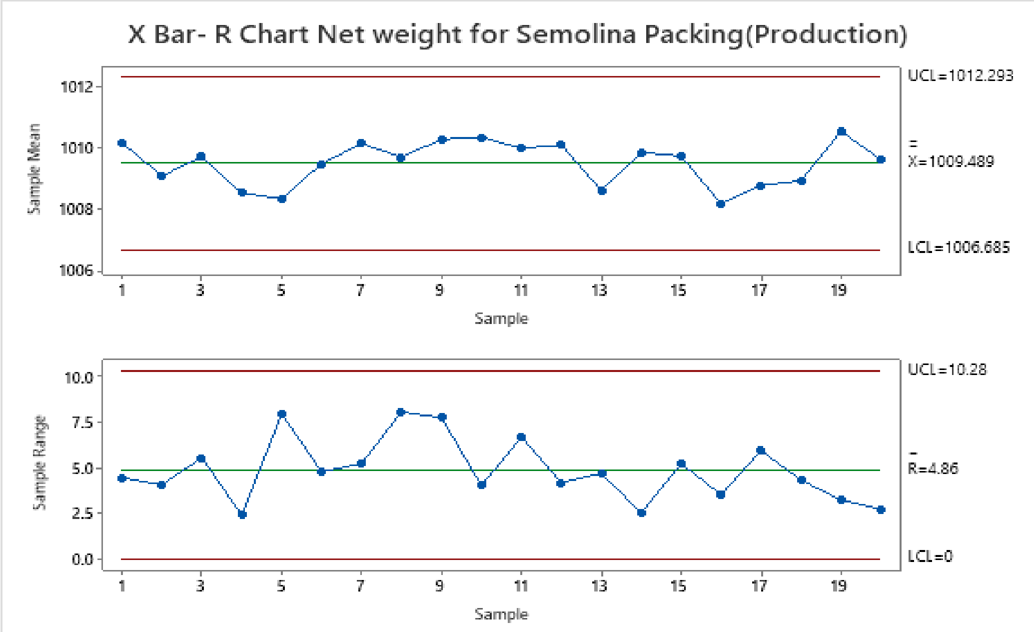

Figure 2. X bar-R Chart showing dispensed net-weight is stable.

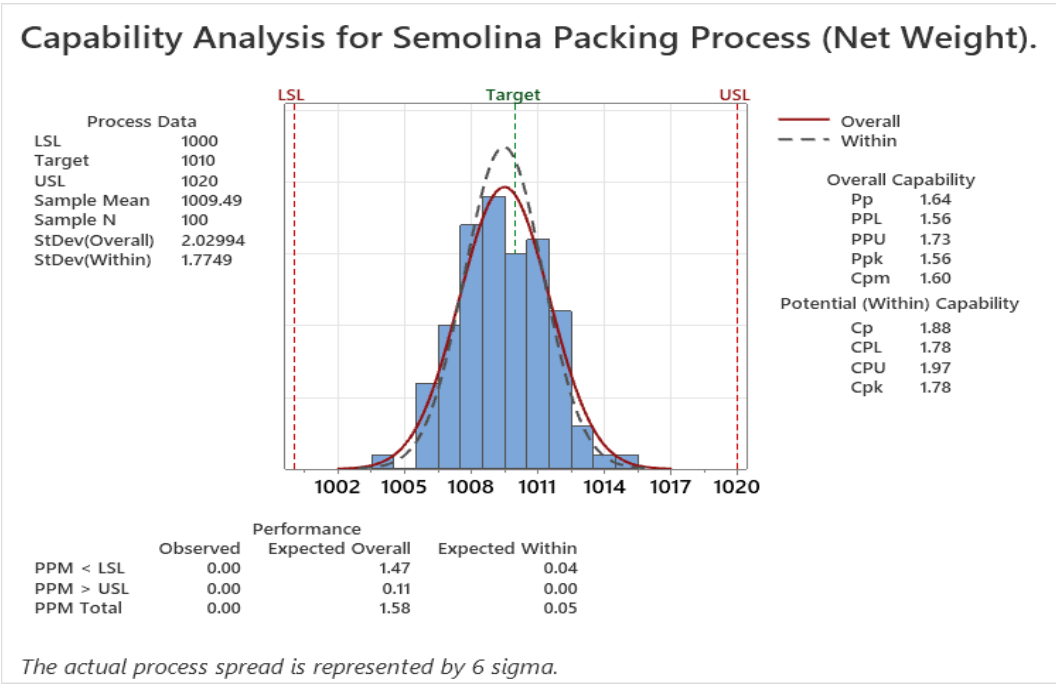

Figure 3. Capability analysis for the dispensing process.

