Çukurova Üniversitesi Mühendislik Mimarlık Fakültesi Dergisi, 31(1), 59-67 ss. , Haziran 2016
Çukurova University Journal of the Faculty of Engineering and Architecture, 31(1), pp. 59-67, June 2016

Determining Process Capability Indices for Shirting Fabric

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Geliş tarihi: 05.01.2016 Kabul tarihi: 31.03.2016

Abstract

Organizations use process capability analysis to produce their products within specification limits for regular manufacturing. Process capability indices, C_p (process potential indices) and C_{pk} (process capability indices), are used as capability measures. In this study, process capability analysis and process capability indices are discussed in the context of a textile factory that produces shirting fabrics in Turkey. In this factory, it is desired that the amount of wastage fabric does not exceed the upper limit that identified from production manager. If the amount of wastage fabric increases, the number of unsatisfied customers will also increase. And, this situation is caused increasing cost and decreasing competitiveness for factory. For these reasons, C_p and C_{pk} indices were calculated for the textile factory. As a consequence of this study, we discovered that the process was inadequate precautions must be undertaken to decrease the amount of wastage fabric. Furthermore, the fabric faults which cause wastage fabric and the reasons for the process' inadequacies were also investigated.

Keywords: Process capability analysis, Process capability indices, Textile, Fabric faults, Case study

Gömleklik Kumaş için Proses Yeterlilik İndekslerinin Belirlenmesi

Özet

Şirketler düzenli üretim yapabilmek için ürettikleri ürünlerin spesifikasyon limitleri dahilinde üretilmesini arzu ederler. Proses yeterlilik indeksleri C_p (proses potansiyel indeksi) ve C_{pk} (proses yeterlilik indeksi) yeterlilik ölçümleri için kullanılır. Bu çalışmada, Türkiye'de gömleklik kumaşlar üreten bir tekstil fabrikasında proses yeterlilik analizi ve proses yeterlilik indeksleri tartışılmıştır. Bu fabrikada, fire kumaş miktarının üretim yöneticisi tarafından belirlenen üst sınırı aşmaması arzu edilmektedir. Eğer fire kumaş miktarı artarsa, memnun olmayan müşteri sayısında da artış olacaktır. Ve bu durum, fabrika için artan maliyete ve azalan rekabet gücüne sebep olacaktır. Bu sebeple, bu tekstil fabrikası için C_p ve C_{pk} indeksleri hesaplanmıştır. Çalışmanın sonucunda, incelenen tekstil fabrikasında prosesin yetersiz olduğu

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ve fire kumaş miktarının azaltılması için bazı önlemlerin alınması gerektiği görülmüştür. Ayrıca, fire kumaşa sebep olan kumaş hataları ve sürecin yetersizliği sebepleri de araştırılmıştır.

Anahtar Kelimeler: Proses yeterlilik analizi, Proses yeterlilik indeksleri, Tekstil, kumaş hataları, Örnek olay çalışması.

1. INTRODUCTION

Nowadays, competitiveness is very important for organizations to continue one's existence. To compete with other organizations it is not enough to produce quality product. Now, customers desire to buy quality product at a cheaper price. For this reason, organizations must put emphasis on both quality and cost. Process capability analysis (PCA) provides opportunity for organizations to improve their product's quality and decrease costs.

In the manufacturing sector, products must be produced within specification limits; process capability analysis can help reach this goal. The first step to measure process capability is to define the process, and the second step is to define the specification limits. In process capability analysis, data obtained from the process are compared with the specification limits to decide whether a process is adequate. C_p and C_{pk}, known as process capability indices, are used to evaluate the process capability.

Some studies of PCA can be seen in the literature. The base studies of C_p and C_{pk} are by Kotz and Johnson (1993) [1] and Kotz and Lovelace (1998) [2]. A pragmatic view of process capability studies and the advantages and disadvantages of PCA were reported by Deleryd (1999) [3]. Some advantages of PCA presented in this paper are the method provides a lot of knowledge of the processes, the method helps identifying improvement priorities. Some disadvantages are it might be hard to motivate co-workers, the method is resource consuming and that it involves some relatively difficult theory. A bibliography of process capability studies was presented by Spiring et al. (2003) [4]. Motorcu and Güllü (2006) [5] presented a case study for machine tool capability and process capability. They detected the machine tool and process capability for the whole process was inadequate and mass production was unstable. Owing to this study, faults were eliminated, quality was improved and productions costs were reduced. Akcan and Kahraman (2008) [6] presented PCA for a machining company. Delaney and Phelan (2009) [7] used process capability data to predict product performance variation early in the design process. In this study, a method by which process capability data can be applied to predict product performance variation early in the design process was presented. Therefore, redesign costs were reduced.

