ADVANCED QUALITY MANAGEMENT

SPRING 2010

APPLYING SIX SIGMA QUALITY MANAGEMENT IN CLOTHES FOLDING

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(ACCORDING TO STUDENT ID)

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ABSTRACT

“Six sigma” is a top down methodology to solve the quality issues in the manufacture or service system. After the birth of it in Motorola in 1980s, six sigma has performed an active role in all industries to improve processes. Based on the knowledge we have learned in the class, we chose to practice our problem solving ability by a self organized project, which aims to improve the efficiency of T-shirt folding by using the classical DMAIC analysis method. Finally, after the whole semester we finished 4 experiments in total and developed a proto-model tool. The continuous improvement process utilized us all-round ability, i.e. Pareto analysis, ANOVA, Measurement system analysis, Brain storming etc. Process ability of different index show significant improvement, for example the Cp of width difference of the upper and lower side, which is the most common defect shown in the experiment, increased from 0.44 to 0.92 and finally reach 2.14. Based on the achievement we have got through the improvement process, we believe that the tool we developed will help our target customer in their daily work.

1 INTRODUCTION

1.1 Motivation

In real world, we will always be bothered by lots of small things, such as tidying the room, doing the laundry, folding the clothes. But smart people always develop advanced tools to help us to get rid of such annoying stuff. We have already got vacuum cleaner and washing machine to easy the work intensity of household duty, but how about the folding clothes? Driven by such curiosity, we start our adventure trying to find a more scientific way to get easier procedure or tools to please our potential customer.

So after the discussion of what we could do through the “clothes folding” project,
we defined the scope of work:

“Our project is to develop a more efficient and easy clothes folding method by trying different methodologies or advanced tools to reduce size variation and time consumption.”

Though we always complain the folded clothes are not identical which lead us impossible to make our wardrobe clean and tidy. But compared with the workers who are responsible for folding T-shirt in manufacturing company and people who sale T-shirt in the mall, our problem is insignificant. So our customer, which defined as the T-shirt folding workers in factory and shops, will benefit from our product and solution. Professional means high standard requirement, so our project’s output for these experienced workers should be consistent size within reasonable time requirement.

According to Linder man et al.’s definition of Six Sigma:

“Six Sigma is an organized and systematic method for strategic process improvement and new product and service development that relies on statistical methods and the scientific method to make dramatic reductions in customer defined defect rates”.

Here we decide to follow Six Sigma’s typical DMAIC steps, which consist of Define Measure Analysis Implement Control, to finish our project.

1.2 Flow chart of project development

Experiments:
- Traditional Method
- Tool 1: bought from Taobao: method 1, method 2
- Tool 2: self made: method 1, method 2
Figure 1-1 Flow chart of project development

Figure 1-1 shows we start from the tradition method. By continuous trying of different methods, we finally publish our wooden board tool. Here we conducted 3 main experiments.

- Experiment 1: traditional method, used as a contrast of the latter ones;
- Experiment 2: tool bought from Taobao, and try 2 methods of using it;
- Experiment 3: made tool by hand, prove our improvement.

1.3 Implementation stages

We divided it into six parts based on the time line as showed in Figure 1-2. We divide the whole project into 3 parts: preparation, conduct and summary.

![Plan of the project](image)

**Figure 1-2 Plan of the project**

**Preparation:**

1. Project analysis:

   Before the brain storming is conducted, we leave a long period for every group member to consider the whole project seriously.

   - Why we need to do this project?
   - Will anyone benefit from our diligent and systematic work?
   - Based on the preliminary clothes folding experiment conducted in class, is there any aspects be also included? Is the measurement significant to justify?

   Similar questions will appear in our mind, and this is the solid foundation of further progress.
2. First stage group discussion

After the intuitive explore of the potential working aspects of clothes folding project, the thoughts sharing process will make us understand each other in a comprehensive way rather than the chapter divided method. A blue picture was finished after the discussion.

- Define: what our goals, problem statements, CTQs, 5M1E etc.
- Measurement: indicators, error recourse, measurement methods etc.
- Analysis: fish-bone chart, process map, potential improvement aspects etc.
- Improvement: process flows, tools etc.
- Control: teaching process and later usage etc.

3. Project define & first stage analysis and proposal

Although the previous discussion has built a solid foundation of the later process, paper work and summary docs are needed to explain the defined aspects clearly. Causal relationship chart, swimming lane process chart, CTQs choosing and so on will be summarized and future experiment plans will be developed.

**Conduct:**

1. First stage experiment

After absorbing the critical experience of the first experiment in class, we come to a conclusion that the T-shirt which has lines made by folding will leads to unrealistic and false appearance short working time. So the first stage will chose a general T-shirt and conducted the experiment again. After that some improved methods is also be tested for further data collection.

