Chapter 8

Control Charts to Enhance Quality

Nefise Gönül Şengöz

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.73237

Abstract

Control charts are important tools of statistical quality control to enhance quality. Quality improvement methods have been applied in the last few 10 years to fulfill the needs of consumers. The product has to retain the desired properties with the least possible defects, while maximizing profit. There are natural variations in production, but there are also assignable causes which do not form part of chance. Control charts are used to monitor production; in particular, their application may serve as an "early warning" index regarding potential "out-of-control" processes. In order to keep production under control, different control charts which are prepared for dissimilar cases are established incorporating upper and lower control limits. There are a number of control charts in use and are grouped mainly as control charts for variables and control charts for attributes. Points plotted on the charts may reveal certain patterns, which in turn allows the user to obtain specific information. Patterns showing deviations from normal behavior are raw material, machine setting or measuring method, human, and environmental factors, inadvertently affecting the quality of product. The information obtained from control charts assists the user to take corrective actions, hence opting for specified nominal values enhancing as such quality.

Keywords: quality, quality improvement, control charts, upper and lower control limits, individual, variable, attribute, interpretation, corrective action

1. Introduction

Quality is regarded as an important build-in feature of a product, whose function is to fit ones needs, while showing no defects. In addition to this, the price has to be right, so that the product may serve its designed life span. Another aspect of quality is that the product has to show the user a favorable characteristic while used other than the aim of the user to buy the product. When all the mentioned measures are met within the product, it may be regarded as a quality product.

Some types of production are done by one person, let us say a tailor; this person is responsible of every step of the product either machine performed, or by hand. As such, that person would take care of any defects as soon as these occur. In addition to this, that one person would add or deduct so-called "excitement" features in the product according to the consumer's taste. This kind of production is called the mentor-protege type. Henry Ford introduced and implemented mass production, where every step of the production is done by someone else with a different machine. Since many people and machines are involved in the production, the chance of deviations and defects increases and may cause quality-specific problems. Furthermore, since the operators do not know who the consumer they are producing for in mass production, research and development departments were created to fulfill the "excitement" features, since this work had to be done by other people than the operator; additionally, research and development departments serve to aim produced goods to different markets.

In order to effectively manage and eliminate quality-specific problems, a number of quality control methods were developed. The following encapsulates some of these:

- Quality control,
- Total quality control,
- Total quality management,
- Quality management,
- Quality improvement,
- Six-sigma quality management, etc.

Statistical quality control is used widely in the modern business world. Indeed, control charts are deemed as one of the primary techniques to enhance quality. Gathering data to prepare a control chart is done according to many national and international standards like British Standards (BS), American Standards (ASTM), German Standards (DIN), Turkish Standards (TSE), etc. Variations in due time or sample order are examined by control charts in order to keep production under control according to the product's desired properties. The purpose of this chapter is to highlight the arising benefits of using control charts and elaborate their impetus on industrial case studies such as to keep production under control, to eliminate defects, and to increase profit, if not, a full understanding of what is going on in production or service will not be conceived.

A process is a system of bonds worked altogether to produce a specific outcome or factors which affect the production and the quality of a product or a function. In order a process to achieve the intended result, the causes of the mentioned process have to be kept under control. To this end, control charts are used [1]. The latter is prepared with numerical data of a particular characteristic of the product, which is controlled. Additionally, control charts

http://dx.doi.org/10.5772/intechopen.73237

provide visual support about the deviations in the characteristics [2]. In doing so, they prevent the formation of defects and increase and develop the efficiency of the processes.

1.1. Aims and objectives

Quality improvement tools are mainly process flow diagrams, cause-and-effect (fishbone) diagrams, check sheets, histograms, scatter plots, Pareto diagrams, and control charts. The aim of this chapter is to focus on the use of only the control charts and provide a qualitative and quantitative insight. As such, it will present industrial cases regarding their use and type. In addition to this, it will discuss on how they are designed, prepared, and interpreted together with research concerning control charts.

In doing so, this work will include:

- Presentation of control charts in the area of quality control;
- Design of a control chart;
- Types of control charts;
- General guidelines to prepare control charts;
- Control charts for variables, that is, individual measurements control charts, means control charts, ranges control charts, and standard deviation control charts with industrial applications;
- Control charts for attributes, that is, control charts for fraction nonconforming, control charts for the number of nonconforming items, control charts for conformities per unit, and control charts for nonconformities with industrial applications;
- Special cases for control charts;
- Interpretation of control charts;
- Research on control charts.

Control charts provide higher efficiency in production, decrease defects and faulty production, increase profit, and diminish costs. These are some of the reasons why control charts are widely used in industry. Indeed, their area of application is quite wide and covers nearly everything from service organizations and providers to financial consulting offices, as well as in various other applications in daily life.

