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STATISTICAL PROCESS CONTROL AS A TOOL FOR QUALITY IMPROVEMENT: A CASE STUDY IN DENIM PANT PRODUCTION

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Abstract

In this study, after defining the concepts of quality and quality control, the concept of statistical process control tools is examined. As a result of the data obtained from denim pants produced by a textile company operating in the ready-to-wear sector, defects were analyzed using statistical process control techniques. In this study, flowchart, control charts, pareto analysis, p-control diagram, cause-effect diagram, and grouping techniques were used. With the use of basic statistical process control tools, the most recurring defects were, and these defects were divided into subheadings for more detailed analysis. In this way, it was tried to prevent the repetition of defects by going down to the root causes of the detected defects. The causes of possible defects that may occur during production and solution suggestions were categorized. By going down to the basic causes of the detected defects and categorized them, defects were prevented by presenting and implementing solution suggestions. It is expected that the study with this different perspective will be an example of the sector and related fields as an alternative method. The aim of this study is to examine quality control practices in the garment industry, contribute to statistical control methods and problem-solving procedures, produce suggestions for problem-solving approaches, and disseminate improvement studies.

Keywords: Statistical process control techniques, Quality, Ready-to-wear, Denim products, Sewing defects

KALİTE GELİŞTİRME ARACI OLARAK İSTATİSTİKSEL PROSES KONTROLÜ: KOT PANTOLON ÜRETİMİNDE BİR VAKA ÇALIŞMASI

Özet

Bu çalışmada, kalite ve kalite kontrol kavramlarının tanımları yapıldıktan sonra istatistiksel proses kontrol araçları kavramı etraflıca irdelenmiştir. Ardından, hazır giyim sektöründe faaliyet gösteren bir tekstil firmasında üretilen denim pantolonlardan elde edilen veriler sonucunda hataların analizleri, istatistiksel proses kontrol teknikleri ile yapılmıştır. Çalışmada akış şemaları, kontrol şemaları, pareto analizi, kontrol şemaları, neden-sonuç diyagramı ve gruplama tekniği kullanılmıştır. Temel istatistiksel proses kontrol araçlarının kullanılmasıyla, en çok tekrar eden hatalar tespit edilmiş ve bu hatalar daha detaylı analiz için alt başlıklara ayrılmıştır. Bu sayede tespit edilen hataların kök nedenlerine inilerek hataların tekrarı engellenmeye çalışılmıştır. Üretim sırasında oluşabilecek olası hataların nedenleri ve çözüm önerileri kategorize edilmiştir. Tespit edilen hatanın temel nedenlerine inilerek ve kategorize edilmiş, çözüm önerileri sunulması ve uygulanması ile hataların önüne geçilmiştir. Bu farklı bakış açısı ile çalışmanın sektöre ve ilgili alanlara alternatif bir yöntem olarak örnek olması beklenmektedir. Bu çalışmanın amacı, hazır giyim sektöründe kalite kontrol uygulamalarını incelemek, istatistiksel kontrol yöntemleri ve problem çözme prosedürlerine katkı sağlamak, problem çözme yaklaşımları için öneriler üretmek ve iyileştirme çalışmalarını yaygınlaştırmaktır.

Anahtar Kelimeler: İstatistiksel proses kontrol teknikleri, Kalite, Hazır giyim, Denim ürünler, Dikiş hataları

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1. Introduction

Along with the pandemic that has afflicted the entire world, the dynamics of change that shape the global economy have significantly impacted the manufacturing industry. Rapidly changing economic conditions, increased global competition, reduced profit margins, and changes in customer profiles and expectations boost the competitiveness of businesses that correctly read and prepare for change dynamics [1]. Companies must produce high-quality products to survive in the current competitive global market. When quality, which is ultimately a customer satisfaction issue, is good, it increases the value of a product or service, builds a brand, and gives ready-to-wear manufacturers a good reputation. As a result, production leads to customer satisfaction, high sales, and a favorable exchange rate for the country.

Ready-to-wear businesses can survive by focusing on customer satisfaction throughout the process, beginning with the design stage, and continuing with after-sales services to meet customer expectations. Demand for lower-cost, higher-value goods and services is increasing. Consequently, ready-to-wear manufacturers must carry out their operations with the highest quality, at the lowest cost, and in the shortest amount of time.