Ozyazgan (2014) [8] presented FMEA analysis and implementation in a textile factory producing woven fabric. In this study some fault types were determined. These were foreign fiber in weft, weft ladder, warp breaks, mesh, oil stains, reed marks, foot ladder, weft ladder and double weft.

This paper shows how PCA can be used in a textile production process by presenting a case study that uses real data from a textile factory that produces shirting fabrics and an outline for performing PCA of manufacturing processes.

The remainder of this paper is organized as follows: Section 2 presents PCA, Section 3 presents goodness-of-fit (GOF) tests, Section 4 presents case study, Section 5 presents results and discussion and conclusions are given in Section 6.

2. PROCESS CAPABILITY ANALYSIS

Process capability analysis is a well-defined tool within statistical process control techniques that continuously improves quality and productivity

[9]. The first aim for using PCA is to obtain information about the process and to determine if the process can be improved [3]. To improve the process, C_p, the process potential indices, and C_{pk}, the process capability indices, are calculated, which were defined by Juran (1974) [10] and Kane (1986) [11], respectively.

C_p and C_{pk} are used to evaluate the process capability for data which fit a normal distribution. While C_p controls only the dispersion of the process, C_{pk} controls both the dispersion of the process and the variation between the mean and target values of the process. These capability indices have been described as:

$$C_p = (USL-LSL)/6\sigma \quad \ldots \quad (1)$$
$$C_{pu} = (USL-\mu)/3\sigma \quad \ldots \quad (2)$$
$$C_{pl} = (\mu-LSL)/3\sigma \quad \ldots \quad (3)$$
$$C_{pk} = \min\{C_{pu}, C_{pl}\} \quad \ldots \quad (4)$$

Here; *USL* and *LSL* are the upper and lower specification limits, μ is the process mean, and σ is the process' standard deviation.
To decide whether a process is adequate according to C_p and C_{pk} indices, see Table 1.

Table 1. C_p, C_{pk} indices and process capability decisions [12]

C_p, C_{pk} indices	Process capability decisions
$C_p \geq 1.33$	Adequate
$1< C_p \leq 1.33$	Satisfactory, but must be closely monitorized
$C_p \leq 1$	Inadequate
$C_{pk} \geq 1.33$	Adequate
$1< C_{pk} \leq 1.33$	Satisfactory, but; if μ go far from the process target, percentage of error can increase
$C_{pk} \leq 1$	Inadequate

3. GOODNESS OF FIT TESTS

A GOF test is a statistical hypothesis test used to describe how well the model fits a set observation. A GOF test outlines the statistical discrepancy between the observed values and the values expected under the model. To decide GOF, different tests are used for different statistical models.

3.1. Chi-square Test

The chi-square test is the oldest GOF test. A chi-square test, also referred to as a χ^2 test, is any statistical hypothesis test in which the sampling distribution of the test statistic is a chi-squared distribution when the null hypothesis is true.

To calculate the chi-square test statistic, the sample must be divided into the entire range of the fitted distribution in *k* adjacent intervals $[a_0,a_1)$, $[a_1,a_2)$, …, $[a_{k-1},a_k)$, where it could be that $a_0=-\infty$, in which case the first interval is $(-\infty,a_1)$, $a_k=+\infty$, or both. N_j= number of x_i's in the *j*th interval $[a_{j-1},a_j)$ for $j=1,2,\ldots,k$. Next, the expected proportion p_j should be calculated. In the continuous case,

$$p_j = \int_{a_{j-1}}^{a_j} \hat{f}(x)dx \quad \ldots \quad (5)$$

where $\hat{f}$ is the density of the fitted distribution.
For discrete data,

$$p_j = \sum_{a_{j-1}\leq x_i < a_j} \hat{p}(x_i) \quad \ldots \quad (6)$$

where $\hat{p}$ is the mass function of the fitted distribution. Finally, the test statistic is

$$\chi^2 = \sum_{j=1}^{k} \frac{(N_j - np_j)^2}{np_j} \quad \ldots \quad (7)$$

If H_0 is true, it will be expected χ^2 will be small if the fit is good (see [13]) for more information).

