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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. Thus, 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. Thus, 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 process. It also considers the response time to new orders or order modifications during the development and manufacturing stages.

Keywords: performance indicators, process quality, supply chain management, supplier monitoring metrics.

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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. Thus, 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. Thus, 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 process. It also considers the response time to new orders or order modifications during the development and manufacturing stages. 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 was first evaluated. Based on the study the machine was upgraded by engineering design and the results were evaluated subsequently. In order to develop an overall performance evaluation system, firstly: the manufacturer's process machine was assessed for capability. These formed the metrics for the performance evaluation of the process. Subsequently, the quality of the raw material supplied by a regular supplier was evaluated together with raw material supplied by two other suppliers. These were compared. The results which mainly constituted statistical analysis showed that the most important criteria of the process metrics was machine performance, followed by supplier quality of raw materials. These formed the performance indicators for the overall process. Generally, the supplier who attained the highest weighted score was the top-performer.

Keywords: performance indicators, process quality, supply chain management, supplier monitoring metrics.

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I. INTRODUCTION

The pressure from globalisation has made manufacturing organisations 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, manufacturing organisations are required to ensure that their processes are continuously monitored and their product quality is improved.

Manufacturing organisations apply various quality control methods to improve the quality of the product 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 is one of the most important product attributes. It contributes to competitive advantage for the organization and inspires confidence in the customer. It relates mainly to the rejection of products delivered to the customer. Rejection can be detected during incoming inspection or during manufacturing [2]. The rejected items can be identified by means of statistical process control and corrective action may be taken at this stage. Companies also consider deviations from the specified quantities or delivery dates in the customer order in relation to the supply chain management [3]. Thus, the supplier has an important role to play in mitigating the manufacturing cost, packaging cost, delivery cost and costs related to non-conforming products [4].

Therefore, it is extremely important for a company to maintain a well-managed performance evaluation system of its processes and that of its suppliers [5]. Currently, there are very little systematic processes to evaluate supplier performance. There is no logical and strategic decision on the supplier selection process. Most of the sourcing is based on the experience of each individual purchaser. Materials will generally be procured from the familiar suppliers and/or suppliers with a good reputation [6].

Moreover, when a new purchaser comes, he will have to manually track back and refer to the previous procurement records which include only information regarding historical price and lead time. In addition, there are no records of the performance on other dimensions, such as product quality, delivery and delay [7]. Thus, the procurement lead time is extended.

The delay in supply of materials by suppliers, which is commonly found at companies contribute to the delay and cost overrun [8]. The quality of supplied materials is another problem commonly found [9]. One of the causes of the aforementioned problems is that there is no systematic supplier performance measurement system put in place [10]. Material sourcing based on the experience of the procurement officer does not always guarantee that the company will award the contract to the suppliers whose performance is best.

However, a number of approaches have been used to assist supplier performance evaluation [11]. Four commonly-used traditional methods stated in several studies are Categorical method, Weighted-point method, Cost ratio approach and Dimensional analysis model [12].

The most important part in the supplier performance evaluation process is the identification of the evaluation criteria which are related to supplier performance [5]. 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 [13]. Tracey and Tan [3] stated in their study that effective supplier evaluation is not easy to achieve if 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 aspect will be fulfilled. Ohdar and Ray [14] cited that there are two main performance measurement attributes for manufacturing companies. The two attributes are "soft" or non-quantifiable criteria like supplier commitment and "hard" or quantifiable criteria like suppler capability.

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 [15]. However, it is fair to accept that 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 [16].

Coordination between the supplier and manufacturer is an important attribute which may lead to sustainability related to the overall process [17]**.** It involves the tasks that are to be taken for linking activities performed by the different members in a seamless manner [18]. 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.

With regard to this, commitment which refers to the willingness of the supplier to perform the extra effort on behalf of the relationship may lead to the establishment of the foundation of the relationship. This may be based on being supportive in solving problems together [19]. A high level of commitment provides the context for the achievement of individual and mutual goals.

Accordingly, trust and information sharing are also of increasing importance in the relationship [20]. This is based on the belief that the partner is reliable and will fulfil its responsibilities acting fairly, in the interest of both parties. Information sharing considers the timeliness, accuracy, adequacy and completeness of the relevant information exchanged.

Finally, of even more significance is conflict management which may be inevitable in any relationship [21]. This measures the degree of intensity and conflict resolution mechanism that exists between the manufacturer and the supplier [22]. 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.

In this study quantitative statistical methods were used to study the inter relationships of supplier-manufacturer metrics. This was mainly with a view to develop a framework to evaluate the performance characteristics of the process related to the quality of raw material supplied by suppliers to the company. The performance indicators were evaluated with respect to the quality characteristics of the products, equipment performance of the process as well as the supplier performance metrics. The studies indicate a revelation to process industries that all is not well in the supplier-manufacturer relationship. A continuous monitoring, evaluation and improvement program might be necessary in order to streamline and standardize the supplier-manufacturer relationship as a measure to ensure long term sustainability.

Ojectives of the Study

The objectives of this study are:

To identify the relevant performance evaluation criteria to determine process quality for the manufacture of steel shafts.

To develop a performance indicator system for the evaluation of supplier quality based on statistical analysis.

II. METHODOLOGY OF THE STUDY

2.1 Materials and Methods

2.1. Study Design

The process engineer of a steel shaft manufacturing company decides to perform quality control checks with respect to a) proportion of defectives for the population of a particular category of steel shafts produced by the company b) performance evaluation of a particular machine c) evaluation of the quality of raw materials from three different suppliers.

2.1.1 The process engineer has three hypothesis tests to perform.

Test 1 is to check whether the population proportion of defectives was less than the target of 5%. That is,

Null Hypothesis: Population proportion of defectives = < 0.05

Test 2 was to check whether the length of the steel shafts from machine A was equal to the target of 10 inches. It was suspected to be less than 10 inches. That is

Null Hypothesis: Product length from machine A = 10 inches

Test 3 was to check whether the mean lengths of the steel shafts were the same across three different raw material suppliers

Null Hypothesis: Mean lengths of the steel shafts are the same across three different raw material suppliers

2.1.2 A cross sectional study was conducted by taking 20 random samples of the steel shafts produced by the process at Machine A. These samples consisted of the raw material supplied by the regular supplier. The lengths of each of the steel shafts was measured and an individual I-MR analysis was performed (Fig 1).

This was with a view to assess the quality of the steel shafts produced by machine A of the company and to test Hypothesis 1 and 2, stipulated by the process engineer. Subsequently, Hypothesis 3 was tested for the comparison of three suppliers in the supply chain.

2.1.3 As the tests revealed that the performance of Machine A was not up to the expected standards, as most of the steel shafts were less than 10 inches (Fig.1) engineering controls were introduced by mechanically adjusting Machine A in order to centre the process and to adjust the deviation in the mean of the samples.

2.1.4 Subsequently, a second set of analysis was conducted which now constituted a longitudinal study of the process on Machine A. Now labelled as Machine A1.

2.1.5 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 [23, 24]. 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.

2.1.6 This study initially focused on the statistical process control of Machine A. This was initiated by the data analysed on the length of steel shafts from the regular supplier. Subsequently, twenty samples were taken at random from two other suppliers and the lengths were measured and compared (Figs.10-12). A Minitab 17 software was used to analyse the data throughout the study.

2.1.7 With regards to this, various statistical tests were conducted in order to evaluate and verify the performance of the process carried out by Machine A. The details of the statistical analysis are as in the following sub-sections.

2.2. Data Handling and Statistical Analysis

2.2.1 To measure the "1 Proportions" defectives test (Hypothesis1), a sample of 150 shafts was taken from Machine A and the length of each shaft was measured. The test and the confidence interval (CI) was performed by the Minitab software (Table1).

2.2.2 Another set of 20 steel shafts from Machine A were taken and their lengths were measured. As the sample size was less than 30, "1 sample t-test" was carried out in order to verify if the lengths of the steel shafts were equal to 10 inches (Table 2).

2.2.3 A summary report of the length of the initial twenty samples of the steel shafts collected at random from the regular supplier was created for Machine A (Fig.2). Summary reports indicate mainly the mean, standard deviation, the confidence interval (CI) and the Anderson-Darling tests for the normality check.

2.2.4 An individual value plot of Machine A was then initiated, with H0 and 95% t-confidence interval for the mean (Fig.3).

2.2.5 A process capability plot of the data from Machine A is indicated in Fig 4. A process capability plot indicates normality by way of a histogram and defines Cp and Cpk of the process. A Cpk level of 1.33 constitutes a good process value.

2.2.6 The initial measurements of Machine A showed that the output from the machine did not meet the expected standards of at least 10 inches in the steel shafts. Thus, engineering controls were initiated on Machine A. Now labelled as Machine A1. This constituted a longitudinal study of Machine A.

2.3.1 The statistical tests conducted on Machine A1 were as follows:

2.3.2 I-MR chart for Machine A: A1 after the application of engineering controls is indicated in Figure 5.

2.3.3 A summary report carried out for Machine A1 (Fig.6) showed distinct improvement in the mean and CI.

2.3.4 A process capability 6 pack test was carried out on Machine A1. The six pack process capability chart showed a slight improvement of the Cpk value at 0.56 (Fig.7)

2.3.5 An individual value plot of Machine A1 showed a mean range of approximately 9.5 to 10.7 inches (Fig 8).

2.3.6 Test and CI for one sample proportion for Machine A1 (Hypothesis 1) by way of the '1-Proportion' defectives test was conducted on another set of steel shafts consisting of 150 samples. The analysis showed an upper bound of 0.0287 and a significant p value of 0.020 (Table 3).

2.3.7 Subsequently, a One-sample T test conducted for Machine A1 (Table 4) indicated an upper bound of 10.601 inches and the t-test was not significant at p value of 0.995 ($p < 0.05$). The interpretation is provided in the 'Results'.

2.3.8 Tests for equal variances: Size vs Sups (Table 5)

Initially, an equal variance test was conducted on samples from the three suppliers for comparison. This was in order to verify the test for equal variances amongst the three suppliers (Hypothesis 3). For this a 95% Bonferroni Confidence Interval for Standard Deviations was conducted and the Levenes test was not significant, p= 0.744 (Table 5)

2.3.9 Tukey's simultaneous 95% CI for equal variance (Fig.9)

The 95% Bonferroni Confidence Intervals for Standard Deviations indicated an individual confidence level of 98.3333% (Table 5). The Levenes test was not significant, indicating that the samples constituted equal variances. This was evident by the overlap exhibited by samples supplied by each of the three suppliers (Fig.9).