After experiments, the analysis and data mining will leads the group some useful conclusions and new ideas will also be designed in the next phase experiment.

2. Second stage experiment
The designed experiments which introduce tools were conducted. During this phase we try different method to make the best use of the bought tool. But finally we decided to make a new one, according to the founding of the experience gathered. At this stage, our group member which is the executor of the experiments will be tested first. And then another group member will be taught in the optimized process and advance tools to test our project result.

**Summary:**

Summary the experience of the DMAIC improvement and finished the data explanation work. Using a top-down methodology to explain our project and finished the over-all doc files.

## 2 CASE STUDY

### 2.1 Define phase

#### 2.1.1 Define customers and requirements

In our project, customers are those workers who are responsible for folding T-shirt in manufacturing company, and people who sale T-shirt in the mall. After folding T-shirt, they continue to put the folded T-shirt in a packing bag. Customers require that they can use less time to finish folding a T-shirt, and also get good quality of T-shirt folding in a scientific way. The requirements of customers can be described in tree graph, as below in Figure 2-1.
Each requirement is defined in details as below:

1. **Time consumption**
   Customers require that time spent on folding beginning from holding the T-shirt in hand to putting the folded T-shirt on a table should be as little as possible.

2. **Width difference**
   Customers require that width difference between the upper side and lower side of the folded T-shirt should be as little as possible.

3. **Characteristic of symmetry**
   Customers require that the folded T-shirt should be symmetric according to the centric line of T-shirt.

4. **Length variation**
   Customers require that the length of the folded T-shirt should be constant, and length variation should be as little as possible.

5. **Width extension**
   Customers require that the width of bottom layer should not be bigger than the upper layer of the folded T-shirt, namely width extension should be close to zero.

6. **Length extension**
Customers require that the length of bottom layer should not be bigger than the upper layer of the folded T-shirt, namely length extension should be close to zero.

The requirements mentioned above can be summed up using math formula in Table 2-1. And the variables existing in formulas can be seen in Figure 2-2.

Table 2-1 Cause and effect matrix

<table>
<thead>
<tr>
<th>Customer requirement</th>
<th>Time</th>
<th>Width difference</th>
<th>Characteristic of symmetry</th>
<th>Length variation</th>
<th>Width extension</th>
<th>Height extension</th>
</tr>
</thead>
<tbody>
<tr>
<td>Formula</td>
<td>t</td>
<td></td>
<td>(2 \times l_4 - l_2)</td>
<td>(-d)</td>
<td>(\sigma(l_3))</td>
<td>(l_5)</td>
</tr>
<tr>
<td>Optimize way</td>
<td>Min</td>
<td>Min</td>
<td>Min</td>
<td>Min</td>
<td>Min</td>
<td>Min</td>
</tr>
</tbody>
</table>

Figure 2-2 Graph of variable

2.1.2. Analyze SIPOC of the project

After brainstorming among our group members, we get the final SIPOC in Table 2-2 as below.

Table 2-2 SIPOC table

<p>| Supplier | T-shirt manufactory, tools manufactory |</p>
<table>
<thead>
<tr>
<th>Input</th>
<th>T-shirt, tools, folding methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process</td>
<td>Flatten T-shirt, folding T-shirt with different tools and methods, putting the folded T-shirt on a plane</td>
</tr>
<tr>
<td>Output</td>
<td>time consumption, width difference, symmetric value, length variation, width-extension, length-extension</td>
</tr>
<tr>
<td>Customer</td>
<td>Workers who take charge of T-shirt folding in clothes manufacture, and people who sale T-shirt in the mall</td>
</tr>
</tbody>
</table>

### 2.1.3. Determine CTQ

Using the initial method, we fold the T-shirt, and measure all the variables in Figure 2. The result can be seen in Table 2-3 roughly.

**Table 2-3 Result of initial experiment**

<table>
<thead>
<tr>
<th>variable</th>
<th>Mean</th>
<th>StDev</th>
<th>Variance</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>t</td>
<td>9.671</td>
<td>0.569</td>
<td>0.323</td>
<td>8.810</td>
<td>10.930</td>
</tr>
<tr>
<td>l1</td>
<td>27.640</td>
<td>0.840</td>
<td>0.706</td>
<td>26.200</td>
<td>29.600</td>
</tr>
<tr>
<td>l4</td>
<td>39.795</td>
<td>2.174</td>
<td>4.728</td>
<td>30.800</td>
<td>41.200</td>
</tr>
<tr>
<td>l3</td>
<td>17.220</td>
<td>0.479</td>
<td>0.229</td>
<td>16.500</td>
<td>18.000</td>
</tr>
<tr>
<td>l2</td>
<td>30.440</td>
<td>0.619</td>
<td>0.384</td>
<td>29.300</td>
<td>31.600</td>
</tr>
<tr>
<td>l5</td>
<td>0.2100</td>
<td>0.2808</td>
<td>0.0788</td>
<td>0.0000</td>
<td>0.8000</td>
</tr>
<tr>
<td>l6</td>
<td>0.0950</td>
<td>0.2038</td>
<td>0.0416</td>
<td>0.0000</td>
<td>0.6000</td>
</tr>
</tbody>
</table>

Before we determine CTQ, we should identify what customers’ criteria are when they judge whether a folded T-shirt is qualified or not, namely USL and LSL, in order to define defects.

