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A Quality Control Application in a Furniture Company

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Abstract

This study deals with a quality control application in a furniture manufacturing company. Furniture manufacturing involves several wood cutting operations in specified dimensions. Based on our investigation in a selected sofa-manufacturing factory, we have observed that cutting operations are not done in accurate procedures and usually result in wood slabs, which deviate from standard dimensions. One of the reasons that wood cutting operations are not done as accurate as the metal cutting operations is because it is easy to recut the excessive part on the longer wood slabs, and to add a small piece to the wood slabs which is cut shorter. These types of simple remedies are not possible in metal cuts. While these extra processes do not appear to be significant, when they are added up in a mass manufacturing system, the waste in workers time, as well as in material usage, becomes substantial.

We have investigated a specific sofa manufacturing system and developed some hypothesis testing procedures to prove to the management the significance of the cutting deviations from the standard requirements. Amount of waste in labor time and material usage are quantified for a selected manufacturing period. Furthermore, some quality control procedures, including control charts, are developed and implemented in the factory to control the cutting operations. The procedures and the results presented in this study can be used by managers as guidelines in furniture manufacturing industry to improve their cutting operations and minimize the waste.

Keywords:
Wood cutting, furniture manufacturing, quality control, cutting specifications, material waste

1. Introduction

Dimensions of assembled products in furniture industry play an important role to decide how well the products have been manufactured. One of the important quality dimensions is quality of conformance. As indicated by Montgomery (2008), the quality of conformance is an indicator of how well the product conforms to the specifications required by the designer. The difficulty level of manufacturing processes rapidly increases with the level of complexity and aesthetic in furniture design, which essentially increases the cost of production. In order for a company to meet customers satisfaction, it should establish very high standards for each process within limitation of variability, which is inversely proportional to quality. To improve the quality, one must reduce the variation in quality characteristics.

Quality characteristics are assessed based on how well they meet specifications. Length is one of the physical quality characteristics in manufacturing specific parts to be used in assembly operations. In furniture manufacturing, length, width, thickness, and height are typical measures that need to meet specifications. Sabra Junior, et al. (2017) presented a study that deals with assessment of quality in the furniture production process of a small furniture industry. The goal was to find potential improvements to the production process. Data are collected over a period and statistically analyzed. Their results suggest that prior to sanding of parts, extensive reworking was needed in many cases. Simanová and Gejdoš (2015) presented a procedure to prevent a decrease in quality during production process in furniture manufacturing. They indicated that there are many tools for achieving operative quality management targets and the most frequent method is probably measurement and evaluation of the capability of processes through capability indexes. Simanová et al. (2019) presented a study dealing with improving the performance and quality of processes by applying and implementing six sigma methodology in furniture manufacturing process,

In this paper, we have considered wood cutting operations in the frame preparation section of a sofa manufacturing facility. There are 2 cutting benches that cut wood strips into required lengths for all sofa models based on order. In this study, length of wood strips is considered as a quality characteristic. There are 23 types of sofa models in the production line. Sofa model II has 15% share of overall production. Each unit of this model requires 6 pieces of 60 cm wood strips in order to assemble wood frame of the sofa. The positions of the wood strip pieces are critical for fitting and thus, they must be accurate in dimensions, since a small inaccuracy in measurements will cause the pieces not to fit in the frame. This in turn will impact negatively on dimensions of quality of the sofa units. Management of the Factory claims that the average length of wood strips produced from cutting benches (1) and (2) are equal and meet the standard requirements set by the model designer as 60 cm long with a tolerance of ±2%. The main problem at this stage of production is that when the wood strips are cut beyond tolerance, they do not fit well and need rework. Reworking process must be applied on these units separately. Due to the wooden raw material, this reworking process appears to be simple and does not cost much when considering each piece. However, with mass production and without any quality control assurance, this cost will add up and become excessive overhead burden on the company. There are several causes that affect the deviations in wood length cut. Unqualified manpower, old machines, bad material used, wrong methods applied, and poor measuring tools result in dimension inaccuracy. As ındicated by Obucina and Hasanic (2018) Cause and Effect Diagram is a tool which assists in association, categorization and illustration of possible causes and problems in quality characteristics. It visually presents the relation of input factors that have impact on the output. These diagrams are also called "fish-bone diagrams" due to their appearance. The fish bone diagram illustrated in Figure 1 shows causes of variations in wood strips obtained in wood cutting operations.

