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Continuous Quality Improvement in Textile Processing by Statistical Process Control Tools: A Case Study of Medium-Sized Company

Benjamin Duraković
International University of Sarajevo
Faculty of Engineering and Natural Sciences
Address: Hrasnička cesta 15,
71210 Ilidža, Sarajevo
Bosnia&Herzegovina
E-mail: durben2@yahoo.com

Hazim Bašić
University of Sarajevo,
Mechanical Engineering Faculty
Address: Vilsonovo šetalište 9,
7100 Sarajevo
Bosnia&Herzegovina
E-mail: basic@mef.unsa.ba

Abstract

Maturity of companies, organizational culture and costs are some of the major limiting factors for implementation of cost-effective six sigma methodology in Bosnian companies. Purpose of this paper is to analyze possibilities of applying six sigma concept in a medium-sized company with 200 employees. Considering all characteristics of the company, in this case, implementation model was proposed and tested. The project included process monitoring using statistical process control charts for two different periods, before and after improvement. Dominant defect and its causes were identified and it was found out that the process was out of control. Implementation of improvement measures, dominant defect was eliminated but the process has remained out of control. As a conclusion, the test indicated that the model is effective but it takes more iteration to achieve the desired state.

Key words: Six Sigma, process improvement, defect, control chart.

1. INTRODUCTION

Six Sigma as more advanced quality system has recently become attractive to many companies especially for those that aspire to business excellence. After many successful stories of implementing Six Sigma in large global companies such as General Electric, Caterpillar and others, today Six Sigma is more likely becoming a successful story in some smaller companies over the globe [1].

Also, there is no unique definition of Six Sigma, but it is possible to outline some positive aspects. Six Sigma utilizes hardware and software of information technology for problem solving [2]. It is a platform for self-assessment and improvement, on a project-by-project basis using statistical tools for real-world applications by specially trained personnel [3]. Six Sigma is a more advanced level of quality, which will certainly implement those organizations that tend to business excellence after QMS certification per ISO9000 series. There are four elements of the Six Sigma definition: parallel-meso structure, improvement specialists, structured method, and performance metrics [4]. Six Sigma is not a certification scheme for quality like ISO9000 or ISO14000. There is no organization that claim to be 'certified to Six Sigma', and there is no internationally recognized body to certify or register companies that are 'Six Sigma compliant' costs [5]. Six Sigma is an opportunity for organizations to increase the product/process quality and profits, and to reduce costs [6].

In statistical terms, sigma (σ) is a measure of scattering processes. It is defined as having less than 3.4 defects per million opportunities or success rate of 99.9997%, which is the ultimate goal to improve and reduce the costs of poor quality at 1÷2 % [7]. Six Sigma is defined as a set of techniques based on Statistical Process Control (SPC), which can help companies to achieve significant improvement in quality and therefore increase competitiveness [8].

Six Sigma provides a comprehensive plan, which helps companies to integrate appropriate statistical tools and other techniques in a "comprehensive" tool, for process improvement. These tools can be applied in individual phases of Define, Measure, Analyze, Improve and Control (DMAIC) methodology in order to establish an effective processes quality improvement system [8] [9]. This structured method is based on Plan, Do, Check, Act (PDCA) cycle, but Six Sigma specifies the tools and techniques to use within each step, which is unique to Six Sigma [10]. The six sigma achievement also depends on the production age [11]. Therefore, following six sigma methodology this research will not attempt to hit the six sigma target. Firstly, the aim of the research is developing and testing a model for defect monitoring in a textile cutting process based on six sigma methodology. Secondly, testing the model for the

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six sigma methodology implementation to optimize a textile cutting production process in a mid-sized company. With the aim of showing state of the process, the data collection was carried out during two periods, i.e. before and after correction measure implementation. The length of the pre-test period was about one month and 168 batches have been checked. The length of the test period after implementation of the correction measures was approximately 30 days and also 154 batches (or 642,636 pieces) have been checked. In the discussion below, results of the analysis for considered periods are presented for three shifts [12].