The definition of USLs and LSLs can be seen in the Table 2-4-Table 2-8.
Table 2-4 Definition of USL and LSL of time consumption

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>define USL and LSL of time consumption</td>
<td></td>
</tr>
<tr>
<td>average of t (e)</td>
<td>9.571</td>
</tr>
<tr>
<td>acceptable error (f)</td>
<td>10%</td>
</tr>
<tr>
<td>tolerance limits (tolerance limits=e*f)</td>
<td>0.9671</td>
</tr>
<tr>
<td>USL=(e+tolerance limits)</td>
<td>10.6381</td>
</tr>
<tr>
<td>LSL</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 2-5 Definition of USL and LSL of width difference & characteristic of symmetry

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>define USL and LSL of width difference &amp; characteristic of symmetry</td>
<td></td>
</tr>
<tr>
<td>average of l₁</td>
<td>27.64</td>
</tr>
<tr>
<td>average of l₂</td>
<td>30.44</td>
</tr>
<tr>
<td>final average (a)</td>
<td>29.04</td>
</tr>
<tr>
<td>acceptable error (b)</td>
<td>5%</td>
</tr>
<tr>
<td>tolerance limits (tolerance limits=a*b)</td>
<td>1.452</td>
</tr>
<tr>
<td>USL (USL=tolerance limits)</td>
<td>1.452</td>
</tr>
<tr>
<td>LSL (LSL=-tolerance limits)</td>
<td>-1.452</td>
</tr>
</tbody>
</table>

Table 2-6 Definition of USL and LSL of length variation

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>define USL and LSL of length variation</td>
<td></td>
</tr>
<tr>
<td>average of l₃ (c)</td>
<td>39.795</td>
</tr>
<tr>
<td>acceptable error (d)</td>
<td>5%</td>
</tr>
<tr>
<td>tolerance limits (tolerance limits=c*d)</td>
<td>1.98975</td>
</tr>
<tr>
<td>USL (USL=c+tolerance limits)</td>
<td>41.78475</td>
</tr>
<tr>
<td>LSL (LSL=c-tolerance limits)</td>
<td>37.80525</td>
</tr>
</tbody>
</table>

Table 2-7 Definition of USL and LSL of width extension

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>define USL and LSL of width extension</td>
<td></td>
</tr>
<tr>
<td>average of l₁</td>
<td>27.64</td>
</tr>
<tr>
<td>average of l₂</td>
<td>30.44</td>
</tr>
<tr>
<td>final average (a)</td>
<td>29.04</td>
</tr>
<tr>
<td>acceptable error (g)</td>
<td>1%</td>
</tr>
<tr>
<td>tolerance limits (tolerance limits=a*g)</td>
<td>0.2904</td>
</tr>
<tr>
<td>USL (USL=tolerance limits)</td>
<td>0.2904</td>
</tr>
<tr>
<td>LSL</td>
<td>0</td>
</tr>
</tbody>
</table>
Therefore, the USLs and LSLs mentioned above can be summed up in Table 2-9.

Table 2-8 Definition of USL and LSL of height extension

<table>
<thead>
<tr>
<th>Define USL and LSL of height extension</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>average of 1σ (c)</td>
<td>39.795</td>
</tr>
<tr>
<td>acceptable error (d)</td>
<td>1%</td>
</tr>
<tr>
<td>tolerance limits (tolerance limits = c*d)</td>
<td>0.39795</td>
</tr>
<tr>
<td>USL (USL = tolerance limits)</td>
<td>0.39795</td>
</tr>
<tr>
<td>LSL</td>
<td>0</td>
</tr>
</tbody>
</table>

Thus, a folded T-shirt can be considered as a defect when its characteristics regarding time consumption, width difference, symmetric value, length variation, width-extension, and length-extension go beyond the USLs and LSLs.

Next step, we analyze the experiment result of our initial method, and get the defect table, as seen in Table 2-10.