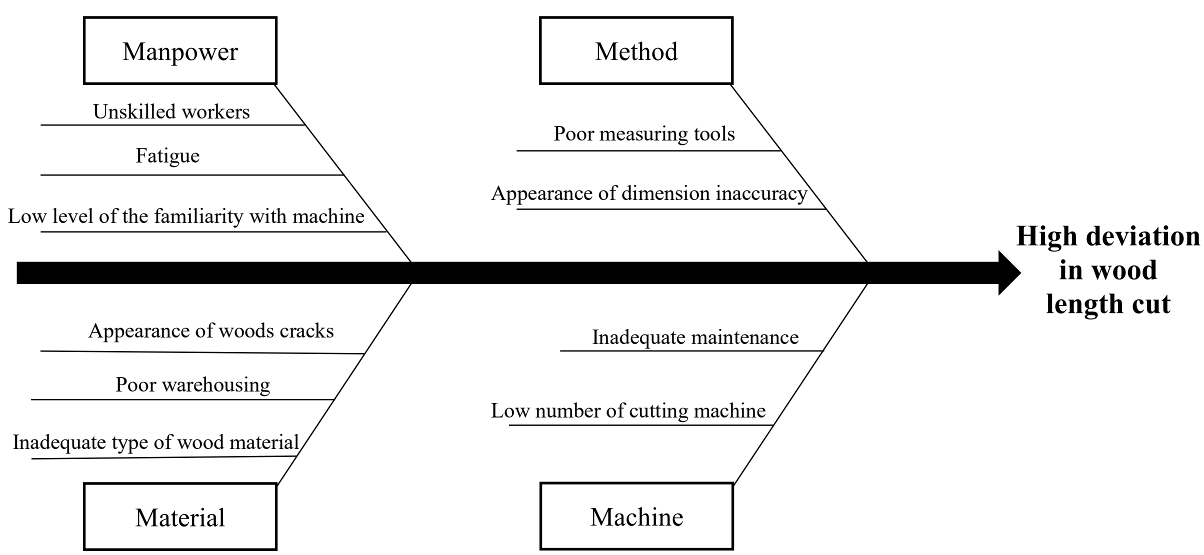


Figure 1. Cause-effect diagram of deviation in wood length cut

The management has no implementation of quality assurance in the sofa manufacturing line, except physical inspection at the end of the production. Furthermore, management claims that two wood cutting benches produce wood pieces, which have the same dimension, and that these dimensions do not deviate from the standard. In order to check the validity of management's claim, we developed a hypothesis testing procedure for testing the difference in mean between the two cutting benches. The objective of the study is to ensure that products meet requirements and are improved on a continuous basis by reducing the variation in the outputs. The aim of this study is to prevent any decrease in quality during production and operational processes. As it is explained in detail by Montgomery (2008) and other countless authors, statistical process control techniques are proven to be very important tools of quality control and improvement. One of the most widely used tools is the Shewhart control chart, which will also be developed and implemented in section 3 for the wood cutting process.

In the existing processes at sofa manufacturing line, neither data are collected nor a statistical process control (SPC) has been implemented. In order to implement such a procedure, some assumptions had to be made. First, data were collected randomly and independently. Second, frequency of sampling was assumed as equal so that process shifts could be detected. These assumptions help the implantation of the SPC charts. In the next section, we present the hypothesis testing for the SPC implementation.

2. Hypothesis Testing for Equality of Means for Wood Cutting Benches

First, we tested the management's claim that two cutting processes of wood strips have equal average cutting dimensions. This was a necessary step in order to decide whether control charts should be established for each bench separately or both benches combined. We proposed a hypothesis testing on equality of mean cutting lengths of wood strips from two different benches of concern. T-test was needed for such a testing procedure, with unknown variances. However, in order to use the T-test, we needed to know if the unknown variances were equal or unequal. To test for the equality of variances of the wood lengths cut in two different benches, F-test for equality of variances had to be used. The goal was to see if management's claim of equal means was true. If the claim was true, it would be enough to construct one quality control chart for the parts coming out of both benches. However, if the claim was not true, it would be necessary to construct control charts separately for each bench to ensure the equality of the outputs. Length of wood strips in cm were collected from cutting benches (1) & (2). Ten samples were measured by measuring tape provided by the company. Table 1 below shows the data recorded in cm. Data were checked by Minitab software to ensure that normality assumption was valid.

Table 1. Length measurements from cutting benches (1) & (2)

Sample number	Bench 1 (cm)	Bench 2 (cm)
1	60.2	60.7
2	60.6	58.7
3	61	60.3
4	60.7	58.9
5	60.4	59.4
6	61.2	60.9
7	60.3	59.4
8	59.8	60.1
9	60.4	60.5
10	60.9	59.1

First, two tail F-test was performed to check equality of variances between cutting processes (1) & (2). Test statistic of the F-test is $F_0 = S_1^2 / S_2^2$, where S_1 is a standard deviation of cutting process 1, and S_2 is a standard deviation of cutting process 2. The null and alternative hypothesis, level of significance, and rejection are shown in table 2 below. By using Minitab, we conducted the equality testing of variances between cutting processes (1) & (2). Form the descriptive statistics we found that the variance in cutting bench (1) is 0.174 and for cutting bench (2) is 0.631. The confidence limits for 95% level of significant are equal to 1.269 and 4.209. The test statistic was equal to 9.43. As indicated by Dyckman and Zeff (2019), P-value is the probability of observing a value of the test statistic that is as extreme as, or more extreme, than the value resulting from the sample, if the null hypothesis is true. The P-value=0.007 < α = 0.05; therefore, we reject the null hypothesis H_o and conclude that there is strong evidence that wood strips produced from cutting processes (1) & (2) have unequal variances.

