



Ignatius Ajuru University of Education, Port Harcourt, Nigeria

Research and Development Centre

1st International Conference and Exhibition on Research, Innovation and Development (ICERID 2026)

Proceedings URL: <https://iauejournals.com/index.php/ICERID>

Website: <https://icerid.online>



ISBN: 978-978-63205-1-9

June 2026; Page No. 256-267

Attributes Control Charts of Three Paint Companies

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Abstract

This study investigated three attribute control charts of three paint companies. The Paint Companies were De Express Integrated Services Limited, Portland Paints & Products Limited and Marshal Paint and Chemical Industries Limited. The three paint companies' monthly paint production (gallons) and monthly number of defects per gallon from March 2022 to March 2023. Three attribute charts were considered: the P Chart, NP chart, and U Chart. The paired t-test statistic was used to test for a significant difference between monthly production and the monthly number of paint defects by the companies. The results are as follows: -The three Paint Companies' total Paint Production (in gal.) distribution seems the same (or similar), and it also showed that the joint variability of two paint companies is constant (i.e. De Express Integrated Services Ltd and Marshal Paint and Chemical Industries Limited). In conclusion. The U chart gave a similar result to the P chart, while the NP Chart contradicted it (i.e. showing no paint sample is out of control).

Keywords: Statistical Quality Control, Chance Variation, Assignable Variation, Product Control.

Introduction

Organising, staffing, leading, coordinating, directing, and planning are all crucial management responsibilities. One of these responsibilities is controlling, which comprises the continuous evaluation and measurement of actual performance, as well as the use of corrective actions as necessary to ensure the achievement of company objectives. Because variations in production processes can affect the final products' quality, dependability, and acceptance, effective control is particularly important in manufacturing firms. As a result, quality control is becoming an essential component of modern industrial and service businesses. The International Organisation for Standardisation (ISO) 9000 set of standards offers globally accepted concepts and recommendations for creating and preserving efficient quality management systems. The standards place strong emphasis on customer satisfaction, process consistency, clearly defined roles, documented procedures, and continuous improvement. These guidelines are crucial for guaranteeing that production processes are conducted methodically and that goods and services meet predetermined standards (Hoogland et al., 1998).

In general, quality is the extent to which a product, service, or process meets predetermined standards and user needs. Statistically, quality can be evaluated using quantifiable traits that show whether a process or product complies with predetermined standards. Total Quality Management (TQM) aims to continuously enhance employee capabilities, organisational procedures, and product quality (Hrynkevych, 2017). While Akinola (2009) defined quality as the degree to which a product, service, or phenomenon complies with a specified standard and compares well with

alternatives, Obadare and Alaka (2013) defined quality in terms of fitness for use. In a similar vein, Kumar et al. (2016) clarified that a product, service, or organisation's quality can be described as its standard.

Quality control is concerned with the systematic procedures used to ensure that products and services conform to predetermined standards and specifications. Gupta (2018) noted that a product is acceptable when it satisfies established specifications. Statistical Quality Control (SQC) applies statistical and probabilistic techniques to the collection, analysis, and interpretation of production data to monitor and improve quality. The application of statistical methods enables manufacturers to identify unusual variations at an early stage and take corrective action before such variations result in excessive defects, waste, scrap, and increased production costs. SQC is applicable across several industries, including paint, chemicals, medical, automotive, textiles, oil and gas, transport, plastics, and electrical manufacturing.

One of the fundamental concepts underlying statistical quality control is that every production process exhibits some degree of variation. This variation can broadly be classified into common causes and assignable (or special) causes. Common causes are inherent sources of variation that operate naturally within a production process. They are generally small, random variations that are difficult to eliminate without changing the process itself. Assignable (or special) causes, on the other hand, are identifiable sources of unusual variation that may arise from defective raw materials, equipment malfunctions, incorrect machine settings, improper handling of equipment, operator errors, inadequate training, or inappropriate production procedures. Assignable causes may occur at any stage of production, from the receipt of raw materials to the final inspection and delivery of finished products.