3.2. Kolmogorov–Smirnov (K-S) Test

If a sample comes from a hypothesized continuous distribution, the Kolmogorov-Smirnov (K-S) test is used to decide GOF. The K-S test is based on the empirical cumulative distribution function (ECDF). Assume that we have a random sample $x_1, x_2, \ldots, x_n$ from some continuous distribution with a CDF $\hat{F}(x)$. The ECDF is denoted by

$$F_n(x) = \frac{[\text{number of observations} \leq x]}{n} \quad \ldots \quad (8)$$

The K-S test statistic (D_n) is the largest (vertical) distance between $\hat{F}(x)$ and $F_n(x)$, defined as

$$D_n = \sup_x \left\{ \left| F_n(x) - \hat{F}(x) \right| \right\} \quad \ldots \quad (9)$$

If the test statistic (D_n) is greater than the critical value obtained from a table, the null hypothesis is rejected at the chosen significance level (see [13] for more information).

3.3. Anderson-Darling Test

The Anderson-Darling test is designed to detect discrepancies in the tails. With the standard normal CDF (F), the Anderson-Darling statistic (A^2) is defined as

$$A^2 = -n - \frac{1}{n}\sum_{i=1}^{n}(2i-1)\left[InF(X_i) + In\left(1 - F\left(X_{n-i+1}\right)\right)\right] \quad (10)$$

An approximate adjustment A^{2*} for sample size is calculated using:

$$A^{2*} = A^2\left(1 + \frac{0.75}{n} + \frac{2.25}{n^2}\right) \quad \ldots \quad (11)$$

If the test statistic, A^{2*}, is greater than the critical value obtained from a table, the null hypothesis (the data follow the normal distribution) is rejected at the chosen significance level [14].

4. CASE STUDY

A medium-sized textile factory in Turkey that has produced shirting fabrics was investigated via PCA in this study. To meet customer satisfaction, the factory desires to produce faultless fabrics, decreasing the total cost and making more competitive prices feasible. For faultless manufacturing, it must be investigated whether the produced fabrics are within specification limits or not. Therefore, PCA was done for this factory. Figure 1 shows a flowchart for PCA.

1193 data points from wastage fabrics were collected for one year. The K-S test was performed to test for normality. The normal probability graph of these data is presented in Figure 2. As seen in Figure 2, since the *P-value* (0.071) is bigger than 0.05, we can say that with 95% confidence that these data come from a normal distribution.

We determined the data scatter within the specification limits using histograms, and the C_p and C_{pk} indices were calculated using a trial version of the statistics software package MINITAB 14 (www.minitab.com), as seen in Figure 3.

5. RESULTS and DISCUSSION

5.1. Results of Process Capability for Wastage Fabric Amount

As seen in Figure 3, capability indices were examined for both overall capability (long-term performance) and potential (within) capability (short-term performance). C_p was 0,37 and C_{pk} was 0,07, as seen in Figure 3. Because these values were smaller than 1, it can be said that the process was inadequate. It is desired that C_p and C_{pk} indices should be greater than or equal to 1,33. As seen in Figure 3, the sample mean of the process is close to the upper limit, meaning that skewness is shown at the upper limit of the process.