2.3.10 Probability plots for Sup1, Sup2, Sup3 (3 suppliers)

Then, supplier probability plots were conducted by measuring 20 steel shafts from each of the three suppliers. The samples from each of the three suppliers showed a normal distribution of the raw material, indicted by the three probability plots (Figs 10-12).

2.3.11 Individual value plot Size vs Supplier: Figure 13

The individual value plots carried out on each of the three suppliers of steel shafts showed that the means of each of the three suppliers were well within the stipulated level of at least 10 inches (Hypothesis 2).

2.3.12 Box plots. The Box plot verified the the values contained in the individual value plot, whereby the means of the steel shafts supplied by the three suppliers conformed to the stipulated value of at least 10 inches (Fig. 14).

2.3.13 Interval plots of size vs Sups. The interval plot of size versus suppliers at 95% CI for the mean showed that all the three means were above the stipulated 10 inches (Fig.15).

2.3.14 Main effects plot for size (Fig. 16).

Although, the three suppliers supplied raw steel shafts within the stipulated standard of 10 inches, it was obvious from the main effects plot that the third supplier stood first, with supplier 1, second; and supplier 2 third (Fig.16).

2.3.15 One-way ANOVA: Size vs Sup (Table 6)

A one-way ANOVA was conducted in order to confirm whether the model fit was significant ($p < 0.05$) and to determine if there was a significant difference amongst the three suppliers.

2.3.16 Tukey's pairwise comparisons

The means from the three suppliers shared a value of A, indicating that there was no significant difference in the quality of raw material supplied by the three suppliers (Table 7).

2.3.17 Tukey plot: Figure 17

The three suppliers were contained at the zero point, whereby the line of fit passes through the means in comparison. This again confirms that the three suppliers were of good quality and there was very little difference between their means, verified by the overlap in the Tukey test plot in comparison of the three suppliers (Fig.17).

2.3.18 Residual plots for size of the raw steel shafts supplied by the three suppliers (Fig.18). The residual plots for size shows multi-variate response. The normal probability plot indicates that all the residuals in the samples of steel shafts followed a normal pattern whereby all the plots were close to the standard curve. The histogram shows a bell shape indicating a normal spread of the means in terms of frequency of the residuals

III. RESULTS

In this study, three hypothesis tests were tested. The proportion defectives produced by the machine, the performance of the process machine, and the quality of the suppliers of raw material. The parameters for these were evaluated by collecting and analysing data from the shaft processing machine (Machine A) using statistical methods. Initially, the raw material for these shafts were supplied by the regular supplier (Supplier1). The quality of the steel shafts which was dependent both on the raw material purchased from the supplier and the machine performance was determined.

This was evaluated, initially, by collecting twenty steel shaft samples during the process from Machine A. Generally, the individual values of each of the steel shafts did not meet the specified limit of 10 inches specified by the engineer (Fig1, Hypothesis2). Subsequently, one hundred and fifty raw steel shafts samples were analysed for proportions defectives (Table1). This was to determine the rate of defectives produced by the machine (Hypothesis1).

The third Hypothesis was tested on the quality characteristics of the three suppliers (Hypothesis3). The quality of raw steel shafts supplied by the three selected suppliers was determined.

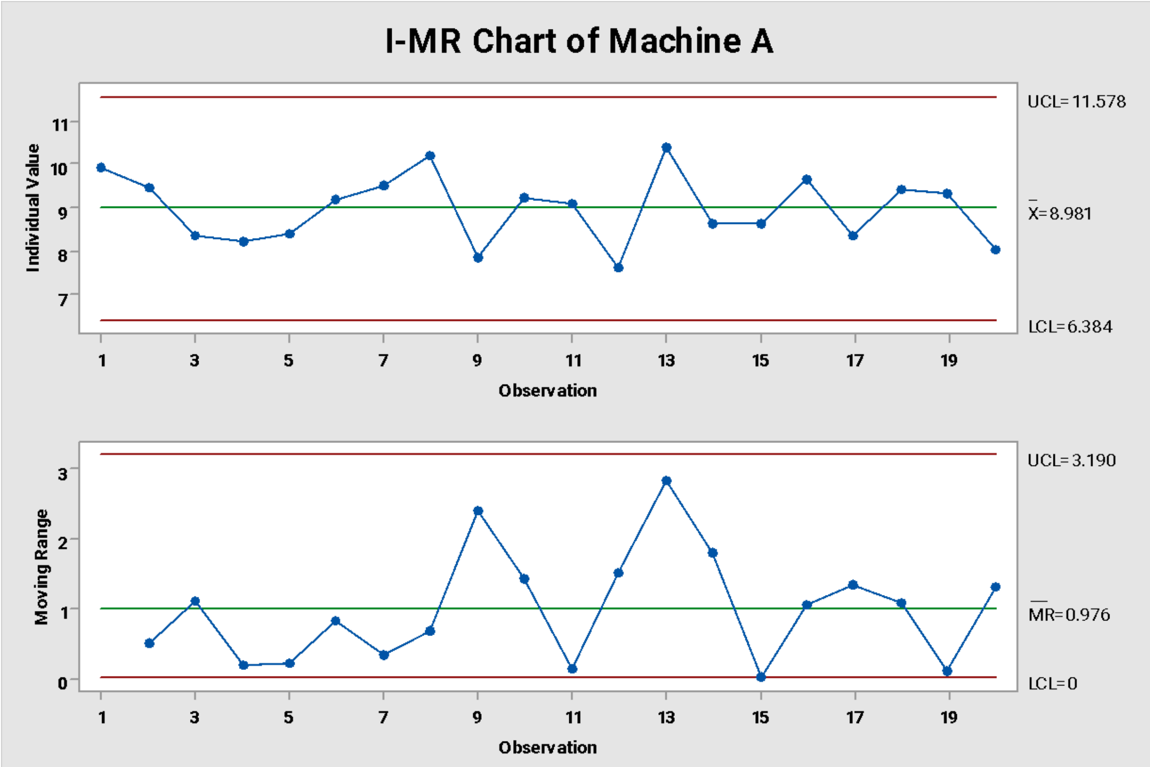

Figure 1: I-MR chart of the length of steel shafts indicating the baseline for Machine A

Although, the I-MR chart (Fig.1) showed the lengths of the individual steel shafts were in process control; many of the staff lengths were below the specified value of 10 inches. The summary report was not satisfactory (Fig. 2). An I-MR chart was used as the sample size was less than thirty.

Table 1: Test and Confidence interval (CI) for "1 Proportion" defectives of steel shafts from Machine A

Test of p = 0.05 vs p < 0.05

Test of p = 0.05 vs p < 0.05						
Sample	X	N	Sample p	95% Upper Bound	Z-Value	P-Value
1	6	150	0.040000	0.066318	-0.56	0.287
Using the normal approximation.						

The '1 Proportion' defective test showed a 95% upper bound of 0.0663 with a p value of 0.287 which was not significant at < 0.05. There were six defectives out of 150 steel shaft samples which constituted approximately 4%. Thus Hypothesis 1, which claims that Machine A produces less than 5% defectives is not rejected.

Table 2: One-sample T of the lengths of steel shafts for Machine A

One-Sample T: Machine A

Test of μ = 10 vs < 10

Test of μ = 10 vs < 10							
Variable	N	Mean	StDev	SE Mean	95% Upper B ound	T	P
Machine A	20	8.981	0.794	0.178	9.288	-5.74	0.000

The 1 sample t-test showed an upper bound of 9.288 inches and the t-test was significant at p value of 0.000 ($p < 0.05$). This indicated that the average steel shafts supplied measured less than 10 inches, thus the null hypothesis 2 is not rejected. Although, machine A produced less than 5% defectives, the 1 sample t test carried out on 20 samples showed that the average length of steel shafts produced by machine A was less than 10 inches (Hypothesis 2). This may be attributed to the large (150) and small sample size (20) taken for the “1 Proportions” and t-test, respectively.