Table 2. Hypothesis Testing for F-test

Null hypothesis:	$H_0: \sigma_1^2 / \sigma_2^2 = 1$
Alternative hypothesis:	$H_1: \sigma_1^2 / \sigma_2^2 \neq 1$
Significance level:	$\alpha = 0.05$
Rejection criterion	$F_0 > F_{\alpha/2,\, n1-1,\, n2-1}$

T-test is a one of statistical tests that is heavily used to differentiate between the means of two groups and it's one of the statistical hypothesis tests in many studies. Samples are extracted from a cutting bench (1) & (2) and population variance is unknown, so we use the sample variance to examine the sampling distribution of the mean, which will resemble a t-distribution (Kim 2015). Based on F-test result, we executed the two tail T-test on difference between two means, variances unknown and unequal variances ($\sigma_1^2 \neq \sigma_2^2$). The Test statistic and the degrees of freedom are shown in the equations below.

$$t_0 = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}} \qquad \text{d.f.} = \frac{(s_1^2/n_1 + s_2^2/n_2)^2}{\left(\frac{(s_1^2/n_1)^2}{n_1 - 1} + \frac{(s_2^2/n_2)^2}{n_2 - 1}\right)}$$

The null hypothesis and the alternative with the level of significance are shown in the table 3 below. Where (μ_1) is a mean of wood strips from cutting process 1, and (μ_2) is a mean of wood strips from cutting process 2.

Table 3. Null Hypothesis for T-test

Null hypothesis:	$H_0: \mu_1 = \mu_2$
Alternative hypothesis:	$H_1: \mu_1 \neq \mu_2$
Significance level:	$\alpha = 0.05$

The confidence interval with 95% level of significance is (-1.363, -0.137). The P-value = 0.02 < α= 0.05. Therefore, we reject the Null Hypothesis H_o and conclude that there is strong evidence that the two cutting processes produce different wood strip lengths. Consequently, we have to establish statistical process control charts for each bench separately.

3. SPC Charts and Implementation for Wood Cutting Benches

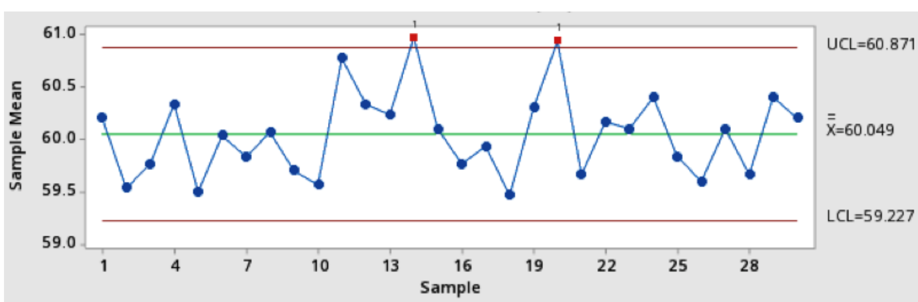
In order to capture the variation from the output of cutting benches (1) & (2) and control the process, we established control charts for $\bar{X}$ & R to monitor the process because our measurements were continuous. Data were recorded by measuring tape. 30 samples (m = 30) of wood strips, each of sample size 3 (n = 3) have been collected from cutting process (1). Table 4 shows the collected length measurements (cm) for wood strips form cutting bench (1). Normality assumption has been checked by probability plot from Minitab software and was valid.

By using Minitab software, we constructed trial control charts for $\bar{X}$ and R for wood strips from cutting bench (1) as shown in Figure 2. As it can be seen from Figure 2, averages of samples 14 and 20 have exceeded the UCL of $\bar{X}$ control chart. Therefore, the process is out-of-control and this control chart could not be adopted for monitoring the process. Furthermore, capability analysis for cutting bench (1) has been conducted by Minitab software as shown in Figure 3. As suggested by Simanová and Gejdoš (2015), capability indexes are used for valuation of capability and are based on normality assumption of data fitting to monitor quality features. Capability index (C_p) is the rate of the hypothetical capability of the process to confirm that the quality feature falls within tolerated quality limits. In practice, C_p= 1.33 can be considered as the minimum benchmark value, because there is always a certain variation, and the measurement process will never be a perfectly matched state as stated by Simanová et al. (2019). The result from Minitab shows that CPU<CPL, which indicates that the process is not centered and it is more likely that units will violate USL.