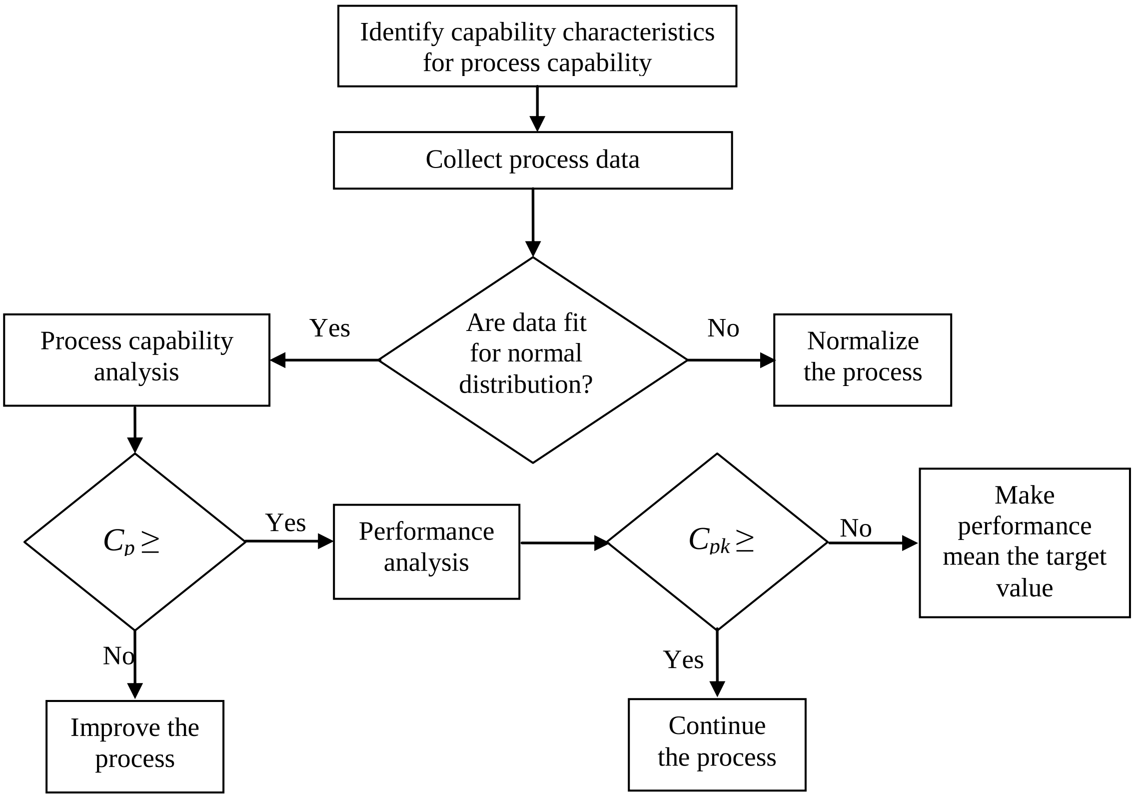

Figure 1. Flowchart of process capability analysis [15]

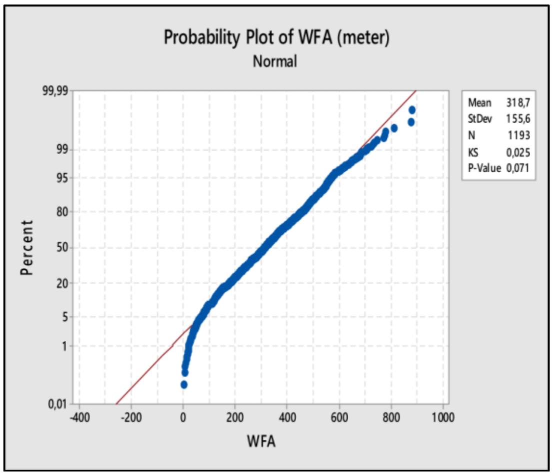

Figure 2. Normal probability plot of wastage fabric amount (WFA)

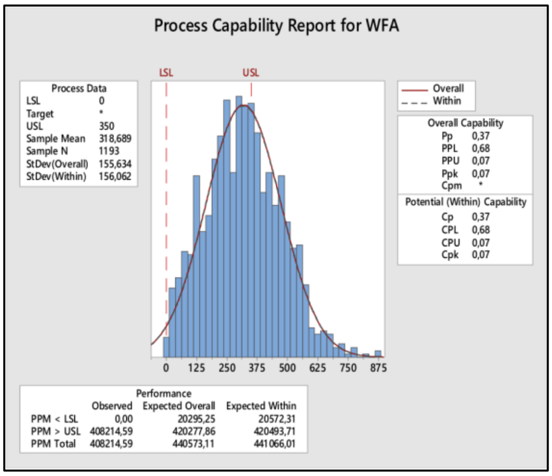

Figure 3. Process capability report for wastage fabric amount (WFA)

To improve the process, firstly, skewness should be investigated (please see [16] for more information about skewed processes).

The expected overall value shows how many data points are out of the limits in the long term and the expected within value shows how many data points are out of the limits in the short term. As seen in Figure 3, approximately 42 % of the data were above the upper limit and approximately 44 % of data were out of the limits.

5.2. Cause and Effect Diagram for Wastage Fabric

Because the process which was investigated in this study was inadequate, cause and effect diagram was generated for investigating the reasons of inadequacy of the process (Figure 4). As seen in Figure 4, eight fault types (stain, broken, yellowing, seam slippage, foreign fiber in weft, weft ladder, warp breaks and reed marks) which are caused for wastage fabric were determined and the reasons of faults were investigated. It was seen that the most of faults resulted from personnel and machine. To resolve these faults; personnel should be trained, the lack of knowledge of personnel should be completed, the motivation of personnel should be increased, training about knowledge of the machine specifications should be given and it should be avoid from work overtime. Furthermore, outdated machine and machine parts should be changed, machine maintenance should be at the right time and the adjustment of reed should be controlled. The external environmental conditions are also important for resolve the faults. Therefore, it should be taken care on temperature and cleanliness of environment for preventing the insects and dusts stick with on fabric.