Implementing Six Sigma in small and medium-sized enterprises is not sufficiently investigated and there is no enough data about successful implementation. The traditional approach to the implementation specific for large companies is expensive and requires a lot of resources. Therefore, implementation of Six Sigma in small and medium-sized enterprises represents an additional barrier to the success of such projects [13].

Six sigma concept discussed in this paper is developed for an export-oriented medium-sized company that employs about 200 workers, which took in account all specifics of business processes and problem faced. The approach in the implementation typical for large companies was modified in a manner that will enable the implementation of projects using fewer resources, which makes it applicable to medium-sized companies [14], [15]. In order to maintain its competitive advantage, the company is dedicated to the programs of implementing advanced quality systems such as six sigma or integrated lean six sigma, immediately after implementation of ISO standards [16].

The purpose of this work is to develop and test model for textile cutting process optimization suitable for medium-sized company. The model can be considered as framework for the widespread use of six sigma in Bosnian companies, particularly in SMEs. The primary goal of the test is to reduce the number of defects that occur in the process. Due to defects in the production process, outages had been observed that lead to delay delivery in some cases. Therefore, additional time, material and transportation are necessary in order to deliver parts to the customer site per Just in Time principle. In the worst case, this leads to reducing regular production time, working under stress, making extra costs, new defect accumulations, which reflects to the regular production process schedule.

2. RESEARCH METHODOLOGY

As a first step in developing model proposal was the approach to the production process mapping and categorizing on the major and side processes (subordinate). Also in this step was developed continuous improvement algorithm proposal and process of nomination and selection of new projects. The second step was the identification of processes that have a determinate process of work, which is one of the main requirements for DMAIC methodology application.

The third step was the analysis of collected data from the process collected over past year and dominant cause identification using statistical tool. Also, in this step were tested process capability indices (C_p and C_{pk}) as indicators of process capability to produce output within specified limits. To get an impression of how well the process fits within the given specification range is represented by process capability index C_p.

$$C_p = \frac{USL - LSL}{6\sigma} \tag{1}$$

USL – Upper Specification Limit
LSL – Lower Specification Limit
σ – standard deviation

C_{pk} index shows how well the process is centered within the specified limits.

$$C_{pk} = \min\left[\frac{USL-\mu}{3\sigma} \quad or \quad \frac{\mu - LSL}{3\sigma}\right] \tag{2}$$

μ – process mean

Calculation and interpretation of these indices included the following assumptions:

- data distribution can be approximated by a normal distribution;
- the process is stable and causes no significant variation (under control);
- process tracking using appropriate control charts (single-sided specification).

Some companies require that the minimum value of C_p index is 1.33. Some other companies raise this requirement up to 1.67 or $Cp \geq 2$, what corresponds to the Six Sigma level. If $C_p<1$, it means that process mean μ is outside of specified range and produces high percentage of defects but if the process is centered in that case $C_{pk} = C_p$, and if $C_p > 1$ then process meets specifications. Also, if the process is "under control" computing capability index does not make sense [15].

The forth step was the improvement measures and result verification. As Six Sigma analysis tools fishbone diagram for brainstorming sessions, p-control chart, Pareto analysis and correlation are used in this step [14]. For the result verification software is used for readings of attribute control charts and capability indices calculation and Pareto.

2.1. Structured Method

Once the improvement project is implemented, the performance of the process is necessary to improve continuously per DMAIC methodology with the aim of business excellence aspiration. This approach allows the effective use of data in order to eliminate the causes of defective products. In accordance with this requirement, the DMAIC methodology application flowchart is designed for the manufacturing process ***Figure 1***.

Process monitoring control charts are used to collect and analyze data, and based on that, it is possible to act proactively in problem solving. Using *p*–control chart it is possible to track "good/bad" part characteristics. Using $\overline{X}$ *R*-control charts it is possible to track measured values of the part features. Fishbone diagrams are used for brainstorming sessions that take into account the main affecting elements of the process quality (man, machine, material, method, environment, and measurement). If any of these elements have significantly changed, the system of the processes will be changed as well, and there will be corresponding changes in product quality.

