CORPUS PUBLISHERS

Current Trends in Engineering Science (CTES)

ISSN: 2833-356X

Volume 3 Issue 5, 2023

Article Information

Received date : August 30, 2023

Published date: September 13, 2023

*Corresponding author

John J Thambirajah, Faculty of Dentistry, AIMST University, Malaysia

DOI: 10.54026/CTES/1043

Keywords

Supplier Quality; Process Capability; Supplier Monitoring Metrics; Performance indicators; Supply Chain Management

Research article

Application of Statistical Process Control for the Assessment of Supplier Performance and Process Capability in an Automotive Manufacturing Company

John J Thambirajah*

Faculty of Dentistry, AIMST University, Malaysia

Abstract

One of the most important attributes to manufacturing is product quality. It relates to the historical rejection rate during a period of time of the products delivered to the customer. Rejection is due to deviations from specifications in the raw material supplied by suppliers, process design, and the quality control of the manufacturing process. The non-conforming parts can be detected during incoming inspection or during work in process. With regards to this, the standardization and maintenance of process equipment are of prime importance in ensuring the quality of a process and the products that are derived. Cost is another important attribute of the product as it affects the bottom-line. In this regard the competence of the supplier of raw material to design, develop and launch products within specifications becomes imperative in a manufacturing process. In the current competitive environment, it is crucial to assess suppliers as good quality raw material are important in the development stage, as this can have an adverse effect on the customers response. Supplier flexibility involves the response time when engineering changes are needed during the development stage. As a result, research and development activities are used to initiate and measure the ability of the supplier to provide support during the process. It is an important attribute as most products, after launching, demand continuous improvement to remain competitive. Procurement of materials and equipment is considered the first step in supply chain management of many companies. It is also broadly known that the performance of suppliers directly influences the company's efficiency and competitiveness. Supplier performance evaluation is a crucial process to identify strengths and weaknesses of suppliers which can help the company to manage them. There are various supplier performance evaluation methods. In this study process quality of the existing system of producing steel shafts for an automotive industry was first evaluated and based on this study the machine was recommended for upgrading by engineering design. This was due to the process capability analysis of the machine, which did not meet the stipulated standard of 1.3 for the machine's capability index. Although, the raw material supplied by the suppliers were within the measured confidence interval, the summary reports did not meet the required standards. In order to develop a performance evaluation system of the suppliers of raw material to the company, four main-criteria, may be developed, namely: quality, delivery, service, and flexibility. Statistical analytical studies performed during the process on five selected suppliers of raw material showed that the most important criteria of the process metrics was machine performance, followed by quality of suppliers in terms of the supply of raw material. Based on this study, the relationship between the quality of the supplier, the performance of the machine and the specification to the consumer may be assessed.

Introduction

The pressure from globalization has made manufacturing organizations to move towards three major competitive arenas: quality, cost, and service. Quality is a universal value and has become a global issue. In order to sustain and be able to provide customers with good quality products, manufacturers are required to ensure that their processes are continuously monitored and their product quality is improved. Manufacturing organizations apply various quality control methods to improve the quality of their products and to reduce the variation in the process. A range of techniques are available to control product and process quality. These include seven statistical process control (SPC) tools, acceptance sampling, quality function deployment (QFD), failure mode and effects analysis (FMEA), six sigma, and design of experiments (DoE) [1].

Quality

Quality is one of the most important product attributes. It relates mainly to the rejection of products delivered to the customer. Rejection is mainly due to deviations from specifications in the manufacturing process. It also considers deviations from the specified quantities or delivery dates in the customer order. With regards to this, the supplier has an important role to play in mitigating the manufacturing cost, packaging cost, delivery cost and costs related to non-conforming products delivered to the manufacturer.

Thus, it is extremely important for a company to maintain a well-managed performance evaluation system of its suppliers. Currently, there is very little systematic process to evaluate supplier performance. There is no logical and strategic decision on the supplier selection process.

Supplier Quality

The delay in supply of materials by suppliers, which is commonly found at companies contribute to the delay and cost overrun. The quality of supplied materials is another problem commonly found. One of the causes of the aforementioned problems is that there is no systematic supplier performance measurement in place.

Supplier Performance Evaluation Methods

A number of approaches are being used to assist the supplier performance evaluation. Four commonly-used traditional methods stated in several studies are Categorical method, Weighted-point method, Cost ratio approach and Dimensional analysis model [2].

Supplier Performance Evaluation Criteria

The most important part in supplier performance evaluation process is the identification of the evaluation criteria which are related to the supplier performance. Several studies have been carried out by way of questionnaires and surveys on key experts in procurement functions and other associated functions to collect and discover the performance evaluation criteria which are currently applied in the real business [2].

Tracey & Tan [3] stated in their study that effective supplier evaluation is not easy to achieve if the customer satisfaction is not considered. Thereby, the criteria used in evaluating suppliers are inclusive of quality, reliability, and performance of the product. This is to ensure that the customer satisfaction will be fulfilled. Ohdar & Ray [4] cited that there are two main performance measurement attributes for manufacturing company. The two attributes are "soft" or non-quantifiable criteria like supplier commitment and "hard" or quantifiable criteria like suppler capability. The supplier performance and process capability are the key issues in the present study.

Other Attributes

Several literatures point out that the supplier performance is not just related to price or quality, instead, supplier performance evaluation requires a multi-criteria evaluation process [5]. However, it is fair to accept that the quality will be on the top priority to satisfy the customer [3]. But there are other attributes which are important and need to be considered. Therefore, the buying companies need to select and identify the evaluation criteria which will serve the company's objectives, activities, and to satisfy the customers. Thus, it is very important to identify the criteria and metrics which are objectively relevant to the company at all levels [6].

The coordination degree between manufacturer and supplier is an important attribute of the relationship as it allows moving together towards the achievement of mutual objectives. Commitment refers to the willingness of the supplier to perform extra effort on behalf of the relationship. It is the establishment of the foundation of the relationship and it is based on being supportive in solving problems together. A high level of commitment provides the context for the achievement of individual and mutual goals.

