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Development of Six Sigma methodology for CNC milling process improvements

M N Ismail[1, 2], A N M Rose, [1], N Z Mohammed [1], M F F Ab Rashid [1]

[1]Manufacturing Focus Group, Faculty of Mechanical Engineering, University Malaysia Pahang, 26600 Pekan Pahang, Malaysia
[2]Department of Quality and Productivity, Kolej Kemahiran Tinggi MARA Kuantan, Km 8 Jln Gambang, 25150 Kuantan Pahang, Malaysia

[*]Corresponding author: mohdnasrul.ismail@gmail.com

Abstract. Quality and productivity have been identified as an important role in any organization, especially for manufacturing sectors to gain more profit that leads to success of a company. This paper reports a work improvement project in Kolej Kemahiran Tinggi MARA Kuantan. It involves problem identification in production of “Khufi” product and proposing an effective framework to improve the current situation effectively. Based on the observation and data collection on the work in progress (WIP) product, the major problem has been identified related to function of the product which is the parts can’t assemble properly due to dimension of the product is out of specification. The six sigma has been used as a methodology to study and improve of the problems identified. Six Sigma is a highly statistical and data driven approach to solving complex business problems. It uses a methodical five phase approach define, measure, analysis, improve and control (DMAIC) to help understand the process and the variables that affect it so that can be optimized the processes. Finally, the root cause and solution for the production of “Khufi” problem has been identified and implemented then the result for this product was successfully followed the specification of fitting.

1. Introduction

In 1987, Motorola developed and organized the Six Sigma process improvement methodology to achieve “world-class” performance, quality, and total customer satisfaction. Since that time, at least 25% of the Fortune 200, including Motorola, General Electric, Ford, Boeing, Allied Signal, Toyota, Honeywell, Kodak, Raytheon, and Bank of America, to name a few, have implemented a Six Sigma program [1] . Six Sigma (SS) is a quality tool for process improvement program in any organisation. It is striving to eliminate the defects up 3.4 parts per million. This research will present the step-by-step application of the Define–Measure–Analyse–Improve–Control (DMAIC) approach as to eliminate the defects caused by CNC Milling process. This study will help the organisation to identify and reduce defects in the process. Hence, this effort could improve productivity and quality of the product. This study is conducted at Kolej Kemahiran Tinggi MARA Kuantan (KKTM), based on facing problem due to fitting on “Khufi”. This product is produced by KKTM as a souvenir product for the visitors and also as a present in any event conducted in KKTM. This souvenir is processed by CNC milling machines by using the aluminium material. It is comprised of three parts which called base, part 1 and part 2. A complete set of Khufi should has part 1 and part 2 assembled on the base. The responsible lecturer has assigned this project to the Semester 3 student, Session July- December 2016 to produce that product for the trial phase. There were 25 units of semi-finished product (based part) produced by the students. The assembled result show the "part 1 and part 2" cannot be slotted properly to the base part. It was due to the dimension of the based, part 1 and part 2 are not accurate as the required specification.

The main objectives of this study are to investigate the opportunities for quality and process improvement based on six sigma methodology, to eliminate potential wastes and variability and the last objective is to develop a model for effective implementation of Six Sigma for CNC milling process. End of the study, the researchers could understand the fundamental elements or factors that contribute to the unfit khufi due to CNC milling manufacturing process and able to determine best practices six sigma implementation during milling process.

1.1 Literature Review
Normally the studies conducted on six sigma methodologies were particularly designed for large organizations but this research is carried out to study the application of six sigma in Computer Numerical Control (CNC) machine operation. In recent years, the interest from the academic community towards six sigma has increased dramatically. However, to date only few papers can be identified for literature review on Six Sigma focusing on the basic concept, implementation and future of Six Sigma Six Sigma has been defined as the statistical unit of measurement, a Sigma that measures the capability of the process to achieve a defect free performance. Six Sigma has the ability to produce products and services with only 3.4 defects per million, which is a world-class performance. Six Sigma has also been described as a high performance data driven approach in analyzing the root causes of business problems and solving them [2] [3].

1.2 Process Sigma
Process Sigma is defined by numeric levels that are related to a process's output of defects per million opportunities. Defects are defined as any failure to meet the customer's specifications. Process yield is used to look up the Process Sigma level from a Table. Yield is based on Defects (D), Units Processed (N), and the number of Opportunities (O) for a defect to occur. Once the yield is calculated the Process Sigma can be found in the process sigma level Table.

$$Process\ Yield = \left(1 - \frac{D}{N * O}\right) * 100 \quad (1)$$

1.3 Define, Measure, Analyze, Improve and Control (DMAIC)
Six Sigma implementation uses five step DMAIC (Define, Measure, Analyze, Improve and Control) methodology, somewhat similar to Plan-Do-Check-Act problem solving methodology defined by Deming. DMADV (Define, Measure, Analyze, Design and Verify) methodology is adopted for new product developments [4].

DMAIC is a closed-loop process that eliminates unproductive steps, often focuses on new measurements, and applies technology for continuous improvement. Some papers focus on explaining the DMAIC contents, with some authors discussing each phase of DMAIC in detail [5]. For example, (Wang 2008) present self-learning training material for DMAIC, using a fictitious application. This paper helps the readers to learn how to carry out a small-scale Six Sigma project, including guidance on the application of tools. It indicates a perceived need for training material and suggests that an avenue for further research is to develop training material to cover a wider range of applications and larger scale projects [2].

Other papers concentrate on specific aspects of DMAIC, such as the project selection process in the Define phase or process control in the Control phase, explaining some key measures in Six Sigma, such as project metrics and Roll Throughput Yield (RTY). For example, (Bożek and Hamrol 2012) emphasizes the importance of the project selection process in the Define phase for the successful implementation while Mason suggests using multivariate statistical process control in the Control phase [6].