Software is used to analyze collected data that automatically show the state of process in the control charts and calculating process capability indices C_p and C_{pk}.

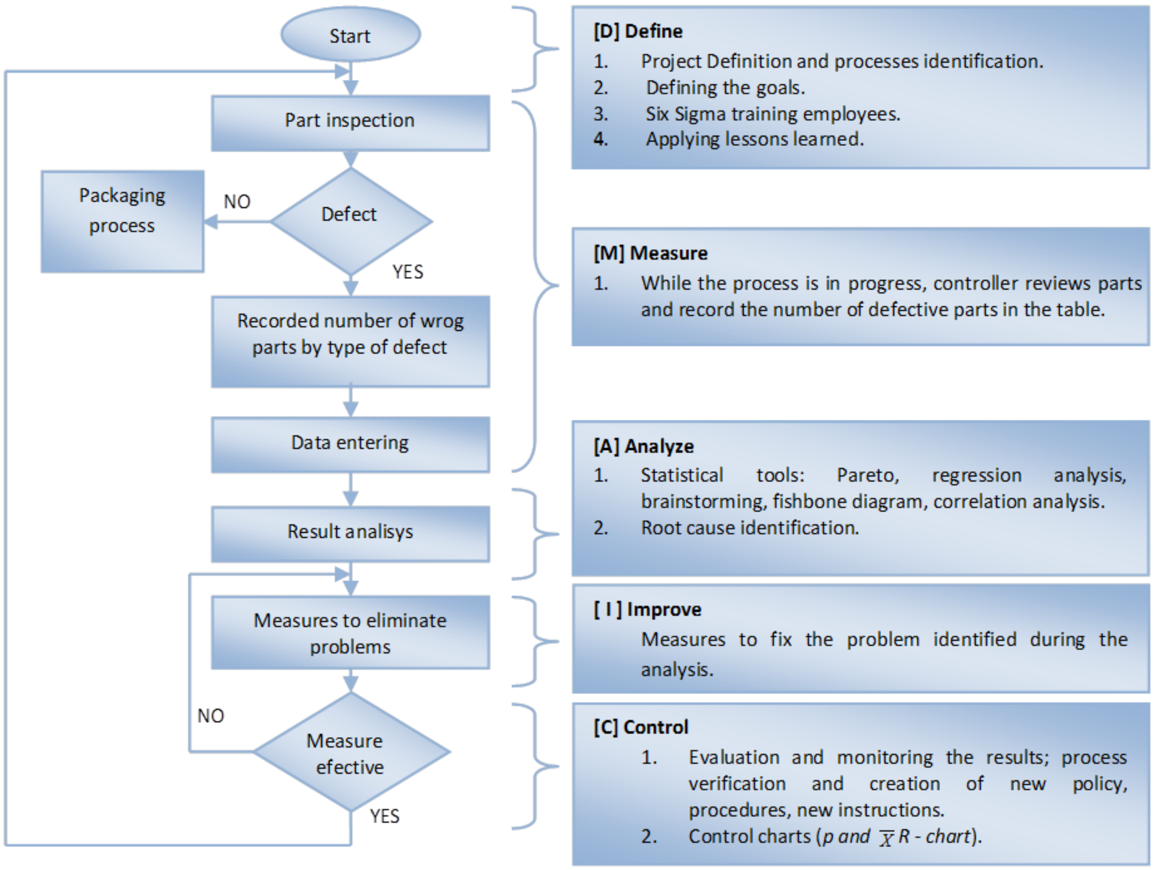


Figure 1. Continuous improvement framework flowchart

2.2. Strategic Project Nomination and Selection

Project approach guarantees a well-founded basic cause analysis and thus optimization sustainability. It is disciplined process that will help managers to focus on developing and delivering improved products and services. The main idea is to build a system for defect monitoring and figure out how to eliminate them trough implemented projects [17].