Information sharing considers the timeliness, accuracy, adequacy and completeness of the relevant information exchanged. Finally, conflict management measures the degree of intensity and conflict resolution mechanisms that exist between the manufacturer and the supplier. The existence of conflict is inherent to interpersonal as well as inter-organizational relationships. However, the manner in which the conflict is managed is essential to the long-term attribute and stability of the relationship.

Process Capability

Process capability can be defined as the aptitude of a process's aptitude to fulfill the expectations of the consumer [7]. Measuring process capability and the quality expectations in terms of quantitative values could pave the way for determining whether the process meets consumer expectations more accurately. Consumer expectations are usually introduced as the specification limits (SLs), which are comprised of lower specification limit (*LSL*) and upper specification limit (*USL*) [8].

The measured capability of a process can take any value. There is an active debate on the precise values of SLs. Process capability analysis generally involves defining process specification limits, defining process capability indices, measuring process capability indices, and determining how much the process is capable. One of the crucial steps in such studies is the selection of process capability indices to measure the process capability. In fact, this selection is of paramount importance since it can be considered as the heart of the analysis. It is well known that many companies are not able to achieve the 1.3 index for process capability.

In this study, quantitative statistical methods were used to study the inter relationships of supplier-manufacturer metrics, in terms of the quality characteristics of the raw material supplied by five suppliers, and equipment performance of the process in terms of process capability. The studies indicate a revelation to process industries that all is not well in the supplier-manufacturer relationship in terms of the performance indicators.

Objectives of the Study

The objectives of this study are:

a) To identify the relevant performance evaluation criteria to determine the quality of raw material supplied by suppliers
b) To determine the process performance of machines in terms of the process capability index in the manufacture of steel shafts for an automotive industry
c) To highlight the importance of raw material quality to machine performance in the automotive industry

Methodology of the Study

Materials and Methods

Study Design

The production manager of an automotive steel shaft manufacturing company decides to perform quality control checks with respect to:

a) quality of raw material supplied by five suppliers of a particular category of steel shafts that are produced by the automotive company
b) performance evaluation of a particular machine in manufacturing steel shafts for the automotive industry, by determining the capability index of the machine
c) determine the relationship between the quality of raw material supplied by suppliers to the performance of machines in companies

The production manager has three hypothesis tests to perform

a) Test 1 is to check whether the quality of raw material produced by five suppliers meet the stipulated standards required by the company
b) Null Hypothesis: Quality of raw material = stipulated standards
c) Test 2 is to check whether the performance of the company's machine complies to the capability index stipulated at 1.3 Cpk.
d) Null Hypothesis: Capability index of company's machine = 1.3 Cpk
e) Test 3 was to check whether there is a relationship between the quality of raw material supplied by suppliers to the performance of process machines
f) Null Hypothesis: there is a relationship between the quality of raw material supplied by suppliers to the performance of process machines

A cross sectional study was conducted by taking 20 samples each consisting of 5 parts from

five different suppliers. The samples were collected.at random. The parts consisted of the steel shafts produced by the process, from the raw material supplied by each of the five suppliers.

This was with a view to assess the quality of raw material supplied by the five suppliers, the variation if any of the steel shafts produced by the process machine of the company and the interrelationship if any between the raw material supplied by the suppliers to the performance of the process machine in terms of the capability index.

.

Initially, a process summary report was created on one hundred samples in order to determine

the performance of the process machine as well as the quality of the raw materials supplied by the five suppliers (Figure 1). Based on these results, engineering controls were to be recommended in order to increase the efficiency of the process machine. This was with a view to achieve a process capability at a Cpk of 1.3 in the process or its approximation.

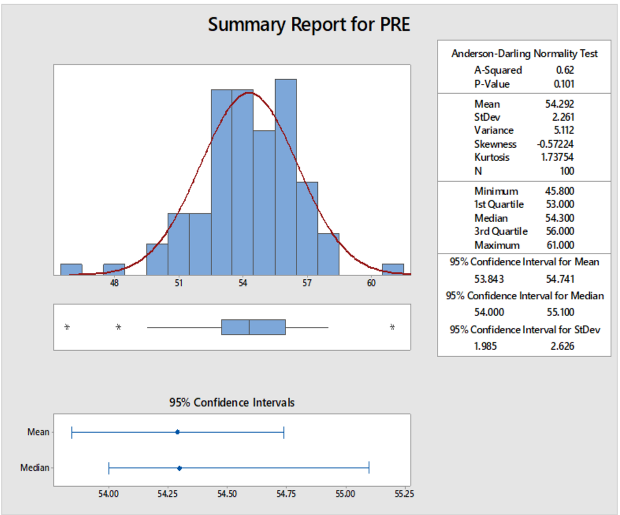

Figure 1: Summary report for the process machine which included one hundred steel shaft samples taken at random from the five suppliers showing the Anderson-Darling Normality Test, mean, StDev, and 95% Confidence Interval. The Anderson-Darling Normality Test was not significant at p- value of 0.101 (p <.05).

a) In any type of field, the goal of statistics is to gain understanding from data. Any data analysis should contain certain steps to be followed to ultimately achieve the goal of the research proposed [9,10].

It should be noted that the major objective of statistics is to make inferences about the population from an analysis of information contained in sample data. This includes assessments of the extent of uncertainty involved in these inferences.

b) This study focuses on the statistical analysis of the data collected from a process machine, on the length of steel shafts from five different suppliers. Samples were taken at random and analyzed. A Minitab 17 software was used throughout the study.

c) Various statistical tests were conducted in order to evaluate and verify the performance of the process carried out by the process machine; as well as the quality of the raw material supplied by five suppliers. The details of the statistical tests are as in the following sub-sections.