The agreed-upon AQL and RQL, as well as the producer and consumer risk, are well tabulated in Table 2, thanks to the sampling plan's lower specification limit of 1000g, manufacturing process standard deviation of 2.16 determined by the normality test, and lot size of 500 packs.

Table 2: Process parameters for the sampling plan

Lower Specification Limit (LSL) in grams (Net-weight)	1000
Historical or Process Standard Deviation	2.03
Lot Size (Numbers)	500
Acceptable Quality Level (AQL) in DPMO	50
Producers Risk (α)	0.05
Rejectable Quality Level (RQL or LTPD)	500
Consumers Risk (β)	0.1

Minitab 2021 was used to process this data. With a critical distance of k = 3.55348 and a sample size of n = 24, we are left with the developed plan that is displayed in Table 3. Table 3 displays the probability of accepting a good lot at an AQL 50 DPMO and rejecting a bad lot at an RQL 500 DPMO, which are 0.95 and 0.901, respectively. Figure 4 shows the OC curve for this design.
The average outgoing quality limit (AOQL) is 90.5 DPMO at 185.4 Incoming lot defectives per million. This is the maximum ordinate observed on the AOQ curve presented in Figure 4 and Table 4, and it should be used if rectification samplings are necessary. This is the lowest possible average quality that might be found during a correctional examination. Additionally, as indicated in Table 3 and as depicted by the ATI curve in Figure 4, under the rectification plan, the average total inspection (ATI) at an AQL of 50 DPMO is 47.5 DPMO, and at an RQL of 500 DPMO is 453 DPMO.

Table 3: Generated Plan (Minitab Output in Appendix)

Sample Size	24
Critical Distance (K Value)	3.55348

Z.LSL = (Mean – Lower Specification)/ (historical/process standard deviation)
Accept lot if Z.LSL ≥ K; Otherwise Reject.

Defects Per Million	Probability Accepting	Probability Rejecting	A0Q	ATI
50	0.950	0.049	45.3	47.5
500	0.100	0.901	47.0	453.0

Table 4: Average Outgoing Quality Limit(s) (AOQL)

AOQL	At Defectives per million
90.5	185.4

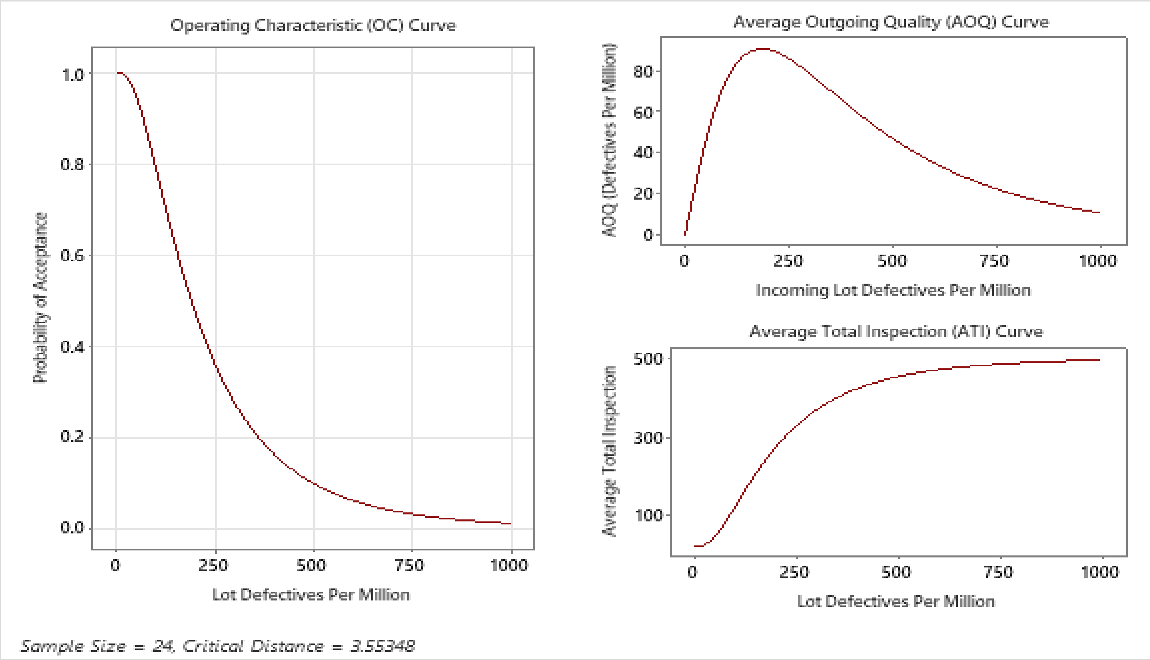

Fig 4: Operating characteristic curves (OC, AOQ, and ATI curves)