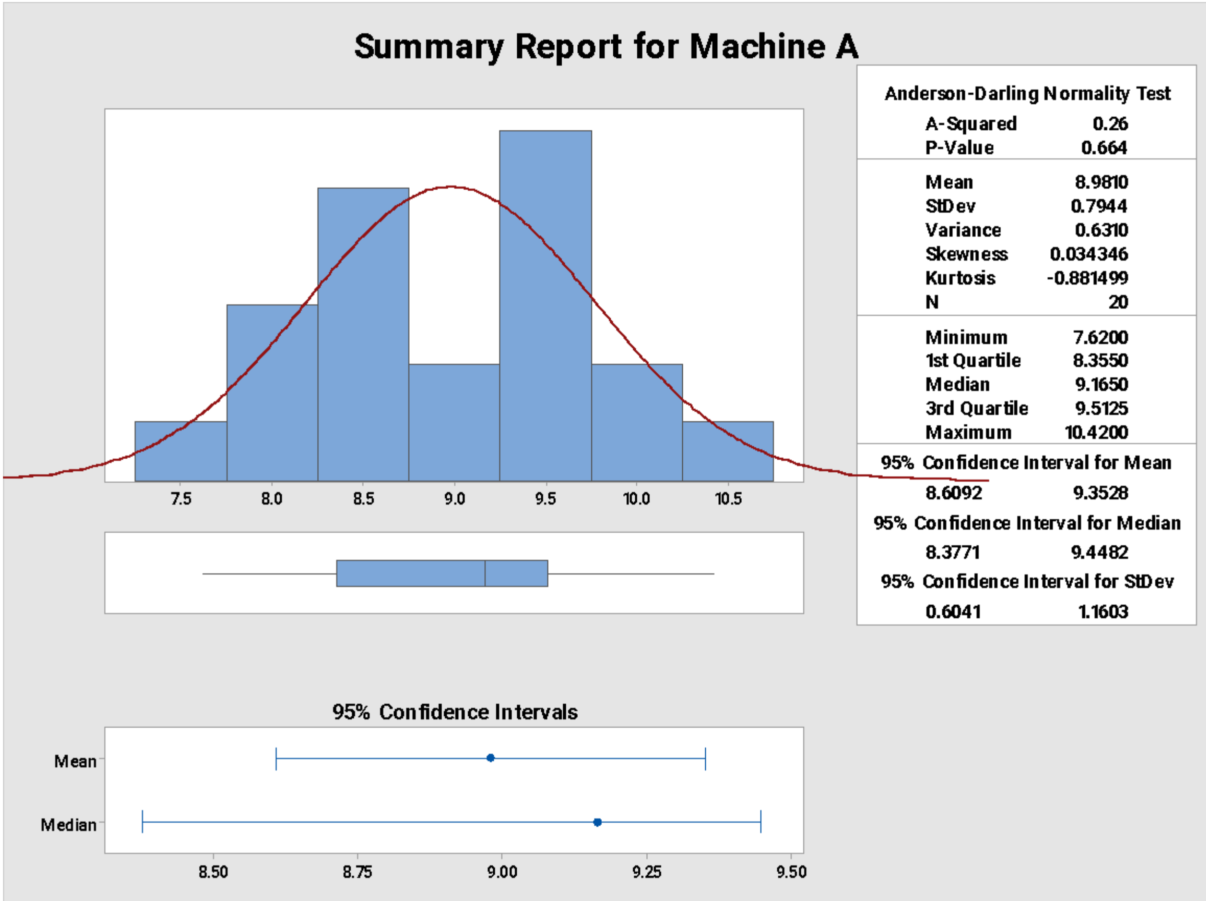

Figure 2: Summary report of descriptive analysis for Machine A

The histogram (Fig,2) in the summary plot, showed that the process was not distributed normally. Many sample points on the upper side of the plot were outside the control limits as indicated by the line of fit on the histogram. The bell curve showed more of a bimodal curve. Meaning that Machine A required maintenance or some sort of engineering control. The specified mean and standard deviation were also not in favour of the specified length of 10 inches. The 95% Confidence Interval showed the length of steel shafts to be between 8.6092 and 9.3528 inches, which was below the specified value of 10 inches.

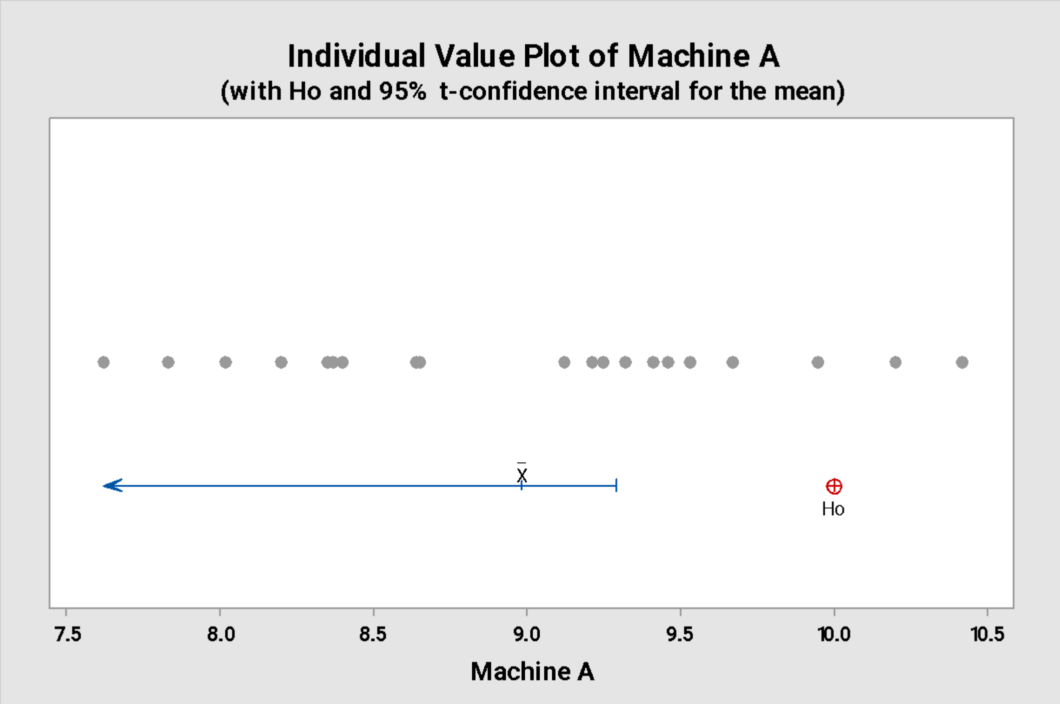

Figure 3: Individual value plot of Machine A with Ho and 95% t- confidence interval for the mean

The individual value plot showed that the mean was centred at approximately 9 inches (Fig.3). This did not conform to the specified standard of 10 inches set in hypothesis 2. Thus, it may be confirmed that Machine A did not produce to the specified level of the steel shafts of 10 inches. Thus, engineering controls were conducted by the process engineer in an attempt to check if the problem was with the machine or the supplier of the raw material.

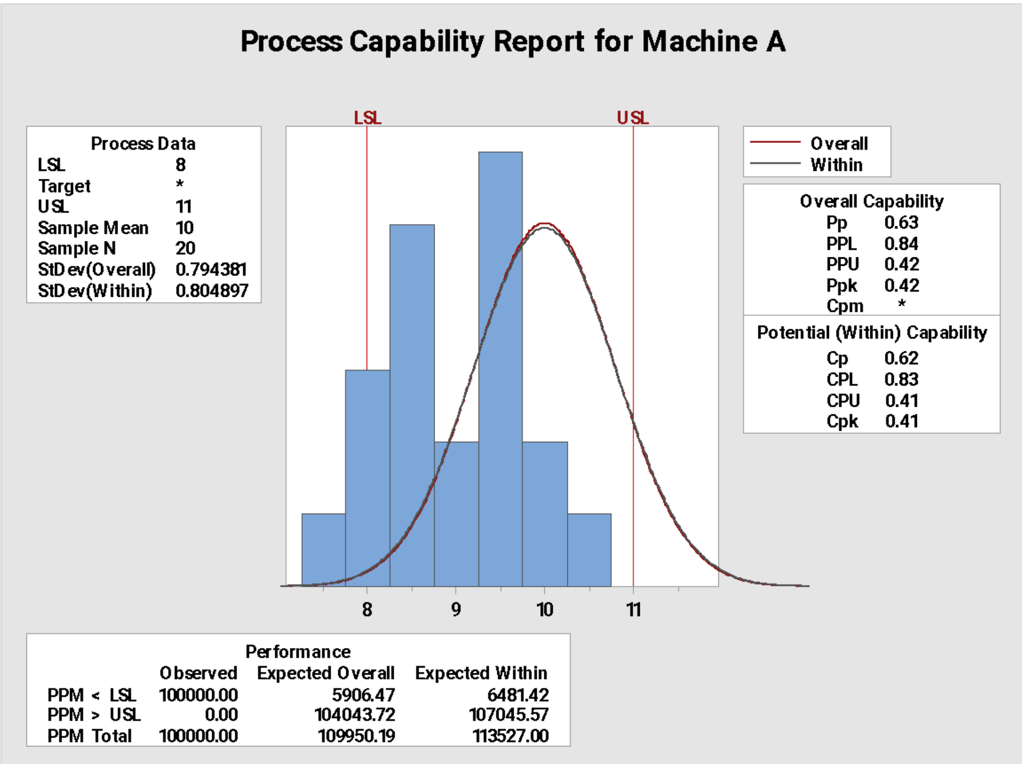

Figure 4: Process capability report for Machine A

The process capability report for Machine A showed that many sample points were outside the specified limits (Fig. 4). This was indicated clearly by the line of fit on the histogram**.** The Cpk value of 0.41 leaves much to be desired, as a standard value for a process to be operating optimally should be at least 1.33.

It was very obvious from these findings that the process needed a lot of improvement. Numerous processes in the manufacturing sector are known to face this problem. Much research would be needed to determine the root causes of problems and to rectify such problems in order to ensure and maintain that the process aligned to the standards.

Maintenance of equipment, statistical process control and monitoring of the process may result in better overall process control. Also, the problems may vary from process to process.

As the products from the process were not in statistical process control, Machine A was subjected to engineering controls, by mechanically manipulating the machine; now named as Machine A1.

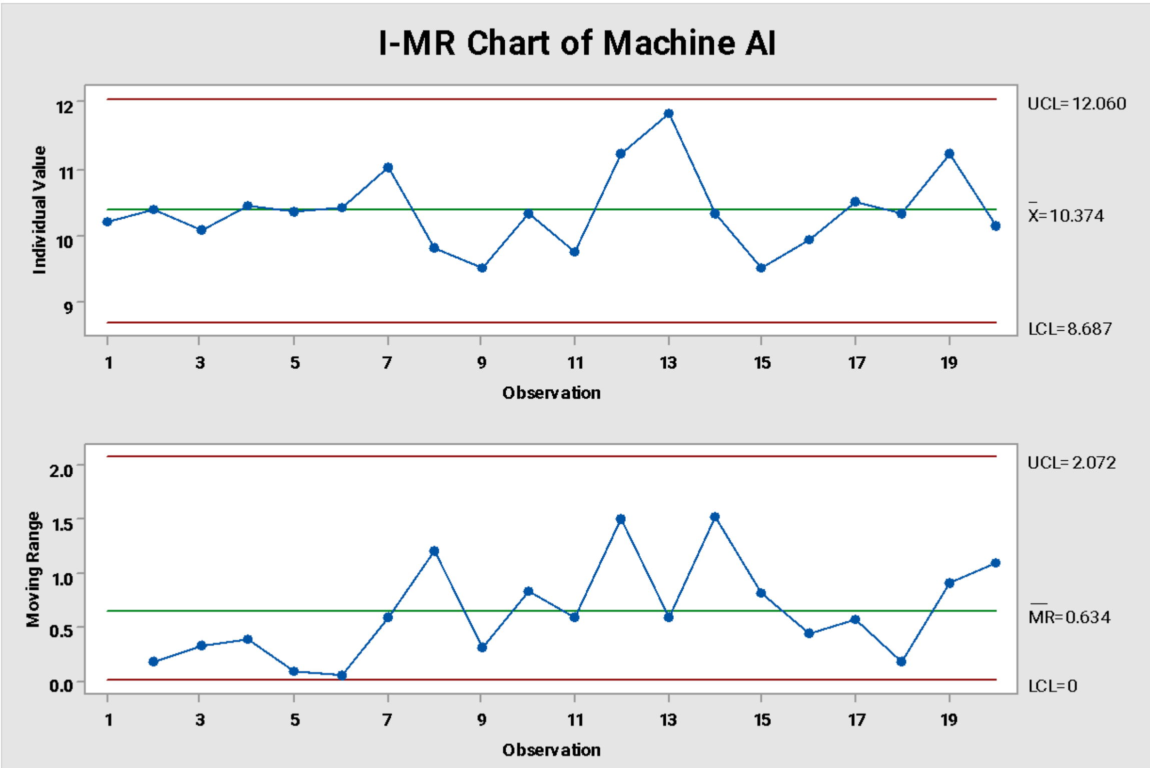

Figure 5: I-MR chart for Machine A: A1 after the application of engineering controls

A total of twenty individual steel shaft samples were taken from the process line once again and subjected to statistical analysis. The I-MR chart (Fig.5) was within the control limits, and the summary report showed an improvement whereby the mean and the confidence interval were above the specified values of 10 inches (Fig.6).