A production process is said to be in statistical control when the observed variation is attributable only to common causes and there is no evidence of assignable or special causes. Statistical control does not imply that a process is necessarily producing perfect products; rather, it indicates that the process is stable and predictable within its existing level of variation. Control charts are an important statistical tool for monitoring such processes. The Shewhart control chart, developed from the pioneering work of Walter A. Shewhart, involves plotting appropriate sample statistics against a central line and statistically determined control limits. In many applications, three-sigma control limits are used. A point outside the control limits, or a systematic non-random pattern within them, may indicate the presence of an assignable cause that requires investigation and corrective action.

For quality characteristics measured as attributes, different types of control charts can be employed depending on the nature of the data. The P chart monitors the proportion or fraction of defective units in a sample, while the NP chart monitors the number of defective units when the sample size remains constant. The U chart monitors the number of defects per unit, particularly when the number of units or opportunities for defects may vary from one sample to another. These control charts provide useful information for determining whether a production process remains statistically stable over time and for identifying periods when corrective action may be required.

Paint manufacturing is a production activity in which quality control is particularly important, as the quality of the final product depends on the consistency of raw materials, formulation, mixing, dispersion, equipment performance, and other stages of production. Bryson (1950) described paint as a liquid suspension of solid pigments in a liquid vehicle, with the vehicle containing components such as drying oil, drier, and volatile thinner. Paint production involves several materials and processing stages, and variations in these factors may affect the characteristics and performance of the finished product. Consequently, statistical quality control can provide a systematic means of monitoring paint production and identifying unusual variation that may lead to defective products.

Defects in paint production may result from variations in raw materials, formulation, equipment, operating conditions, or production practices. Such defects can affect the appearance, consistency, coverage, durability, and general performance of the finished paint. Persistent production defects may also result in material wastage, reprocessing, customer dissatisfaction, increased production costs, and loss of competitiveness. The application of statistical control charts can therefore assist manufacturers in distinguishing normal process variation from unusual variation and in identifying stages of production that require corrective attention.

This study focuses on statistical quality control of two types of paint: emulsion paint and silk paint. The study uses attribute control-chart techniques to examine defect occurrence and determine whether the paint production processes operate within statistically acceptable limits. In particular, the P, NP, and U control charts provide statistical evidence of production process stability and defect occurrence. These techniques are expected to provide useful information for improving quality control, reducing production defects and waste, and promoting more consistent paint production.

This study aims to investigate attributes and multivariate Hotelling process control charts in three paint companies (or apply statistical quality control in three paint companies),

The objectives of this study are to:

- 1) examine if the three paint companies' production variations are similar.
- 2) determine if the attribute charts show process control in the monthly paint production (in gal.) and the number of monthly paint defects (P, NP and U Charts).
- 3) Test for a significant difference between monthly paint production and the number of defective paints using paired t-test statistics.

Materials and Methods

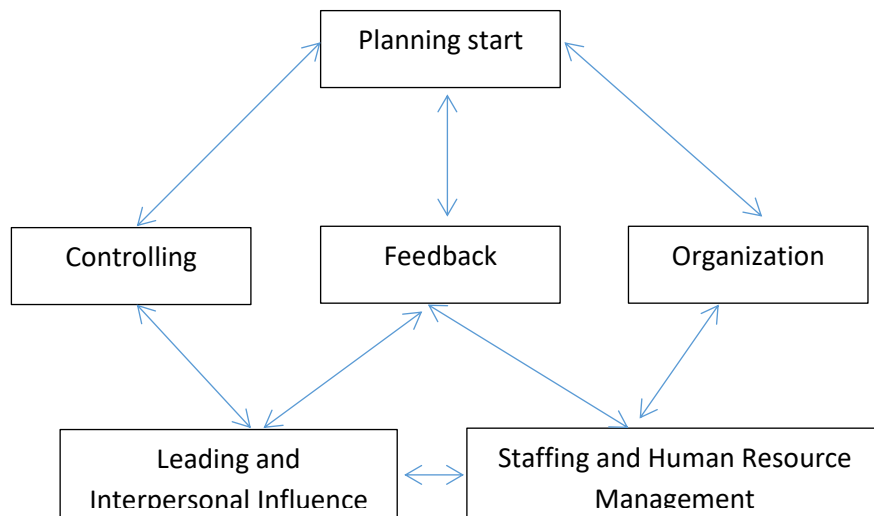


Figure 1: Management Process Chart

Control charts are statistical process control tools used to determine if a manufacturing or business process is in a state of control. It is also graphical device used to monitor the statistical process. Control Charts are categorised into X-Chart, P Chart, NP Chart, U chart, C chart, MR Chart, Individual MR Chart, Custom Data control chart, etc. Statistics is a discipline that concerns the collection, organisation, analysis, interpretation and presentation of data. Quality control is a procedure or set of procedures intended to ensure that a manufactured product or performed service adheres to a defined set of quality criteria.