2. Methodology

This section explains the methodology adopted for this case study. Scientific investigation on innovating a system or improvement to the existing one needs to begin with good plan. The plan of investigation was conceived so as to obtain answers to research questions in the research design. This research will pursue a systematic approach for empirical study. It consists of six steps as in Figure 1. Step 1 literature review is intended to understand the implementation of Lean Six Sigma in the manufacturing process. The main focus of this reviewing process is to identify the most important lean six sigma implementing techniques. Step 2 data collection will be carried out through sampling from the student project in advance machining subject. The sampling part will be take and measure for the dimension and parameter based on specification given. For Step 3 the data gathered will be analysed using the statistical process analysis. The data analysis will go through the DMAIC phase in six sigma methodology. Then, step 4 model will be used in developing the integration model for lean six sigma implementation in CNC milling manufacturing process. Step 5 is the validation of the model developed will be carried the case study to implementing the solution. The data from the case study will be used in this validation process.

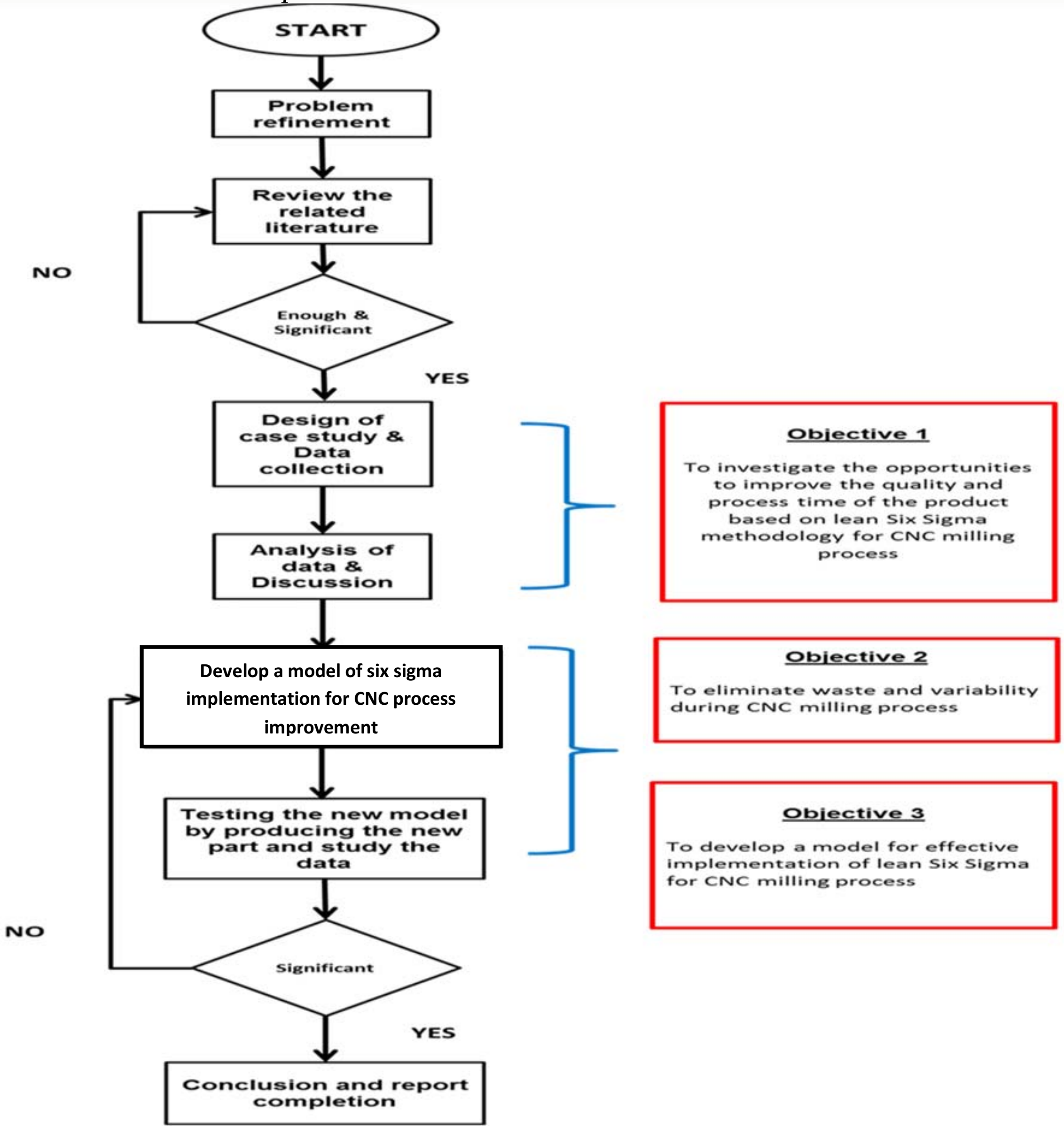

Figure 1. Process flow for the project methodology

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3. Results and Discussion

This case study conducted based on problem of part 1 and 2 could not be slotted into the base part. Based on the initial design of Khufi, the base part is used as the female part which there are two slots on the top. While part 1 and 2 as a male part which its design have a rib at the bottom of the part for assembly purpose. Some samples were taken and conducted the fitting test. The results discover all parts cannot be assembled correctly because some of them are loose and too tight. Therefore, a study based on the DMAIC methodology was conducted to identify the cause of this problem.