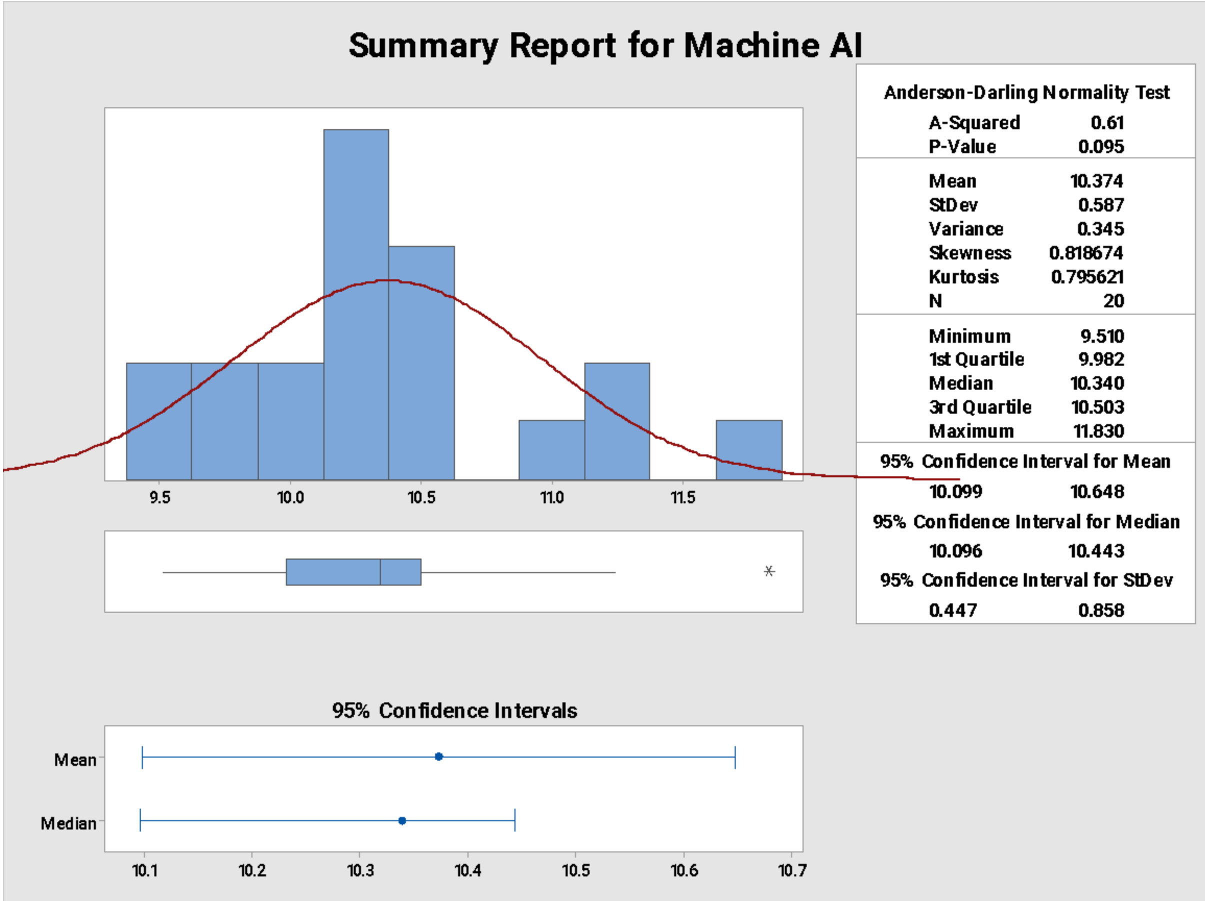

Figure 6: Summary report for Machine A1

The summary report showed a distinct improvement in the mean and CI. The mean was 10.374, with a 95% Confidence Interval of 10.099 to 10.648 against the expected value of 10inches. But, the overall process was not centred (Fig. 6). The histogram showed many sample points outside the control limits and it was not normally distributed as indicated by the line of fit. There was an uneven spread. This might indicate that R & D efforts may be required in order to evaluate the performance of the machine, such that corrective action may be taken.

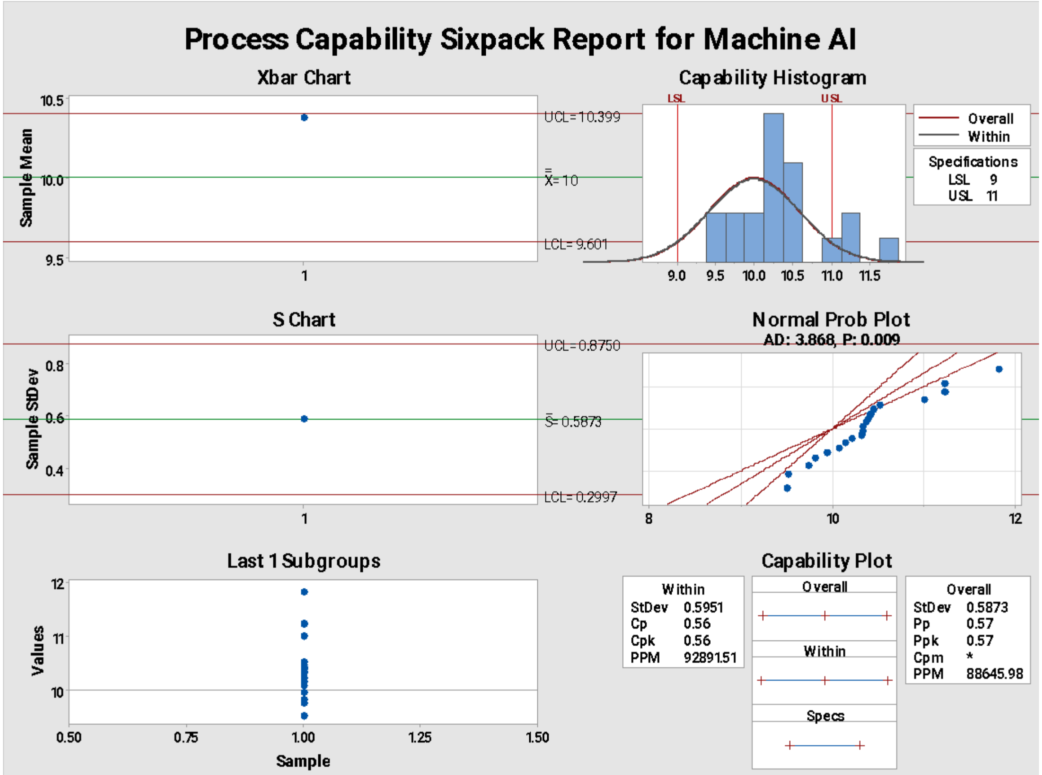

Figure 7: Process capability Six pack report for Machine A1

The six pack process capability chart (Fig.7) for Machine A1 showed a slight improvement of the Cpk value at 0.56 compared to the previous value of 0.41 for Machine A. Thus, the engineering controls conducted on the machine had some effect on the overall performance of the process. However, this was way below the optimum of 1.33. The normal probability plot showed many sample points outside the standard line (Fig.7). The histogram showed many points outside the upper specification limit and it was also not normally distributed as indicated by the line of fit.

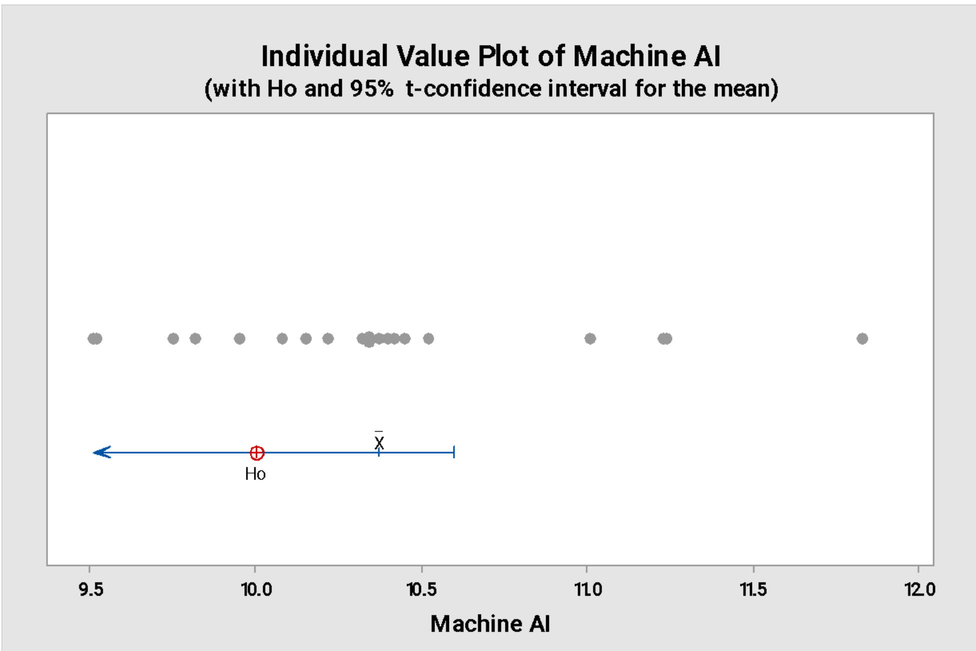

Figure 8: Individual value plot of Machine A1 with Ho and 95% t-confidence interval for the mean

The individual value plot (Fig. 8) of Machine A1 showed a mean range of approximately 9.5 to 10.7 inches with 95% t-confidence interval of the mean, with an upper bound value of 10.601. The overall spread in the measurements of the samples may have contributed to a large deviation in the results.