Theoretical Framework

A. Control chart Theory by Shewhart (1924);

Control charts are:

- 1) Variable control charts plot measurable process data in a time-ordered sequence.
- 2) Attribute control charts plot data that are counted instead of being measured.

X- Charts present variable data. Each data point is the statistical mean of a subgroup of values. The statistical principles used in calculating the UCL and LCL are based on the normal distribution. By default, UCL and LCL are calculated at three standard deviations from the mean,

P-Charts are used for data that are counted. Each data point is a ratio of its own discrete sample set; P-Charts can display fraction nonconforming data values. The statistical principles used in calculating the UCL and LCL are based on the binomial distribution.

NP-Charts present the number of nonconforming or conforming items. The sample subgroup size must be uniform. The statistical principles used in calculating the UCL and LCL are based on the binomial distribution.

C-Chart displays the number of conforming or non-conforming items within a consistent unit size, or the probability of a specified number of occurrences in a specific period of time. The statistical principles used in calculating the UCL and LCL are based on the Poisson distribution.

U-Chart displays the average count of nonconforming items per unit when the unit size is variable. The UCL and LCL are calculated using the Poisson distribution.

MR-Chart displays the moving range over time to monitor process variation for individual observations. The UCL and LCL are based on the moving range between observations.

Individual MR-Chart: This displays individual observations and the moving ranges over time for variable data. The UCL and LCL are based on the moving range between observations.

Custom Data Control Chart can be created, for which you must manually enter a control data column, UCL, CL and LCL.

Central Limit Theorem

In probability theory, the central limit theorem states that the distribution of a sample variable tends to a normal distribution as sample size becomes larger, assuming that all samples are identical in size, and regardless of the population's actual distribution shape (Turney, 2022). With the CLT, for a large sample size, the sample mean is approximately equal to the population mean. As the sample gets larger, the sample variance approaches the population variance, according to the law of large numbers. Abraham de Moivre first developed this concept in 1733. Hungarian mathematician George Pólya later seconded it.

Conditions for Central Limit Theorem

The central limit theorem states that the distribution of sample means approximates a normal distribution as the sample size gets larger, regardless of the population's distribution. Sample sizes of 30 or more are often considered sufficient for the CLT to hold. A key aspect of the CLT is that the average of the sample means and standard deviations will equal the population mean and standard deviation. A sufficiently large sample size can predict the characteristics of a population more accurately. CLT is useful in finance when analysing a large collection of securities to estimate portfolio distributions and traits for returns, risk and correlation.

Khalidi (2007) used a Shewhart control chart to monitor uncorrelated quality characteristics. Advancement in manufacturing technology and increased complexity of products and systems raise the need to monitor correlated characteristics. This research was aimed at quantifying the statistical and economic consequences of utilising the Hotelling's T^2 multivariate control chart as an alternative to the traditional Shewhart $\bar{x}$ chart. Consequently, there were two main objectives of this research. The first objective was to identify the levels of correlation between the charted variables where the statistical performance of the $\bar{x}$ chart deteriorates compared to that of an equivalent T^2 chart. The second objective was to assess the economic feasibility of utilising a T^2 chart as an alternative to the two $\bar{x}$ charts. Results indicated that the switch to a multivariate T^2 chart would result in economic savings under all levels of the process and chart variables considered. It is hoped that this research will encourage practitioners to implement appropriate multivariate statistical techniques in monitoring their processes.

