

Development of a New Fabric Grading System with a Demerit Control Chart in the Apparel Industry

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Abstract

Fabric defects are usually manually identified by quality control staff in the apparel industry. Control charts are an appropriate tool to achieve this goal. In this study, knitted fabric often used in an apparel factory were used in both the detection and classification process. The systematic classification of fabric defects such as critical, major, and minor types was achieved. Then, by calculating the “D” scores of fabric types, the types of errors out of the lower and upper control limits were determined. According to the results of the experiment, it was shown that the fabric grading process can be performed with demerit control charts.

Key words: apparel industry, fabric grading, control charts, demerit control charts, quality control.

ti-scale dictionary learning and the adaptive differential evolution algorithm [10].

Although the different defect determination methods described above for fabric control provide necessary data to researchers, it is a different research subject to evaluate these data and make a judgment about the fabric grading. Fabric grading is different from fabric inspection, which is essential for eliminating rejection due to the poor quality of fabric. It is also a precaution to remove unexpected defects on finished goods. The quality of a finished garment is dependent on that of the fabric when sourced from the supplier.

It is therefore essential to identify those diverse types of visual defects that affect the overall quality of the fabric and, in turn, the garment. There are many formal systems for evaluating and grading the quality of fabric, such as the Graniteville “78” system, Dallas system, Four-point system, and Ten-point system. In these systems, the operator calculates the numbers of major and minor defects as point values per square metre and then grades the fabric quality as ‘first’ or ‘second’ quality [11]. In all of the fabric grading systems mentioned above, a scoring system with the same scale is used for each fabric type. However, fabric manufacturing involves the use of many types of yarns and knitting patterns. The complexity associated with raw materials and the formation of textile structures can lead to various faults/defects. Therefore, it is important to grade fabric, unlike other methods, with a statistical analysis system. Control charts are an appropriate tool to achieve this goal.

One of the earliest studies on control charts belongs to Hossain et al. (1996), who used a software tool (Paragon 500) for monitoring and controlling a pump speed control system [12]. In 1997, Cook et al. developed software that used X-R charts in order to determine welding process variation and develop recommendations for situations outside the limit [13]. Bai and Lee tried to design an economic sampling interval for X control charts. A cost model is constructed which involves the cost of false alarms, that of detecting and eliminating the assignable cause, that associated with production in an out-of-control state, and the cost of sampling and testing [14]. While some scientific studies worked to develop control charts [15-17], they found a limited application area in the field of textile and apparel.

Bircan and Gedik investigated the causes of production faults using statistical process control techniques in a sewing department. It is observed that the production process is under control according to “p” and “np” control graphs [18]. Ertuğrul and Karakaşoğlu examined whether production is under control or not in a textile company by using 24-week data and p control charts [19]. Yıldız and Vahaplar used distribution-free quality control charts on fancy shirting fabric production. False Alarm Rate (FAR) and Average Run Length (ARL) values for different design parameters are calculated, and it is concluded that the process is statistically in control [20]. Ertuğrul and Özçil used ‘p’ (Defect Percentage of Charts) and ‘p-CUSUM’ (The Cumulative Sum of Charts) to research whether or not production is suitable for the

Introduction

Measurement of fabric quality is highly important to apparel production in lowering costs and improving the finished product. Presently, much of the fabric inspection is performed manually by human inspectors, with visual inspection being an important part of quality control in the textile industry [1]. As the textile industry has been moving toward automated fabric inspection, this subject has attracted the attention of many research teams. Scientific studies on the subject address the following topics; developing a computer image based inspection system for fabric inspection [1-4], using an expert system to give an analysis of the characteristics of fabric faults as well as solutions for rectifying these faults [5], and developing a fabric fault classification by using pattern recognition artificial neural networks [6], a Probabilistic Neural Network (PNN) [7], the burgeoning multiscale and geometric analysis method [8], fuzzy c-means (FCM) [9], mul-