The process of nomination and selection of projects is carrying out per the following algorithm (*Figure 2*). Everyone in the company is eligible for submitting project ideas and according to customer needs project of interest will be selected. Project selection process includes idea recognition, evaluation and finally selection. After this, according to the project complexity team can be assembled.

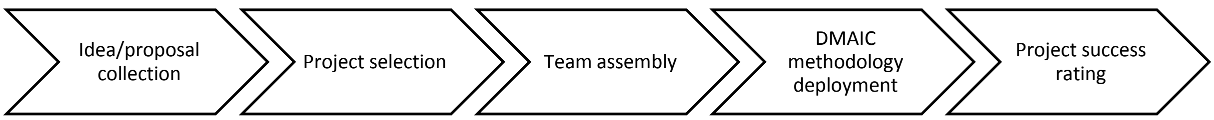


Figure 2. Strategic project selection and implementation

2.3. Improvement Specialists and Metrics

Due to the size of the company, it is anticipated that the project teams work "part time" on the project, and to be supervised by a Black Belt improvement specialist, who will manage projects and train team members [18].

Process performance will tend to improve with the use of the *Six Sigma structure* to reduce variation in organization processes by using *Black Belt improvement specialists*, a structured improvement procedure, and Six Sigma performance metrics with the aim of achieving strategic goals [19] [20]. Impact of various Six Sigma elements on project success within different project contexts such as parallel structure, *improvement specialists*, *structured method*, and clarity of *performance metrics* can together determine the success of process-improvement projects. Leadership engagement, strategic project selection, and psychological safety can positively affect these elements, on different ways in different project environments. Also, small and midsized companies have a low level of Six Sigma maturity, which could be successful in executing their project [21] [22].

Using this model, the company has a framework for optimizing textile cutting process, where it is necessary to take corrective action first in order to stabilize the process and then undertake improvement steps.

3. RESULTS AND DISCUSSION

According to the algorithm ***Figure 1***, in this section is applied DMAIC methodology step by step as described above.

2.4. Process Mapping

The main production process of textile cutting is carried out in four phases and consists of nine CNC machines. Features of this process are high flexibility, high production, a large number of defective units, and longer production time per unit. On that basis, the main process operation had been identified in the following stages (*Figure 3*).

A side process of the textile cutting is “cutting through” (press cutting) that takes place in four phases and consists of three presses. Features of the process are high speed per unit of the product, a low number of defective pieces, modular parts (inflexibility) and low productivity.

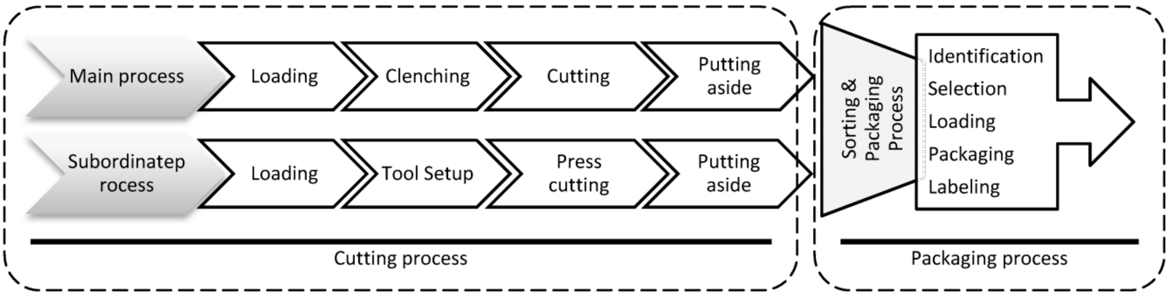


Figure 3. Textile cutting process

Another side process of sorting and part preparation for the next process of sewing had been identified as well. This process consists of selection and packaging of the parts per sewing plan. Features of this process are: small available space, slow identification and large variety of parts. On basis of sewing plans, workers pack required quantities of assemblies and sub-assemblies. Dominant defects from this process are wrong quantities and wrong parts, what is caused by workers. The previous three processes represent manufacturing process of textile cutting in which defects occur [12].