Golnabi (1998) used univariate quality control; the bar $\bar{X}$ -Charts, R-Charts, and S-Charts were useful for controlling process parameters (the process mean and process variability). It was very useful to have similar charts applied to the multivariate case. Existing methods do not provide all the information a quality control practitioner would like, such as indicating which variables are causing the process to be out of control. This thesis has two main subjects, concerned with controlling the process mean and the process variability, respectively. The first subject focuses on selecting an appropriate critical region. We assume the process is multivariate normal, with parameters known from historical data or estimated from a large sample. We call this method "Multivariate Shewhart Chart (MS Chart)" because it reduces

to the Shewhart Chart when the process involves only one variable. The second subject concerns controlling the covariance structure, based on sample partial correlations. The procedures outlined have been illustrated with the help of simulated data and examples, which have been frequently used by other authors in this field.

Capilla (1991) concurred that control charts are statistical methods widely applied to improve the quality and productivity of products and processes. The statistical properties of these procedures were studied, with the aim of determining their optimal application to control the mean of a quality characteristic. The sampling frequency and size are analysed, evaluating the performance of the control chart for the sample mean as a function of the sampling scheme under several out-of-control situations and process capabilities. The statistical properties of this chart are studied when supplementary rules are considered, and compared with the CUSUM chart and the sample means chart with only one out-of-control signal (a point outside the control limits). The statistical performance of the moving averages chart is determined as a function of the grouping size. The effectiveness of this chart is compared with that of the individuals chart and CUSUM and EWMA procedures. Finally, the effect of serial correlation on the statistical properties of all the control charts mentioned above is analysed.

Hrynkevych (2017) implemented the idea of using control charts (CC) to identify exit points of the educational process from a stable/controlled status. If the expected sample value ($\bar{X}$) is compared to the characteristics of the quality setting, and its range of variation, then in the absence of a specified pre-setting, its control map will be determined by the central line (CL), upper (UCL) and lower (LCL) limits; (1) $UCL = \bar{X} + A_2\bar{R}$ (2) $LCL = \bar{X} - A_2\bar{R}$ and (3) $CL = \bar{X}$. The value of the constant A_2 in formulas (1) and (3) is calculated and is dependent on the sample size n . To monitor the quality of students' learning and identify risk zones in the educational process, a control chart of quality by the indicator "Student average performance by subjects" is built. A control chart is based on the progress data of a student group at the Faculty of Economics at the Ivan Franko National University of Lviv / LNU (Ukraine) in 37 academic disciplines for the period of 2012-2016. The general average value of students' progress in the disciplines ($\bar{X}$) is 71.14, and the average range of variation ($\bar{R}$) is 41.67. Given that the sample size (n) of the students was 25 people, the tabulated value of constant A_2 is 0.153. Thus, the characteristics of the control chart of students' average performance (if there are no given values for this indicator) will be as follows: (4) $UCL = \bar{X} + A_2\bar{R} = 71.14 + 0.152 \times 41.67 = 77.4$; where $\hat{\sigma} = \frac{\bar{R}}{d_2} = \bar{R} \cdot \frac{1}{d_2}$ ($R_1 + R_2 + R_3 + \dots + R_k$) $= \frac{1}{k} \sum R$ and $A_2 = \frac{3}{d_2\sqrt{n}}$ is a constant that depends on sample size n . (5) $LCL = \bar{X} - A_2\bar{R} = 71.14 - 0.153 \times 41.67 = 64.81$ and (6) $CL = \bar{X} = 71.14$.

The control chart of the students' average performance was calculated above. The study showed that the educational process has the area of statistical quality control for stable/controlled status with approximately 6 (i.e. $77.4 - 71.14 = 6.26$). Maysaa (2015) identified a decline in the quality of petroleum products and its bad effect on human health and the environment. He identified that the fuel contains sulfur, which increases pollution. His work was aimed at evaluating petroleum products quality diesel and gas oil, in Khartoum refinery. Using a statistical control chart. The main hypothesis was that using statistical method in petroleum product quality more effectively to know changes in the production process compared to the current system. Samples from petroleum products were taken, and control charts for the mean using ($\bar{X}$ -bar, $\bar{R}$ -bar), ($\bar{X}$ -bar, S) were prepared. The results showed that the diesel quality in Khartoum refinery does not meet the specification based on diesel density and flash point tests. But the criterion number for diesel quality in Khartoum refinery does not meet the specification. The statistical control tests show that the gas oil density does not meet the specification. The study recommends using statistical control charts to control petroleum product quality in Khartoum refinery for its usability and accuracy in production decision-making. Also, this study recommends training for people who work in the refinery quality control section to use statistical control charts and continuously update petroleum product specification limits to meet international standards. Recommends the use of 6 Sigma to control the quality of petroleum products.