Data Handling and Statistical Analysis

d) In order to assess the quality of the raw material supplied by each of the five suppliers, initially, a summary report was conducted on twelve samples taken at random from supplier 'one' in order to measure the length of the steel shafts produced by the process machine (Figure 2). A Minitab ver 17 software was used to analyze all the data in this study.

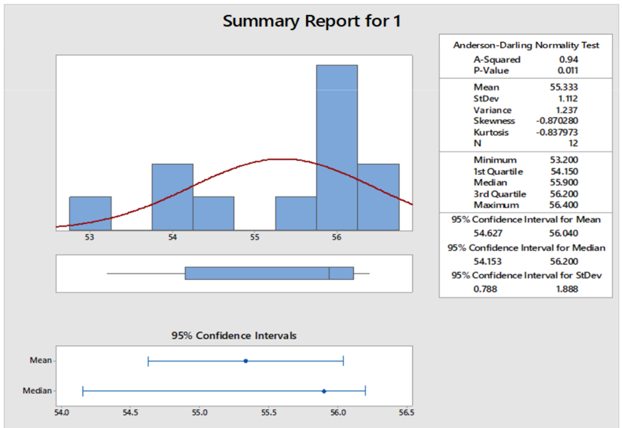

Figure 2: Summary report for twelve samples taken at random from supplier one showing the Anderson-Darling Normality Test, mean, StDev. And 95% Confidence Interval. The Anderson-Darling normality test showed a significant value for product number one at p= 0.011(p<0.05).

e) Subsequently, summary reports were prepared for the remaining suppliers 2-5 (Figures 3-6).

The summary reports indicate mainly the mean, standard deviation, the confidence interval (CI) and the Anderson-Darling tests for the normality check.

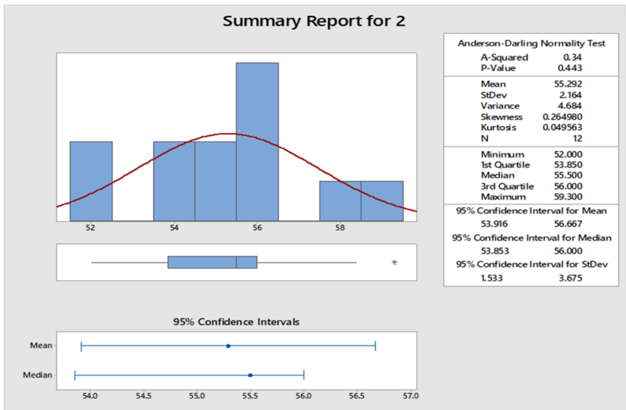

Figure 3: Summary report of twelve samples taken at random from supplier two showing the Anderson-Darling Normality Test, mean, St Dev. And 95% Confidence Interval. The Anderson-Darling normality test value was not significant at p = 0.443.

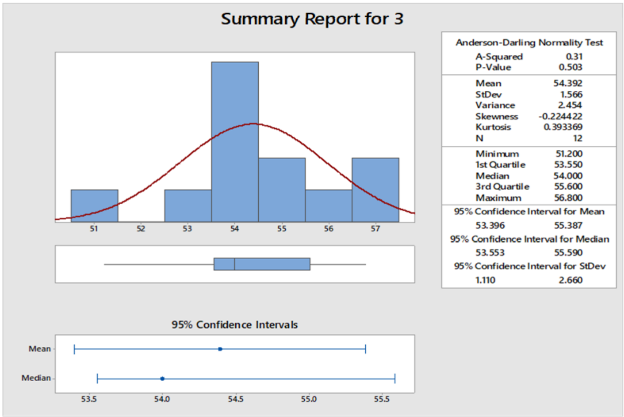

Figure 4: Summary report of twelve sample taken at random from supplier three showing the Anderson-Darling Normality Test, mean, StDev. And 95% Confidence Interval. The Anderson-Darling normality test statistic was not significant at p = 0.508.

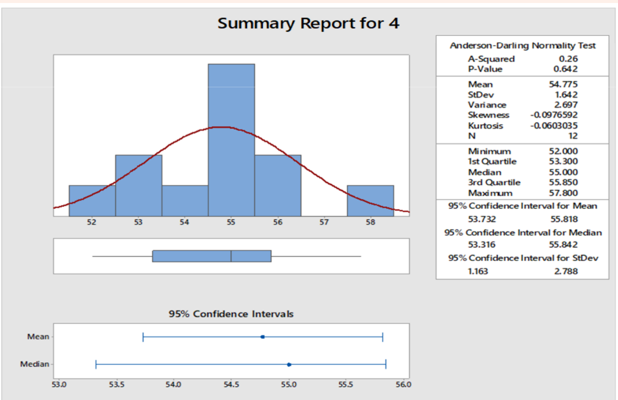

Figure 5: Summary report of twelve samples taken at random from suppler four showing the Anderson-Darling Normality Test, mean, StDev. And 95% Confidence Interval. The Anderson=Darling normality test report showed p= 0.642.

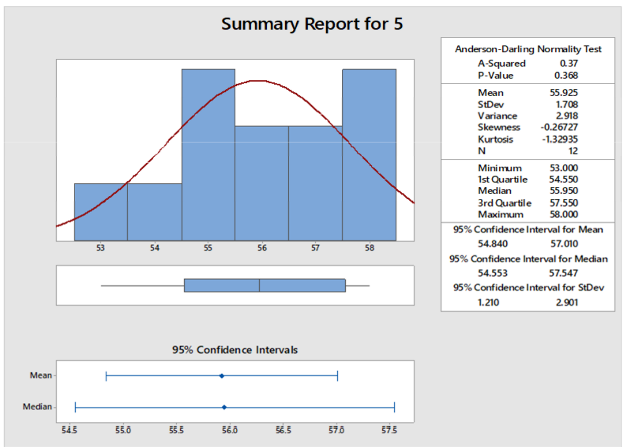

Figure 6: Summary report of twelve samples taken at random from supplier five showing the Anderson-Darling Normality Test, mean, StDev. And 95% Confidence Interval. The Anderson=Darling report showed p=0.368.

f) I-MR charts were created for 20 samples each, taken at random from the process machine, in order to measure the length of the shafts supplied by the five suppliers (Figures 6-10). This was with a view to determine whether the machine as well as the suppliers were in a state of statistical process control. I-MR charts were conducted due to the sample size of twenty each. The results are indicated in figures 6-10, respectively.