Table 3: Test and CI for one sample proportion for Machine A1

Test and CI for One Proportion
Test of p = 0.05 vs p < 0.05

Test of p = 0.05 vs p < 0.05						
Sample	X	N	Sample p	95% Upper Bound	Z-Value	P-Value
1	2	150	0.013333	0.028737	-2.06	0.020
Using the normal approximation. The normal approximation may be inaccurate for small samples.						

The test for '1-Proportion' defectives was conducted on another set of steel shafts consisting of 150 samples from the process. This constituted the measurement of steel shafts after the engineering controls were effected. The analysis showed an upper bound of 0.0287 and a significant p value of 0.020 (Table 3). This indicated that only 1.3% of the samples did not meet the specified length of 10 inches. This was in conformance with Hypothesis 1. Thus, the null Hypothesis which stated the percent defectives of steel shaft samples was less than 5% was not rejected and the p value was significant at 0.020 ($p < 0.05$). Thus, the steel shafts supplied by the regular supplier appeared in conformance with the overall objectives of the study. This result was better than that of Machine A, where the 1-proportions test result showed that 6 out of 150 samples did not conform to the standard with an upper bound of 0.06 (Table 1).

Table 4: One-sample T for Machine A1

One-Sample T: Machine AI

Test of μ = 10 vs < 10

Test of μ = 10 vs < 10							
Variable	N	Mean	StDev	SE Mean	95% Upper Bound	T	P
Machine AI	20	10.374	0.587	0.131	10.601	2.84	0.995

Another set of twenty samples were taken after the engineering manipulation of Machine A, and the t-test was conducted. The 1 sample t-test conducted on Machine A1 showed an upper bound of 10.601 inches and the t-test was not significant at p value of 0.995 ($p< 0.05$). This indicated that the average steel shafts supplied measured at 10.374 inches which conformed to the specified level of at least 10 inches. Thus, the null hypothesis 2 was rejected.

Table 5: Test for Equal Variances: Size versus Sup

Method	
Null hypothesis	All variances are equal
Alternative hypothesis	At least one variance is different
Significance level	α = 0.05

In order to evaluate the third Hypothesis whether the raw material which consisted of steel shafts supplied by three suppliers conformed to the specified level of 10 inches, an equal variance test was conducted initially to verify the parameter of equal variances across the suppliers. For this a 95% Bonferroni Confidence Intervals for Standard Deviations was conducted and the Levenes test was found to be not significant. Thus, indicating that the three suppliers showed equal variances in the samples.

95% Bonferroni Confidence Intervals for Standard Deviations.

Method	
Null hypothesis	All variances are equal
Alternative hypothesis	At least one variance is different
Significance level	α = 0.05

95% Bonferroni Confidence Intervals for Standard Deviations

95% Bonferroni Confidence Intervals for Standard Deviations			
Sup	N	StDev	CI
Sup1	20	0.845783	(0.558029, 1.45623)
Sup2	20	0.744443	(0.526381, 1.19600)
Sup3	20	0.903350	(0.653064, 1.41947)
Individual confidence level = 98.3333%			

Tests

Tests		
Method	Test Statistic	P-Value
Multiple comparisons	—	0.630
Levene	0.30	0.744

Figure 9: Test for equal variances size vs suppliers

In order to determine the quality of the suppliers (Hypothesis 3), initially, tests for equal variances was conducted on the steel shafts supplied by each of the three suppliers (Table 5, Fig 9). A 95% Bonferroni Confidence Intervals for Standard Deviations indicated an individual confidence level of 98.3333%. The Levene's test was not significant, indicating that the samples constituted equal variances.

This was confirmed by the overlap exhibited by samples supplied by each of the three suppliers (Fig.9). Three suppliers of raw material were compared with a view to evaluate supplier selection and performance relevant to the process of supply chain management. This would also help to determine whether it was the quality of raw material supplied by suppliers in comparison to the performance of the process machine in question.