The denim industry is an important sector in the economic development process, and its effectiveness for countries must be recognized due to the added value created in the production process and its high share of foreign sales revenues. For businesses to become global players in the denim industry, they must have a sufficient number of denim ready-to-wear manufacturing machines, advanced model room infrastructure, qualified personnel, an experienced design team preparing collections, and production infrastructure[2].
The sewing department in ready-to-wear enterprises significantly affects product quality because it has the most labor-intensive features in the production process. Many factors influence ready-to-wear production quality, including organizational defects, information flow disruptions, education, quality awareness, corporate culture, operator knowledge and skills, material, machine, method, environmental conditions, and so on [3, 4]. Human factors are the primary factors that can eliminate these factors, manage them, and achieve quality and efficiency, or vice versa [3].
Defects that can occur at any production stage in ready-to-wear, a labor-intensive industry, deteriorate product quality, reduce production efficiency, and increase production costs [5]. Therefore, it is essential to minimize defects, prevent and improve poor quality, increase productivity, and reduce production costs [6].

In the literature, there are studies in which SPC tools are used in problem solving, quality assessment, and decision stages in various sectors. Although there are some studies on this subject in the textile and ready-to-wear industry, it has been determined that more research is needed in terms of the number, application area, and research method and approach.

SPC tools are used to minimize final control defects in home textile products [7], examine quality defects after washing in denim fabrics using statistical methods [8], improve process performance in waste management applications in the fashion and textile industry [9], create a quality improvement plan based on a complex product analysis [10], improve process quality in pants production, evaluate pre-sewing, post-sewing, and pre-loading control results [11], analyze sewing defects and their causes [12], evaluate as a problem-solving technique in the ready-to-wear industry [13], and determine whether the production of dresses is under control [14].

In this study, sewing defects that occurred during the production of denim pants were identified, their causes were examined, and solutions were offered to prevent defects. This study aims to take quick action in possible situations related to sewing defects that may occur during production.

In this study, unlike the studies in the literature, sewing defects with a high defect rate were analyzed up to their root causes.

2. Common Sewing Defects on Denim Products

The production of high-quality clothing requires several factors besides fabric quality. Converting a two-dimensional fabric into a three-dimensional garment involves numerous other interactions, such as optimizing sewing parameters, the simplicity of converting fabric into a garment, and the actual performance of a sewn fabric. Strength, elasticity, durability, stability, and appearance are the characteristics of a high-quality seam. Seam strength, slippage, shrinkage, appearance, and thread breakage are variables that affect the performance and appearance of garments after sewn [15].
To increase the added value of fashion denim products, wet (washing, bleaching, etc.) and dry (abrasive, laser shaping, rodeo, etc.) processes are applied [16]. The permanent visual effects obtained by these processes add a unique feature to the denim products. However, re-sewing and repairing these processes in denim products reduces the quality of these special effects. Therefore, defect-free production is a susceptible issue for denim products [16].

3. Statistical Process Control

In today's world, where resource constraints and production costs are increasing, it is becoming increasingly clear that decisions should be based on facts rather than opinions. Consequently, information must be gathered and analyzed. In this stage, statistical process control tools should be used to assist in decision-making and determine whether the process is operating at an acceptable level [17].

It is aimed that by using these techniques, defects in production can be detected and eliminated by addressing their root causes. In ready-to-wear businesses that use traditional methods, defective products detected in the final inspection are reserved for repair. After determining the source of the defect (operator, operation, or material), the quality is ensured by correcting the workmanship or changing the material. This application wastes time and resources by utilizing the business workforce unnecessarily. The company incurs losses due to wasted raw materials and energy in non-compensable defects by discarding the product. On the other hand, innovative businesses eliminate the cause of defects by using statistical process control tools or different strategies. Thus, they benefit more from the workforce and avoid waste of time and energy.

4. Research Methodology

4.1. Material

The sample group in this study was determined as denim pants. The research findings provided a model for all ready-to-wear products.

The model examined in this study is a classic 5-pocket denim pants (two in the front, two in the back, and a small change pocket on the front right pocket). The raw material content of the examined products was 98% cotton and 2% elastane, and the weight of the fabric was 350 gr/m^2. The fabric was woven with a 2/1 twill weave pattern.

The photos of the examined model are shown in figures 1,2,3,4.

F

Figure 2. Front of denim pants

Figure 4. Zipper

Figure 3. Watch pocket

4.2. Method

Statistical process control tools were used in this study. The tools used were as follows.

1. Flowchart: Flowcharts are created by examining a product's phases and allow us to understand which phases the product goes through at any given time. In other words, it is a diagram showing the processes between a material or substance and the final product in the correct order [18, 19].