3.1. Project Selection

Statistically speaking, it was shown that the main process contributes most to the production of defective units and therefore according to the *Figure 2* this process is selected as an experimental project No. 1 for the optimization. The scope of the experimental project included project definition and DMAIC methodology application, where was done the following:

1. Existing data analysis over the past 12 months;
2. Dominant defect identification;
3. Identification of main defect causes;
4. Correction measure proposals and implementation;
5. Measurements of process after improvement and its analysis.

Experimental testing of the model was carried out on the main textile cutting process for three shifts. Attribute characteristics of the process output were monitored using *p*-chart. For this purpose all parts were inspected, defects were recorded, and process indicators were calculated. The process consists of CNC machines and has the following stages: textile loading, vacuum clenching, textile cutting and putting aside (*Figure 4*).

Figure 4. Production process line

The material is loaded in multiple layers using a vacuum clenching to the bench. The knife cuts at the same time all loaded sheets of the material per CAD generated contour. In case something goes wrong during the cutting operation, the knife will not produce only one defect but just as many as the sheets of the material is loaded.

3.2. Process Measure

While the process was running controller was monitoring the process and inspecting the parts using *p-chart* to track percentage of defective parts per batch. *Figure 5* shows the state of the process for both periods.

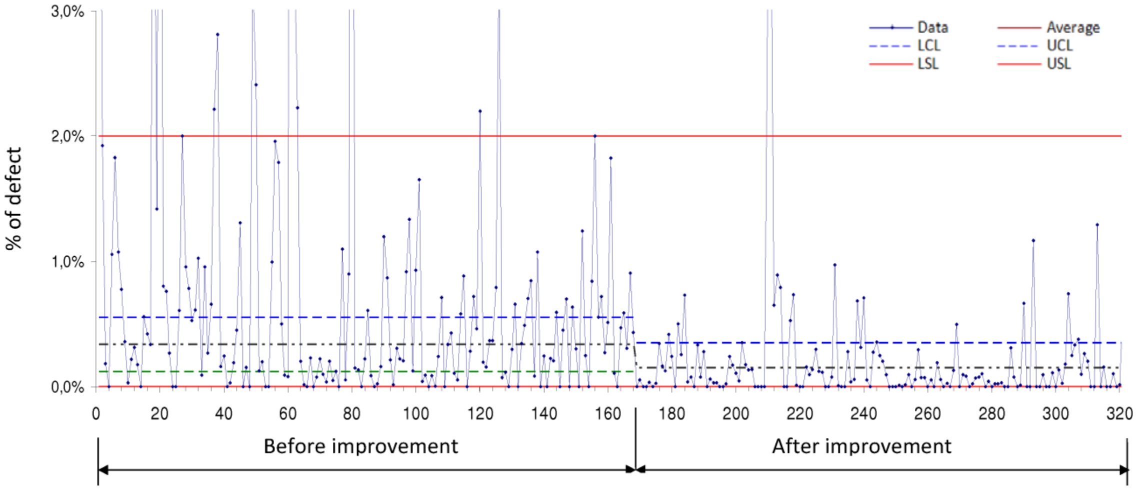


Figure 5. Process before and after changes

The process is not under statistical control because it does not operate within its natural process limits i.e. Upper Control Limit (UCL). Upper Specification Limit (USL) for the process is 2%, which in this case is not satisfied also. The process is very unstable and it is necessary to stabilize process first in order to obtain realistic values of process parameters.

3.3. Histogram Analysis

Figure 6 shows the defect histograms for both periods before and after improvement measures. These histograms do not correspond to the normal distribution; it is more asymmetric distribution, i.e., the binomial distribution, which is characteristic for the attribute quality characteristics, which is the case here. In the period before improvement, histogram shows that only 64 batches (out of 168) have 0.2% of defects and 30 batches have 0.4% of defects. Also, the rest of the batches have some percentage of the defects.