Suppli	Fabri	Roll	Area n	Mino	Majo	Critical	D	3 UCL	2 UCL	2 LCL	3LCL	2UCL	3UCL
												Problem	Problem
Supplier 2	F1	1	78,3	5	0	6	0,753191	0,702546	0,542509	-0,09764	-0,25768	Problem	Problem
Supplier 2	F1	2	78,1	19	0	1	0,358638	0,702546	0,542509	-0,09764	-0,25768	Ok	Ok
Supplier 2	F1	3	75,8	6	0	0	0,079149	0,702546	0,542509	-0,09764	-0,25768	Ok	Ok
Supplier 2	F1	4	75,6	13	0	0	0,172043	0,702546	0,542509	-0,09764	-0,25768	Ok	Ok
Supplier 2	F1	5	76,8	7	0	1	0,20834	0,702546	0,542509	-0,09764	-0,25768	Ok	Ok
Supplier 2	F1	6	79,9	6	0	1	0,18766	0,702546	0,542509	-0,09764	-0,25768	Ok	Ok
Supplier 2	F1	7	79,7	6	0	1	0,188298	0,702546	0,542509	-0,09764	-0,25768	Ok	Ok
Supplier 2	F1	8	79,4	12	0	0	0,151149	0,702546	0,542509	-0,09764	-0,25768	Ok	Ok
Supplier 2	F1	9	79,1	20	0	0	0,252766	0,702546	0,542509	-0,09764	-0,25768	Ok	Ok
Supplier 2	F1	10	80,5	11	0	0	0,136681	0,702546	0,542509	-0,09764	-0,25768	Ok	Ok
Supplier 2	F1	11	77,8	5	0	1	0,179915	0,702546	0,542509	-0,09764	-0,25768	Ok	Ok
Supplier 2	F1	12	80,8	15	0	1	0,297191	0,702546	0,542509	-0,09764	-0,25768	Ok	Ok
Supplier 2	F1	13	80,2	12	0	0	0,149617	0,702546	0,542509	-0,09764	-0,25768	Ok	Ok
Supplier 2	F1	14	77,8	3	0	3	0,385532	0,702546	0,542509	-0,09764	-0,25768	Ok	Ok
Supplier 2	F1	15	78,3	10	0	2	0,357447	0,702546	0,542509	-0,09764	-0,25768	Ok	Ok
Supplier 2	F1	16	79,7	16	0	2	0,426809	0,702546	0,542509	-0,09764	-0,25768	Ok	Ok
Supplier 2	F1	17	77,8	12	0	4	0,616851	0,702546	0,542509	-0,09764	-0,25768	Problem	Ok
Supplier 2	F1	18	79,1	4	0	0	0,050553	0,702546	0,542509	-0,09764	-0,25768	Ok	Ok
Supplier 2	F1	19	81,9	8	0	0	0,097702	0,702546	0,542509	-0,09764	-0,25768	Ok	Ok
Supplier 2	F1	20	80,5	2	0	0	0,024851	0,702546	0,542509	-0,09764	-0,25768	Ok	Ok
Supplier 2	F1	21	82,2	28	0	0	0,340766	0,702546	0,542509	-0,09764	-0,25768	Ok	Ok
Supplier 2	F1	22	80,2	12	0	1	0,26183	0,702546	0,542509	-0,09764	-0,25768	Ok	Ok
Supplier 2	F1	23	80,5	4	0	0	0,049702	0,702546	0,542509	-0,09764	-0,25768	Ok	Ok
Supplier 2	F1	24	81,9	3	0	0	0,036638	0,702546	0,542509	-0,09764	-0,25768	Ok	Ok
Supplier 2	F1	25	79,9	2	0	0	0,025021	0,702546	0,542509	-0,09764	-0,25768	Ok	Ok
Supplier 2	F1	26	79,1	8	0	0	0,101106	0,702546	0,542509	-0,09764	-0,25768	Ok	Ok
Supplier 2	F1	27	79,1	11	0	0	0,139021	0,702546	0,542509	-0,09764	-0,25768	Ok	Ok