2. Control charts: Control charts are used for various purposes. For example, control charts are created using a specific sample size or time criterion for each process specified in the flowchart. At the same time, the company can use control charts within a particular process rather than applying control charts to all processes. Moreover, by using control charts, it is possible to understand the extent to which the defect is prevented after it has been previously uncovered and defect optimization of the process has been performed. This chart is important because it provides the quality manager with precise data on whether a defect exists in the process [20, 21].

3. Pareto analysis: Pareto analysis is performed using data from control charts. In this analysis, the process with the highest number of defect repetitions was prioritized to improve or eliminate defects. The choice of priority also depends on a company's strategy. For example, if the second most repeated defect puts the company in greater financial difficulty, priority may be given to the second defect. The preferences in the process run parallel to the company's priorities [22-24].

4. Grouping: In this study, the grouping method was examined under three headings: human, machine, and method. Because the basis of this study is the ready-to-wear section, the problems related to the fabric were not evaluated. Therefore, the "material" section is not included in the "grouping" section. The grouping method is a method that allows us to separate the defect groups. Thus, categorizing the defects makes it easier to understand which part is prioritized according to defect accumulation [25-26].

5. Control diagram (p): Control diagrams are an analysis based on the data from the control diagrams at different points in the process prioritized in the pareto analysis. The control diagrams show if the product is under control at different time points in the considered process. The control diagrams consist of three different limits. These are the upper control limit, middle limit and lower control limit. The product is not under control if a value is within the upper control limit. In the diagram, if the product is in the middle or near the lower control limit, it is under control. In this study, the p control diagram was used. This is because the data can be measured (size/length/width/weight, etc.) and are used in other diagrams. In this study, the p diagram was preferred because it is a control type that does not depend on quality value [27–30].

6. Cause-effect diagram: This allowed us to determine the cause of the defect by targeting the defect to be eliminated by examining the grounds of the defect in the subheadings. To analyze the causes of failure, it is necessary to examine the process under some subheadings, as described above. These subcategories are material, environment, machine, human, and method. In this analysis method, the causes of failure were determined by classifying the failures under specific subcategories. This analysis method shows how to prevent defects based on identified causes [29, 31].

The six methods described above are examined in detail in Chapter 5.

5. The Research Findings and Discussion

5.1. Flowchart

Denim pants sewing steps have been evaluated in different ways in different sources or production areas (businesses) and factories. Operating conditions, existing infrastructure, machine capacity, operator quality, and model difficulty influence the operation order and layout. However, the sequence of operations for a basic denim varies only slightly.

Figure 5 shows the order of operations in the enterprise in which this study was conducted. In addition, bar tack stitching (decorative stitching) was applied to the watch pocket, zipper, and side seams. However, because the positions of these stitches change depending on the model, this step is not included in the flowchart. The data from some preparation stages, such as drawing, preparation, and bonding, were not included in the flowchart.

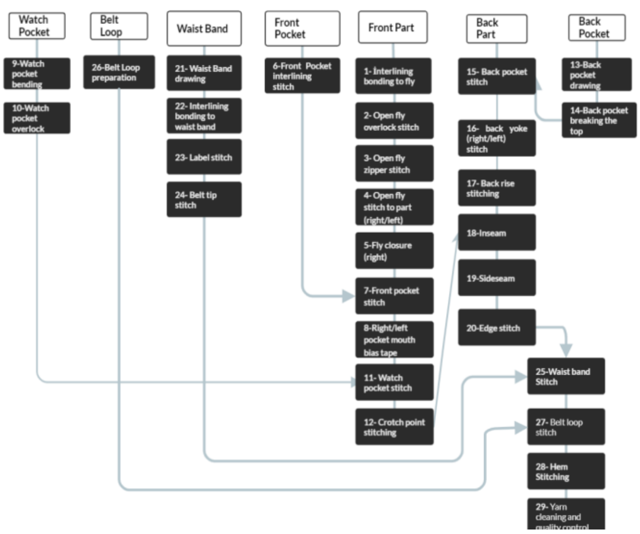

Figure 5. Denim pants flowchart

This study was based on the ready-to-wear data. Table 1 lists the types of machines used in the processes according to the order of use.