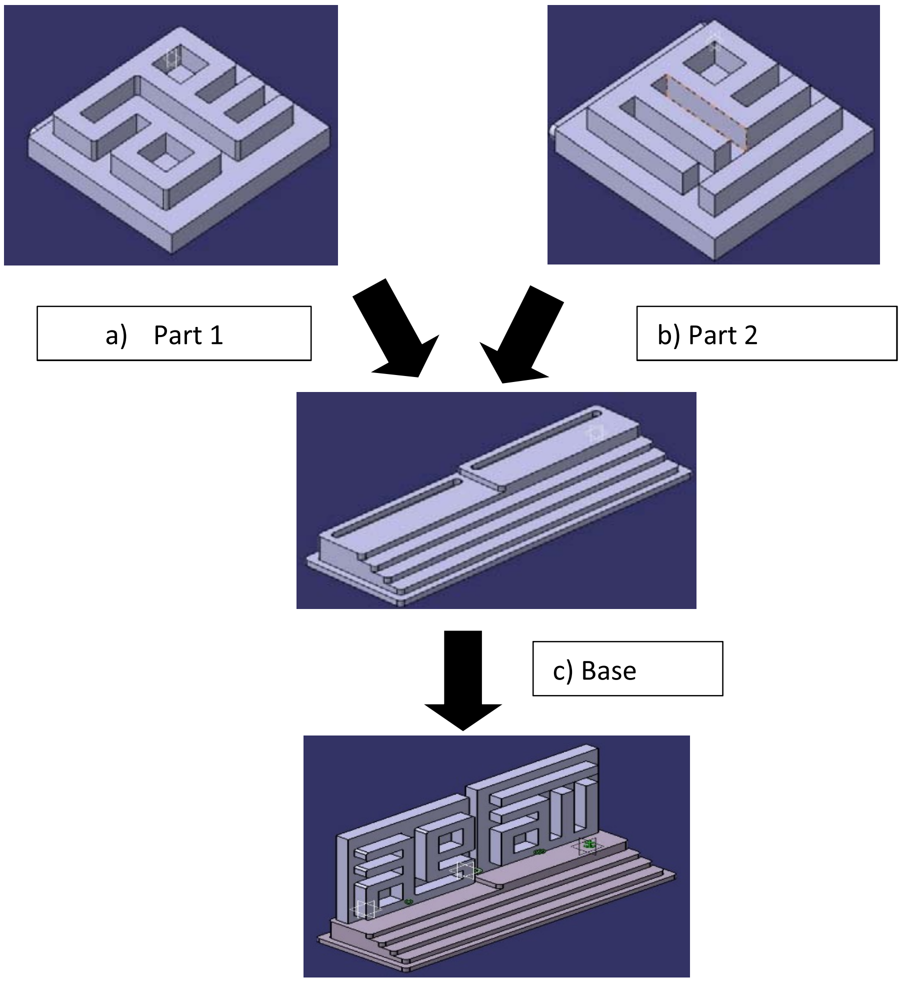

Figure 2. Assembled part of Khufi

3.1 Define

25 units of base part had been measured using the Coordinate Measuring Machine (CMM) .Before the measurements are made, two dimensions (A & B) have been identified as a critical dimension to be control during machining process. Therefore, this two dimension has been measured and verified based on the required specification.

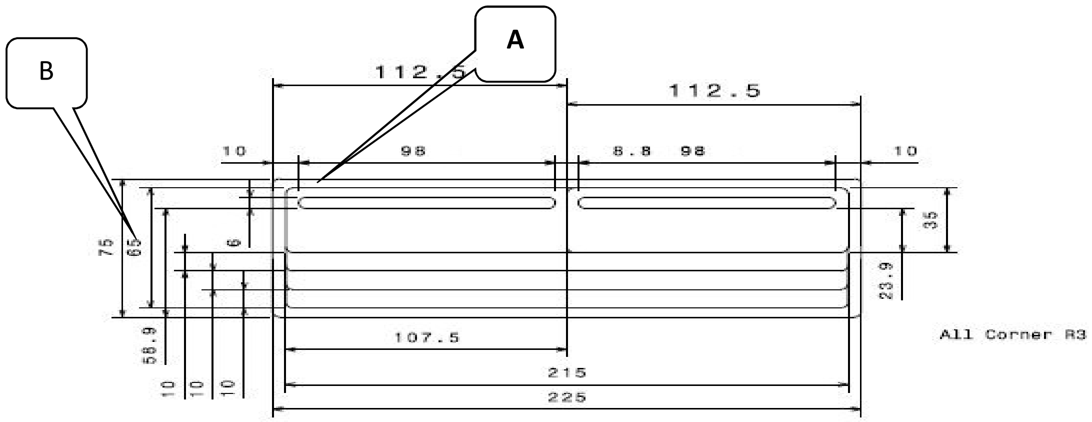

Figure 3. Technical drawing for base part

3.2 Measure
In this stage, a check sheet has been developed in order to record all the data from the measured part. The data has been separated into two categories, dimension A and dimension B. All measured data for dimension of A & B are highlighted in Table 1

Table 1 Measurement for dimension A and B

Parts	Dimension A (mm)	Dimension B (mm)
1	97.99656	6.04060
2	98.03733	6.10923
3	98.0542	6.08104
4	98.07508	5.98632
5	98.01746	6.09286
6	97.95087	6.09393
7	98.03882	6.10794
8	98.06297	6.10600
9	98.00606	5.99135
10	98.06782	6.01106
11	98.01281	5.99395
12	97.98396	6.05732
13	98.09409	6.05423
14	98.07179	6.02820
15	98.00491	6.05689
16	98.04085	6.02283
17	97.97587	6.00241
18	97.94062	6.09148
19	98.04602	6.09875
20	98.07852	6.08838
21	98.07089	6.07921
22	97.99526	6.00217
23	98.01653	6.10740
24	98.17584	6.12667
25	98.05817	6.09221

The I-MR control chart as in Figure 4 and 5 have been developed based on collected data as in Table 2.