Figure 1. Screenshot of calculations.

standards or desired quality level [21]. Maros et al. introduced a control chart for monitoring various defect types occurring on chenille yarns. It is found that the modified EWMA control chart can be used successfully for monitoring different types of chenille yarn defects [22]. Patır investigated the process control of the winding process in a textile manufacturing by using X and S control charts. It is found that the array number of sample points is at the desired level, thus there is no systematic error in the process and it is under control [23]. Dülgeroğlu Kısaoğlu investigated loom stoppages using their causes and defects on the fabric were detected during the running of looms in the process inspection using “c charts”. At the conclusion of the woven fabric quality evaluations, it was determined that the rate of defects originating from yarn is rather higher than that of defects originating from the weaving preparation & weaving process. Aslangiray and Akyüz used fuzzy logic to establish process control charts, and a relevant application is given. It is seen that the number of out-of-control points was higher in the u-control than in the fuzzy control charts. “Partially under control” and “partially

out of control” decisions can be given as alternatives for the “under control” and “out of control” decisions of u-graphics [24]. In this study, unlike the previous ones, application of the demerit chart used for attributes is discussed in the apparel industry.

Materials and methods

The control chart is a graphical display of a quality characteristic that has been measured or computed from a sample versus the sample number or time. The chart contains a centre line that represents the average value of the quality characteristic corresponding to the in-control state. Two other horizontal lines, called the upper control limit (UCL) and the lower control limit (LCL), are also shown on the chart [25]. There are two types of control charts; for variables and for attributes. Control charts for variables require actual measurements, such as length, weight, tensile strength, etc. Charts for attributes can only be used in cases where it is desired to count the number of nonconforming items or the number of nonconformities in a sample.

Attribute control charts have the advantage that several quality characteristics can be considered jointly and the unit classified as nonconforming if it fails to meet the specification on any one characteristic. On the other hand, if the several quality characteristics are treated as variables, then each one must be measured, and either a separate R chart must be maintained on each or some multivariate control technique that considers all the characteristics must simultaneously be employed. There is an obvious simplicity associated with the attributes chart in this case. Furthermore, expensive and time-consuming measurements may sometimes be avoided by means of attribute inspection [25]. In the attribute charts, all nonconformities and nonconforming units have the same weight, regardless of their seriousness [26]. This situation presents an incorrect evaluation of the product quality. A demerit control chart system will correct this deficiency. Demerit Control charts are established and plotted for the count of demerits per unit. A demerit per unit is given by *Equation (1)*:

$$D = w_c u_c + w_{ma} u_{ma} + w_{mi} u_{mi} \quad (1)$$

Where, D – demerits per unit;
 w_c, w_{ma}, w_{mi} – weights for the three classes (critical, major, and minor);
 u_c, u_{ma}, u_{mi} – count of nonconformities per unit in each of the three classes – critical, major, and minor. In this study, w_c, w_{ma}, w_{mi} are taken as 9, 3, and 1, respectively.

The D values calculated from **Equation (1)** are posted to the chart for each subgroup.

The central line and 3σ control limits are obtained from the following formulas:

$$D_0 = 9u_{oc} + 3u_{oma} + 1u_{omi} \quad (2)$$

$$\sigma_{ou} = \sqrt{\frac{9^2u_{oc} + 3^2u_{oma} + 1^2u_{omi}}{n}} \quad (3)$$

$$UCL = D_0 + 3\sigma_{ou} \quad LCL = D_0 - 3\sigma_{ou} \quad (4)$$

Where, u_{oc}, u_{oma} and u_{omi} represent the standard nonconformities per unit for the critical, major, and minor classifications, respectively. The nonconformities per unit for the critical, major, and minor classifications are obtained by separating the nonconformities into the three classifications and treating each as a separate u chart [26]. Formulas used for u chart are as follows:

$$u = \frac{c}{n} \quad (5)$$

Where, c – count of nonconformities in a subgroup;
 n – number inspected in a subgroup;
 u – count of nonconformities/units in a subgroup.