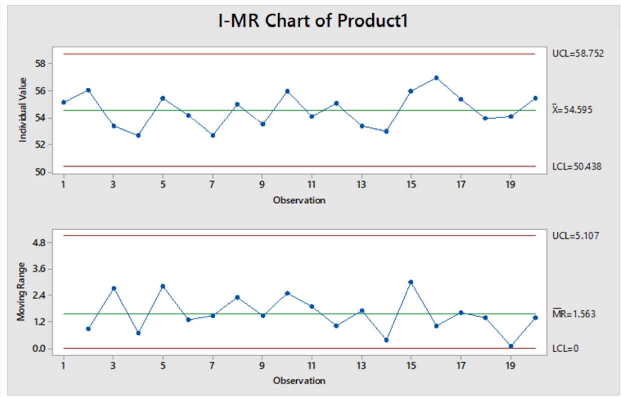

Figure 7: I-MR Chart of Product1for twenty samples taken at random. The samples are within the statistical control limits

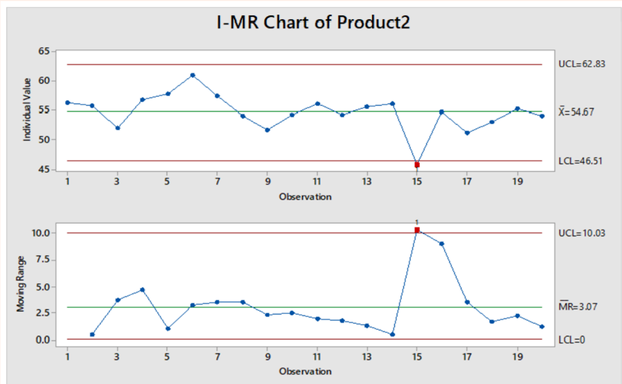

Figure 8: I-MR Chart of Product2 for twenty samples taken at random. Sample number 15 was out of the control limit.

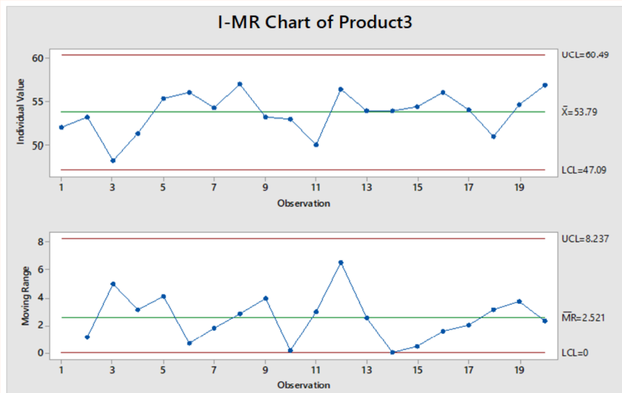

Figure 9: I-MR Chart of Product3 for twenty samples taken at random. All the samples were within the control limits

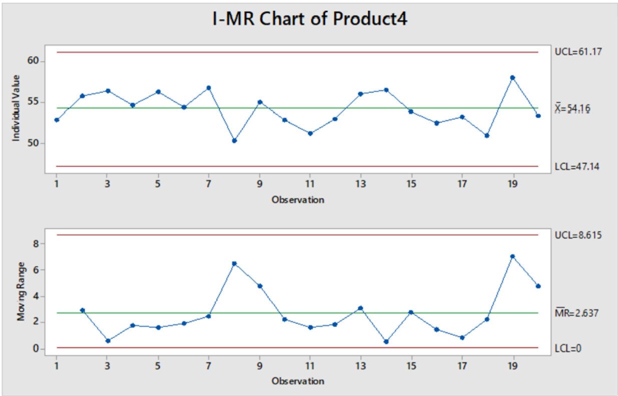

Figure 10: I-MR Chart of Product4 for twenty samples taken at random. All the samples were within the control limits.

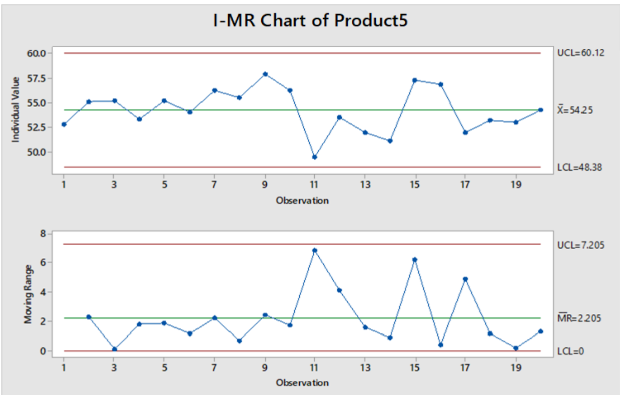

Figure 11: I-MR Chart of Product5 for twenty samples taken at random. All the samples were within the control limits.

g) Process capability reports of the data from the process machine are indicated in figures 12-16. A process capability plot indicates normality by way of a histogram and defines Cp and Cpk of the process machine. Process capability plots indicate the efficiency of the process in terms of its production.

h) A Sixpack process capability plot was prepared for process1 in order to highlight the normality check of the process (Figure 16).