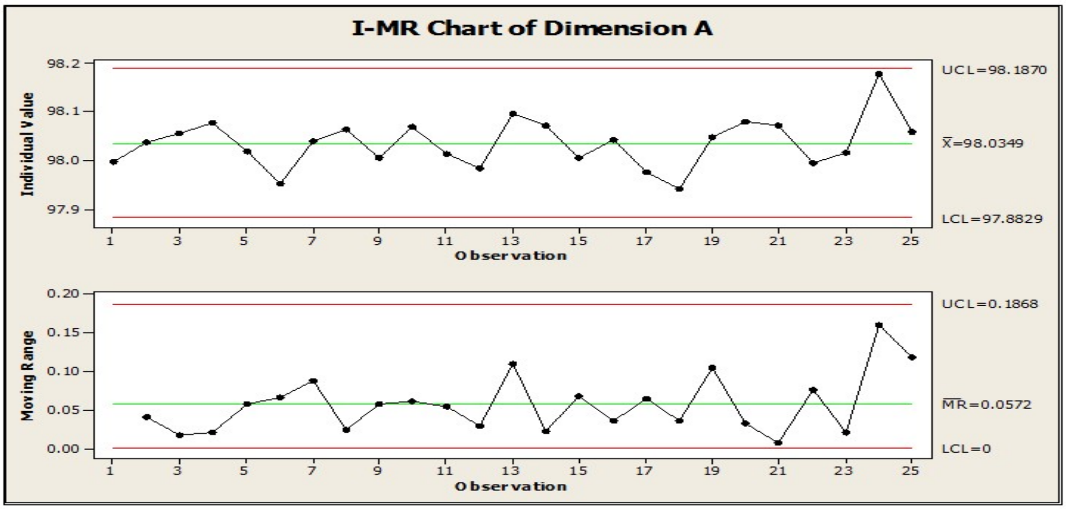

Figure 4. Control chart for dimension A

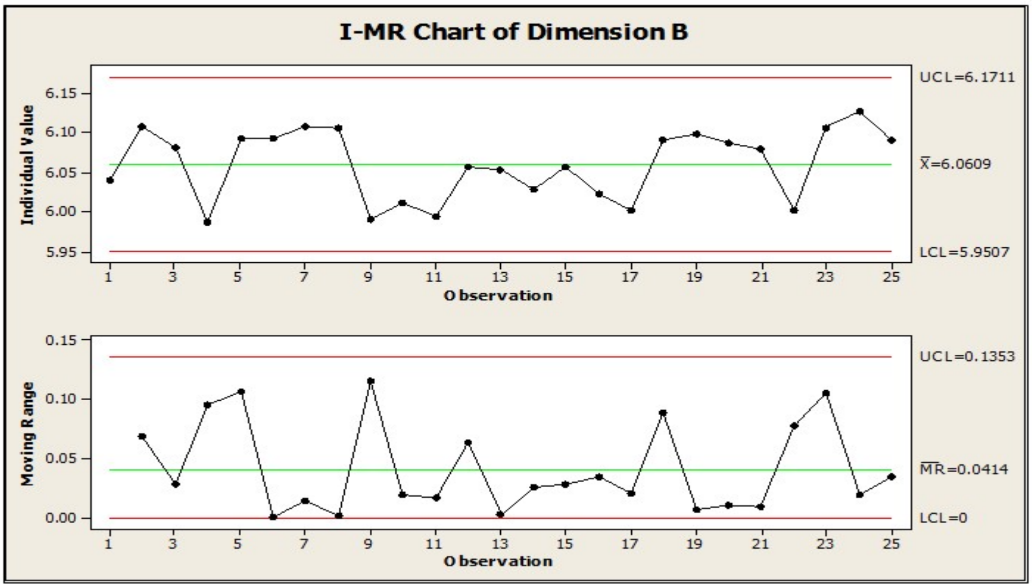

Figure 5. Control chart for dimension B

Figure 4 and 5 show the I-MR chart for the dimension A and B. All data obtain from both chart are still within the UCL and LCL value. The variation of the data from the mean value is not too high as shown in individual value chart but for the moving range is quite large compared to dimension A. The UCL and LCL value for this dimension are almost same with dimension A which the data obtained are over the specification limit. Therefore, this dimension also needs to be analysed in order to identify the cause of dimension out of specification.

Further analysis is to calculate the standard deviation and also process capability (Cp) value based on process capability chart. The Cp is a measurable property of a process to the specification, expressed as a process capability index. Two parts of process capability are measure the variability of the output of a process, and compare that variability with a proposed specification or product tolerance.