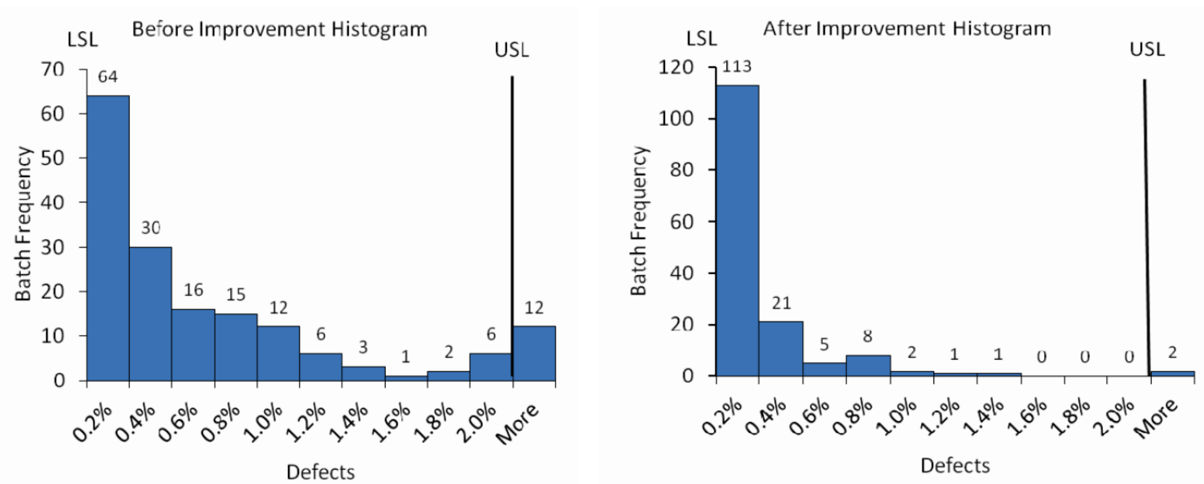


Figure 6. Histograms before and after improvement

Comparing with the period after improvement, histogram shows less spread of the defect through the batches. This improvement is significant because 113 batches (out of 154) had only 0.2% of defects, 21 batches had 0.4% of defects. Also, there are no batches with 1.6% to 2% of defects.

Outliers are evident in both cases. In the first period there were 12 batches outside USL which makes the process unstable. In the period after improvement outliers are still evident and there were two batches over 2%, which make the process unstable. So, after first iteration and dominant defect reduction process improvement is obvious but still unstable.

3.4. Discussion of Process Capability Indices

Based on calculated index value of C_p = 4.64, it is not possible to determine process sigma level. On the other hand, if PPM value is observed, which is 3352, that means that the process is about 4.2 σ. This discrepancy between the PPM and C_p is explained by the fact that the process is not under control and that the values of process capability indices are meaningless. The value of standard deviation (σ = 0.00072), is much higher than in the other case for the period after improvement.

A similar comment applies to the period after improvement (*period II*), where C_p = 5.58, and value of PPM is 1491, which means that the process takes about 4.5σ level but still is not under statistical control. Thus, in both cases, none of the above process capability indices are unacceptable. This means that is necessary to stabilize the process first and then make other improvements. The standard deviation in this case is smaller than for the period before improvement (*period I*) (σ = 0.000597), which can be visually inferred from the control chart. Therefore, the process capability index values are unrealistic because the process is not under statistical control.

In both considered periods there are outliers that appear to deviate markedly from the normal process flow. These extremes are usually caused by people not by machines. The actual value of the standard deviation will be smaller if outliers are neglected.

3.5. Pareto Analysis

Pareto diagram and regression are used to analyze collected data where interdependance between number of defects and batch size is explored. *Figure 8* shows defect frequencies from the process for both periods with the following meaning:

- Pulled fabric thread (defect code "28D")
- Marked defect on material (defect code "73"),
- Wrong cut - *holes*, *„V-cut“*, *notch* (defect code "68B")
- Dirty (defect code "28J"),
- Uncategorized defects (defect code "OS").