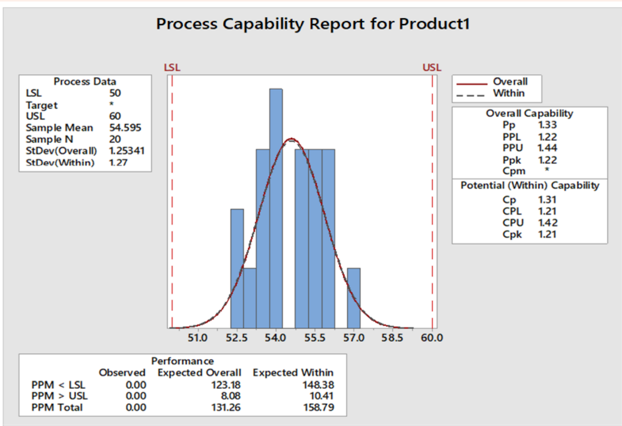

Figure 12: Process Capability Report for Product1 showing a Cpk of 1.21. The expected value for process capability is 1.3.

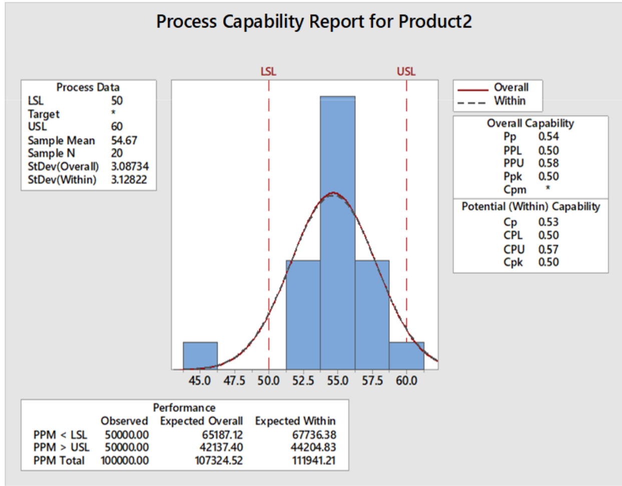

Figure 13: Process Capability Report for Product2 showing a Cpk of 0.50.

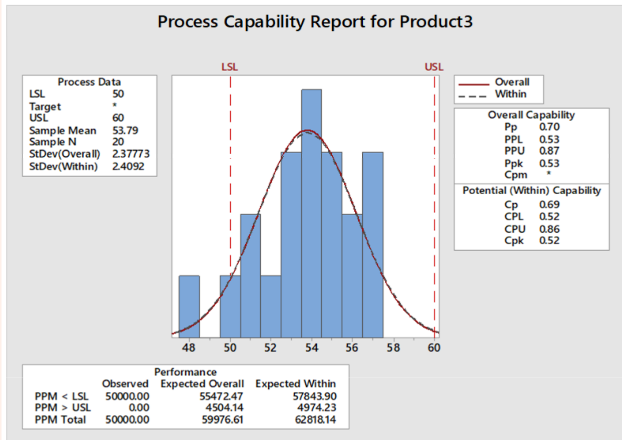

Figure 14: Process Capability Report for Product3 showing a Cpk of 0.52.

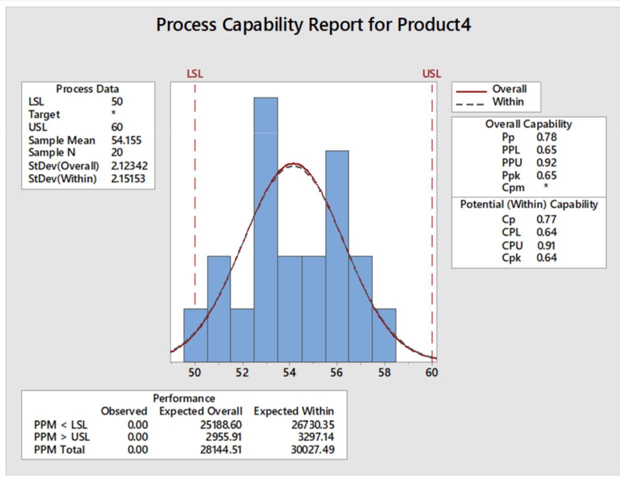

Figure 15: Process Capability Report for Product4 showing a Cpk of 0.64.

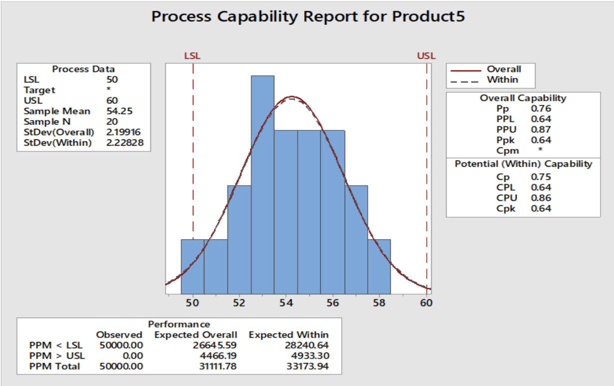

Figure 16: Process Capability Report for Product5 showing a Cpk of 0.64.

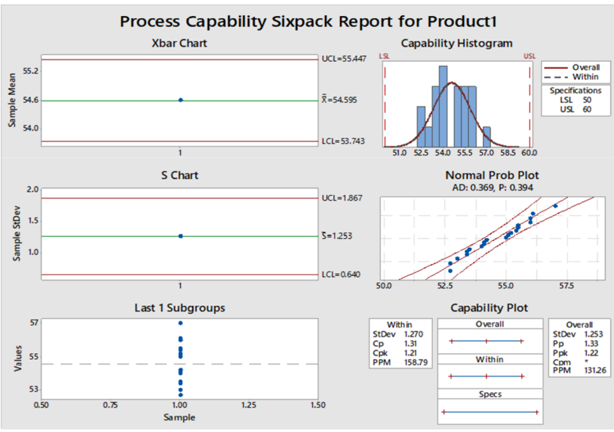

Figure 17: Process Capability Sixpack Report for Product1 showing mainly the histogram and the normal probability plot.

i) As the initial measurements of the process machine showed that the output from the machine did not meet the expected standards of approximately 1.3 Cpk, engineering controls were to be recommended for the process machine. However, the products appeared to be in statistical control which was indicated by the I-MR charts (Figures 7-11).

j) Residual plots for size, for products 1-5 is indicated in figure 18. The normal probability plot shows that the data are normally distributed. There is an even spread and the histogram also shows a normal distribution.