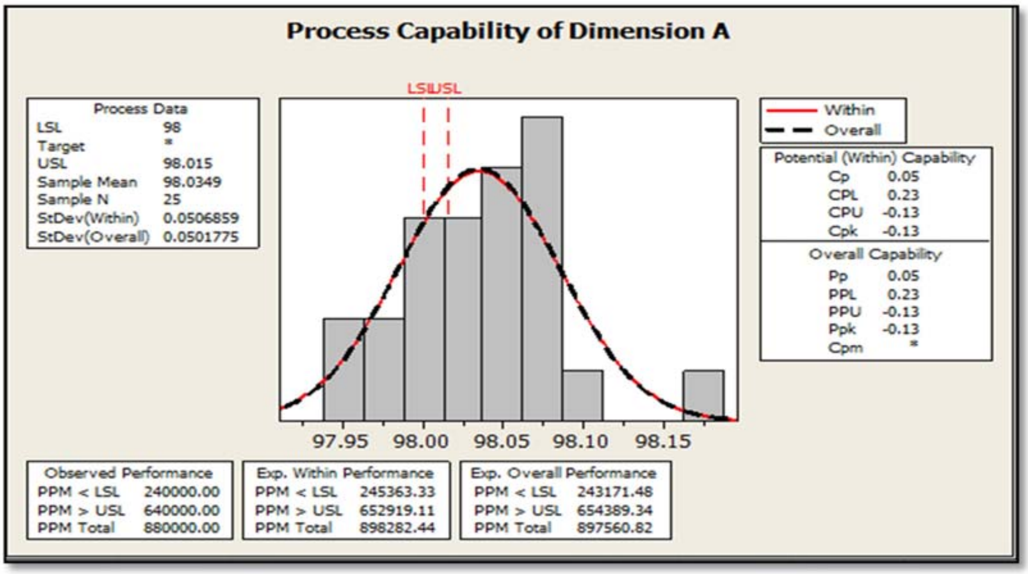

Figure 6. Process capability chart for dimension A

From the process capability chart in Figure 6, it shows almost all the dimensions from 25 unit parts are out of specification. The standard deviation for this data is not too large (0.05), meaning it does not deviate much from the average. While for the Cp we get the value is 0.05. Based on literature review, the best Cp must be above than 1.2. If the value is less than 0.5 it means that the variability of the process is more than the specification limits.

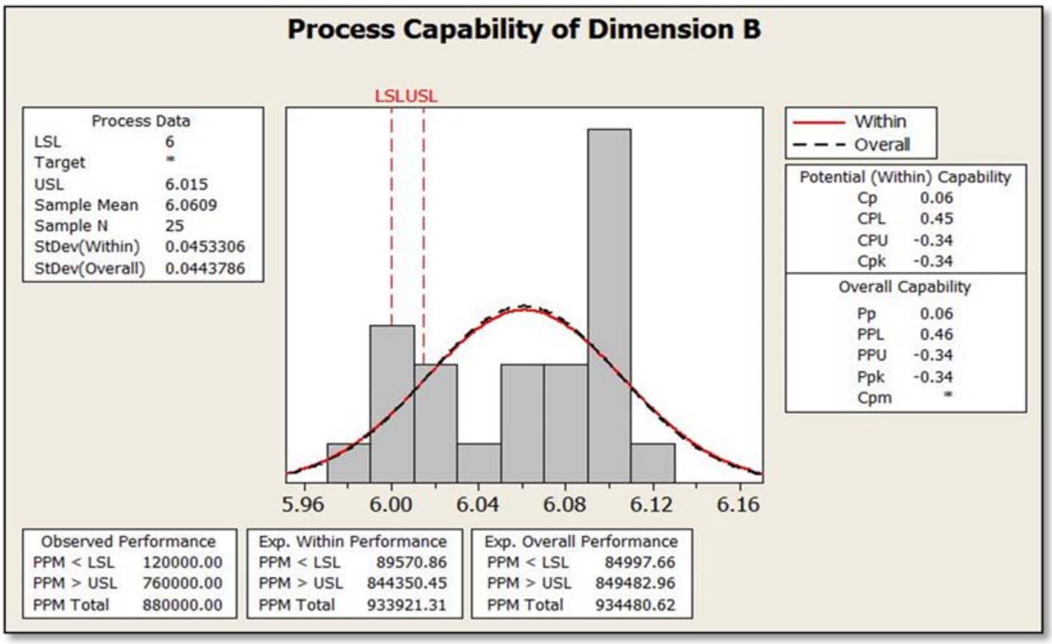

Figure 7. Process capability chart for dimension B

Base on Figure 7, it shows the dimension B is same results as dimension A. There were 22 over 25 units are not according to specifications. The standard deviation and Cp value also almost the same, 0.04 and 0.06. Conclusion for this issue shows both of dimensions have a same problem and root cause. A solution is necessary to improve this process in order to get results according to the required specifications.

3.3 Analysis

Data analysis were conducted to identify the root cause and the possible solution as to improve out of dimension problem. Fishbone diagram used as a tool to study the causes of problem based on five criteria which is man, machine, method, measurement, material and environment. The first cause is probably came from measurement factor which is because of inaccurate cutting tool size. Second cause is from material which is maybe due to cutting tool worn out. Man also one of the factor that cause to this problem which is CNC machine was conducted by low skill operator. The third cause is came from method which is inaccurate parameter setting will also contribute to this problem. All causes were verified through experiment for improve the existing process.

Experiment 1 has been conducted to study the effect of feedrate and depth of cut parameter to the product dimension. This experiment is divided into two which is first to increase the feed rate with constant depth of cut and second is increase depth of cut with constant feed rate. Table 2 shows the result obtain from the experiment.

Table 2. Data for Experiment 1

No	Comment	Spindle speed (RPM)	Feed rate (mm/m)	DOC	Measurement (6mm + 0.015)	Production time (min)	Result
1	Change the Feed rate value	4000	500	0.1	5.982	38m 49s	All data is out of spec and trend is decreased
2		4000	800	0.1	5.981	24m 19s	
3		4000	1000	0.1	5.979	19m 29s	
1	Change the DOC value	4000	1000	0.2	5.978	9m 47s	All data is out of spec and trend is decreased
2		4000	1000	0.3	5.977	6m 41s	
3		4000	1000	0.4	5.976	5m 08s	

In this experiment, 6 samples were proceed for machining process based on parameter setting defined in Table 2. The dimension of the sample has been measured and the result show all the dimension is out of specification. Based on that result, it show the trend of the dimension is decrease when value of feed rate and depth of cut is increase.