This study was performed in an international apparel producer which sells to more than 10 primary customers in different countries. Fabrics coming into the facility are manually controlled in the quality control department, where 20 people work. Fabric faults observed as a result of the control process are recorded in a standard form, in which defect types are handled in three different classifications: dyeing, yarn and knitting.

The fabrics inspected show measurable fault types, such as horizontal stripes, dye spots, stains etc. as well as countable faults such as holes or cracks. In order to use demerit control charts in fabric control, some measurable faults had to be converted into countable ones. In this context, an estimated length of 1 size (approx. 50 cm) in the marker plan was taken into account. For faults up to

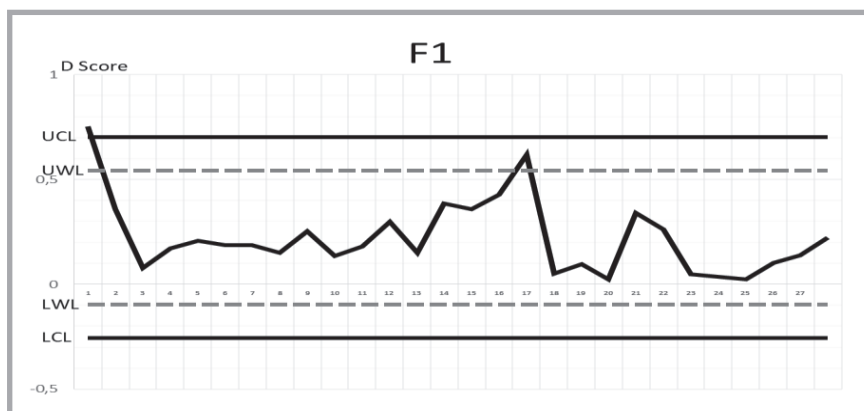


Figure 2. Demerit control chart for F1 fabric.

Table 1. Demerit chart results of all fabrics.

No	Fabrics	Number of fabric roll	D_0	σ_{ou}	LCL	UCL
F1	30/30/12 70% cotton 30% polyester brushed futter	27	0.2224	0.1600	-0.2578	0.7025
F2	20/1 vortex cotton polyester single pique	89	0.0632	0.1115	-0.2715	0.3979
F3	30/1 cotton polyester double pique	145	0.0678	0.1160	-0.2802	0.4159
F4	30/30/12 cotton polyester futter	24	0.0510	0.1084	-0.2741	0.3762
F5	30/30/16 vortex cotton polyester futter	24	0.1092	0.1421	-0.3173	0.5358

50 cm and 50-75 cm, each fault of 1-metre length was determined as minor, major and critical, respectively. In addition, as the “n” value in the calculations, the fabric area is taken into consideration using **Equation (6)**. Decimal numbers were rounded up to narrow the control limits, with all calculations made in Microsoft Excel (**Figure 1**).

$$Fabric\ area = \frac{weight\ of\ fabric\ roll\ (kg)}{fabric\ mass\ (\frac{kg}{m^2})} \quad (6)$$

Results and discussion

During the study, 5 different fabric types belonging to four different orders were examined. The upper and lower control limits calculated for the fabric types are given in **Table 1**.

The presence of points that plot below the lower control limit on a chart, even though they indicate an out-of-control situation, are desirable because they also indicate an improvement in the process. Although 8 control chart rules were taken into account in some other studies, UCL was used in this study with the expectations of the company. In the demerit control chart, if the lower control limit is calculated to be less than zero, it is

converted to zero [27]. However, in this study, the lower limit interval was left as in the calculations. When **Figures 2-6** are examined, it is seen that no point falls below zero. The important thing is to check whether it goes out of UCL for each fabric. The demerit control charts of the fabrics examined are presented from **Figure 2** to **Figure 6**.