Table 1. Process flow and machines used in denim pants production

Order of Process	Process	Machine Types
1	Open fly stitching	Overlock sewing machine
2	Open fly zipper stitching	Straight sewing machine
3	(left-right) Open fly stitching to part	Straight sewing machine
4	Fly closure	Overlock sewing machine
5	Front pocket interlining stitching	Overlock sewing machine
6	Front pocket stitching	Widely spaced-twin needle-straight sewing machine
7	Watch pocket inseam	Overlock sewing machine
8	Watch pocket stitching	Straight sewing machine
9	(left-right) Pocket mouth bias tape	Widely spaced-twin needle-straight sewing machine
10	Crotch point stitching	Widely spaced-twin needle-straight sewing machine
11	Back pocket breaking the top	Narrow spaced-twin needle-straight sewing machine
12	Back pocket stitching	Straight sewing machine
13	Back yoke (left/right) stitching	Chain sewing machine
14	Back rise stitching	Widely spaced-twin needle-straight sewing machine
15	Inseam	Overlock sewing machine
16	Sideseam	Chain sewing machine
17	Edge stitching	Straight sewing machine + bar tack machine
18	Waistband stitching	Waistband sewing machine
19	Belt top stitching	Straight sewing machine
20	Belt loop stitching	Belt loop sewing machine
21	Hem stitching	Straight sewing

machine

In Figure 6, you can see the parts of a classic denim pants.

Figure 6. Parts of a classic denim pants

5.2. Control Charts

As described in Title 5.1, there are twenty-nine operations to create denim pants. As shown in Table 1, twenty-one operations were performed with the sewing machine. Operations were performed with the sewing machine. On the other hand, the operations where no defects were detected in the control chart were not included in Table 2.

Table 2 listed the number of defects detected during sewing operations. The company where the production occurred was visited four times.

Table 2. Number of defects detected in denim pants production in four days

Process	Number of Defects Per Day				Total
	1. Day	2. Day	3. Day	4. Day	
Open fly zipper stitching	6	4	3	-	13
Fly closure	2	3	1	4	10
Watch pocket stitching	2	1	-	-	3
Crotch point stitching	3	2	4	5	14
Back-front pocket stitching	2	3	1	2	8
Back yoke (left-right) stitching	8	11	15	12	46
Back rise stitching	11	14	13	16	54
Inseam	4	2	3	3	12
Sideseam	3	4	2	3	12
Edge stitching	1	2	1	3	7
Waistband stitching	8	7	11	10	36
Belt top stitching	3	2	1	2	8
Belt loop stitching	5	3	4	3	15
Hem stitching	11	12	9	13	45
Yarn cleaning	8	10	8	9	35
Total defects	77	80	76	85	318
Sample size	90	130	130	150	500

The control chart in Table 2 highlights operations with the most defects in red. Table 3 listed the defects observed during the operations highlighted in red in Table 2. Table 3 listed the frequencies of the grouped defects detected in these processes.

Table 3. Frequencies of grouped defects detected in the processes

Process	Defect Descriptions	Defects	Frequency	Total
Back yoke (left-right) stitching	When sewing the back yoke, the fabric has shrunk.	40	%87	46
	It was noted that the right and left back yoke on the denim pants were not the same height.	6	%13	
Back rise stitching	Irregular stitch pitch defect detected	18	%33	54
	Irregular detected in back mid-stitching	7	%13	
	The fabric has shrunk due to sewing.	29	%54	
Waistband stitching	It was found that the yarn is collected on the back of the fabric.	6	%17	36
	The belt has shrunk due to sewing	11	%30	

	Pucker in fabric was detected in the area of the belt	19	%53	
Hem stitching	Threads were detected on the hem coming out of the stitch	6	%14	45
	Shrinkage has occurred at the hem	13	%29	
	Irregularities in hem spacing in hemming stitching	21	%46	
	Irregular stitch pitch defect detected	5	%11	
Yarn cleaning	Threads not cleaned properly	35	%100	35

5.3. Pareto Analysis

Pareto analysis was used to establish the relationship between the total number of defects detected and the number of defects that occurred in each process.

Quality control of five hundred denim pants was made, and three hundred and eighteen sewing defects were detected in the products. The detected defects are grouped under fifteen sub-headings, as shown in Table 4. Defect groups were listed from largest to smallest according to the number of occurrences; thus, it was possible to facilitate the analysis of the factors causing the defect. Pareto analysis showing the distribution of defects is shown in Figure 7.