The research design that will be used is the T^2 Hotelling multivariate control chart. This research design was introduced by Harold Hotelling in 1947. This design allows multivariate observations to be plotted in a single chart. As such, this design applies to this study, as the machine uptime, product characteristics and raw material characteristics will be monitored in this research. The population of the study is a yearly production estimate of 10796 drums of paint. A

total of 32 drums of paint were recorded from the sales point. Using the sample size for a known population. With a population of 10,796, a 95% confidence level, and a 5% margin of error, the sample size for this study is 381 drums of paint. The study used a probability sampling technique. Probability sampling uses random procedures to ensure every element or member of the population has a known probability of being chosen for the sample. (Katz, 2006).

The Use of Control Charts and Sampling Inspection Plan

$$E(t) = \mu_t \quad (1)$$

and

$$\text{Var}(t) = \sigma_t^2 \quad (2)$$

Since the statistic is normally distributed, the total area is given as 0.9973.

$$P(\mu_t \pm 3\sigma_t) = 0.9973 \quad (3)$$

The value of t varies within the limit

$$E(t) \pm S.E(t) = \mu_t \pm 3\sigma_t \quad (4)$$

$$Z = \frac{t - S.E(t)}{S.E(t)} = \frac{t - \sigma_t}{\sigma_t} \sim N(0,1) \quad (5)$$

Calculation of mean and Range for sample for samples

$$\bar{X}_i = \frac{1}{n} (\text{Sum of observations in the } i^{\text{th}} \text{ sample}) \quad (6)$$

$$R_i = X_L - X_S \quad (7)$$

where X_L is the largest and X_S is the smallest observation in the i^{th} sample.

Computation of Control Limits

$$E(\bar{x}) = \mu \text{ and } S.E.(\bar{x}) = \frac{\sigma}{\sqrt{n}} \quad (8)$$

where σ = standard deviation and n is the sample size.

$$E(\bar{x}) \pm 3S.E.(\bar{x}) = \mu \pm \frac{3\sigma}{\sqrt{n}} \quad (9)$$

Control limits in terms of the standard deviation of the sample

$$UCL_{\bar{x}} = \bar{\bar{x}} + A_1 \bar{s} \quad (10)$$

$$LCL_{\bar{x}} = \bar{\bar{x}} - A_1 \bar{s} \quad (11)$$

$$\bar{s} = \frac{1}{k} \sum s \quad (12)$$

$$\text{Note } A = \frac{3}{\sqrt{n}}. \quad (13)$$

where A is a constant in terms of sample size.

Control Chart for fraction Defective or P-chart.

$$\text{Fraction defective} = \frac{\text{Total number of defective units}}{\text{Total number of units}} \quad (14)$$

$$\text{Mathematical stated as } p = d \div n \quad (15)$$

$$\text{Therefore, } d = np. \quad (16)$$

where (population) P is the fraction defective, d = the number of defective units in the sample.

$$E(p) = P \quad (17)$$

$$S.E.(p) = \sqrt{PQ} \div n \quad (18)$$

where $Q = 1 - P$.

3- σ control limits for p-chart are given by

$$E(p) \pm 3S.E(p) = P \pm 3\sqrt{PQ} \div n \quad (19)$$

Sample fraction defective is plotted against the sample line.

Control Chart for Number of defectives or np-Chart.