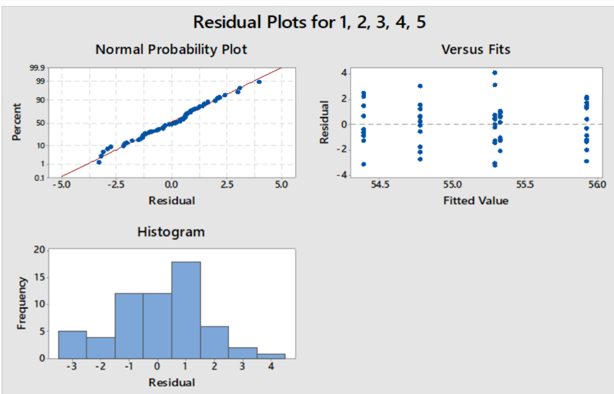

Figure 18: Residual Plots for 1,2,3,4,5.

k) An Individual value plot showed the spread of the samples for the five suppliers (Figure 19).

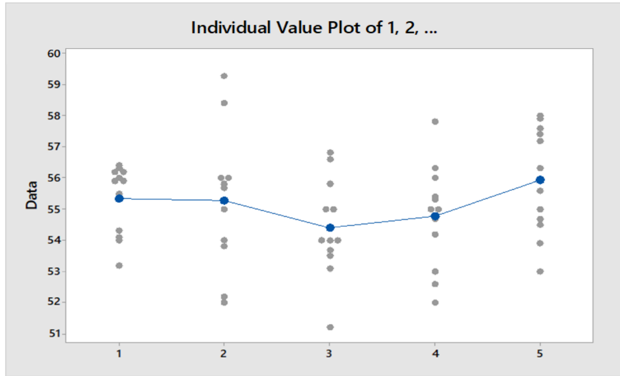

Figure 19: Individual Value Plot of 1,2, 3, 4, 5 showing the spread of the samples.

l) Boxplots for the five suppliers indicated that all the five suppliers were within the stipulated control limits of the confidence interval (Figure 20).

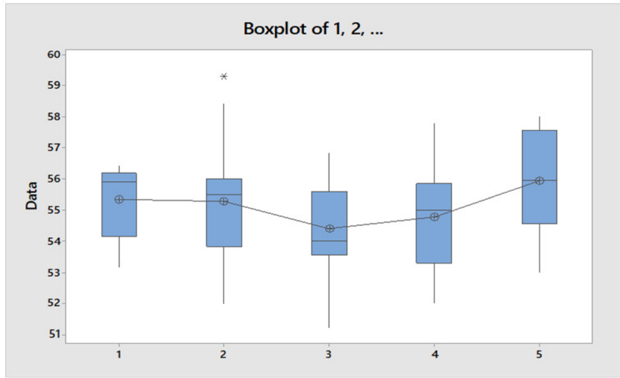

Figure 20: Box Plot of 1,2,3,4,5 indicating the sample means from the five suppliers were within the confidence interval (CI).

m) Interval plots of the five suppliers at 95% CI for the mean are indicated in figure 21.

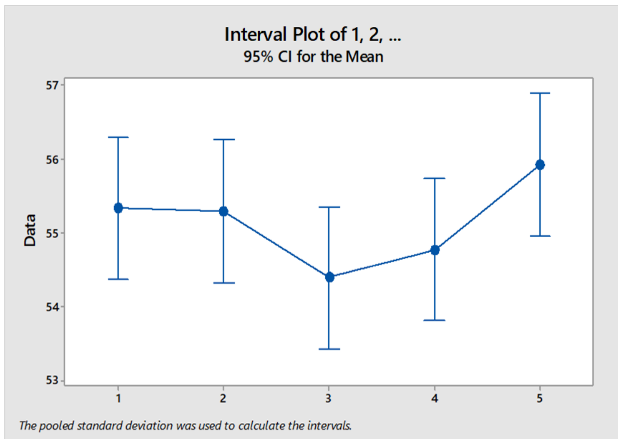

Figure 21: Interval Plot of 1,2,3,4,5 at 95% CI for the Mean.

Table 1: One-Way ANOVA 0F 1,2,3,4,5 at 95% CI for the Mean.

Method	
Null hypothesis	All means are equal
Alternative hypothesis	At least one mean is different
Significance level	α = 0.05
Equal variances were assumed for the analysis.	
Factor Information	
Factor Levels	**Values**
Factor 5	Product1, Product2, Product3, Product4, Product5
Analysis of Variance	
Source	DF Adj SS Adj MS F-Value P-Value
Factor	4 10.14 2.536 0.49 0.746
Error	95 495.93 5.220
Total	99 506.07
Model Summary	
S	R-sq R-sq(adj) R-sq(pred)
2.2848	2.00% 0.00% 0.00%
Means	
Factor N Mean StDev 95% CI	
Product1 20 54.595 1.253 (53.581, 55.609)	
Product2 20 54.670 3.087 (53.656, 55.684)	
Product3 20 53.790 2.378 (52.776, 54.804)	
Product4 20 54.155 2.123 (53.141, 55.169)	
Product5 20 54.250 2.199 (53.236, 55.264)	
Pooled St Dev = 2.28480	

One-way ANOVA: Product1, Product2, Product3, Product4, Product5

a) Tukey simultaneously pairwise comparisons at 95% CI's of the five products, showing difference of means for products 1-5 are provided in figure 22.

Results

The one-way analysis of variance shows:

The p value is not significant at 0.746 (p<.05) for the five suppliers. Meaning, there is no significance differences between the means of the raw material supplied by each of the five suppliers. This is confirmed by the appearance of the Boxplots (Figure 20).