Table 4. Percentage distribution of detected defects

Rank	Process	Total Defects	Percentage (%)
1	Back rise stitching	54	17,0%
2	Back yoke (left-right) stitching	46	14,5%
3	Hem stitching	45	14,2%
4	Waistband stitching	36	11,3%
5	Yarn cleaning	35	11,0%
6	Belt loop stitching	15	4,7%
7	Crotch point stitching	14	4,4%
8	Open fly zipper stitching	13	4,1%
9	Inseam	12	3,8%
10	Sideseam	12	3,8%
11	Fly closure	10	3,1%
12	Belt top stitching	8	2,5%
13	Back pocket stitching	8	2,5%
14	Edge stitching	7	2,2%
15	Watch pocket stitching	3	0,9%
	Total	318	%100

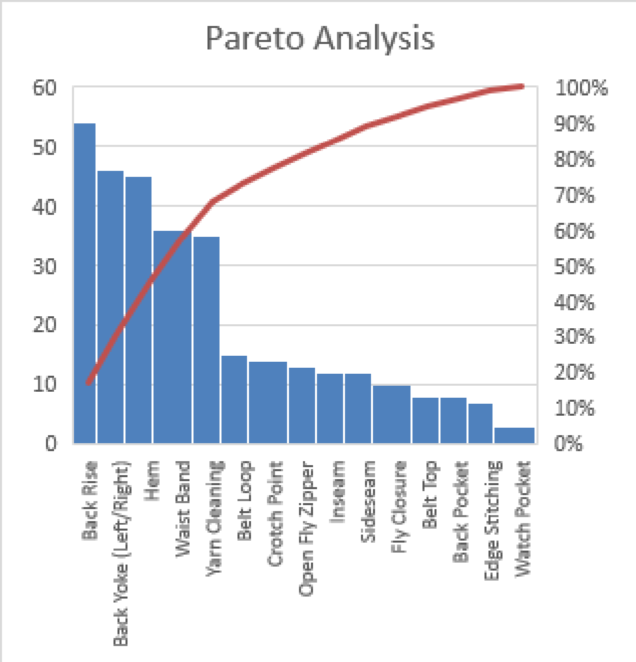

Figure 7. Pareto analysis chart

The back rise operation, which has the highest defect percentage in the pareto analysis, was determined to be a priority in this study.

5.4. Grouping

The grouping technique makes it possible to separate the data and make them easier to understand. The grouping method is a way to avoid problems or defects before they occur.

Table 5. Defects source-based classification

Source of Defects	**Defects**	**Total Defects**	**Percentage %**	**Source of Defects (%)**
Human	Shrinkage of the fabric at the seams	117	36,8%	
	Warping of the seams.	37	11,6%	

	Warping of the fly	4	1,3%	63,2%
	Warping/shrinking of the zipper	8	2,5%	
	Cleaning the thread	35	11,0%	
Machine	Needle damage to fabric	8	2,5%	20,8%
	Back rise, hem, crotch point, etc. skipping stitches in operations	31	9,7%	
	Waist loops are not asymmetrical	15	4,7%	
	Thread accumulation on the back of the fabric	7	2,2%	
	Stitches that detach from the fabric	5	1,6%	
Method	Deformity of the waistband	19	6,0%	16%
	Deformation of the left/right back yoke	6	1,9%	
	Shrinkage of the fabric	26	82%	
	Total defects	318	100%	100%

The sources of the defects are examined under the three headings listed in Table 5. These are human, machine, and methods, respectively. Man-defects are more than other defect sources because the ready-to-wear industry is based on labor. In this case, it becomes clear how important it is to provide job-related training to employees, and the company's necessity to teach the flexible production approach to its employees with training and seminars draws attention.

5.5. Cause-Effect Diagram

Cause-effect diagrams are among the most common techniques for problem-solving, process improvement, and identifying root causes of quality problems. A cause-effect diagram has been created to identify the root causes of the defects and prevent their reoccurrence in the "back rise" operation, where most defects are made. As shown in Figure 8, the factors causing the malfunction are discussed under human, machine, environment, material, and method headings.

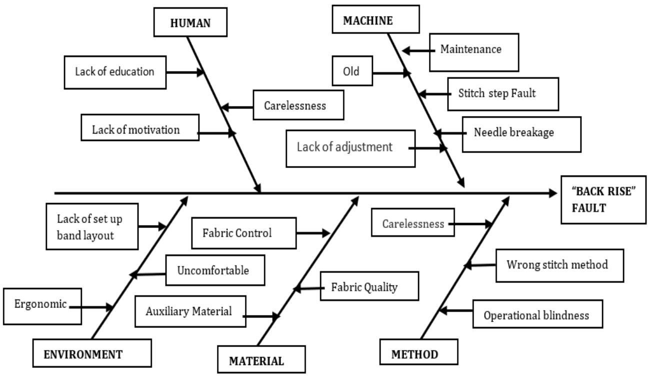

Figure 8. Cause-effect diagram

It has been revealed that the human factors cause 63.2% of the defects in operations. The defect rate caused by machinery and materials accounts for almost 1/3 of human defects. The human factor plays a significant role in this operation as well as in other operations. Employees are expected to be well-trained, competent, experienced, and able to do their job.