A different number of fabric rolls were checked for all fabric types. In all fabrics except F5, fabric rolls outside the upper control limit were observed. Also, 2 sigma (warning) limits ($WL = D_0 \pm 2\sigma_{ou}$) are shown with dashed lines to show the warning limits. As can be seen in **Table 1**, each fabric type has its own control limit. When the errors belonging to the fabrics outside the upper control limit were examined, it was determined that the most common types of fault in the fabrics purchased from the same supplier were holes and dye spots. Thus, the fabric supplier was warned to take the necessary precautions against the related faults.

Also, it should be noted that the raw material mixing ratios of each type of fabric and the physical and chemical processes they undergo during the production phase are different. This causes different types of defects to occur on different fab-

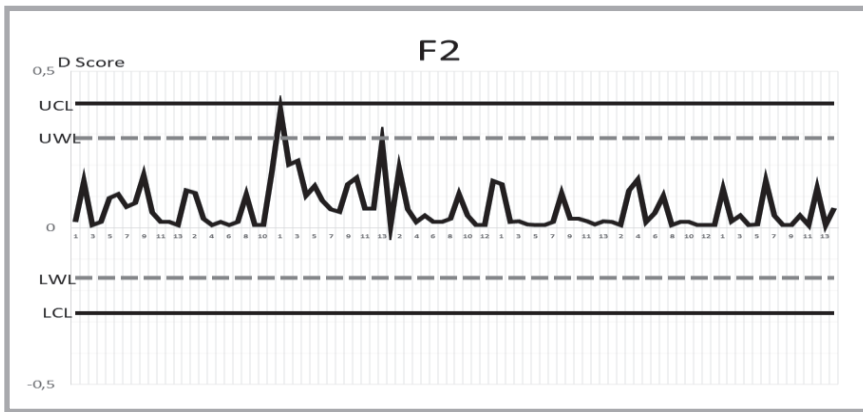


Figure 3. Demerit control chart for F2 fabric.

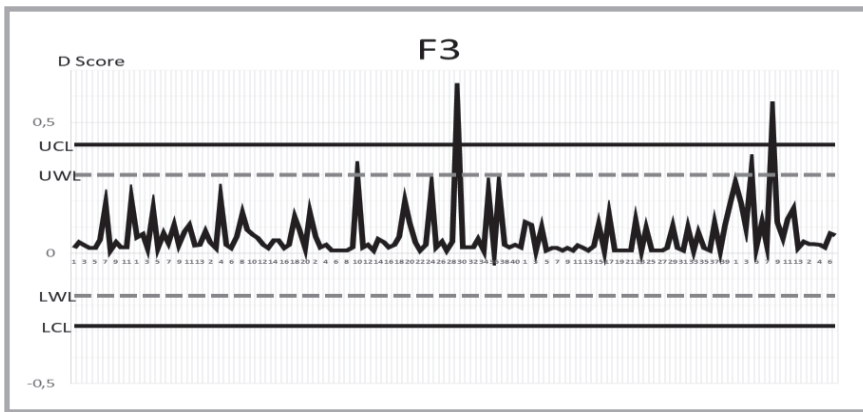


Figure 4. Demerit control chart for F3 fabric.

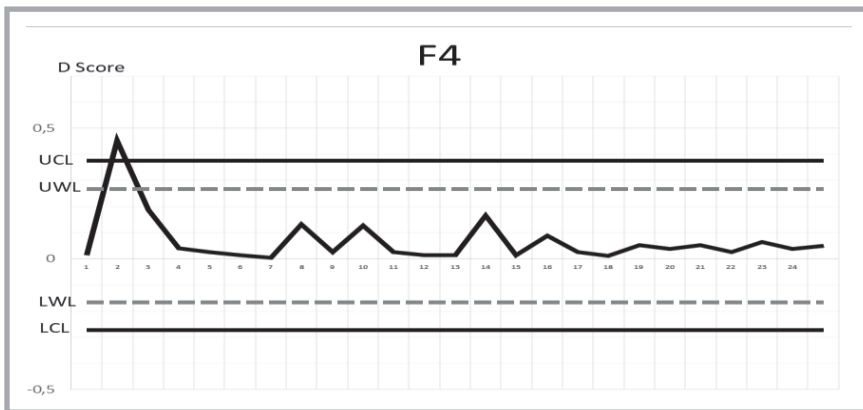


Figure 5. Demerit control chart for F4 fabric.