Emptying the semolina flour packs to determine the net weight will not be necessary at the time this sample program is implemented. The gross weight must thus be used to create an X-bar-R quality control chart, just as we did with the net weight. Figure 5 displays the chart. It is advised that the manufacturer monitor the product packing process using this chart, which shows the gross weight control limits guaranteeing the process output of an appropriate lot quality by continuously monitoring and maintaining the product gross weight within predetermined limits.

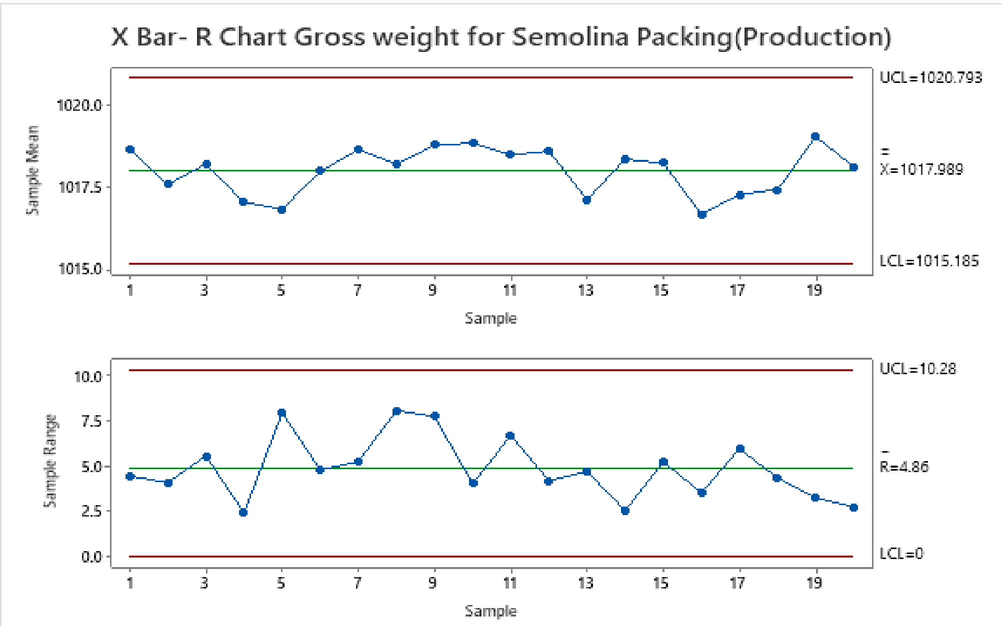

Fig 5: X bar-R chart for 100 samples of semolina flour (gross weights)

Furthermore, a clear example of how to use the product's gross weight to implement the sample strategy is provided. to illustrate potential applications for the sampling program. First and foremost, it is important to realize that it is not anticipated that the flour bags would be ripped apart and their contents removed in order to determine the net weight during sampling or lot testing. The lower specification limit (LSL) for the gross weight to be used for the sampling plan can be obtained by simply adding the net weight lower specification limit (1000g) to the average tare weight (8.5g). Consequently, (1000g + 8.5g = 1008.5g) becomes the lower specification limit that applies to the gross weight deployment. This makes it more likely that the contents of the pack won't weigh less than the stated 1000g net weight.

Steps for the proposed plan

STEP 1: Collect samples randomly of size; n = 24 from a lot N=500.

STEP 2: Obtain the mean gross weight $(\bar{x})$of all 24 packs.

STEP 3: Use the relationship;$Z_{LSL} = \frac{\bar{x}-1008.5}{\sigma_{process}} \geq 3.55348$; then,

accept lot if $Z_{LSL} \geq k$; reject if $Z_{LSL} < k$.

Where, $\bar{x}$ = Mean of 24 packs(Gross weight), LSL= 1008.5, $\sigma_{process} = 2.03$, k= 3.55348.