If the sample size is constant for all the samples, say n , d = Number of defectives in the sample = np .

$$E(d) = nP \text{ and } S.E(d) = \sqrt{nPQ} \quad (20)$$

$$E(d) \pm 3S.E.(d) = nP \pm 3\sqrt{nPQ} \quad (21)$$

Control Charts of defects per unit (c-Chart)

$$E(c)=\lambda \text{ and } S.E.(c)=\sqrt{\lambda} \quad (22)$$

$$UCLc=E(c)+ 3S.E.(c)= \lambda+3\sqrt{\lambda} \quad (23)$$

$$LCLc= E(c)- 3S.E.(c)=\lambda-3\sqrt{\lambda} \quad (24)$$

$$Clc=E(c)=\lambda \quad (25)$$

If λ is not known. Then we use its unbiased estimate provided by the given samples.

$$\lambda = \bar{c} = \frac{\sum c_1 + c_2 + \dots + c_k}{k} \quad (26)$$

when λ is not known, control limits for the c-chart become

$$UCLc = \bar{c} + 3\sqrt{\bar{c}} \quad (27)$$

$$LCLc = \bar{c} - 3\sqrt{\bar{c}} \quad (28)$$

$$CLc = \bar{c} \quad (29)$$

Note $\bar{c}$ is the average of defects found in the k samples inspected. For t-test $n-p < 40$, we use the formula.

Product Control

When marketing the paint product, product control is achieved by considering customer requirements and/or the firms that receive finished products. This control is achieved using a single sampling inspection plan. The basic tool used to examine finished products is acceptance sampling, in which a decision to accept or reject a lot is made based on random samples drawn from it. Acceptance sampling plans for Attributes: Acceptance Quality Level and Producer's Risk. A lot is relatively good if there is a small fraction defective.

$P(\text{rejecting a lot of quality } p_1) = \beta$. This is the probability of type-I error. (30)

Rejection Quality Level and consumer's Risk. The lot quality

, which a consumer is prepared to tolerate only a small fraction of the time in an accepted lot, is known as the as rejection quality level. This is also referred to as the lot tolerance fraction defective, and 100%. p_t is called a lot tolerance percentage defective. A lot of p_t should be normally rejected; thus, a customer demands adequate protection in accepting such a lot.

The probability of this quality is called consumer's risk and is denoted by β .

$P(\text{accepting a lot of quality } p_t) = \beta$ and taken as 10%. This the probability of type 2 error (31)

Average outgoing Quality. The main function of sampling plans is to guarantee a certain quality level, which is termed as a function of the incoming lot quality "p".

The maximum value of AOQ subject to variation in "p" is known as the average outgoing quality limit AOQL.

Procedures in Single Sampling Plan:

A lot is accepted or rejected by examining a single sample.

N: Lot size

n: Sample size

c: Acceptance number, i.e. maximum number of allowable defectives in the sample

d: Number of defectives in the sample.

Steps to single sampling;

1. Taking a random sample of size n from the lot size N
2. Inspect the sample 100% and count the number of defectives d in the sample
3. If $d \leq c$, accept the lot, replacing all the defectives piece found in the sample with good ones
4. If $d > c$, reject the lot. In this case, we resort to 100% inspection of the lot and replace or defects by standard one.

Curve for the single sampling plan.

Average Inspection (ATI): It shows the graphical representation of the incoming lot quality p and the average total number of units inspected per lot, including sampling and sorting 100%

The curve is given by
 $ATI = n + (N - n)(1 - P_a(p))$.

(32)

N = the total no to be inspected
 n = no of items actually inspected

$P_a(p)$ is the probability of acceptance for lot of incoming quality p .

Data Collection and Statistical Software Used for Analysis.

Data will be analysed using SPSS or Minitab. Interpretation of the $\bar{x}$ -chart and R chart. A process is termed to be in statistical control if both the $\bar{x}$ and R charts exhibit control. i.e. all the points fall within the control limits, whereas when one or more points in any or both charts go out of the control limits, we say the process is not in statistical control.

Results

The three paint companies' total production in gallons and the number of defect gallon were summarised in Table 1 and Figure 1 from March 2022 to March 2023.

Table 1: Paint sample (Production) in gallons and Defective Paint

Colours	Overall DEI Paint in gal total by Colour	Overall PPP Paint in gal total by Colour	Overall MPC I Paint in gal total by Colour
barren white	50	60	45
off white	1104	596	955
brill white	1937	987	1770
chocolate	303	159	271
peach	35	20	30
lilic	60	30	65
calabash	605	380	541
cream	1403	710	1252
rich brown	310	165	285
apple green	105	54	100
green gag	40	30	36
silve green	50	35	45
nat green	50	35	45
dove green	605	305	541
dark green	345	175	319
leaf green	735	380	660
lemon green	240	120	222
navy blue	20	10	20
lagoon blue	860	440	772
sky blue	80	50	75
poso red	60	30	56
Latrite red	50	25	45
red oxide	480	240	455
orange	350	180	315
purple	140	70	155
rose pink	510	255	460
sunflower	290	145	267
Total Monthly MPC I PAINT in gal.	10817	5686	9802
Total Monthly Defect Paint in gal	102	39	98