Pareto analysis showed that dominant defect for pretesting is pulled fabric thread "28D" (***Figure 8***). After brainstorming session and problem solving procedure, defect 28D is reduced. This is systemic defect caused by machine due to irregular sharpening of material cutting knife (***Figure 9***). Due to bumps on the knife cutting edge, formed by sharpening grinding wheels, the knife couldn’t cut the last fabric thread on the cutting contour, causing drawn fabric thread in the next step "putting aside" (see *Figure 4*).

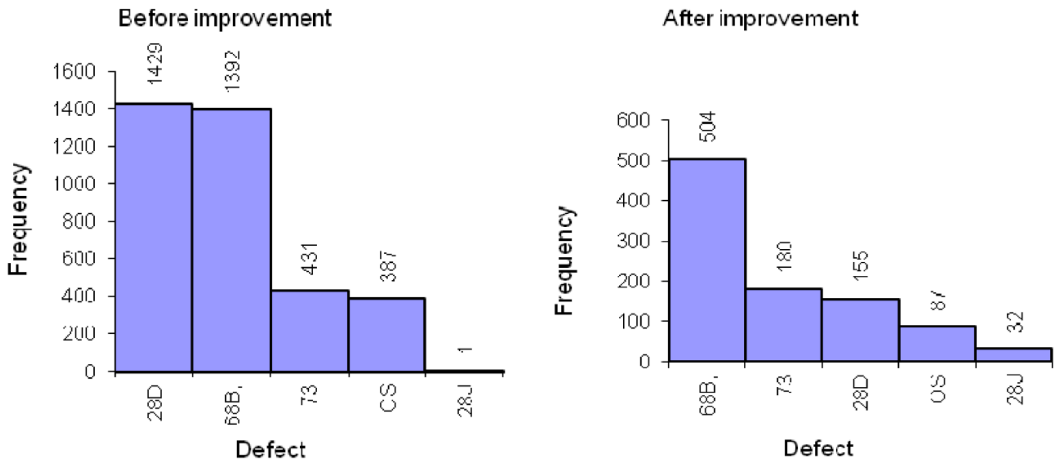


Figure 7. Two-period defect analyses

Another reason for the drawing thread is the blunt knife tip, where the first knife sting into the material and usually draws material thread. The cause of this bluntness is first sting knife tip hitting to knife guides or workbench in some cases.

3.6. Number of Defects and Batch Size Correlation

There was very small correlation between the batch size and number of defects (*Figure 8*), which means that little propagation of defects is evident from the increase in the number of material sheets of the batch. That means, if machine cuts 20 sheets at once, and if the operator mistakenly put an improper diameter drill, the drill will go through all 20 sheets and thus produce at least 20 defects. In that case, defect propagation is much higher than with a smaller number of sheets. Correlation was slightly higher for the period of "I" and was r = 0.38, while for the period of "II" correlation coefficient was smaller r = 0.21, which means that none of the calculated values are statistically significant and therefore they are not further discussed.