Table 4. Length measurements (cm) for wood strips from cutting bench (1)

Sample number	Sample size			$\bar{X}_i$	R_i
	n1	n2	n3		
1	61	59.3	60.3	**60.2**	**1.70**
2	59	59.3	60.3	**59.5**	**1.30**
3	59.7	59.9	59.7	**59.8**	**0.20**
4	60.1	60.7	60.2	**60.3**	**0.60**
5	59	59.3	60.2	**59.5**	**1.20**
6	60.1	59.8	60.2	**60.0**	**0.40**
7	59.7	60.2	59.6	**59.8**	**0.60**
8	60.1	60.3	59.8	**60.1**	**0.50**
9	60.1	59.7	59.3	**59.7**	**0.80**
10	59	59.5	60.2	**59.6**	**1.20**
11	60.5	60.7	61.1	**60.8**	**0.60**
12	60.5	60.2	60.3	**60.3**	**0.30**
13	60.2	60.6	59.9	**60.2**	**0.70**
14	61	60.8	61.1	**61.0**	**0.30**
15	60	60.2	60.1	**60.1**	**0.20**
16	59.8	58.9	60.6	**59.8**	**1.70**
17	59.9	59.9	60	**59.9**	**0.10**
18	59.2	59.7	59.5	**59.5**	**0.50**
19	59.9	59.8	61.2	**60.3**	**1.40**
20	61	61.1	60.7	**60.9**	**0.40**
21	59.7	59.8	59.5	**59.7**	**0.30**
22	60.5	59.9	60.1	**60.2**	**0.60**
23	59.8	60.8	59.7	**60.1**	**1.10**
24	60.8	60.3	60.1	**60.4**	**0.70**
25	59	61	59.5	**59.8**	**2.00**
26	60.1	59	59.7	**59.6**	**1.10**
27	60.8	59.7	59.8	**60.1**	**1.10**
28	59.8	59.6	59.6	**59.7**	**0.20**
29	60.4	59.7	61.1	**60.4**	**1.40**
30	59.8	60.1	60.7	**60.2**	**0.90**
Overall Average				**60.05**	**0.803**

$\bar{X}$ - chart



R - chart

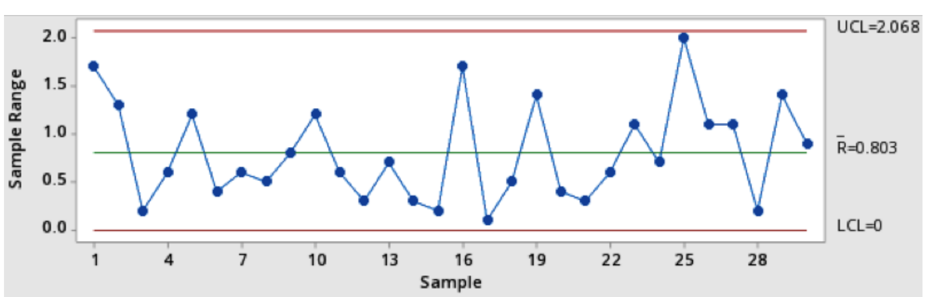


Figure 2. $\bar{X}$ and R Control Charts for cutting bench (1)

The Cpk, Ppk, and Cpm are all smaller than 1.33, which does not reach the minimum value for a capable process benchmark industry. Ppk<Cpk, which indicates that the overall capability of the process could be improved as indicated by Montgomery (2008). Therefore, we concluded that the cutting length process is not capable to produce the wood bar within the specified limits. Based on this estimation, the process would produce approximately 35,000 ppm fallouts the specification limit, which results in excess burden cost and wasted time. Therefore, we conclude that the cutting length bench (1) is not capable to produce the wood strips efficiently. Control charts are revised by eliminating the points which are out of control and reconstructing new limits.