5.6. "P" Control Diagram

The most common p control diagram is used in control diagrams. This method is used when the sample size of a large manufacturing firm's variable instruments is one hundred or more. The p control method, one of the qualitative control diagrams, allows us to measure the defect rate in the samples obtained from the production process and to see the state of the process.

The quality characteristics of the products obtained from the process were evaluated and recorded as defective or flawless. The defect rate for each sample was obtained by dividing the number of defects in each sample by the sample volume. The final decision to be made as a result of this method is the acceptance or rejection of the sample. As a result of the analysis, the sample was indicated as suitable or unsuitable for the selected quality feature. The meanings of the symbols used in the p control method are as follows:

- p = Defect rate
- c = Number of defects in the sample
- X= Amount of defect
- n = Sample size
- k= The k value in the formula indicates the number of days the study was performed

Table 6. Number of defects and defects rate by days

Day	**Sample Size (n)**	**Number of Defects in the Sample (c)**	**Defect Rate (p)**
1	90	11	0.122
2	130	14	0.107
3	130	13	0.1
4	150	16	0.106
Total	500	54	0.435
Average	125	13,5	0,108

Care should be taken to ensure that the sample volume to be taken np > 1. Only when this condition is met, can one speak of the adequacy of the sample. If this ratio is less than one, the result may not correspond to the actual conditions. In the absence of standards, the average of the ratios obtained from the samples (p) determines the centerline, and the upper and lower control limits are established. These values are shown in Equations (1-2).

$$LCL = p - 3\sqrt{\frac{p(1-p)}{n}} \qquad (1)$$

$$UCL = p + 3\sqrt{\frac{p(1-p)}{n}} \qquad (2)$$

Since the standards are not clear, the p-value must be found. This value was calculated according to Equation (3).

$$p = \frac{\sum X}{n*k} = \frac{54}{125*4} = 0{,}108 \qquad (3)$$

n=125

$$(n * p) = 125 * 0.108 = 13{,}5 \qquad (4)$$

n*p = 13,5 >1
Because it is greater than one, the sample are sufficient.

p = (Mid Line) = 0,108
According to Equation (1),

$$LCL = 0{,}108 - 3\sqrt{\frac{0{,}108(1-0{,}108)}{125}} = 0{,}191 \qquad (1)$$

$$LCL = 0{,}108 - 3\sqrt{\frac{0{,}108(1-0{,}108)}{125}} = 0{,}024 \qquad (2)$$

As a result of the calculations, the p control diagram is shown in Figure 9.

The UCL and LCL are upper and lower control limits on a control chart, respectively. A control chart is a line chart that expresses the state of the production process over time. The quality control of the product was provided by using the control chart. Thanks to control charts, it is determined whether the product is under control during the production process. It also shows whether a change in the production process with the lower and upper control limit values on a control chart is a natural condition or is caused by any abnormal condition that may affect the quality of the product.

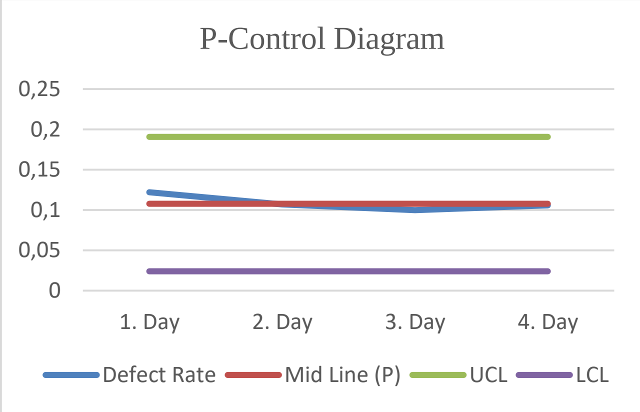

Figure 9. P control diagram

6. Conclusion

This study, in which statistical process control (SPC) techniques were used as a quality improvement tool, was carried out at the "OMS Textile Factory", which produces denim pants.

Sewing defects detected in the final inspection at the factory were analyzed using SPC techniques, such as flowchart, control chart, pareto analysis, grouping, p control diagram, and cause-effect diagram. At the beginning of the analysis, the flowchart of the production stages of denim pants has been created.

Subsequently, the sewing process in which the detected defects occurred and the daily defect numbers of these processes were listed on the control chart. According to the control chart, based on the data reviewed in production, the most common defects occurred in the order of back rise, back yoke, hem, waistband, and yarn cleaning. Then, these five most common defects were classified by defect type.