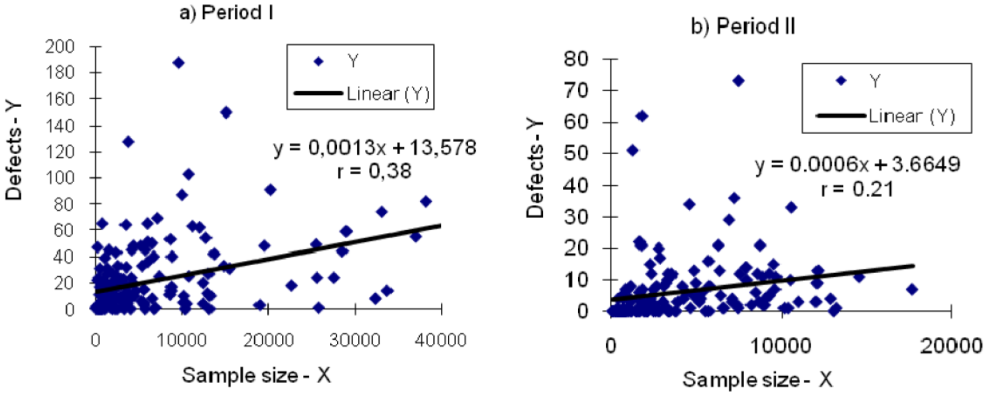
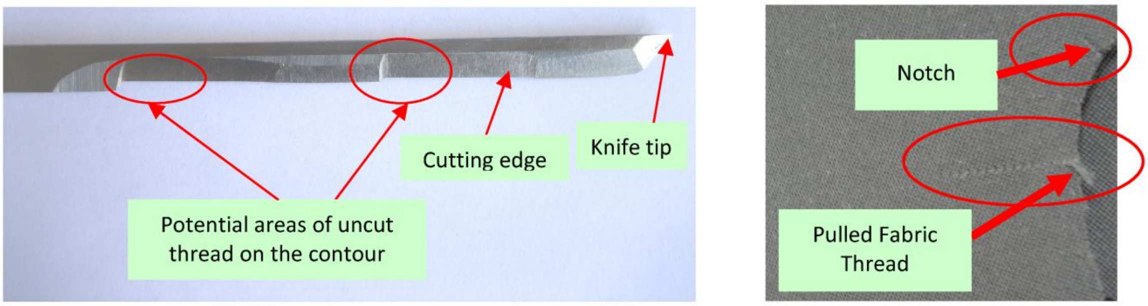


Figure 8. Defects depending on the batch size

As a next step it is necessary to maintain statistical process control per DMAIC methodology principle. Based on the previous iteration results it is necessary to take new actions in order to stabilize the process and then continue with the improvements that lead to six sigma quality level. This includes evaluation and monitoring of the each previous phase results, process verification and modification and creation of new policies, procedures, instructions to the employees. Software for defect monitoring in the production process provides a clear summary report of all process parameters creating a good history record.

3.7. Improvement

Pulled fabric thread defect is solved by changing method of knife sharpening, as a result of brainstorming. The new sharpening method uses a fine sandpaper belt instead of grinding wheels, which is incomparably much more convenient for setting grinder and making knife cutting edge uniform.



a) *b)*

Figure 9. Samples: a) Irregular knife sharpening; b) Pulled fabric thread "28D" and notch “68B”

With these changes the dominant defect “28D” (pulled fabric thread) is significantly reduced. Defect “68B” (irregular cut) caused by human factor became a new dominant defect. The process could be under control if the defect "68B" is neglected. In that case process picture becomes quite different, and process capability index becomes acceptable.

3.8. Control

Process control includes the evaluation and monitoring of the previous stage results, verification of the process modifications and creation of new policies, procedures, and instructions to the employees. In this phase basic tools are control charts: p-chart for qualitative characteristics and $\overline{X}$ R chart for quantitative monitoring of quality characteristics such as the depth of the notch, the position of the hole, “V cut” etc. Based on ***Figure 1***, it is necessary to maintain statistical process control, and in accordance with the results of the process monitoring to undertake actions. Software for defect monitoring gives a concise and clear picture of all the process parameters.

4. CONCLUSION

The main result of applying the described method can be suitable solutions applicable to small and medium-sized organizations and using project part time workers. Application of the algorithm promises success in improving the process because it provides a scientific basis in decision-making process to eliminate defects. Systemic and systematic approach can be applicable to the entire production process, allows that in any moment the process parameters can be easily calculated (natural process limits, standard deviation ...), and process capability indices C_p, C_{pk}. On that basis sigma level of the process can be determined. Software enables company managers to have in one place all information's about the process. Accordingly, it is possible to take appropriate corrective and preventive actions.

Proof of this is an iteration of the experimental testing of the concept in order to evaluate the model efficiency and influence of certain factors on the process stability. In the first iteration dominant defect caused by machine was reduced and some improvements had been achieved but the process was not stabilized yet. After implementation of the process changes, another defect became dominant, which is most likely caused by workers. This can be proved in the next iteration. The next iteration should focus on measures to reduce this defect and make other improvements that lead the process to be controlled. Continue repeating these iterations until it reaches the desired goal.

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