Table 2-9 USLs and LSLs according to customers’ requirements

<table>
<thead>
<tr>
<th>Request</th>
<th>LSL</th>
<th>USL</th>
</tr>
</thead>
<tbody>
<tr>
<td>time consumption</td>
<td>0s</td>
<td>10.6381s</td>
</tr>
<tr>
<td>width difference</td>
<td>-1.452 cm</td>
<td>1.452 cm</td>
</tr>
<tr>
<td>symmetric value</td>
<td>-1.452 cm</td>
<td>1.452 cm</td>
</tr>
<tr>
<td>length variation</td>
<td>37.80525 cm</td>
<td>41.78475 cm</td>
</tr>
<tr>
<td>width-extension</td>
<td>0</td>
<td>0.2904 cm</td>
</tr>
<tr>
<td>length-extension</td>
<td>0</td>
<td>0.39795 cm</td>
</tr>
</tbody>
</table>

Table 2-10 Defect table

<table>
<thead>
<tr>
<th>Defect type</th>
<th>number of defect</th>
</tr>
</thead>
<tbody>
<tr>
<td>time consumption</td>
<td>2</td>
</tr>
<tr>
<td>width difference</td>
<td>18</td>
</tr>
<tr>
<td>symmetric value</td>
<td>6</td>
</tr>
<tr>
<td>length variation</td>
<td>1</td>
</tr>
<tr>
<td>width-extension</td>
<td>8</td>
</tr>
</tbody>
</table>
Finally, we use Minitab software to get the Pareto Chart of defect type, as seen in Figure 2-3.

![Pareto Chart of defect type](image)

**Figure 2-3 Pareto Chart of defect type**

We can see that in Pareto Chart the frequency of defects, including width difference, width extension and symmetric value, has accounted for nearly 80% of total defects. Besides, time consumption is a significant variable, and it should be as little as possible. Consequently, the aim of our project is to minimize time consumption, the width difference between upper and lower side of a folded T-shirt, and width extension, and to make the folded T-shirt a symmetric one. In other words, our CTQ is time consumption, width difference, width extension and symmetric value.

2.1.4. **Determine variables we should measure**

After determining two criteria as our CTQs, which are width difference and symmetric value, we should choose proper variables, which should be measured in our experiment, to define the CTQs. Basing on CTQs, we can easily choose these variables, including time consumption (t), width of bottom edge of T-shirt (l₁), width of top border of T-shirt (l₂), length from trademark to one side (l₄), and width...
extension ($l_5$). And the CTQs can be calculated in this way.

- Time consumption = $t$
- Width difference = $|l_2 - l_1|$
- Symmetric value = $2 * l_3 + d - l_2$
- Width extension = $l_5$

Besides, when we reduce the defects caused by the CTQs, we should not increase the defects caused by other aspects. Therefore, we should measure $l_3$ and $l_6$ in order to monitor their situation.

Finally, the goal statement of the project defined by the team members was the reduction of defects from 1 DPU to 0.067 DPU (defects per unit).

### 2.2 Measurement phase

Measurement is the second phase of the DMIAC project; it is a critical step to identify the relationship of the output and the input factors. Based on the CTQ defined in the define phase, through the measurement phase, we have to clarify measurement of the output, and collect the data to describe output quantification. Especially, through the process capability analysis can we identify the fluctuate rule of the output ‘$Y$’ and catch up the potential chance to improve. Hence, the measurement phase has the purpose of mapping the current process through flow chart and establishing cause and effect diagram that describe the project output ‘$Y$’.

#### 2.2.1. Mapping the current process

According to the analysis of the team, we used flow chart to map our process show as Figure 2-4:
2.2.2. Cause and effect diagram

After identifying the process of folding T-shirt, we proceeded to analyze the potential causes of the defects. Cause and effect analysis was carried out to illustrate the various causes that affect the quality and velocity. Figure 2-5 shows the potential causes that could generate a failure in the T-shirt folding operation.

![Cause and effect diagram](image)

2.2.3. Data collection plan

Though we have already found the potential causes of the defects of folded T-shirt, but due to the constraint of the time and resources, we just focused on the aspects of the methods and measurements. Besides, our projects’ goal is to provide a way for a manufacturing company and people who sale T-shirt in the mall, hence, we don’t consider the manpower, material and other aspects. Since they have to fold all different kinds of clothes in various places, though these various factors would
influence their performance.

Hence, in our project, we focus on the measurements and methods to fold clothes. Based on the defects we define, we give the indictors; we have to measure the indictors and collect data in different situation, including $l_1 - l_6$ showed as bellow and time to finish one time folding.

2.2.4. Measurement System Analysis

In the part of measurement system analysis, we want to identify the accuracy and precision of our measurement system which are always indicated by the bias and variation. According to the Gauge R&R analysis, the variation in measurement system is sub-divided into variation due to the repeatability and variation due to the reproducibility. In the first improvement experiment we have two persons to measure the folded T-shirt twice each. We analyzed the data and the result showed as bellow.