5.3. Investigating the Connection between Wastage Fabric and Months

When we investigate the connection between wastage fabric amount and months seen in Figure 5, it can be seen that most of wastage fabrics occur in spring and summer months. It was observed that, the motivation and care of personnel are low and the dirtiness of environment is high in summer months. Therefore, the faults are increase and correspondingly the amount of wastage fabric is increase, too. It is also seen in Figure 5 that the first three faults are broken, stain and yellowing, respectively.

5.4. The Effect of Pattern Difficulty on Wastage Fabric

To see the effect of pattern difficulty on wastage fabric, the difficulty level was separated into four groups (1-very difficult, 2-difficult, 3-average and 4-not difficult). As seen in Figure 6, the textile factory investigated in this study produces mostly the fabrics which have not difficult patterns. The faults which are caused wastage fabric were seen mostly in group 4. Then, group 3, group 1 and group 2, respectively. Therefore, it can be said that the pattern difficulty is not affect the amount of wastage fabric. It can also be seen in Figure 6 that the first three faults are stain, broken and yellowing respectively.

6. CONCLUSIONS

In this study, PCA was performed for a medium-sized textile factory in Turkey that produces shirting fabrics. As a result of this analysis, it was seen that the process was inadequate. Because the process was inadequate, the reasons for the process' inadequacies were also investigated.

To improve the process and decrease the amount of wastage fabric, some precautions have to be taken. For example, operators have to be trained, machines have to be maintained regularly. If these precautions are taken, the amount of wastage fabric will decrease, increasing customer satisfaction and decreasing costs. PCA analysis of data that are not normally distributed will be investigated in a future study.

7. ACKNOWLEDGEMENTS

The author would like to thank the staffs of the textile factory, and the reviewers for their contributions to the paper.