A low R square of 2%. R square shows the relationship between the independent and dependent variables. In this study the R square value was as low as 2% which explained the relationship between the independent and dependent variables. The independent variables were the raw material supplied by the five suppliers, while the dependent variable was the capability index of the process machine.

For each of the twenty samples taken at random from the five suppliers, the means and standard deviation were close to each other, respectively. The values were within the control limits (I-MR Charts) and the St Dev were quite low for each of the suppliers.

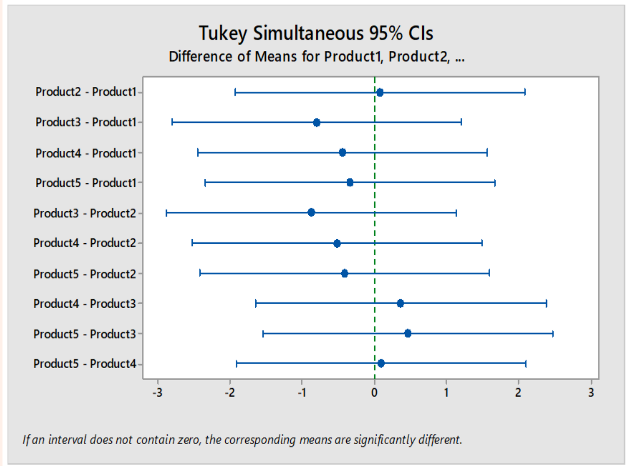

Figure 22: Tukey Simultaneous 95% CIs: Difference of Means for Product1, 2,3,4,5. All the measurements passed through the zero value, indicating that there was no significant differences in the comparison of the iive suppliers.

Summary of the Results

Understanding diverse information demands an ability to be aware of the process of analyzing data and interpreting results [11]. This allows for the communication of information to be valid. This knowledge and ability not only gives undeniable advantages in the increasingly numerate world of manufacturing technology, but it also requires that the practitioners have some experience with statistical methods [11].

Graphical displays are basic forms which provide indications of how the sample data are distributed [10]. This is also possible using table forms such as frequency tables. In this study, the ANOVA table (Table1) is self-explanatory. Graphs and tables can also be used to display descriptive statistics, which include a number of summary values such as the measures of central tendency and variation [10]. Graphs and charts have the advantage of giving a more rapid overview, and they can indicate possible trends, effects and relationships.

A variety of figures, graphs and tables are possible, which allow rapid illustration of results. These summaries are taken further in statistical process control where measures such as the mean value are plotted 'live', as a process is ongoing [11]. The graphs such as control charts used include limit lines which are set by using other statistical methods. This allows detection of out-of-limit material as indicated by the I-MR control charts in this study. The statistical process control as a methodology is applied for checking whether an actual measurement is within the normal range of variability in order to determine the validity of the result [12]. The SPC methodology is based on control charts. These are plots of the data over time with control limits superimposed [12]. The plotting aspect is the most important, but the limits can also play a certain role for detecting drift and outliers. The assumption behind the most basic SPC control chart, the Shewart control chart, is that when the process is under control, within the normal variation range, all observations are independent and identically distributed [12]. Usually, they are assumed to have a normal distribution which was evident in this study.

Although, it is possible to evaluate scientific data without involving statistical analysis, once data accumulate and time is limited, such judgment can suffer from errors. In these cases, simple statistical summaries can reduce large data blocks to a single value. Now, both the enlightened novice and the experienced analyst can judge what the statistics reveal. Consequent decisions and actions will now proceed with improved confidence and commitment [9]. Thus, statistical techniques play a part in monitoring and reporting of such results. This gives confidence that results are valid which will benefit the consumers in terms of their surety [9]. This study has provided ample evidence as to the significance of statistical application in the manufacturing industry. The results of which will be relevant to manufacturing industries.

Discussion

The ever-intensifying pace of market competition among industry players urges firms to improve processes to cut costs and increase process efficiency [13]. Contemporary firms have less or no control over the increase of input material costs and the pressure of the market to decrease the prices of the final products while increasing the quality.

Therefore, they have to optimize their process costs and increase process quality to alleviate the pressure and make value for consumers and the stakeholders [14]. With regards to this, this study emphasizes the fact that a suitable relationship needs to exist between suppliers of raw material and the efficiency of process machines. Thus, the monitoring of raw material supplied by suppliers and the maintenance of process machines in an efficient manner are imperative for a sustainable process. Statistical Process Control (SPC) is a methodology that helps firms continuously improve processes by using control charts to evaluate the process capability and specification standards [8]. Many firms that have successfully implemented SPC have reported significant improvements in efficiency and other performance measures.

The unit cost is highly dependent on the raw material supplied by suppliers. Therefore, purchasing can be regarded as one of the most important activities in an organization [15]. It should be considered as the essential strategy for producing a high-quality product at a low cost to manage the relationship with suppliers. Generally, most previous research categorizes supply chain management (SCM) into the following three major parts: purchasing, manufacturing, and distribution [16]. The purchasing function focuses on obtaining raw materials for manufacturing, which is an essential component to start supply chain execution [17]. In this study, the five suppliers of raw material were in compliance with the stipulated mean values were within the confidence intervals as indicated by the statistical analysis in terms of the summary plots and the control charts. However, the process machine was not up to the required standard as indicated by the process capability indices. Process capability indices can provide management with valuable information about the processes. Such information, which is crucial to the functional improvement of the system, can be used to boost processes and make them more efficient and capable, and cut production costs while increasing customer satisfaction [18]. It is known that the quality of the final products obtained from processes is subject to variations. Process capability indices are designed to scrutinize processes and differentiate between the process capability studies and machine capability indices. Both of these approaches are intended to identify and evaluate random and systematic process variability [19].