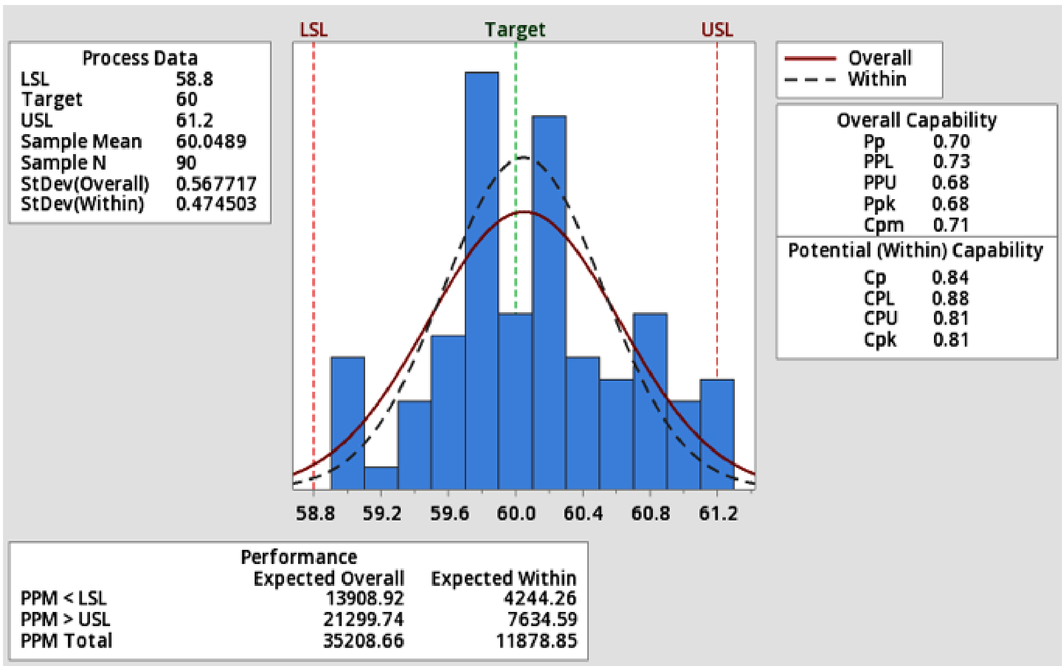


Figure 3. Process capability analysis for cutting bench (1)

Control charts were established for cutting bench 2, like bench 1. Again 30 samples (m = 30) of wood strips, each of sample size 3 (n=3), have been collected from cutting bench (2). Normality assumption was valid by testing probability plot by Minitab software. Data in Table 5 represent length measurements (cm) for wood strips form cutting bench (2).

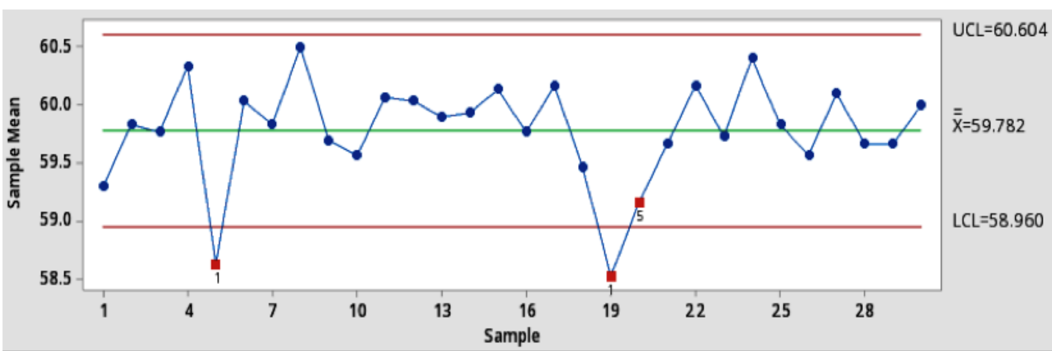
By Minitab software, we constructed trial control charts of $\bar{X}$ and R for cutting length of wood strips from bench (2) as shown in Figure 4. Minitab provides tests for special causes to identify specific patterns in the data. The test failed at data points 1 and 19. Average of samples 1 and 19 have exceeded the LCL (3-sigma) of $\bar{X}$ control chart. Also, the test failed at point 20, in which two out of three points were more than 2σ away from the center line (same side). Therefore, the process is out-of-control and these control charts could not be adopted for monitoring the process at phase II. Process capability analysis for cutting bench (2) has been conducted by Minitab software as shown in Figure 5 below.

The CPL<CPU, which indicate that the process is not centered, and it is more likely that production units will violate LSL. The Cpk, Ppk, and Cpm are all smaller than 1.33, which is half of the value for a capable process benchmark industry. And Ppk < Cpk, which indicates that the overall capability of the process could be improved. Therefore, we conclude that the cutting length process is not capable to produce the wood bar. Expected overall fallouts from the specification limit of the process is approximately 55,8620 ppm. The process of cutting length bench (2) is out-of-control, so these control limits also could not be adopted for monitoring the process in phase II. The control limits are revised by eliminating the points that are out of control limits and by constructing new limits.