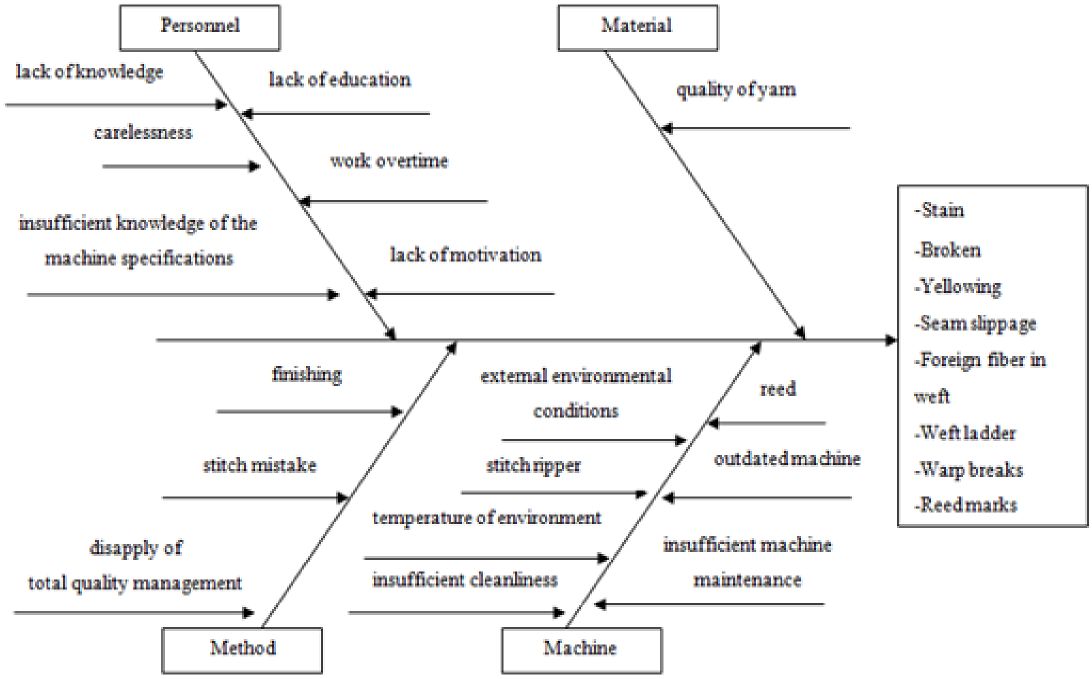

Figure 4. Cause and effect diagram for wastage fabric

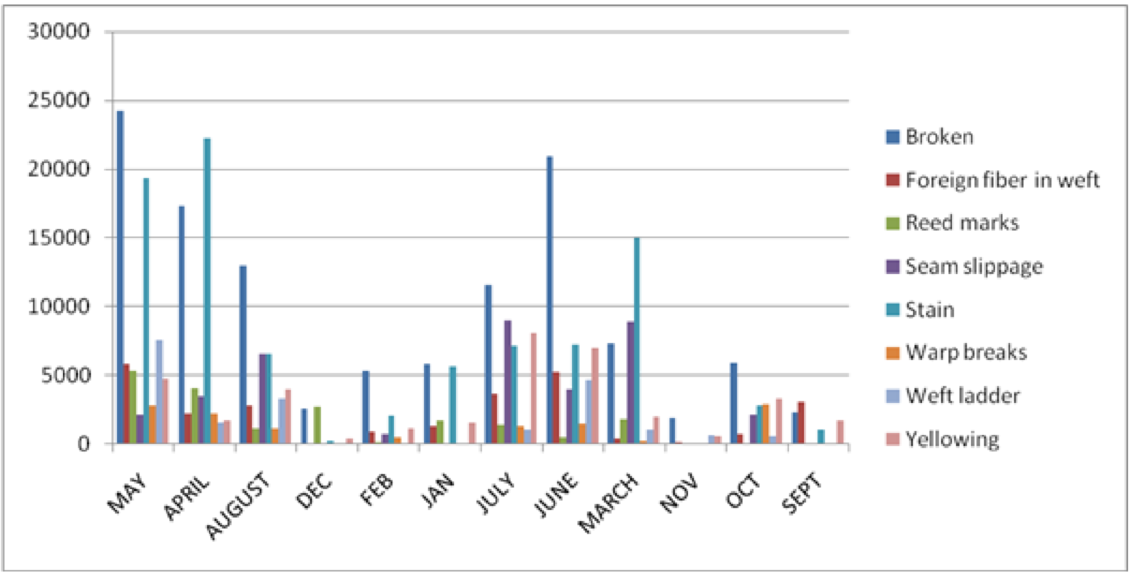

Figure 5. Investigating the connection between wastage fabric and months

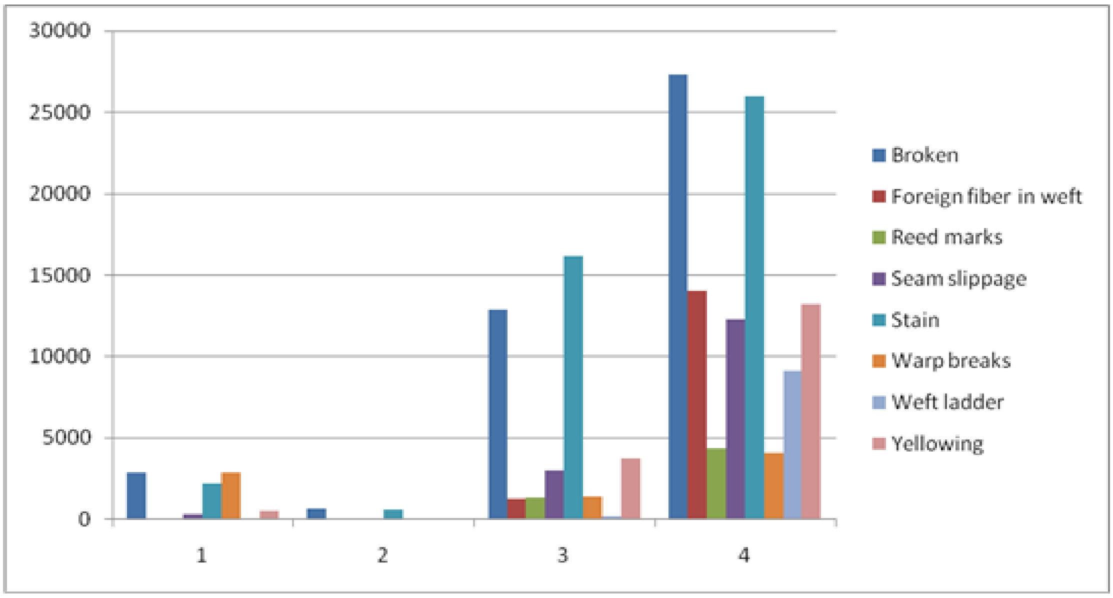

Figure 6. The effect of pattern difficulty on wastage fabric

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