The interrelationship between suppliers and the capability of the process machines has often been over looked. Very often companies perform at a much lower rate of efficiency than what meets the requirements of the standards. A process capability index of 1.3 is often not achieved by most companies. In this context, the present study develops a decision-making framework for supplier selection and supplier monitoring based on the quality of the raw materials supplied by five suppliers. It also specifies the importance of process efficiency required of the machines used in the process. The framework that determines the quality characteristics of the suppliers can be divided into the following three steps. The first step is the identification of the main dimensions and important criteria for selecting and monitoring of suppliers. In the second step, the main dimensions and criteria are prioritized. Thirdly and finally, a comparison of the criteria is performed.

Thus, a standardized framework is proposed to understand the differences between supplier selection and monitoring and its interrelationship with the process capability of process machines by the application of statistical process control measures. This was determined by the analysis of samples taken at random of five suppliers which was matched with the performance of the process machine.

Conclusion

Several methods have been proposed for solving the supplier selection problem such as vendor profile analysis (VPA), multi-objetive programming (MOP), data envelopment analysis (DEA) and analytic hierarchy process (AHP) [20]. Evaluation and ranking of potential suppliers involves both tangible and intangible criteria. This is because overall assessment of suppliers should not only consider quantitative performance data but also some other criteria that are critical for successful partnerships and are not directly quantifiable, such as trust and commitment [3]. Therefore, the AHP method developed by Saaty [21] is a useful method to select suppliers as it deals with both types of criteria. In addition, AHP aims at integrating different measures into a single overall score for ranking decision alternatives [21].

Furthermore, suppliers play an important role in implementing sustainable supply chain initiatives and in achieving economic, social, and environmental gains [22]. Also, sustainable supplier management (SSM) has been interrelated with essential purchasing function.

Process capability indices can provide management with valuable information about the processes. Such information, which is crucial to the functional improvement of the system, can be used to boost processes and make them more efficient and capable, and cut production costs while increasing customer satisfaction [18]. It is known that the quality of the final products obtained from processes is subject to variations. Process capability indices are designed to scrutinize processes and differentiate between the process capability studies and machine capability indices. Both of these approaches are intended to identify and evaluate random and systematic process variability [19].

References

1. Wu D (2009) Supplier selection: A hybrid model using DEA, decision tree and neural network. Expert Syst Appl 36: 9105-9112.
2. Humphreys P, Cadden T, Wen LL, McHugh M (2011) An Investigation into Supplier Development Activities and Their Influence on Performance in the Chinese Electronics Industry. Production Planning & Control 22(2): 137-156.
3. Tracey M, Tan CL (2001) Empirical analysis of supplier selection and involvement, customer satisfaction, and firm performance. Supply Chain Management: An International Journal 6(4): 174-188.
4. Ohdar R, Ray PK (2004) Performance measurement and evaluation of suppliers in supply chain: an evolutionary fuzzy-based approach. Journal of Manufacturing Technology Management 15(8): 723-734.
5. Kwong CK, Ip WH, Chan JWK (2002) Combining scoring method and fuzzy expert systems approach to supplier assessment: a case study. Integrated Manufacturing Systems 13(7): 512-519.
6. Cormican K, Cunningham M (2007) Supplier Performance Evaluation: Lessons from a Large Multinational Organization. Journal of Manufacturing Technology Management 18(4): 352-366.
7. Hadian H, Rahimifard A (2019) Multivariate statistical control chart and process capability indices for simultaneous monitoring of project duration and cost. Computers & Industrial Engineering 130: 788-797.
8. Guarnieri JP, Souza AM, Jacobi LF, Reichert B, Da Veiga CP (2019) Control chart based on residues: Is a good methodology to detect outliers? Journal of Industrial Engineering International 15(1): 119-130.
9. Freund J (2001) Modern elementary statistics (4th Edition). Prentice-Hall. London, pp. 621-730.
10. Shahbaba R (2012) Biostatistics with R: an introduction to statistics through biological data. Springer, New York, pp. 1-12.
11. Weiss N (1999) Introductory Statistics. In: (5th Edition), Addison Wesley Longman. New York, pp. 270-287.
12. Montgomery D (1997) Introduction to Statistical Quality Control (6th Edition). John Wiley & Sons, Inc. New York pp. 3-42.

13. He QP, Wang J (2018) Statistical process monitoring as a big data analytics tool for smart manufacturing. Big Data: Data Science for Process Control and Operations 67: 35-43.

14. Senvar O, Akburak D (2019) Implementation of Lean Six Sigma for airline ground handling processes. In: Calisir F, Cevikcan E, Camgoz AH (Eds.), Industrial engineering in the big data era. Springer International Publishing, pp. 53-66.

15. Chen CC, Yang CC (2003) Total-costs Based Evaluation System of Supplier Quality Performance. Total Quality Management & Business Excellence 14(3): 325-339.

16. Tan KC, Lyman SB, Wisner JD (2002) Supply chain management: a strategic perspective. International Journal of Operations & Production Management 22(6): 614-631.

17. Ghodsypour SH, Brien CO (2001) The Total Cost of Logistics in Supplier Selection, under Conditions of Multiple Sourcing, Multiple Criteria and Capacity Constraint. International Journal of Production Economics 73(1): 15-27.

18. Selmi S, Ben AS, Ben FN, Kobi A, Ben SI (2018) Process capability indices and R control chart limit adjustments by taking into account measurement system errors. The International Journal of Advanced Manufacturing Technology 95(5-8): 1919-1930.

19. Nikzad E, Amiri A, Amirkhani F (2018) Estimating total and specific process capability indices in three-stage processes with measurement errors. Journal of Statistical Computation and Simulation 88(15): 3033-3064.

20. Moeller S, Fassnacht M, Klose S (2006) A Framework for Supplier Relationship Management (SRM). Journal of Business-to-business Marketing 13(4): 69-94.

21. Saaty TL (1980) The Analytical Hierarchy Process: Planning, Priority Setting, Resource Allocation. McGraw-Hill, New York, NY.

22. Carter JR, Narasimhan R (1994) The Role of Purchasing and Materials Management in Total Quality Management and Customer Satisfaction. International Journal of Purchasing and Supply Management 30 (3): 3-13.