Table 5. Length measurements (cm) for wood strips from cutting bench (2)

Sample number	Sample size			$\bar{X}_i$	R_i	Sample number	Sample size			$\bar{X}_i$	R_i	Sample number	Sample size			$\bar{X}_i$	R_i
	n1	n2	n3				n1	n2	n3				n1	n2	n3		
1	59.2	59.8	58.9	**59.3**	**0.90**	11	60.5	60	59.7	**60.1**	**0.80**	21	59.7	59.8	59.5	**59.7**	**0.30**
2	59.3	59.9	60.3	**59.8**	**1.00**	12	60.5	60.2	59.4	**60.0**	**1.10**	22	60.5	59.9	60.1	**60.2**	**0.60**
3	59.7	59.9	59.7	**59.8**	**0.20**	13	60.2	59.6	59.9	**59.9**	**0.60**	23	59.8	59.7	59.7	**59.7**	**0.10**
4	60.3	60.7	60	**60.3**	**0.70**	14	59.4	59.9	60.5	**59.9**	**1.10**	24	60.8	60.3	60.1	**60.4**	**0.70**
5	58.6	58.4	58.9	**58.6**	**0.50**	15	60.1	60.2	60.1	**60.1**	**0.10**	25	59	61	59.5	**59.8**	**2.00**
6	60.1	59.8	60.2	**60.0**	**0.40**	16	59.8	58.9	60.6	**59.8**	**1.70**	26	60	59	59.7	**59.6**	**1.00**
7	59.7	60.2	59.6	**59.8**	**0.60**	17	60.6	59.9	60	**60.2**	**0.70**	27	60.8	59.7	59.8	**60.1**	**1.10**
8	60.1	60.8	60.6	**60.5**	**0.70**	18	59.2	59.7	59.5	**59.5**	**0.50**	28	59.8	59.6	59.6	**59.7**	**0.20**
9	60.1	59.7	59.3	**59.7**	**0.80**	19	59	58.2	58.4	**58.5**	**0.80**	29	58.9	59.4	60.7	**59.7**	**1.80**
10	59	59.5	60.2	**59.6**	**1.20**	20	58.9	59	59.6	**59.2**	**0.70**	30	59.8	59.5	60.7	**60.0**	**1.20**
												Overall Average				**59.78**	**0.803**

$\bar{X}$ - chart



R - chart

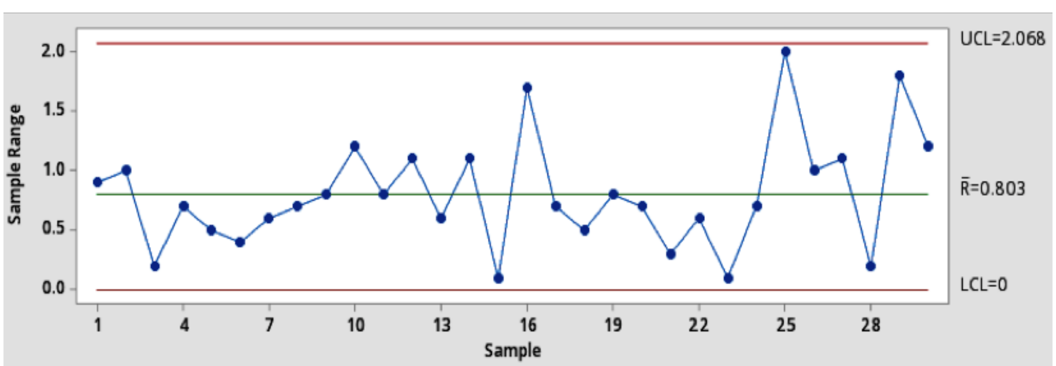


Figure 4. Control chart for cutting bench (2)