Based on finding on experiment 1, the second experiment has been conducted by reducing the feed rate and depth of cut value to the minimum parameter. For this experiment, three samples has been used for machining and the result shows in Table 3

Table 3. Data for Experiment 2

No	Comment	Spindle speed (RPM)	Feed rate (mm/m)	DOC	Measurement (6mm + 0.015)	Production time (mnt)	Result
1	Reduce to minimum value of Feed Rate & DOC	4000	300	0.1	5.984	1h 4m 37s	All data is out of spec and trend is increased
2		4000	200	0.1	5.984	1h 36m 51s	
3		4000	100	0.1	5.985	3h 13m 35s	

In this experiment, the feed rate has been set to 100 mm/m while the depth of cut set to 0.1mm. The result obtain is increase but still didn't archive to the required specification. In order to get the exactly value for this two parameter, a regression equation is an option to get the right formula to define the actual value of parameter.

3.4 Regression analysis

Linear regression attempts to model the relationship between two variables by fitting a linear equation to observed data. One variable is considered to be an explanatory variable, and the other is considered to be a dependent variable. Multiple linear regression attempts to model the relationship between two or more explanatory variables and a response variable by fitting a linear equation to observed data. Every value of the independent variable x is associated with a value of the dependent variable y. For this experiment, the dependent variable is the dimension of B while the independent variables are feed rate and DOC. I have use the formula below in order to generate the regression equation for my case study.

$$Y = a + b_1 X_1 + b_2 X_2 \tag{2}$$

Y = Dependent variable/Output (Required dimension = 6 +0.0015)
a = intercept
b = slope
X1= Independent variable 1 (Feed rate)
X2 = Independent variable 2 (Depth of Cut)

All the value has been calculated using the Microsoft Excel software based on regression formula. The result from calculation is obtain in Table 4 below

Table 4. Regression analysis

	Y	X1	X2	X1*Y	X2*Y	X1*X2	X1^2	X2^2
	5.982	500	0.1	2991	0.5982	50	250000	0.01
	5.981	800	0.1	4784.8	0.5981	80	640000	0.01
	5.979	1000	0.1	5979	0.5979	100	1000000	0.01
	5.977	1200	0.1	7172.4	0.5977	120	1440000	0.01
	5.976	1500	0.1	8964	0.5976	150	2250000	0.01
	5.978	1000	0.2	5978	1.1956	200	1000000	0.04
	5.977	1000	0.3	5977	1.7931	300	1000000	0.09
	5.976	1000	0.4	5976	2.3904	400	1000000	0.16
	5.974	1000	0.5	5974	2.987	500	1000000	0.25
	5.984	300	0.1	1795.2	0.5984	30	90000	0.01
	5.984	200	0.1	1196.8	0.5984	20	40000	0.01
	5.985	100	0.1	598.5	0.5985	10	10000	0.01
SUM	**71.8**	**9600**	**2.2**	**57386.7**	**13.2**	**1960**	**9720000**	**0.62**
AVG	**5.9794**	**800**	**0.183**	**4782.225**	**1.0959**	**163.3333**	**810000**	**0.05167**
^2		92160000	4.84	3293233337	172.95	3841600	9.44784E+13	0.3844

Table 4. Regression analysis (continued)

x1y	**-15.7**
x2y	**-0.003816667**
x1x2	**200**
x1^2	**2040000**
x2^2	**0.216666667**
B1	**-0.00000656302**
B2	**-0.011557214**
a	**5.986785904**

From the Table 4, the result shows the value of b1, b2 and a. This value will substitute into the regression equation of Y and become a complete equation.

Y= 5.99 – 0.000007 X1 – 0.0116 X2

Then, using this equation to get the X1(feed rate) and X2 (DOC) value based on required Y (dimension). For example, the required Y (dimension) is 6 then the X1 and X2 get from the calculation below:

Y= 5.99 – 0.000007 X1 – 0.0116 X2

Rearrange the equation to make X1 & X2 as subject

X1 = 6 + 0.0116X2 – 5.99/(-0.000007)-------------1

X2 = 6-5.99+0.000007X1/(-0.0116) ----------------2

Sub 2----->1

X1 = 6+0.0116[-517.24+516.38-0.0006X1]-5.99/ (-0.00007)

X1 = -42.25

Sub -42.25----->2

X2 = 6-5.99 + (0.000007 x -42.25)/-0.0116

X2 = -0.837

The results from these calculations can be concluded, in order to get the dimension Y for 6mm, the required parameter for feed rate and DOC are -42.25 and -0.837. The value of feed rate and DOC that obtain from the calculation is impossible to be implemented at the actual process because of value is too small and negative. Therefore, the parameter setting problem is not the root cause of this problem and no possible solution from this parameter and need to proceed for the next experiment.

The next experiment (experiment 3) is to change the tool radius. In the CNC programme, there is a setting namely tool wear offset for length and radius. The function of this setting is to change the cutting tool setting (length and radius) if that was worn out. For this experiment, only the radius value is changed and monitor whether affect the product dimension or not

The tool radius for the first sample is change to +0.018, while the second sample reduce to -0.018. This change value is based on the best result obtain from the experiment 2.