The many-to-less ordering of the specified defects was revealed by pareto analysis, as can be seen from the control chart: the five processes mentioned above accounted for 68% of the defects. The process to be improved in this analysis was the back rise process, with a value of 17%. The defects detected using the grouping method were examined under three headings: human, machine, and method. In this analysis, human defects were calculated as 63.2%.

The main problems and sub-problems that cause defects related to the "back rise" process, which is the most repeated defect, are discussed in the cause–effect diagram. The back rise operation was examined in the p control diagram analysis, the back rise operation was examined. As a result, this operation turned out to be under control.

As a result of these analyses, it was determined that the operations are under control. However, it should be handled as a situation that can be prevented from recurring defects in certain operations.

As determined in the grouping method, since the highest factor causing defects is human, it was recommended to start the improvements by teaching the job descriptions, workflow and process flow, and quality criteria to the employees descriptively and clearly, and conducting practical training.

Of course, the experiences, visions, and intuitions are valuable. However, due to increasing resource constraints and production costs, it is becoming increasingly clear that judgments must be based on facts rather than opinions based on experience and intuition. However, although subjective evaluations are not ignored at the decision stage, seeking solutions with scientific techniques and approaches is necessary to make an objective evaluation. While deciding whether the efficiency of production and quality are at the targeted level, it is necessary to collect data at an accurate and sufficient level and evaluate them using proper techniques and approaches.

This study is anticipated to contribute to the literature by demonstrating the role of statistical process control tools in quality improvement in the evaluation and decision-making phases.

7. Acknowledgement

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8. References

[1] M. İslam and A. Khan, M. R. Khan, "Minimization of Reworks in Quality and Productivity Improvement in The Apparel Industry," *International Journal of Engineering and Applied Sciences,* vol. 1, no. 4, pp. 38-40, 2013.

[2] İhkib, "İstanbul Hazır Giyim ve Konfeksiyon İhracatçıları Birliği," Denim Konfeksiyon Uluslararası Rekabetçiliğin Geliştirilmesi Projesi, 18 December 2016. [Online]. Available: https://www.ihkib.org.tr/fp-icerik/ia/d/2017/01/26/denim-konfeksiyon-urge-ihtiyac-analizi-raporu-web-versiyonu-201701261511540063-80CD6.pdf. [Accessed 7 April 2023].

[3] S. Kaya and M. Ç Erdoğan, "Konfeksiyon İşletmelerinde Operatör Özelliklerinin Dikim Bölümündeki Kalite Hatalarina Etkisi," *Tekstil ve Konfeksiyon,* vol. 17, no. 3, pp. 207-213, 2007.

[4] M. Erdoğan and İ. D. Kayaalp, "Konfeksiyon İşletmesinde Dikiş Hatalarının İstatistiksel Proses Kontrol Yöntemlerini Kullanarak Azaltılması," *Textile and Apparel,* vol. 2, no. 7, pp. 23-31, 2009.

[5] S. M. Uddin and C. Rahman, "Minimization of Defects in The Sewing Section of a Garment Factory Through DMAIC Methodology of Six Sigma," *Research Journal of Engineering Sciences,* pp. 21-26, 9 11 2014.

[6] B. Kırık, Bir Konfeksiyon İşletmesindeki Son Kontrol Hatalarının İstatistiksel Yöntemlerle Analizi, Tekirdağ: Namık Kemal Üniversitesi Fen Bilimleri Enstitüsü, 2017.

[7] S. Ata, M. S. Yıldız, İ. Durak "Statistical Process Control Methods For Determining Defects of Denim Washing Process: A Textile Case From Turkey," *Tekstil ve Konfeksiyon,* vol. 30, no. 10, pp. 208-219, 2020.

[8] H. C. Pham, I, Ulhaq, P. Yeow and M. Akbari, Other Lean Tools in Fashion and Textile Manufacturing, Singapore: Springer Singapore, 2022.

[9] R. Brad, Statistical Quality Control Practices in Clothing Industry, Austria: DAAAM International, 2010.

[10] G. Bek, Bir Konfeksiyon İşletmesinde Proses ve Kalite Kontrol, Adana: Çukurova University, 2008.

[11] Ö. Yücel, "Dikimde Hata Oluşturulan Nedenlerin Belirlenmesine Yönelik İstatistiksel Bir Araştırma," *Journal of Engineering Sciences ,* vol. 9, no. 3, pp. 327-332, 2003.