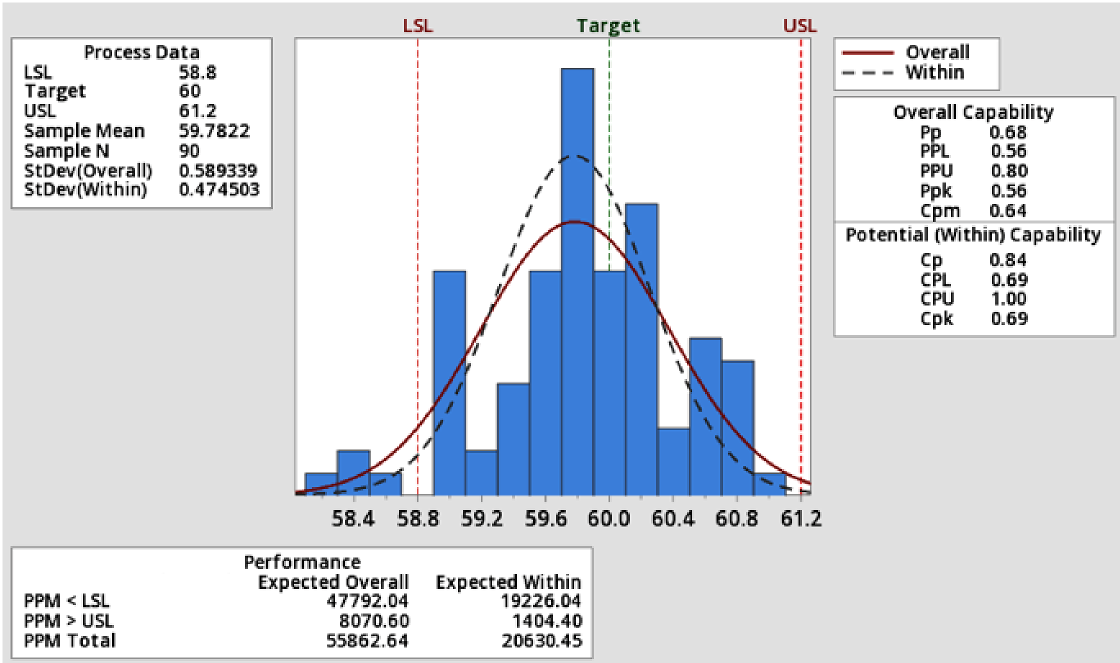
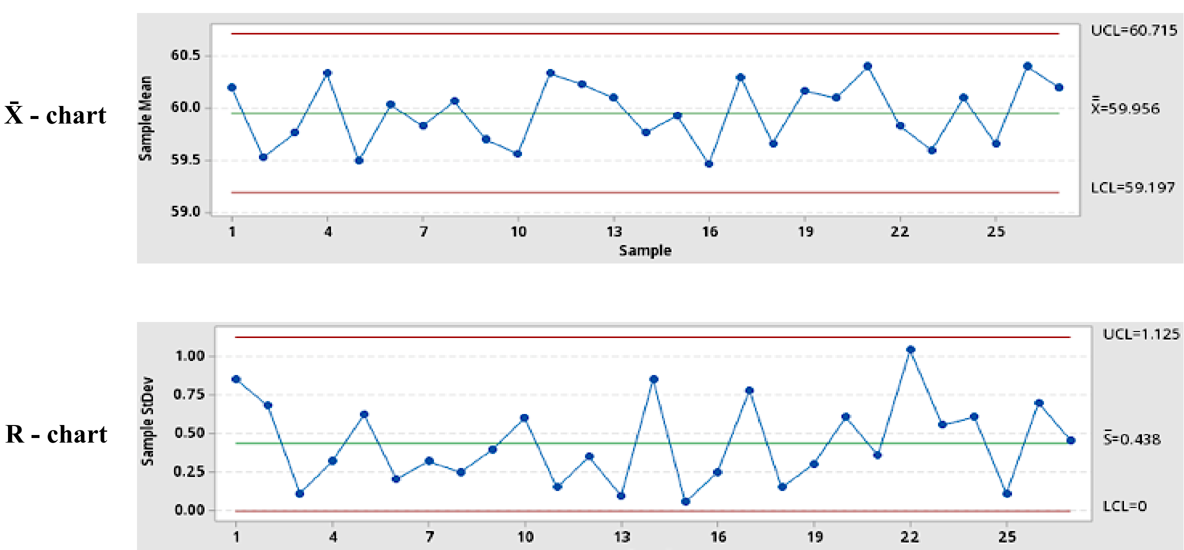


Figure 5: Process capability analysis for cutting bench (2)

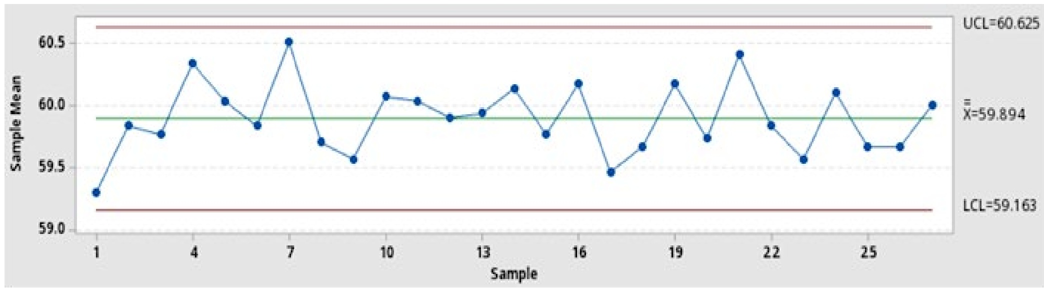
4. Revised Control Charts for Bench (1) and Bench (2)

In order to monitor the process in the future, control charts must be established based on the capability of the process. Therefore, previously constructed control charts for both cutting benches will be revised by removing out of control points. The out of control points 14 and 20, as shown in Figure 2, had exceeded the UCL of $\bar{X}$ control chart of cutting bench (1). After removing these points, we conduct the new control chart as shown in Figure 6 below. The center line (CL) has been decreased from 60.049 cm to 59.956 cm with no out-of-control points. These SPC carts can now be used for the cutting bench 1 to control the process in the future.