If ($Z_{LSL} < k$), we review the lot and replace under-weight packages.

The factory floor's lot inspection and quality control unit can perform this straightforward calculation by hand.

4.Conclusion

Given worldwide regulatory regulations pertaining to the net weight of packaged goods, producers of goods intended for public consumption need to start realizing that they have a responsibility to their customers to make sure the goods they put on the market adhere to the necessary standards. Customers will benefit from these criteria, and their own firm will survive in today's cutthroat market. In order to comply with international standards for packaged goods, this study created a variable sampling plan (VSP) for lot inspection on the factory floor. Based on the producer (α) and consumer (β) risk within approved limits, as suggested by best practices, the average outgoing quality (AOQ), average outgoing quality limit (AOQL), average total inspection (ATI), and the operating characteristics curve (OC Curves), developed with Minitab 2021 recommends a sample size of n = 24 per lot. The tare weight has been considered in the sample plan, and an X-bar-R chart for gross weight monitoring has also been developed for the process, as it is not anticipated that the packs will be destroyed and emptied of their contents during the application of this plan. It is advised to monitor the packing process to make sure it stays stable by using this gross weight chart in conjunction with the sample plan. Moreover, an example of how the design might be used has been provided for practical purposes.

References

[1] D. C. Montgomery, *Introduction to Statistical Quality Control*, 6th Editio. John Wiley & Sons Inc, 2009.

[2] A. Mitra, *Fundamentals of Quality Control and Improvement*, Fourth Edi. New Jersey: John Wiley & Sons Inc, 2016.

[3] K. Ezewu, E. C. Enujeke, and M. E. Amagre, "Design of Variables Sampling Plan in Agro-Allied Industry for Packed Yam Flour in-view of International Regulatory Standards," *J. Appl. Sci. Environ. Manag.*, vol. 28, no.

5, pp. 1583–1591, 2024, doi: 10.4314/jasem.v28i5.30.

[4] NIST, “Checking the Net Contents of Packaged Goods,” in *103rd National Conference on Weight and Measures 2018*, National Institute of Standards and Technology (NIST), 2019. doi: 10.6028/NIST.HB.133-2019.

[5] F. W. Breyfogle, *Implementing Six Sigma: Smarter Solutions using Statistical Methods.*, Second Edi. Hoboken, New Jersej: John Wiley & Sons Inc, 2003.

[6] APEC, “Handbook on Prepackaged goods.” Asia-Pacific Economic Cooperation, Shah Alam, 2006.

[7] A. H. I. Lee, C. W. Wu, and Z. H. Wang, “The construction of a modified sampling scheme by variables inspection based on the one-sided capability index.,” *Comput. Ind. Eng.*, vol. 122, pp. 87–94, 2018.

[8] M. Aslam, C. H. Yen, C. H. Chang, and C. H. Jun, “Multiple states repetitive group sampling plans with process loss consideration.,” *Appl. Math. Model.*, vol. 37, no. 20, pp. 9063–9075, 2013.

[9] K. Ezewu, M. E. Amagre, and B. Abovie, “Sampling Plan for Process Average Based on the Modeling of the Process Output in a local Manufacturing Enterprise.,” *J. Sci. Technol. Res.*, vol. 5, no. 4, pp. 106–117, 2023, doi: 10.5281/zenodo.10426444.

[10] L.-C. Sheu, C.-H. Yeh, C.-H. Yen, and C.-H. Chang, “Developing Acceptance Sampling Plans based on Incapability Index Cpp,” *Appl. Math. Inf. Sci.*, vol. 8, no. 5, pp. 2509–2514, 2014, doi: 10.12785/amis/080548.

[11] M. Aslam and M. A. Raza, “Design of New Sampling Plans for Multiple Manufacturing Lines Under Uncertainty,” *Int. J. Fuzzy Syst.*, 2018, doi: 10.1007/s40815-018-0560-x.

[12] W. L. Pearn and C. Wu, “A closed form solution for the product acceptance determination based on the popular index Cpk.,” *Qual. Reliab. Eng. Int.*, vol. 29, no. 5, pp. 719–723, 2013.

[13] M. Aslam, C. W. Wu, M. Azam, and C. H. JUN, “Variables Sampling inspection for resubmitted lots based on process capability index Cpk for normally distributed items.,” *Appl. Math. Model.*, vol. 37, pp. 667–675, 2013.