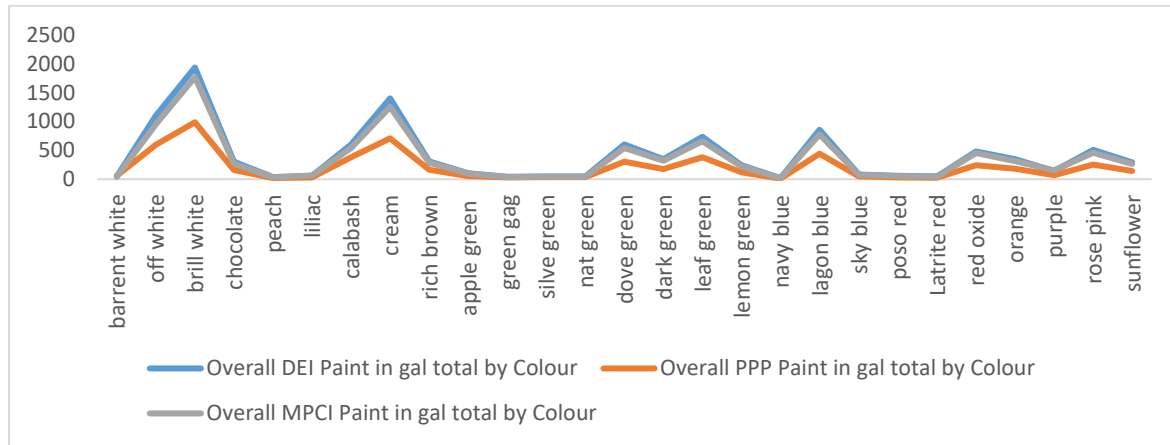


Figure 1: Three Paint Companies' Total Paint Production (in gal.) Distribution Plot

Figure 1 indicates that the three paint companies' production variations are similar and also shows that the joint variability of two paint companies is constant (i.e. De Express Integrated Services Ltd and Marshal Paint and Chemical Industries Limited).

Table 2: Total Monthly Paint Production and Total Monthly Defective Paint (in gal).

Year	Month	Total Monthly DEI Prod. Paint in gal.	Total Monthly DEI Defective Paint in gal	Total Monthly PPP Prod. Paint in gal.	Total Monthly PPP Defect Paint in gal	Total Monthly MPC Prod. Paint in gal.	Total Monthly MPC Defect Paint in gal
2022	Mar	1115	8	555	4	1002	5
	Apr	1030	12	525	5	947	6
	May	500	4	250	3	450	3
	Jun	590	7	397	2	530	4
	Jul	380	9	290	1	340	14
	Aug	159	6	125	2	170	4
	Sep	570	2	289	3	517	5
	Oct	775	15	339	4	708	12
	Nov	1355	4	683	2	1214	15
	Dec	1186	9	594	1	1077	11
2023	Jan	857	13	430	3	762	3
	Feb	930	6	480	2	848	7
	Mar	1370	7	729	7	1237	9

Then, to track both the process level and process variation at the same time from March 2022 to March 2023, as well as detect the presence of out-of-control production and the number of defect gallon. Three attribute charts were considered, that is P Chart, NP Chart and U Chart

Table 2 indicated that the paint sample points are out of control using P and U Charts, while the NP Chart indicated under control. Both P and U Charts indicated that the process level and process variation were out of Control from March 2022 to March 2023. Next, the three Multivariate Charts were used to monitor the joint effect of monthly Paint Production (gal) and monthly number of defective paint (gal) over the considered time (Months). The multivariate charts are the T-squared chart, Generalised Variance Chart and Multivariate EWMA Chart. The descriptive statistics of the three paint companies in Table 2 were computed in Table 3

Table 3: Descriptive Statistics of three paint companies' monthly Production and Defect Paint

Variable	Mean	Sum	Minimum	Maximum
Total Monthly DEI PAINT Prod.	832	10817	159	1370
Total Monthly DEI Defect Paint	8	102	2	15
Total Monthly PPP PAINT Prod.	437	5686	125	729
Total Monthly PPP Defect Paint	3	39	1	7
Total Monthly MPC I PAINT Prod.	754	9802	170	1237
Total Monthly MPC I Defect Paint	8	98	3	15

The paired t-test in Table 4 tests the mean difference between paired observations of paint production and defective paint in Table 2.