The same procedure is repeated for the cutting bench (2). First, excluding out-of-control points and then conducting the new control charts by Minitab, the SPC charts shown in Figure 7 could be used for monitoring the bench 2 process in the future. The CL become closer to nominal value of 60 cm in this case. By using these charts, operator can respond when an out of control or special cause is detected by plotting the outcome of the process. SPC requires immediate response to a special cause signal.

$\bar{X}$ - chart



R - chart

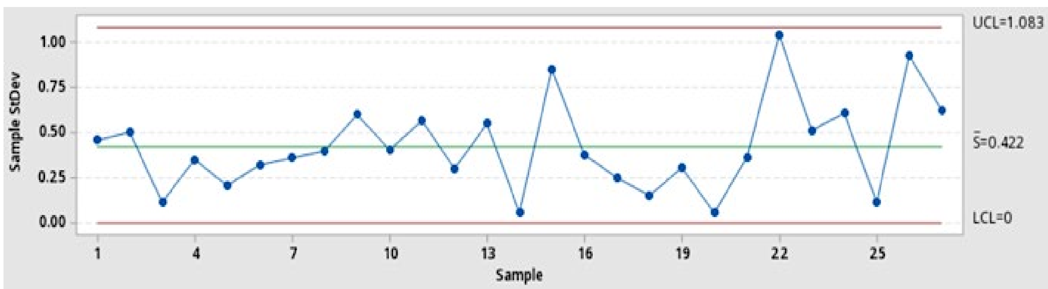


Figure 7 Revised control chart for cutting bench (2)

5. Discussion and Evaluation

From our observations of the cutting processes in the factory, we noticed that the operators were taking measurements with bended measuring tape, which is one of the main reasons or the assignable cause for the sample to be out-of-control in the process at cutting bench (1). This also resulted in the process being not capable to produce wood strips within control limits. Also, the absence of a locking template to secure the wood strips properly before cutting is another reason for the out of specification cuts. The cutting table as well as the locking template are made of wood and thus the sawdust generated around them play major role in sliding the template couple of mm and causing out of specification cuts. Furthermore, the lock itself has no safety device to protect the template from getting loose by time; it pushes the wooden bars into the template. Lastly, the operator uses his hand to tight the template which probably vary from operator to operator. The consequence is a shifting in the process. We recommended to add a rigid tape which can be fixed in the edge of the table and on top of the template, so no wrong measurement is taken. For the lock in the template, secured double sided lock could significantly reduce number of parts produced out of the specification limits. Normally, automated machines with accurate cutting measures are heavily used in furniture manufacturing industry. This will increase productivity and reduce number of parts falling out of tolerance limits.

The economic evaluation of the proposal was that estimated number of units exceeding the tolerance limit is more than 10% in total. Any wood strips fallout of the tolerance limit by 2% would have to be fixed by sending the wood strips back to reworking station. On average, Reworking process takes 4 minutes. The expected overall estimation shows that 43,714 parts per year falls outs of the specification limit. Without any improvements in these processes and no out-of-control-action plan (OCAP) will result in (4 min.)x(43714 fallouts)/60=2915 hours of wasted time as reworking process per year. The result is factory loss opportunity of producing 114 sofa units, or average company monetary loss in total of 7,030 KWD (or about 22,200 US Dollars) per year. This loss is also ignoring the material lost as a result of these fallouts. Based on these analysis, the management was asked to take the necessary actions in order to improve the quality of cutting wood strips in order to avoid the losses calculated.

6. Conclusion

This project aims to improve the quality of sofa furniture production by implementing engineering statistics & quality control techniques to reduce process variability. This results in reducing excess material waste and opportunity loss, as well as increasing the level of perfection in order to meet customer requirements. Based on the study, we were able to address a significant analysis which could result in improvement of furniture manufacturing processes by applying statistical process control tools. Based on capability analysis, the company has huge opportunity to reduce financial burden by increasing the capability of production processes up to (1.25). Also, by applying quality control charts, company could be able to assure accurate monitoring of the process stability and eliminate erroneous results.

As a further research, it is helpful to establish quantitative indicators to easily capture any sort of shifting of a certain process which can be used to cut off overhead cost significantly. Other quality attributes, in addition to length of strip wood cuts, should be monitored by control charts, which would play important roles in process monitoring in furniture industry. One of important measure that should be stringently controlled is the fabrics cut and sewn to fit the sofa units. A lot of wasted material and quality control problems can be seen in these processes and need detailed study and analysis. Such studies can minimize wasted fabric material, contribute to company profits and also economy of the country in general. Because of time limitations, this issue could not be included in this study.

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