We have six indicators to measure showed as below figure, the tool we use is a ruler and its accuracy reaches to ‘cm’. The measure process is very simple, we just put the ruler to the indicators we want to measure and read the data we get. So we have to evaluate the measurement system to determine whether the system can meet our requirement.

Table 2-11 show the analysis results

<table>
<thead>
<tr>
<th>Variable</th>
<th>Study Var(%SV) (before improve)</th>
<th>Study Var(%SV) (after improve)</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1</td>
<td>24.41%</td>
<td>26.24%</td>
</tr>
<tr>
<td>L2</td>
<td>53.87%</td>
<td>28.45%</td>
</tr>
<tr>
<td>L3</td>
<td>14.05%</td>
<td>14.05%</td>
</tr>
<tr>
<td>L4</td>
<td>46.33%</td>
<td>10.39%</td>
</tr>
<tr>
<td>L5</td>
<td>53.87%</td>
<td>0</td>
</tr>
</tbody>
</table>
From the second column of Table 2-11, we can see the P/TV value of the measurement system of ‘L2’ and ‘L4’ are 53.87% and 46.33% separately, which are for more large than 30%, so the variation is too big to accept. Besides, the number of groups is 2, which is also less than 5, the discrimination capability still can’t satisfy our demand. Hence, we have to improve the measurement system in order to obtain more reliable data.

The third column of Table 2-11 show the improvement of the measurement system, we can find that the measurement system is more accurate and precise, which is more reliable to use for measuring. Therefore, comparing the previous measurement system, the proposed measuring system shows a relative good measurement system capability.

2.2.5. Process capability analysis

First experiment:

The precondition of the process capability analysis is the output has to follow normal distribution, so before analysis, we have to test the normal distribution of the data.

For the first experiment, L5 don’t follow the normal distribution. After Box-Cox transferring, we obtain the process capability for every parameter, showed as Figure 2-6. According to the process capability analysis, we can see that the index of the process capability is very low; it means that there is large space to improve.

![Figure 2-6 Process capability of symmetric and width difference](image-url)
Second Experiment (First improvement experiment)

Using the Minitab “normal test” command, we have that P-value of L5 which is indicator of the width extension is just 0.056. We set the level to be 0.1, and it is less than the level, so it doesn’t follow the normal distribution; we have to transfer the data to normal distribution using Box-Cox transferring.

![Diagram](image)

Figure 2-7 Process capability of L3, width difference, symmetric and defects Pareto chart

After the first improvement, we calculate the process capability index for each indicator, we find that after improvement, the variance decreases and every point is more close to the target we set showed in Figure 2-7. The defects which are caused by width deference and symmetric problem decrease a lot, but width extension problem increases sharply. Besides, though the variation is very low, all the process capabilities are not very high, and the highest \( C_p = 1.26 \). Besides, most of the points are a little far away from the target. We have to figure out methods to improve the process, not only decrease the variation, but also get close to the target or even equal to the target.

From Figure 2-7, we can see that the defects also decrease a lot, defects caused
by the width difference and symmetric problems decrease sharply, but another factor caused defects increase. Besides, the process capability index is not high enough and time consumption increases. Hence, there is still space to improve.

**Third Experiment (Second improvement experiment)**

After the second improvement experiment, we got the data. Using Minitab to statistic the data, the process capability shows as Figure 2-8. We can see that the process capability improve a lot, the highest $C_p$ reaches to almost 3. Hence, the improvement is acceptable and effect.

![Figure 2-8 Process capability after second improvement](image)

### 2.3 Analysis phase

Since our objective is trying to minimize the mean value width difference, width extension, symmetry and variance value of length, as well as try to spend less time to fold the T-shirt. Therefore, in analysis part, we will analyze these five results one by one.
2.3.1. Analysis of first experiment

Table 2-12 Descriptive statistics of the data of second experiment

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>StDev</th>
<th>Variance</th>
<th>Minimum</th>
<th>Median</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Width difference</td>
<td>-2.800</td>
<td>1.012</td>
<td>1.023</td>
<td>-4.700</td>
<td>-2.850</td>
<td>-1.100</td>
</tr>
<tr>
<td>Width extension</td>
<td>0.2100</td>
<td>0.2808</td>
<td>0.0788</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.8000</td>
</tr>
<tr>
<td>Symmetry</td>
<td>0.500</td>
<td>1.252</td>
<td>1.568</td>
<td>-1.100</td>
<td>0.100</td>
<td>2.900</td>
</tr>
<tr>
<td>Length</td>
<td>39.795</td>
<td>2.174</td>
<td>4.728</td>
<td>30.800</td>
<td>40.100</td>
<td>41.200</td>
</tr>
<tr>
<td>Time</td>
<td>9.671</td>
<td>0.569</td>
<td>0.323</td>
<td>8.810</td>
<td>9.540</td>
<td>10.930</td>
</tr>
</tbody>
</table>

From above figure, we get the descriptive statistics of those five parameters we will evaluate. In this experiment, the means of width extension, symmetric value are -2.800, 0.2100, 0.500 respectively, where the means of width difference, symmetric value are too big. Moreover, although the mean of length is within our expected bound [37.80525, 41.7847], its variance 4.728, is too large. Lastly, the time we take is too long, 9.671 second. In a word, we need make another experiment to get our expected goal.