Table 4: Paired t-test Statistics and Correlation Coefficient between the three Paint Companies' monthly Production and Defective Paint

Paired Samples Statistics	Mean	SD	SEM	Correlation (p-value)	T test (p-value)
Total Monthly DEI Prod. Paint in gal.	832.0769	378.12310	104.87248	0.976 (0.000**)	6.841 (0.000**)
Total Monthly PPP Prod. Paint in gal.	437.3846	178.19069	49.42121		
Total Monthly DEI Prod. Paint in gal.	832.0769	378.12310	104.87248	1.000 (0.000**)	6.773 (0.000**)
Total Monthly MPC I Prod. Paint in gal.	754.0000	337.91024	93.71944		
Total Monthly PPP Prod. Paint in gal.	437.3846	178.19069	49.42121	0.974 (0.000**)	-6.742 (0.000**)
Total Monthly MPC I Prod. Paint in gal.	754.0000	337.91024	93.71944		
Total Monthly DEI Defect Paint in gal	7.8462	3.76046	1.04296	0.211 (0.490)	4.619 (0.001**)
Total Monthly PPP Defect Paint in gal	3.0000	1.68325	.46685		
Total Monthly DEI Defect Paint in gal	7.8462	3.76046	1.04296	0.137 (0.655)	0.211 (0.836)
Total Monthly MPC I Defect Paint in gal	7.5385	4.21536	1.16913		
Total Monthly PPP Defect Paint in gal	3.0000	1.68325	.46685	-.176 (0.565)	-3.404 (0.005**)
Total Monthly MPC I Defect Paint in gal	7.5385	4.21536	1.16913		

Footnote: ** =Sig. at 0.05

Discussion

Table 4 indicates differences between paired observations of paint production (Monthly DEI Prod. and Monthly PPP Prod.; Monthly DEI Prod. and Monthly MPCl Prod.; Monthly PPP Prod. and Monthly MPCl Prod.). The p-values ($p = 0.000$) are below the 0.05 level of significance, further suggesting that the data are inconsistent with $H_0: \mu_d = 0$, that is, the three companies' paint production does not perform equally. Specifically, DEI paint production (mean = 832 gal.) performed better than MPCl paint production (mean = 754 gal.) and PPP paint production (mean = 437 gal.) over the thirteen-month test period (March 2022 to March 2023). This work is in consonance with the work of Hrynkevych (2017), who implemented the idea of using control charts (CC) to identify exit points of the educational process from a stable/controlled status.

Similarly, Table 4 also suggests a difference between the paired observations (Monthly DEI Defect Paint and Monthly PPP Defect Paint; then Monthly PPP Defect Paint and Monthly MPCl Defect Paint). The p-values ($p = 0.001$ and 0.005) are less than the 0.05 significance level. This further suggests that the data are inconsistent with $H_0: \mu_d = 0$, that is, the two companies' defective paint are not equal. Likewise, Table 4 suggests no difference between the paired observations of Monthly DEI Defect Paint and Monthly MPCl Defect Paint, since its p-value ($p = 0.836$) is greater than the 0.05 level of significance. In conclusion, the monthly PPP Defect Paint in gallons (mean = 3 gal.) is less than the other two companies, with means of 7.8 gal. and 7.5 gal.

Conclusion

Multivariate EWMA Charts seem more adequate for determining process level and variation when checking for out-of-control conditions. However, *Brill white* was produced more than the other paint colours, followed by Cream, Off white, Lagoon blue, Leaf green and Calabash colour.

Recommendations

1. P and U Charts are recommended in place of NP Charts when checking process level and process variation.
2. Brilliant white colour was recommended over the other paint colour

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