Table 5. Data for Experiment 3

No	Comment	Spindle speed (RPM)	Feed rate (mm/m)	DOC	Measurement (6mm + 0.015)	Production time (min)	Result
13	Change tool radius ware (+0.018)	4000	500	0.1	5.951	38m 45s	This parameter is not the original setting
14	Change tool radius ware (-0.018)	4000	500	0.1	6.081	38m 48s	

From the Table 5, the result shows the measurement for No 13 is reduce and far from the specification. While, for No 14, result shows the dimension is increase and closer to the specification. Therefore, this experiment shows the change of tool dimeter is drastically effect the dimension of product change. This situation gives a clue that, this new tool size is not exactly as specified by the manufacturer. To prove this matter, next experiment has been conducted to measure the actual size of the cutting tool.

The experiment 4 has been conducted as to verify the dimension of the cutting tool as indicated by the manufacturer. The dimension of diameter claimed by the manufacturer is 4mm as shown in Figure 8.

However, the measured diameter by vernier calliper was 3.86mm, which is different as claimed by the manufacturer. By using this new measured diameter, two samples were machined for the result verification. The result shows these samples were over than specification. This phenomenon might due to the measurement by vernier calliper is not accurate on cutting tool which has three tooth. Second measurement has been conducted by using the Coordinate Measuring Machine (CMM) to measure the cutting tool. The new measurement was 3.95mm which is a bit different compared to previous measurement. Then, the next verification on new diameter was performed on two samples. The positive results obtained when the dimension between the required specifications but at maximum area. Therefore, the next experiment has been conducted in order to get the optimum dimension for this product.

This final experiment (experiment 5) is intended to get the optimum dimension of the product. The result which obtained in the experiment 4 shows the dimension is already in specification but almost at the maximum limit. Therefore, experiment 5 will combine the theory that get from the experiment 2 which is the dimension will slightly decrease when the value of Feed rate and DOC is increase. In this experiment, only DOC is increase, while the feed rate value was remain at 1000mm/m. The final result obtained as in Table 7.

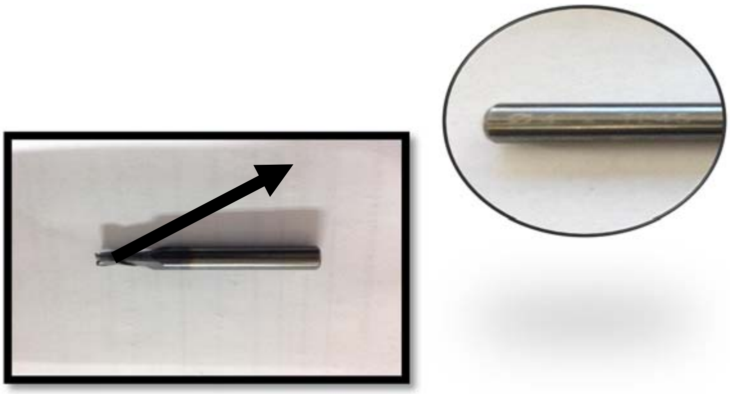

Figure 8. cutting tool diameter

Table 6. Data from experiment 4

No	Comment	Spindle speed (RPM)	Feed rate (mm/m)	DOC	Measurement (6mm + 0.015)	Production time (min)	Result
1	Measure the cutting tool size using Vernier calliper, Dimension =3.86mm	4000	1000	0.2	6.196	9m 45s	Measurement using calliper is not accurate
2		4000	1000	0.2	6.194	9m 44s	
1	Measure the cutting tool size using CMM Dimension =3.95mm	4000	1000	0.2	6.015	9m 44s	Data in spec but hit the maximum limit
2		4000	1000	0.2	6.015	9m 46s	

Table 7. Data for Experiment 5

No	Comment	Spindle speed (RPM)	Feed rate (mm/m)	DOC	Measurement (6mm + 0.015)	Production time (mnt)	Result
1	Increase the DOC value for reduce the processing time	4000	1000	0.5	6.013	3m 58s	All data is accepted with faster processing time
2		4000	1000	0.5	6.012	3m 58s	
3		4000	1000	0.5	6.013	3m 56s	

Experiment 5 was conducted to verify the new cutting tool diameter with the best parameters setting get from previous experiment whether effect the final product dimension. Based on Table 7, it show all dimensions are in the specification and accepTable. Beside that the production time also was improved a lot and become more faster than the initial process. The finding and solution from this experiment can be accepted for improving product quality on dimensions and also become more productive to manufacture in large quantity.

3.5 Improve

In the improve phase, it is about the implementation of true solution that obtained from the analysis phase. There are lot of inputs and findings were gained from the experiment conducted during the analysis phase. For this case study, all inputs were considered for developing a model for effective lean six sigma implementation for CNC milling process. This model will used as a guideline for machinist in order to get the best quality with high productivity.

In statistics, a mediation model is used to identify and explain the mechanism or process that underlies an observed relationship between an independent variable and a dependent variable via the inclusion of a third hypothetical variable, known as a mediator variable. In this project, the mediation model has been developed based on three independent variables to achieve the two dependent variables.