2.3.2. Analysis of second experiment

Descriptive statistics

Table 2-13 Descriptive statistics of the data of second experiment

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>StDev</th>
<th>Variance</th>
<th>Minimum</th>
<th>Median</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Width difference</td>
<td>-0.441</td>
<td>0.555</td>
<td>0.309</td>
<td>-1.815</td>
<td>-0.313</td>
<td>0.240</td>
</tr>
<tr>
<td>Width extension</td>
<td>0.3905</td>
<td>0.3404</td>
<td>0.1159</td>
<td>0.0000</td>
<td>0.4587</td>
<td>1.3350</td>
</tr>
<tr>
<td>Symmetry</td>
<td>0.296</td>
<td>0.645</td>
<td>0.416</td>
<td>-0.837</td>
<td>0.379</td>
<td>1.488</td>
</tr>
<tr>
<td>Length</td>
<td>29.552</td>
<td>0.552</td>
<td>0.305</td>
<td>27.898</td>
<td>29.663</td>
<td>30.348</td>
</tr>
<tr>
<td>Time</td>
<td>11.348</td>
<td>0.747</td>
<td>0.558</td>
<td>10.265</td>
<td>11.115</td>
<td>12.885</td>
</tr>
</tbody>
</table>
From above figure, we can get better results of width difference and length variance, and the mean of width extension is not too bad, but the results of symmetric value and time are awful. We will give the detailed hypothesis test in the following parts.

**Width difference**

1. **First step: variance test**

![Boxplot of Width difference](image)

Figure 2-9 Test for equal variance for width difference

From the Figure 2-9, we can see p-value of F-test is 0.012, so we can conclude the variance of width difference in two experiments are equal. Therefore, we will choose t-test to see if two experiments have equal mean of width extension.

2. **Second step: mean test**

The p-value is 0.000 showed in Figure 2-10, so we can get the conclusion that we have get better result of width difference, namely, smaller mean value.

![Boxplot of Width difference](image)

Figure 2-10 mean test

**Width extension**
Since p-value of F-test is 0.409>0.05 showed as Figure 2-11, so the variance of width extension in two experiment are different. We can choose t-test without assumption of equal variance. The result is that the p-value is 0.076>0.05, so we will rejected the null hypothesis, which means the result of width extension is almost the same as the result got in first experiment.

Symmetric value

1. First step: variance test

Since p-value of F-test is 0.006>0.05 showed in Figure 2-12, so the variance of symmetric value in two experiment are equal.

2. Second step: mean test

The p-value is 0.520>0.05 and the mean of symmetric value in second experiment is 0.296 showed as Figure 2-13, smaller than the result of first experiment.
(0.50), so we can say symmetric value in second experiment is better than the result in first experiment.

![Boxplot of Symmetry](image)

**Figure 2-13** Symmetry mean test

**Variance of length**

Since we do not care about the absolute value of length, what we expected is just the minimizing the variance of length, so we will go to variance test directly.

![Test for Equal Variances for Length](image)

**Figure 2-14** Variances of length test

Using F-test of two samples in Figure 2-14, where p-value is 0.000<0.05; moreover, the variance in second experiment is obvious smaller than the result in first one. Therefore, we can say that second experiment has better result of variance of length, which is what we expected.

**Time**

1. **First step: variance test**
Since p-value of F-test is 0.244>0.05 showed Figure 2-15, so the variance of time in two experiment are different. We can choose t-test without assumption of equal variance.

2. Second step: mean test

The p-value is 0.000<0.05 showed in Figure 2-16, we can conclude that the effect of factor tool is obvious. However, the mean of second experiment’s time is longer than the first experiment (as shown in the above and below figures), which means we need go on further to improve this output.