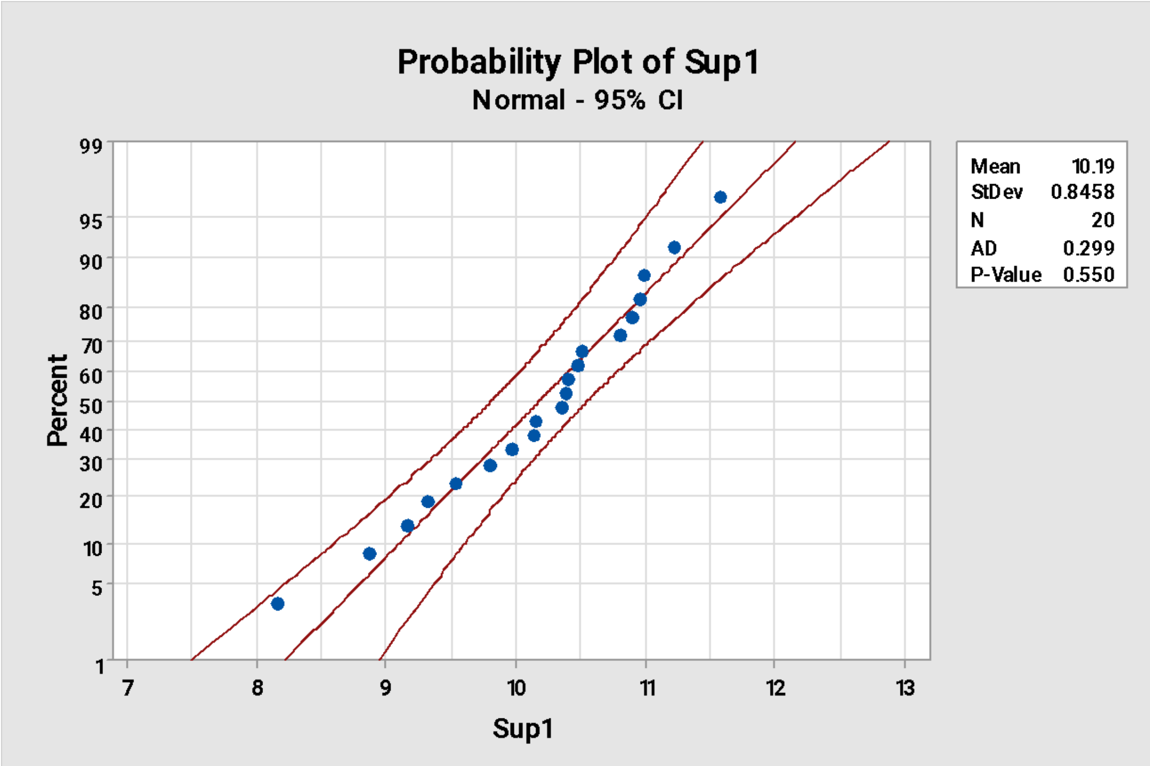

Figure 10: Probability plot of supplier 1, normal 95% CI

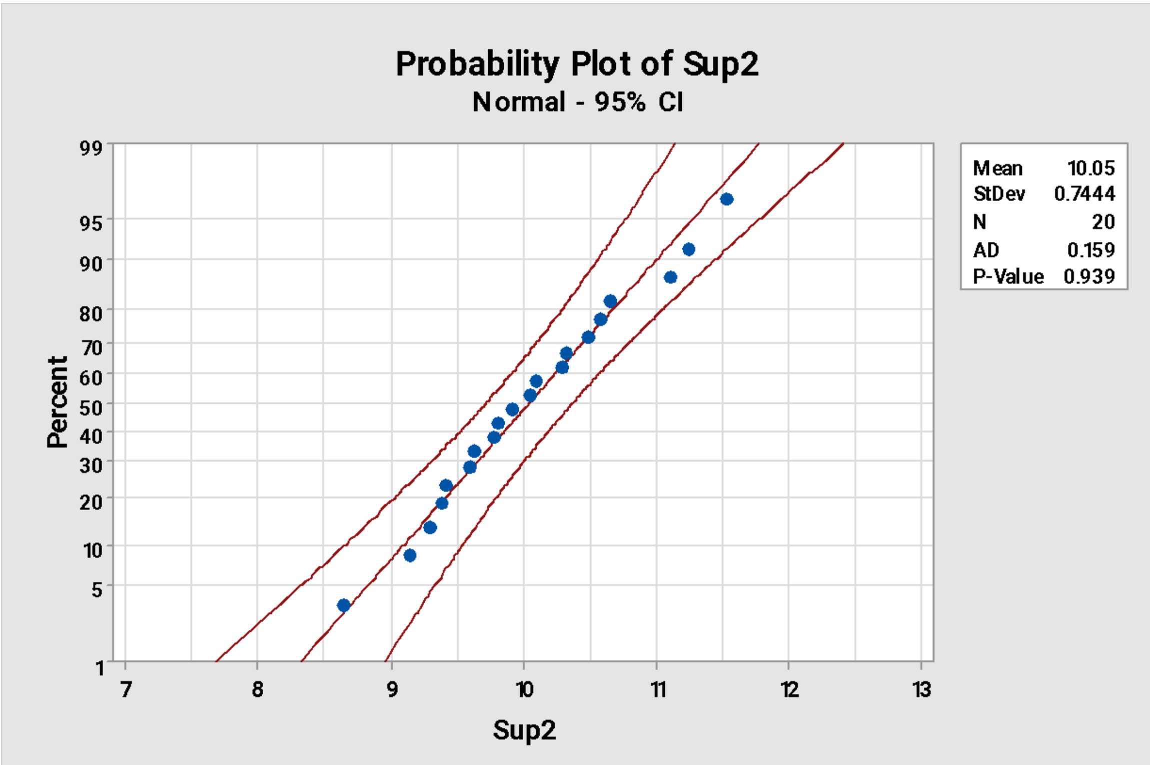

Figure 11: Probability plot of supplier 2, normal 95% CI

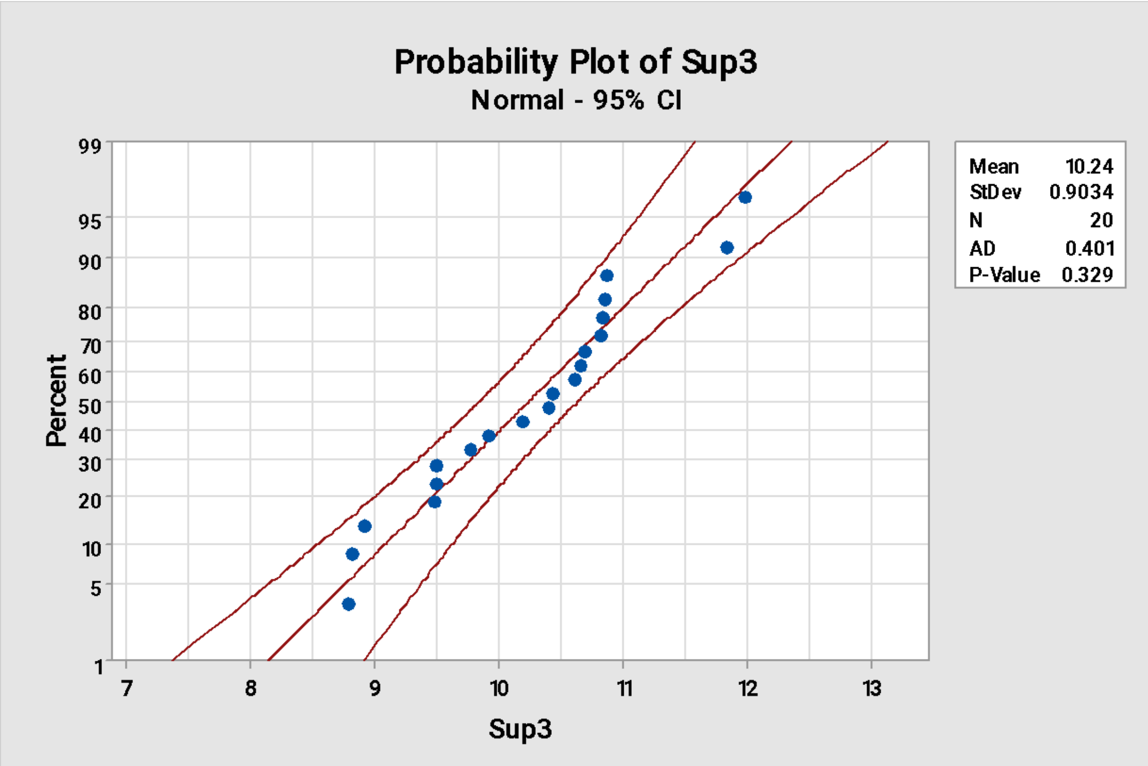

Figure 12: Probability plot of supplier 3, normal 95% CI

After confirming equal variances of the three suppliers, supplier probability plots were carried out by measuring 20 steel shafts from each of the three suppliers (Figures 10-12). The samples from each of the three suppliers showed a normal distribution of the raw material, indicted by the three probability plots, whereby, all the points were within the normal prescribed limits with means averaging 10.19, 10.05 and 10.24, respectively (Figs 10-12).

Also, the p-values were not significant in each of the three cases, which indicated that there was no significant difference between the quality of the raw material supplied by each of the three suppliers. This finding confirmed Hypothesis 3, which was to test the differences between the quality of the three suppliers.

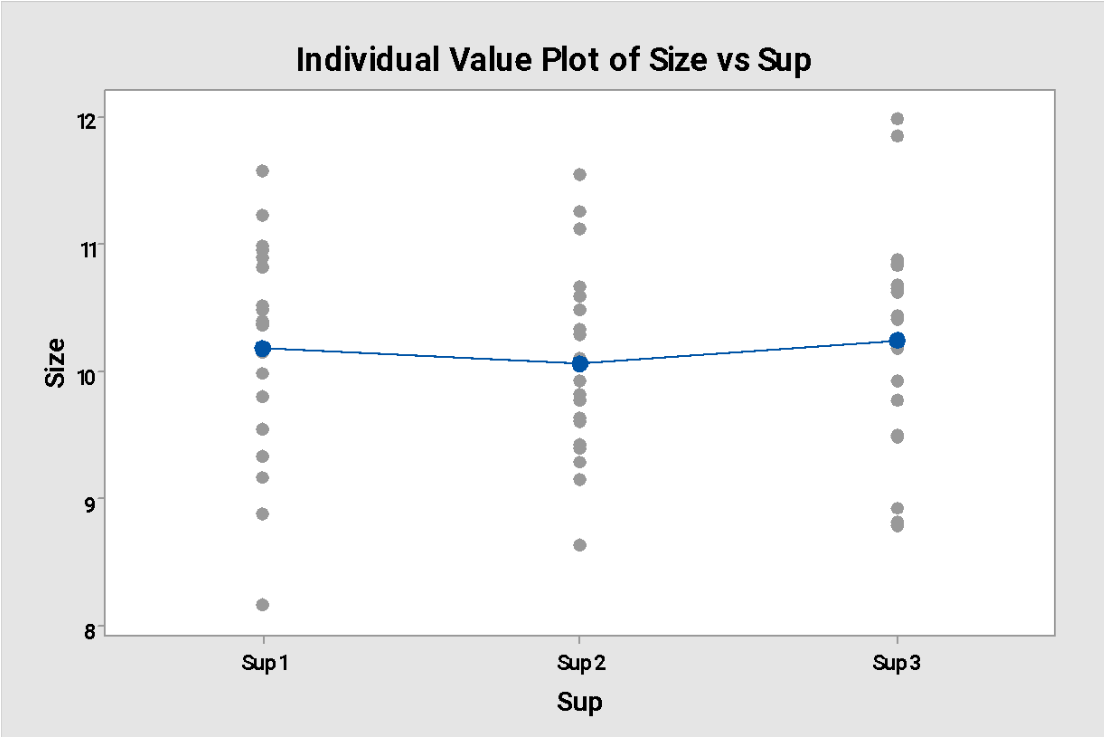

Figure 13: Individual value plots of size vs suppliers

The individual value plots conducted on each of the three suppliers of steel shafts showed that the means of each of the three suppliers were well within the stipulated level of at least 10 inches (Hypothesis 2). This finding was also indicated by the values in the box plot and the interval plots.

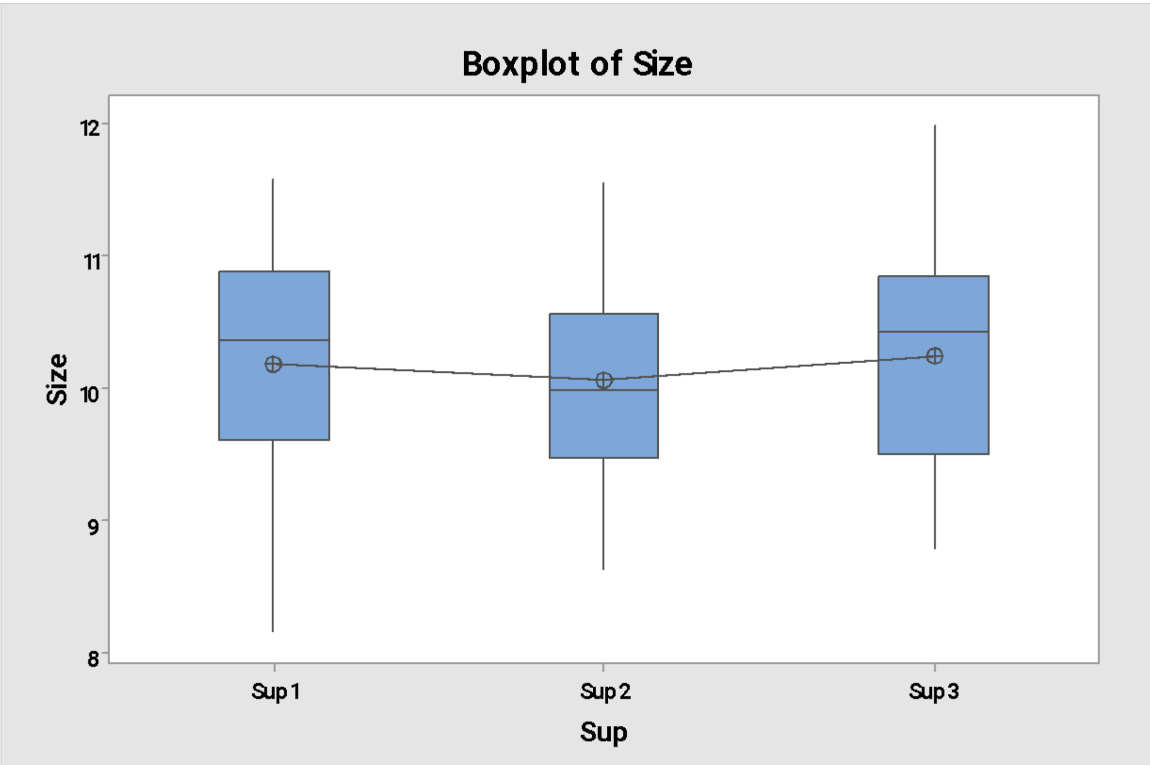

Figure 14: Box plot of size of the steel shaftes supplied by each of the suppliers

The Box plot verified the the values contained in the individual value plot, where the means of the steel shafts supplied by the three suppliers conformed to the stipulated value of at least 10 inches (Fig. 14). This was clearly indicated by the line of fit connecting the three means in the Box plot, indicating mean values which were above 10 inches in the case of each of the suppliers.