[14] M. S. Fallahnezhad and S. T. Akhavan Niaki, “A new monitoring design for uni-variate statistical quality control charts.,” *Inf. Sci.*, vol. 180, no. 6, pp. 1051–1059, 2010.

[15] I. Negrin, Y. Parmet, and E. Schechtman, “Developing a sampling plan based on Cpk-unknown variance.,” *Qual. Reliab. Eng. Int.*, vol. 27, no. 1, pp. 3–14, 2011.

[16] C. H. Yen, C. H. Chang, and M. Aslam, “Repetitive variable acceptance sampling plan for one-sided specification.,” *J. Stat. Comput. Simul.*, vol. 85, no. 6, pp. 1102–1116, 2016.

[17] H. Rasay, F. Naderkhani, and A. M. Golmohammadi, “Designing variable sampling plans based on lifetime performance index under failure censoring reliability tests,” *Qual. Eng.*, 2020, doi: 10.1080/08982112.2020.1754426.

[18] C.-W. Wu and Z.-H. Wang, “Developing a variables multiple dependent state sampling plan with simultaneous consideration of process yield and quality loss,” *Int. J. Prod. Res.*, 2016, doi: 10.1080/00207543.2016.1244360.

[19] M. S. Fallahnezhad, S. T. A. Niaki, and M. A. Vahdatzad, “A new accptance sampling design using Bayesian modeling and backwards induction,” *Int. J Eng*, vol. 25, no. 1, pp. 45–54, 2012.

[20] S.-W. Liu, C.-W. Wu, and Y.-H. Tsai, “An adjustable inspection scheme for lot sentencing based on one-sided capability indices,” *Appl. Math. Model.*, vol. 96, pp. 766–778, 2021, doi: 10.1016/j.apm.2021.03.034.

[21] K. Ezewu, M. E. Amagre, and E. C. Enujeke, “Application of SQC for Equipment Selection in an Agro-Based Industry,” *NIPES J. Sci. Technol.*, vol. 5, no. 1, pp. 260–271, 2023, doi: 10.5281/zenodo.7745972.

[22] Minitab, “Process data for Normal Capability Analysis.,” *Copyright 2023 Minitab, LLC*, 2023. support.minitab.com (accessed May 18, 2023).

[23] K. Ezewu, M. E. Amagre, and O. M. Chuks, “Machine selection for improved precision and scrap reduction in manufacturing using PCIs : a case study,” *J. Mater. Eng. Struct. Comput.*, vol. 3, no. 2, pp. 31–41, 2024, doi: 10.5281/zenodo.11479414.

[24] L. Truett, “Using Operating characteristic (OC) Curves to Balance Cost and Risk (Best Practices),” 2013.

[25] C.-W. Wu and S.-W. Liu, “Developing a sampling plan by variables inspection for controlling lot fraction of defectives,” *Appl. Math. Model.*, vol. 38, pp. 2303–2310, 2014, doi: 10.1016/j.apm.2013.10.043.

[26] Y. Wooluru, D. R. Swamy, and P. Nagesh, “The process capability analysis- A tool for process performance measures and metrics - A case study.,” *Int. J. Qual. Res.*, vol. 8, no. 3, pp. 399–416, 2014.

[27] V. N. Sambrani, “Process Capability- A Managers Tool for 6 Sigma Quality Advantage,” *Glob. J. Manag. Bus. Res. Interdiscip.*, vol. 16, no. 3, 2016.

Appendix

Table 2: Process parameters for the sampling plan (In manuscript)

Method

Lower Specification Limit (LSL)	1000
Historical Standard Deviation	2.03
Lot Size	500
Acceptable Quality Level (AQL)	50
Producer's Risk (α)	0.05
Rejectable Quality Level (RQL or LTPD)	500
Consumer's Risk (β)	0.1

Table 3: Generated Plan (In Manuscript)

Generated Plan(s)

Sample Size	24
Critical Distance (k Value)	3.55348

Z.LSL = (mean - lower spec)/historical standard deviation
Accept lot if Z.LSL ≥ k; otherwise reject.

Defectives Per Million	Probability Accepting	Probability Rejecting	AOQ	ATI
50	0.951	0.049	45.3	47.5
500	0.099	0.901	47.0	453.0

Table 4: Average Outgoing Quality Limit(s) (AOQL)(In Manuscript)

Average Outgoing Quality Limit(s) (AOQL)

AOQL	At Defectives per Million
90.5	185.4