2. Literature review

It is worth mentioning at this point that in nature as well as in service and production companies, no two products of the same substance are exactly the same. This implies that at least two of the same substance or characteristic are always different, or at least there is a small difference between them. This, however, is normal as long as it affects small variations. To produce every piece in a lot exactly to the specified nominal characteristic is both hard and costly. The measurements of some quality characteristic like length, width, temperature, weight, etc., vary slightly and maybe unavoidable. This variability depends on equipment, machinery, materials, equipment, environment, people, etc., and is acceptable. These types of variability are referred to as "normal", "random", or "natural".

In view of the above, it is preferred that the variability has to be reduced as much as possible in the process, if it is not eliminated. The distances of the points from the mean line give the user information about its variability. There are chance causes of variation in statistical control, but there are also assignable causes which are not a part of the chance causes. These show important, large, and unusual differences. The reasons for this may be:

- Material is taken from a different lot,
- The machine setter makes a new setting,
- Any kind of "operator error".

The above may cater for the "abnormal" or "unnatural" variations. In a production where the aim is to achieve quality and to meet the consumers' requirements, the presence of assignable causes may draw the process out-of-control. Since the objective of studied quality characteristic is to be stable and repeatable, the occurrence of assignable causes must be detected instantly and the investigation of the process and corrective action ought to take place before further nonconforming units are manufactured. Control charts are widely used in order to interpret the variability a characteristic possesses between nominal and actual settings. The differences between "normal" and "abnormal" variations are detected, and the characteristic is kept under control by taking all the necessary measures. The purpose of control charts in quality control is prevention, which is better than cure [3].

The amount of variation to be allowed in any manufacturing process is of paramount importance. It is impossible to examine the records of past data and evaluate data by looking and thinking without doing statistical calculations.

In some factories, technical staff checks out the data and estimates on an *ad hoc* level the limits of the process. These may be too wide or too narrow, which in turn, may be both affecting the production negatively causing it to go out-of-control. If the limits are too wide, the process will posses an excess of variation; if it is too narrow, extra work may be required so as to maintain set limits. It is worth noting at this point, both of them prevent corrective action to take place which is suitable for production. On the other hand, when the limits are calculated on a scientific basis, the exact amount of expected variation in a product will be determined and will be confidently used, so guesswork will be eliminated [4]. Examples for limits can be seen in **Figures 6–12**.

Shewhart developed the control charts first in 1924 and are as such called Shewhart control charts. The usage of control charts became common as its benefits were recognized in due time. Its benefits can be listed as:

http://dx.doi.org/10.5772/intechopen.73237

- Knowing how the production proceeds,
- Diminishing costs,
- Increasing production by doing it right the first time so to prevent defects,
- Being aware of the effects of raw material, machine, worker, and environmental factors by analyzing the patterns occurring on the control chart
- Saving time by preventing the error of searching for special reasons that effect the processes even they do not exist;
- Making it easier to find the factors that negatively affect the process;
- Used to seek if the desired efficiency of a machine is achieved;
- Useful in decreasing the variations in a product or in a process;
- Useful in decreasing the number of rejected pieces or waste;
- Ensuring to decrease the cost of testing and control;
- Enabling the specifications and orders at a more realistic level;
- Helpful in making the processes more stable;
- Advantageous in preparation of reports near to real about the processes or operations to present to the managers;
- Expedient in keeping sensitive and reliable records;
- Used in deciding the renewal time of the production machines;
- Substantial reference in research and development practices;
- Helpful in cost and financial analysis;
- Used in stocks control [5].

The areas where control charts can be used are areas such as production-not least on say, count of the yarn or the weight of fabric in textiles, costs, sales, circulation of workers, material, chemicals, etc., in a certain period of time.

Quality control charts are statistical technique tools which have a wide application in scientific research, in industry, and even in daily life. This concept makes the use of control charts as important as cost control and material control. Information about the design and types of control charts and general guidelines to prepare control charts, and the likes are given below.

2.1. Design of a control chart

A control chart is a graph mainly derived from a normal distribution curve. The y-axis denotes a quality characteristic or a particular characteristic of the product or process, which is controlled and is marked in units, in which the test value is expressed. The x-axis consists of time intervals or sample number. There is a center line, which is the average of the value of the studied matter or may also indicate the nominal value. The upper boundary characterizes the upper control limit (UCL), while the lower designates the lower control limit (LCL), respectively. The gathered data are plotted in sequence, and then, the pattern occurring on the chart is interpreted. A sample of a control chart is given in **Figure 1**.