Result

In this section, we get better result of width difference and variance of length, and almost the same result of width extension. However, the result of symmetric value and time are bad. Therefore, we will make another experiment to carry out our expectation.
2.3.3. Analysis of third experiment

Descriptive statistics

Table 2-14 Descriptive statistics after experiment

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>StDev</th>
<th>Variance</th>
<th>Minimum</th>
<th>Median</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Width difference</td>
<td>0.2988</td>
<td>0.2376</td>
<td>0.0565</td>
<td>-0.1225</td>
<td>0.3075</td>
<td>0.7400</td>
</tr>
<tr>
<td>Width extension</td>
<td>0.000000</td>
<td>0.000000</td>
<td>0.000000</td>
<td>0.000000</td>
<td>0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>Symmetry</td>
<td>0.115</td>
<td>0.487</td>
<td>0.237</td>
<td>-1.035</td>
<td>0.143</td>
<td>1.120</td>
</tr>
<tr>
<td>Length</td>
<td>39.037</td>
<td>0.217</td>
<td>0.0470</td>
<td>38.658</td>
<td>39.057</td>
<td>39.352</td>
</tr>
<tr>
<td>Time</td>
<td>7.720</td>
<td>0.663</td>
<td>0.440</td>
<td>6.785</td>
<td>7.783</td>
<td>9.030</td>
</tr>
</tbody>
</table>

From Table 2-14, we can scan that we have get better result almost all of output parameters. We will analyze in detail below. Especially, width extension becomes zero in third experiment, which is a great improvement we have done.

Width difference

Since p-value showed in Figure 2-17 is 0.000<0.05 obviously, and the result in the residual plots, we can conclude that we have get a better width difference.

Width extension
Figure 2-18 Residual test for width extension

From Figure 2-18, p-value is 0.000<0.05 obviously, we can say the effect of different tool is different. Since our width extension is zero in third experiment, certainly we cannot get a better result of this parameter showed as Figure 2-19.

Figure 2-19 Width extension mean test

Symmetric value
Figure 2-20 Residual test for symmetry

The p-value in this test showed in Figure 2-20 is also 0.373>0.05, so we say the factor tool do not have an obvious impact on symmetry. So we can say that in third experiment, we have not got a worse result at least. Moreover, the variance value of symmetry is reduced one experiment by one.

Variance of length

Figure 2-21 Residual test for length

Since p-value showed in Figure 2-21 is 0.000<0.05, the effect of factor tool on length is also obvious. But what we really care about is the variance of length. Since the variation value is just 0.217, the smallest in three experiment. We think our third
experiment is great and successful.

**Time**

![Residual Plots for Time](image1)

**Figure 2-22** Residual test for time

According the results got from Figure 2-22, we can conclude that the effect of factor tool is obvious. Moreover, the mean of third experiment’s time is smallest, i.e., 7.720, as showed in Figure 2-23.

![Boxplot of Time](image2)

**Figure 2-23** Box-plot of time

**Result**

Since we have get better result of all parameters we want to improve, we think our third experiment is successful and our improved tool (denoted by number 2) is deserved.
2.4 Improvement phase

In this project, after detailed dimensions and begin-end time measurement standardization, firstly we folded the T-shirt without any tools, measured all the indexes and conducted data analysis. Through this phase of data analysis, we found out that although the consuming time as definition is short, the variance of the other four indexes were still cannot meet our needs.

Step One

So we add a cloth folder to do our experiment again. The shape of the tool we used is shown in Figure 2-24.

![Easy folding tool](image)

Figure 2-24 Easy folding tool

Table 2-15 First easy folding way using first tool

<table>
<thead>
<tr>
<th>Steps</th>
<th>Graphical Representation</th>
<th>Description</th>
</tr>
</thead>
</table>
| 1     | ![T-shirt](image)        | Put the T-shirt face down and head up  
Flatten the T-shirt on the tool  
Align center |
2. Fold the bottom side of T-shirt up
   (Because the T-shirt is larger than the folder tool, so we need to fold the extended part up)

3. Fold the left sleeve with the tool

4. Fold the right sleeve with the tool
5 Fold the extended left sleeve with the tool

6 Double and lap the T-shirt
After added tool to help us fold T-shirt, we also conducted the data analysis to check whether the variance is smaller than before and whether the time used is shorten. With this cloth folder, there were totally 7 steps showed in Table 2-15 to finish the T-shirt folded and flatten out on desk. With all the data, we could see that although variance is reduced greatly, the completion time is increased. Furthermore, the degree of symmetry is not high enough. To analyze the reason, we review the folding progress and then found with the tool the time from begin to finish folding is shorten, but the time that is used from picking the T-shirt to flatten it on the desk would took up very long. So we began to consider how to reduce the unnecessary time, namely to remove the step 7 or reduce the time used on this phase.