[12] N. Çetin, Kalite Kontrol Uygulamaları ve Örnek Bir Çalışma, Ankara: Gazi Üniversitesi Eğitim Bilinleri Enstitüsü, 2008.

[13] C. Duran and A. Çetindere "Konfeksiyon Sanayiinde Faaliyet Gösteren Bir İşletmede İstatistiksel Proses Kontrol Teknikleri ile Ürün Hatalarının Analiz Edilmesi," *Ç.Ü. Sosyal Bilimler Enstitüsü Dergisi,* vol. 21, no. 2, pp. 233-254, 2012.

[14] B. Behera, S. Chand, T. Singh and P. Rathee, "Sewability of Denim," *International Journal of Clothing Science and Technology,* vol. 9, no. 2, pp. 128-140, 1997.

[15] E. Akcagun, N. Öz Ceviz, A. Yılmaz and A. A. Mazari "Analyzing The Effects of Special Washing Processes on Characteristics of Sewing Threads," *The Journal of The Textile Institute,* vol. 108, no. 11, pp. 1926-1932, 2017.

[16] M. Saunders, P. Lewis and A. Thornhill, Research Methods for Business Studies, India: Financial Times, 2010.

[17] J. S. Oakland, Statistical Process Control, London: Routledge, 2007.

[18] A. Majumdar, A. Das, R. Alagirusamy and V. K. Kothari Process Control in Textile Manufacturing, India: Woodhead Publishing Series in Textiles, 2014.

[19] K. Marilyn and F. Robert, Statistical Process Control Techniques, Oregon: Statit Software, 2007.

[20] S. Jadhav, G. S. Sharma, A. M. Daberao, "Improve Productivity in Garments Industry with Time Study," *International Journal on Textile Engineering and Processes,* vol. 3, no. 4, pp. 1-6, 2017.

[21] S. Ata, M. S. Yıldız and İ. Durak, "Statistical Process Control Methods For Determining Defects of Denim Washing Process," *Textile and Apparel,* vol. 30, no. 3, pp. 208-219, 2020.

[22] A. Pedro and C. Carlos, P. Paranhos, S. Ribeiro and H. Gouveia, "Selection of the Most Suitable

Statistical Process Control Approach for Short Production Runs: A Decision-Model," *International Journal of Information and Education Technology,* vol. 5, no. 2, pp. 303-310, 2015.

[23] G. Koksal, W. A. Smith Jr. and C. B. Smith, "A System Analysis of Textile Operations," *Textile Chemist & Colorist,* vol. 24, no. 10, pp. 30-35, 2016.

[24] V. Arya, V. Jain, "Basics of Process Control in Textile Manufacturing," in *Indian Institute of Technology*, Delhi, India, Woodhead Publishing Limited, 2013, pp. 3-13.

[25] M. A. Abtew, S. Krop, Y., Hong and L. Pu, "Implementation of Statistical Process Control in the Sewing Section of Garment Industry for Quality Improvement," *AUTEX Research Journal,* vol. 18, no. 2, pp. 160-172, 2018.

[26] T. K. Kapuria, M. Rahman and S. Haldar, "Root Cause Analysis and Productivity Improvement of An Apparel Industry in Bangladesh Through Kaizen Implementation," *Journal of Applied Research on Industrial Engineering,* vol. 4, no. 4, pp. 227-239, 2017.

[27] C. Prakash, "Implementation of Lean Tools in Apparel Industry to Improve Productivity and Quality," *Current Trends in Fashion Technology & Textile Engineering*, vol. 4, no. 1, pp. 1-6, 2018.

[28] B. Durakovic and H. Basic, "Continuous Quality Improvement in Textile Processing by Statistical Process Control Tools: A Case Study of Medium-Sized Company," *Periodicals of Engineering and Natural Sciences,* vol. 1, no. 1, pp. 39-46, 2013.

[29] İ. Ertuğrul and A. Özçil, "The Application of "p" and "p-Cusum" Charts into Textile Sector in the Statistical Quality Control Process," *Textile and Apparel,* vol. 24, no. 1, pp. 9-14, 2014.

[30] İ. Ertuğrul and E. Aytaç, "Construction of Quality Control Charts by Using Probability and Fuzzy Approaches and an Application in a Textile Company," *Journal of Intelligent Manufacturing,* vol. 20, no. 4, pp. 139-149, 2009.

[31] A. A. Yazdani and R. T. Moghaddam, "Integration of the Fish Bone Diagram, Brainstorming and AHP method for Problem Solving and Decision Making," *The International Journal of Advanced Manufacturing Technology,* vol. 63, no. 9, pp. 651-657, 2012.