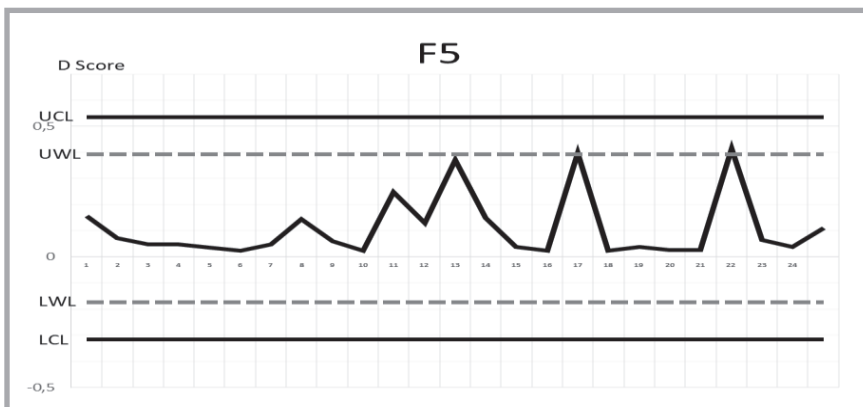


Figure 6. Demerit control chart for F5 fabric.

rics and, in turn, various effects of each type of defect on the error rate, that is, their weights. This is the main reason for different types of fabrics to have different error distributions.

One or more of the rolls in the lot goes out of the limit due to the following reasons: Whichever roll or rolls come across unexpected processes in the production phase, its error rate will be higher and will show anomaly outside the control limits in the graphic.

Conclusions

It is well known fact that the quality of a garment has a direct correlation with that of fabric. It is the responsibility of fabric manufacturers as well as garment manufacturers to provide the final quality product to the consumer. The word 'quality' in the garment industries relate to the visual examination or review of raw materials (such as fabric, accessories, trims, etc.). In order to indicate when variations in quality observed are greater than those that could be when left to chance, the control chart method of analysis and presentation of the data should be used. It is a graphical record of the quality of a particular characteristic, showing whether or not the process is in a stable state.

Within this study, which types of fabrics used in knitwear ready-made garments as well as which types of errors are out of the control limits are analysed, and by considering the "D" scores of fabrics obtained from a particular supplier, those fabrics outside the control limit among those purchased from the supplier were determined. Determining which type of fault and which fabric is outside the upper control limit in fabric evaluation also provides a new application and analysis for the apparel industry. Since each fabric type will be evaluated with its own specific upper limits, it will be possible to intervene before the related fabric enters production. Various reasons for the rejection and refusal of an order will be established on a scientific basis, thereby creating an objective judgment in fabric evaluation.

The demerit control chart gives a different upper/lower control limit value for each fabric. For this reason, it is not possible to talk about a standard result for any fabric. As the data set expands, the control card's ability to represent the population will im-

prove and its limits will change. During the fabric control process, UCL will vary according to the number of defects in the upcoming new rolls. Thus, the purpose of the system is not to obtain a universal UCL value for each fabric type, but to compare and filter the faulty fabric roll that the company bought with fabrics of the same construction previously supplied. For example, if any new coming fabric roll “D” score is higher than the UCL of the relevant fabric, it can be quickly decided not to put the fabric into production. For this reason, one of the important points of this system is that it works with monitoring software that tracks production. In addition, it will be possible to evaluate the fabric performances of suppliers with some filters to be implemented in the software.

In the future, researchers working on this subject are advised to focus on new research topics, such as the statistical relationship of finished product defects and fabric faults, and maintenance management analysis that can be applied at the fabric supplier. Also, it may be possible to add 8 control chart rules to the fabric evaluation process in line with business demands.

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