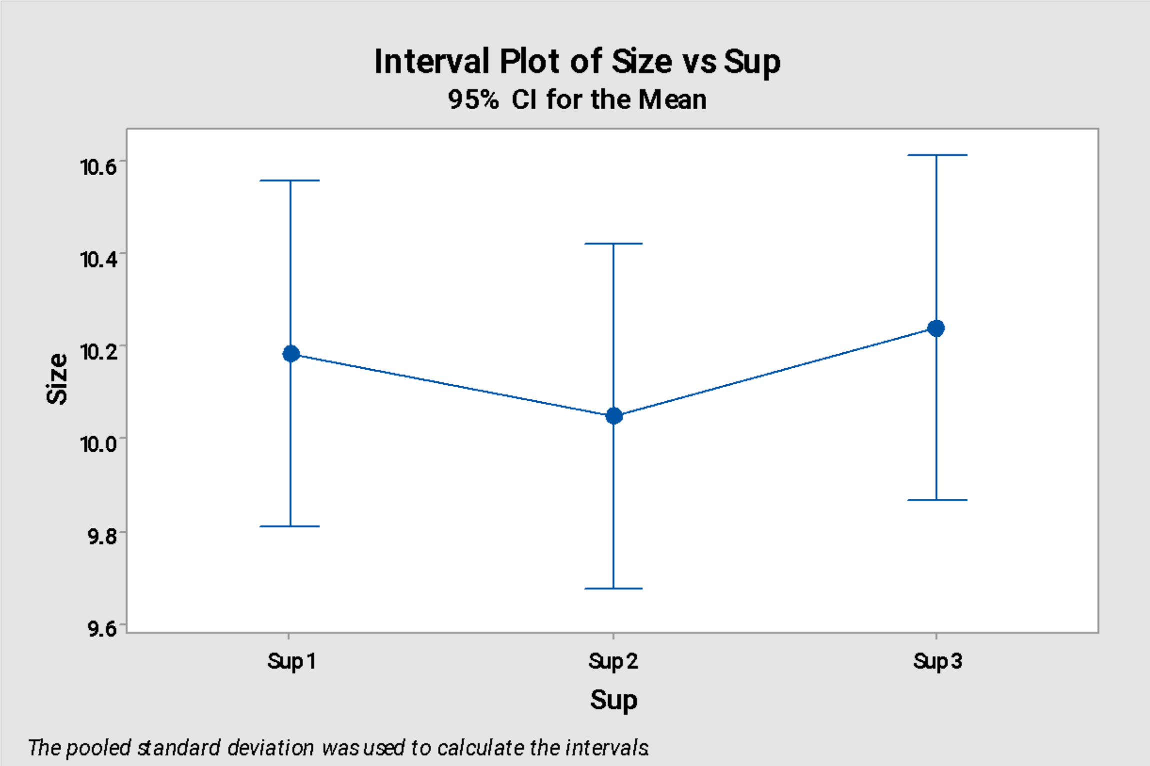

Figure 15: Interval plot of size vs suppliers at 95% CI for the mean

The interval plot of size versus suppliers at 95% CI for the mean showed that all the three means were above the stipulated 10 inches. This again confimed the earlier findings as in the Box plot for the suppliers of the steel shafts to the company.

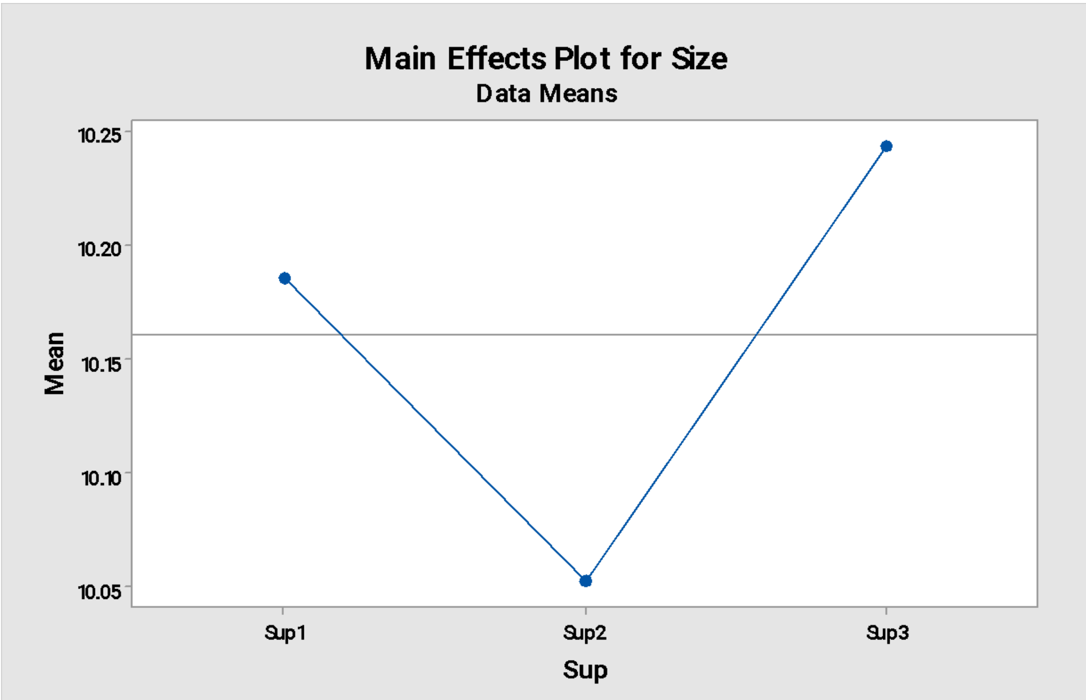

Figure 16: Main effects plot for size: data means

Although, the three suppliers supplied raw material within the stipulated standard of 10 inches, it was obvious from the main effects plot that supplier three stands first, with supplier 1, second, and supplier 2 third (Fig.16).

A one way ANOVA was conducted in order to confirm whether the model fit was significant ($p < 0.05$) and to determine which of the three suppliers, if any were significantly different from each other.

Table 6: One-way ANOVA: Size versus Sup

Method

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 Information		
Factor	Levels	Values
Sup	3	Sup1, Sup2, Sup3

Analysis of Variance

Analysis of Variance					
Source	DF	Adj SS	Adj MS	F-Value	P-Value
Sup	2	0.3844	0.1922	0.28	0.759
Error	57	39.6261	0.6952		
Total	59	40.0105			

Model Summary

Model Summary			
S	R-sq	R-sq (adj)	R-sq (pred)
0.833784	0.96%	0.00%	0.00%

Means

Means				
Sup	N	Mean	StDev	95% CI
Sup1	20	10.186	0.846	(9.812, 10.559)
Sup2	20	10.052	0.744	(9.679, 10.426)
Sup3	20	10.244	0.903	(9.870, 10.617)
Pooled StDev = 0.833784				

The one way ANOVA showed that the p value was not significant 0.759 ($p<0.05$). Thus, indicating that there was no significant differences in the means of the length of steel shafts supplied by each of the three suppliers. Although it was indicated by the process engineer that the quality of the steel shafts conformed to the stipulated level of 10 inches, the company wished to determine if there was a significant difference in the means between the three suppliers. This was with a view to classify the three suppliers according to priority in terms of the purchasing decision.

The R squared value was high at 96%. This indicated that the dependent variable could be explained at 96% level by the independent variables. Thus, the ANOVA test conducted on the three suppliers were accurate and significant with a high value of R squared. Also, the p value was not significant at 0.759 ($p<0.05$). Thus, there was no evidence to indicate any significant difference between the three suppliers of the raw material (Hypothesis 3).

Table 7: Tukey Pairwise Comparisons

Grouping Information Using the Tukey Method and 95% Confidence

Grouping Information Using the Tukey Method and 95% Confidence			
Sup	N	Mean	Grouping
Sup3	20	10.244	A
Sup1	20	10.186	A
Sup2	20	10.052	A
Means that do not share a letter are significantly different.			

The Tukey paiwise comparisons confirmed the earlier interpretation that the three suppliers were in conformance of the standard requirement of at least 10 inches indicated by the process engineer. All the means shared a value of A, indicating that there was no significant difference in the quality of raw material supplied by the three suppliers. Thus, confirming the third Hypothesis.

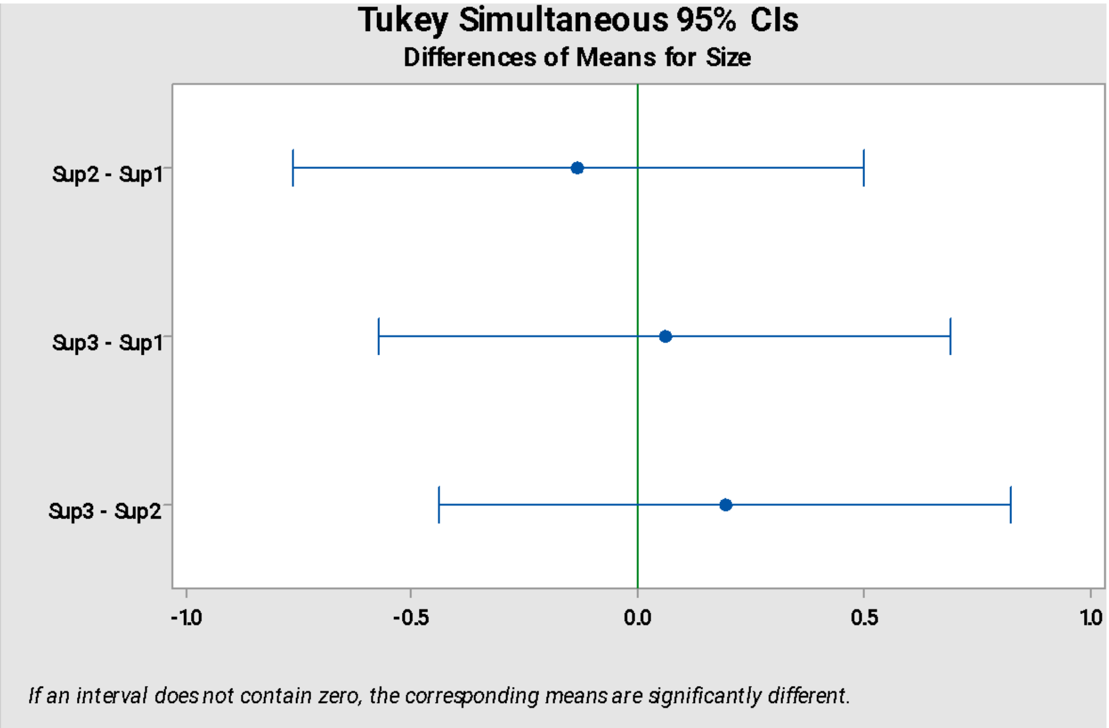

Figure 17: Tukey simultaneous 95% Cis: Differences of means for size

In the Tukey simultaneous 95% CI plot, the three suppliers were contained at the zero point, whereby the line of fit passes through the means in comparison. This again confirms that the three suppliers were of good quality and there was very little difference between their means, verified by the overlap in the Tukey test in comparison of the three suppliers (Fig. 17).