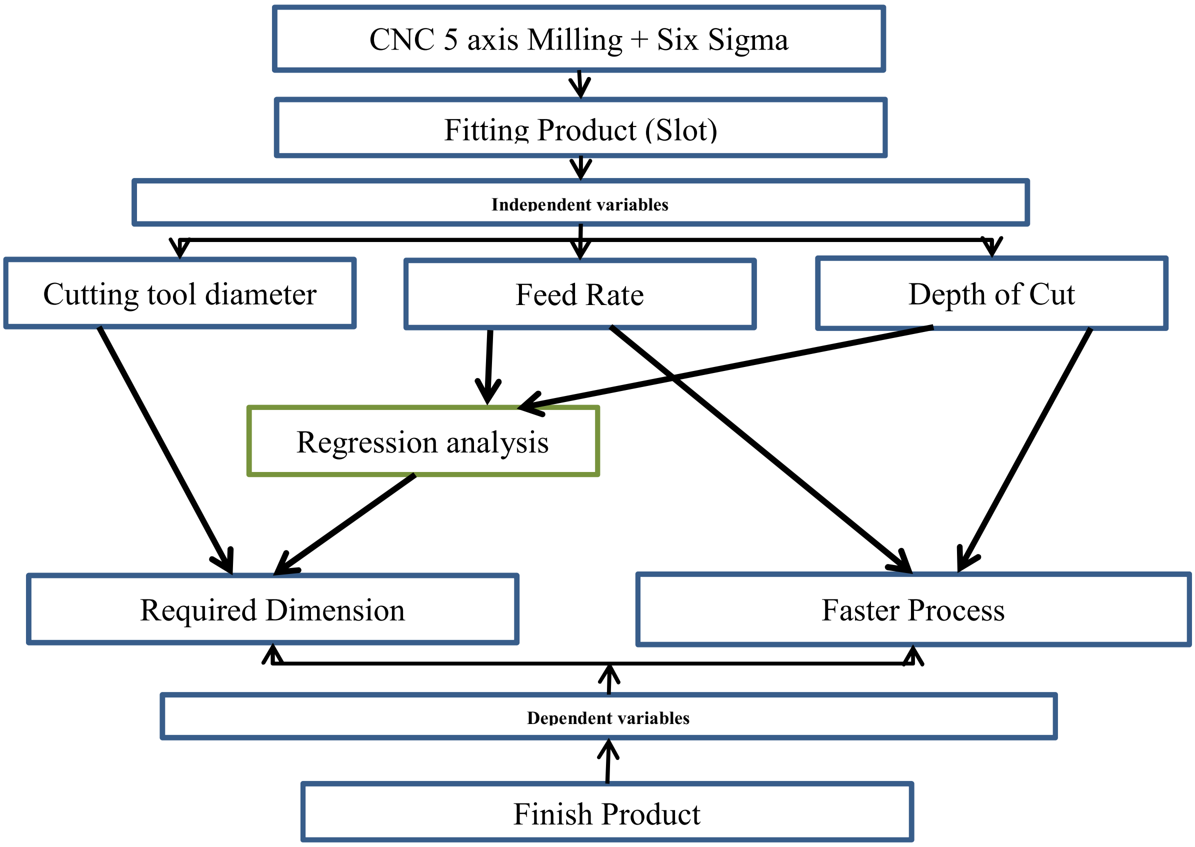

Figure 9. Mediation Model

This model was established by examining the inter relationship between cutting tool diameter, feed rate, depth of cut (DOC) and quality & productivity of the product. In this model, cutting tool, feed rate and DOC were made as a predictor variable. While the product quality & productivity (dimension and process time) as the outcome variable as illustrated in Figure 9.

From the five experiment conducted, the result shows that the feed rate and DOC have a direct positive influence on process time and the tool diameter is influence to the dimension Most interesting findings from this research is the combination of this three independent variables will produce the best product quality and productivity in term of product dimension and also the faster process time.

Therefore, by implementing this model, it will eliminate the all the wastes that contribute to the process and directly increase the production productivity.

3.6 Validate the model
The validation model was established as to ensure the final result obtained is according to the specification target. A case study has been designed and developed for producing 25 samples of machining parts based on procedure and parameters as suggested in the developed model. This case study used the new cutting tool diameter 3.97mm with the suggested parameters of feed rate 1000mm/m and depth of cut 0.5mm.

In the improvement phase, the investigation was carried out by doing the comparison between the improvements result and the initial process. Four factors have been selected as the benchmarking values to prove the improvement process is better than the initial process. These factors are standard deviation, process capability (Cp), Yield and sigma level.

Table 8. Comparison for dimension A and B

	Dimension A	
	Before improvement	**After improvement**
Standard deviation	**0.05**	**0.0008**
CP value > 1.2	**0.05**	**2.75**
Yield =100%	**12%**	**100%**
Sigma level=6σ	**0.3σ**	**6σ**
	Dimension B	
	Before improvement	**After improvement**
Standard deviation	**0.04**	**0.0008**
CP value > 1.2	**0.06**	**2.86**
Yield =100%	**12%**	**100%**
Sigma level=6	**0.3σ**	**6σ**

Table 8 shows the significant result obtained for both dimension A and B. The dimension variation has improved from 0.05 to 0.0008. In term of Cp, the process show very high capability compared to initial process, from 0.05 and 0.06 to 275 and 2.86. In addition, the result also show the process is drastically improves from the 12 % yield to 100% yields. The process achieve the highest sigma value of 6 means the measurement is the nearest of specification limits.

3.7 Control
Control is the last step of the Six Sigma five step process DMAIC. The objective of Control is to develop and implement the best controls to maintain the gains and to celebrate, share and reward the successes. In this project, the control has been set by documenting and standardizes the procedures and parameter as carried out in the analysis phase. The machinist who will manufacture khufi must understand the model and how it is work. A proper training and explanation from the expert is necessary to ensure the process is running as per plan in order to produce the good quality product.

4. Conclusions
The implementation of six sigma in the production of kuhfi has been considered successful because the process performance was improved tremendously. This research has been successfully eliminate the process variability and unfit product through identifying actual cutting tool diameter. In order to ensure the process is sustained, the improvement process was transformed into model development as per objective no 3. This model has been positively validated through four selected factors such as standard deviation, process capability, yield and level of sigma. As a conclusion, Lean Six Sigma

implementation can be helpful in eliminating the nonconforming product or improving the organization quality and cost reduction.

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