Step Two

Based on this consideration, we began to think about another way to fold the T-shirt. This way would reach the result that when we finish the fold behavior, the T-shirt would be face upward position, so we could directly move it on the table. The new T-shirt folding method is shown in the chart below.
### Table 2-16 Second easy folding way using first tool

<table>
<thead>
<tr>
<th>Steps</th>
<th>Graphical Representation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>![Image 1]</td>
<td>Put the T-shirt face and head down</td>
</tr>
<tr>
<td></td>
<td>![Image 2]</td>
<td>Flatten the T-shirt on the tool</td>
</tr>
<tr>
<td></td>
<td>![Image 3]</td>
<td>Align center</td>
</tr>
<tr>
<td>2</td>
<td>![Image 4]</td>
<td>Fold the bottom side of T-shirt up</td>
</tr>
<tr>
<td></td>
<td>![Image 5]</td>
<td><em>(Because the T-shirt is larger than the folder tool, so we need to fold the extended part up)</em></td>
</tr>
<tr>
<td>3</td>
<td>![Image 6]</td>
<td>Fold the left sleeve with the tool</td>
</tr>
</tbody>
</table>
4. Fold the right sleeve with the tool.

5. Fold the extended left sleeve with the tool.
In this step showed in Table 2-16, through several attempts, we found that it’s was a quick way to fold the T-shirt, however, because the material of the cloth folding is not hard enough, so there might be more detective. What’s more, the folder size
cannot match the big T-shirt, so it still needs to fold the bottom side of T-shirt up, which would cost some time. Based on these considerations, we decide to do a tool by ourselves which is more proper and effective.

**Step Three**

The new folding tool is made of several hardboards, which are strong and difficult to deform when we folding a cloth. And its size is big enough to meet different cloth size conditions.

When we tried to make this cloth folding, there were many difficulties. Because the hardboard itself has a thickness, so how to fix the hardboard’s position and make it stable became our first issue. After the first try and experiment, the up width still does not meet the down size. Through brainstorming, we found that the upper T-shirt’ width goes with the board, yet the lower part is the sum of board’s width added by a gap between the upper moving hardboard and hardboard. So we chamfered the hardboard to make the gap narrower. Additionally, we also found that when folding the cloth, if the operator holds in the middle of the upper moving board, the difference between chamfer’s width and lap’s width would be lower.

The folding ways are shown in Table 2-17.

Table 2-17 Easy folding ways using second improvement tool

<table>
<thead>
<tr>
<th>Steps</th>
<th>Graphical Representation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><img src="image.png" alt="Image" /></td>
<td>Put the T-shirt face down and head up</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Flatten the T-shirt on the tool</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Align center</td>
</tr>
</tbody>
</table>
2 Fold the left sleeve with the tool

3 Fold the right sleeve with the tool
Double and lap the T-shirt

Pick the T-shirt
Put it on the desk
Flatten it

2.5 Control phase

The Control phase aims to establish standard measures to maintain performance and to correct problems as needed, including problems with the measurement system. This includes:

- validate measurement systems;
- Implement process control with control plan to ensure that the same problems don’t reoccur by continually monitoring the processes that create the products or services.
- Documentation

Measurement system validating

In the second improvement experiment, we still use our proposed measurement system to measure the variable. After evaluation, though the measurement capability
is between 10% and 30%, the capability is acceptable and in control.

**Process monitoring and validating**

After improvement, we want to know whether the process is stable, due to the restrictions, we couldn't do many experiments. We just have done one experiment only, and then using Xbar-R chart to monitor the data collected from the experiment showed as Figure 2-25, we can see that the process is in control.

Besides, the process capability of this improvement was traced by measuring all the variables, the smallest process capability $C_p = 1.20$, which is still large enough to accept the improvement of the process.

![Xbar-R Chart for width difference and symmetry](image)

**Documentation**

Another important thing we have done is to document what we have done in the whole project. The most important is to establish a standard process for the clothes folding by using our designed tool showed in Table 2-17. Following the steps, the defects will be decreased sharply compared with no standard process and tool to assistant clothes folding.

**3 CONCLUSION AND FUTURE WORK**

**3.1 Conclusion**

Using the methodology of Six Sigma, we have fulfilled our detail goal, namely reduction of defects from 1 DPU to 0.067 DPU. In fact, defects number is 0 DPU now showed as Figure 3-1.
Besides, we have established a standard process and developed a useful tool for clothes folding and document what we have done. By using our established process and tool, folding process can be in control and the results will be good enough to accept.

### 3.2 Future work

Though in our experiment, the defects decrease sharply to zero, the sample is too small to convince we reach our goal.

Besides, the tool we used is not that perfect, there are some more factors to consider. By using our tool, if we fold too fast, the clothes will be sticky on the board, which make the folded clothes a defect. Hence, the speed of folding clothes is restricted. One of the future work, we can do is to improve the tool to increase the speed of folding clothes.

### 4 REFERANCER

马林，何祯. 六西格玛管理. 北京：中国人民大学. 2007