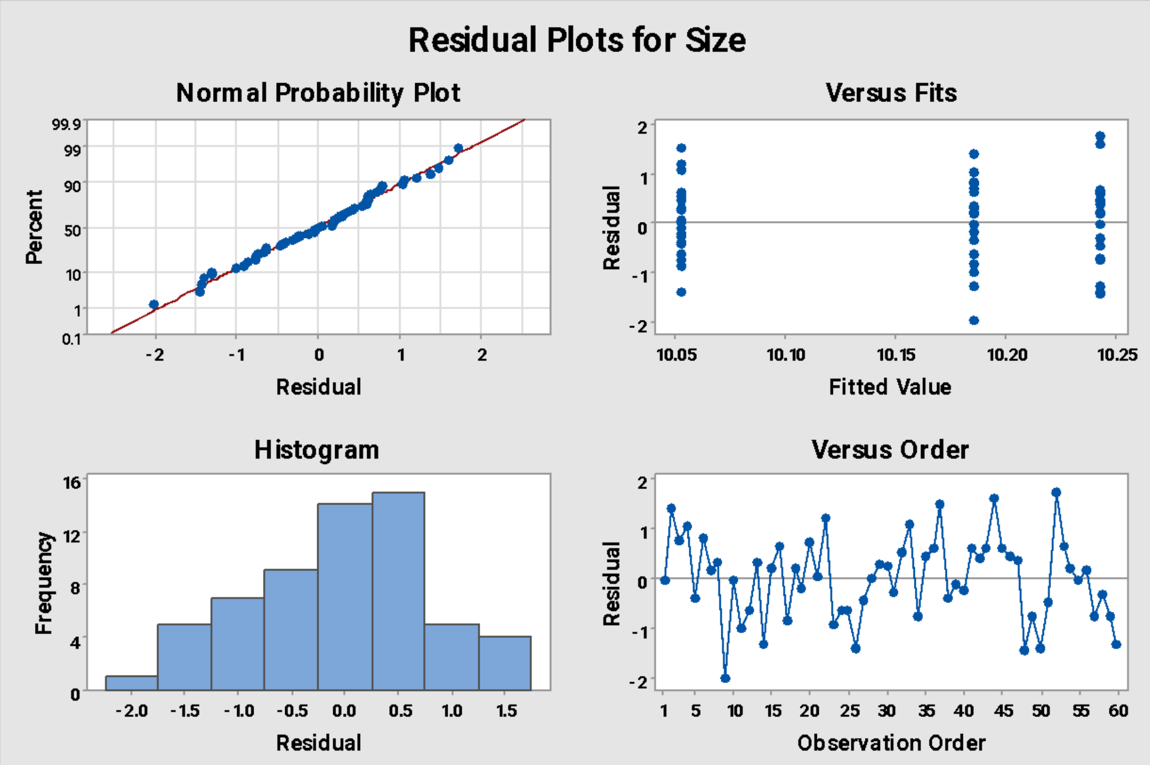

Figure 18: Residual plots for size of steel shafts

The residual plots for size shows a multi-variate response. The normal probability plot indicates that all the residuals in the samples of steel shafts follow a normal pattern where all the plots are close to the standard curve. The versus plot indicates that the three suppliers meet the specified standars of at least 10 inches in the raw material which constitute steel shafts for further processing by the company. The samples range from 10.05 to 10.25 inches and are evenly placed through the zero residual.

The histogram shows a bell shape indicating a normal spread of the means in terms of frequency of the residuals. The versus order shows a random movement of the observation to the residual. Thus, it is evident that the three suppliers of raw steel shafts to the company were of good quality. However, further evidence would be needed in order to determine other aspects of supplier performance before a selection decision could be made with respect to priority in terms of selection issues.

IV. DISCUSSION

There are two aspects to processing efficiency and productivity in the manufacturing industry. These constitute the performance of the machines and the suppliers of quality raw material. It is understood that the product quality would be determined mainly by both these aspects. It is also well known that the performance of a system would depend on a number of internal factors. These include man, material, machine, methods and the environment. With regards to this, the supply chain also has a major role to play in determining the result of a process as the raw material supplied to the company has to be of high quality in order to ensure the quality of the product [18].

Generally, in manufacturing the quality of a product determines competitive advantage to the organization. This particularly inspires confidence to the customer and determines the extent of satisfaction. Quality in this respect relates to the rejection of products and deviations from specifications in the manufacturing process.

However, statistical process control can be instituted in order to determine non-conforming parts which can be detected during incoming inspection or during the manufacturing process. Thus, leading to corrective action, quality assurance and preventive maintenance [2, 3]. There may also be deviations from the specified quantities or delivery dates in the customer order in relation to the supply chain management. In this regard, the supplier has an important role to play in mitigating the manufacturing cost, packaging cost, delivery cost and costs related to non-conforming products which would affect the bottom line.

Generally, most previous research categorizes supply chain management (SCM) into the following three major parts: purchasing, manufacturing, and distribution [25]. The purchasing function focuses on obtaining raw materials for manufacturing, which is an essential component to start supply chain execution [26]. Furthermore, the quality of products depends on both the efficiency of the process as well as the raw material procured from the supplier. In particular, manufacturing companies spend about 70% of the cost on purchasing materials from suppliers [27]. Therefore, the unit cost is highly dependent on suppliers.

Thus, purchasing can be regarded as one of the most important activities in manufacturing [2,3]. It should be considered as the essential strategy for producing a high quality product at a low cost to manage the relationship with suppliers. In this study, the raw material procured from the three suppliers were of good quality and met with the specifications stipulated by the company. However, the performance of the process equipment needed to be standardised and monitored regularly for improvement in order to ensure the quality of the product.

Currently, globalization of the supply chain enables securing any material from the worldwide market [28]. It is the most challengeable decision making in outsourcing, which plays a critical role in the success of a supply chain [29]. Outsourcing has become one of the essential requirements of companies to obtain some of the products and services for supporting manufacturing. However, outsourcing many components to manufacturing companies' of suppliers can lead to a high complexity and uncertainty in the business environment, such as financial crisis.

Furthermore, suppliers play an important role in implementing sustainable supply chai initiatives and in achieving economic, social, and environmental gains [30]. Sustainable supplier management (SSM) has been interrelated with essential purchasing functions; however, the operations, such as sustainable supplier selection, supplier monitoring, and supplier development, are independent [31]. Therefore, supplier selection is a vital issue and a significant strategic decision in the management of a sustainability-focused supply chain [32]. Furthermore, supplier monitoring is an essential process in enhancing the overall supply chain performance while achieving the goal of SSM [33].

However, a great deal of previous research has focused on how to select the appropriate suppliers by presenting different frameworks. Therefore, few studies have compared and analysed the differences of factors involved between supplier selection and monitoring [34]. In this context, the present study develops a decision-making framework for supplier selection and monitoring. This framework 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. As the second step, the main dimensions and criteria are prioritized. Thirdly and finally, a comparison of the criteria in supplier selection is performed.

The present study, also proposes a novel framework to understand the differences between supplier selection and monitoring. The sets of criteria and their relative importance are obtained by using statistical analytical methods to compare the performance of three suppliers and the relative weights are secured for the supply of steel shafts of a defined length for further processing. In this regard the efficiency of the process is coupled with the quality of the suppliers in order to reduce the rate of defects in a process and to achieve the goals and to maintain sustainability.

V. CONCLUSION

Several methods have been proposed for solving the supplier selection problem such as vendor profile analysis (VPA), multi-objective programming (MOP), data envelopment analysis (DEA) and analytic hierarchy process (AHP) [35]. Evaluation and ranking of potential suppliers involves both tangible and intangible criteria. This is because the 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.

The performance characteristics of the process equipment used in manufacturing plays an important role in ensuring the overall quality of the final product which is to be released to the customer. The relationship between the suppliers of raw material and the manufacturing organizations are extremely important to ensure the overall success of the process. Organizations generally ensure product quality by adopting various quality management concepts and activities in their processes.

Thus, as the supplier coupled with manufacturing relationship is important, the AHP method developed by Saaty,1980 [36] is a useful method to select suppliers as it deals with integrating different measures into a single overall score for ranking decision alternatives. The AHP model for casting supplier assessment is based on four groups of criteria: product development capability, manufacturing capability, quality capability, and cost and delivery.

These resonate well with the present study, which proposes an integrated approach to manufacturing processes based on a steel shaft processing facility. In this study, three Hypothesis have been tested by a quality engineer of a manufacturing company in the fabrication of steel shafts meant for further processing. With regards to this, quality of the product, percent defectives produced by the process and supplier quality were selected as the framework for the overall evaluation of the steel shaft manufacturing process.

The competence of the supplier to design, develop and launch products within the agreed period of time according to the product specifications was assessed. This would enable the company to compare the performance characteristics of the process with the quality characteristics of the supplier. In the current competitive environment, it is a crucial attribute to assess suppliers, as delays in the development stage can affect the end customer response during the launching stage. This would also affect flexibility which involves the response time of the supplier when engineering changes are required during the various stages.

Finally, R&D initiatives are important in manufacturing processes. This is to ensure a good integrative working relationship between the organization and its suppliers. In a highly competitive market environment which prevails in a globalized business setting, R&D activities may assist manufacturers to effectively measure the ability of suppliers to provide support during the product development and processing stages. It is an important attribute as most products, after launching, demand continuous improvement to remain competitive. In reality it may be assumed that the efficiency and productivity of manufacturing processes require much input in terms of research and development activities in order to remain competitive and to ensure the sustainability of the organization.

Based on this study, it may be necessary for manufacturers to pay attention to three aspects of their processes, namely, manufacturing excellence, supplier metrics and customer satisfaction. These aspects contribute to the performance indicators which should be considered as priorities by organizations in their processes in order to remain competitive in this volatile market encompassing an era of globalization. Although, this study focuses on the processing of steel shafts, the model could be applied generally to a wide range of processes where organizations wish to remain competitive and experience the best of sustainability in the business.

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