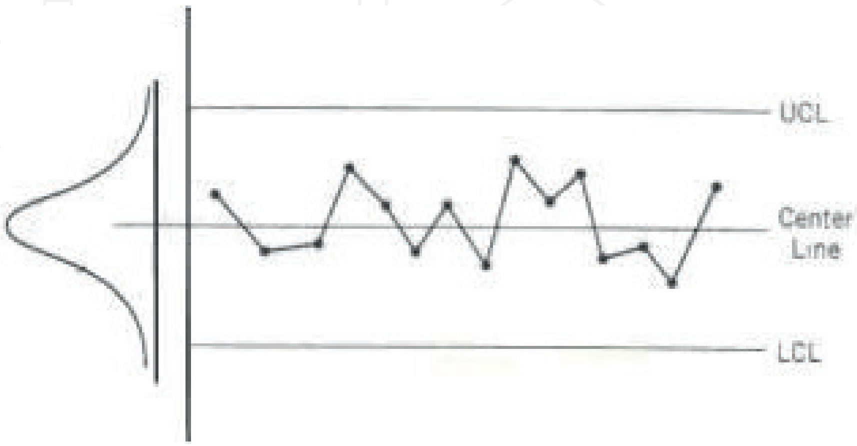

Figure 1. Sample of a control chart.

As can be seen from **Figure 1**, there is a close relationship between the normal distribution curve and the control chart. Control charts are constructed on the basis of expanding the sigma limits above and below of the mean. By taking a deeper look, it can be expressed that expansion of 1.962σ from the mean may be regarded as the "warning limit," and the expansion of 3.09σ from the mean is the "action limit" for large samples (**Figure 2**). Similarly, $2\sigma/\sqrt{n}$ and $3\sigma/\sqrt{n}$ are the same limits, respectively, for small samples (**Figure 3**) [6].

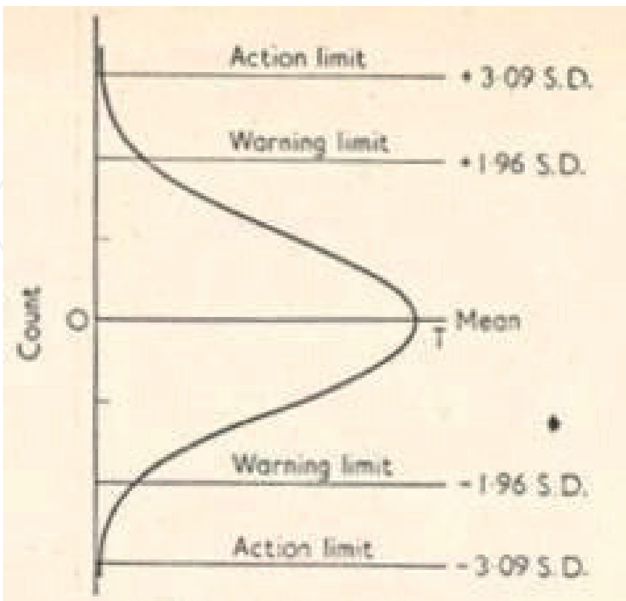

Figure 2. Warning and action limits for large samples.

http://dx.doi.org/10.5772/intechopen.73237

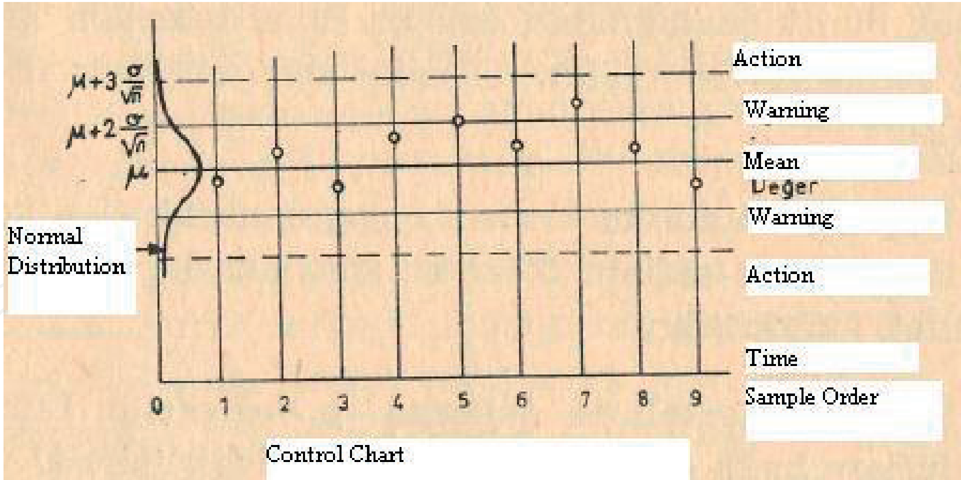

Figure 3. Warning and action limits for small samples.

The center line of a control chart stands from the past data or new data got from the measurements in the process or applied from what the consumer wants. If the clients have specified limits for their orders, production has to be done according to the specification limits of the client. In this case, the UCL and LCL have to be in the specification limits (**Figure 4**). If the control limits take place out of the specification limits (**Figure 4**), then that is an undesirable

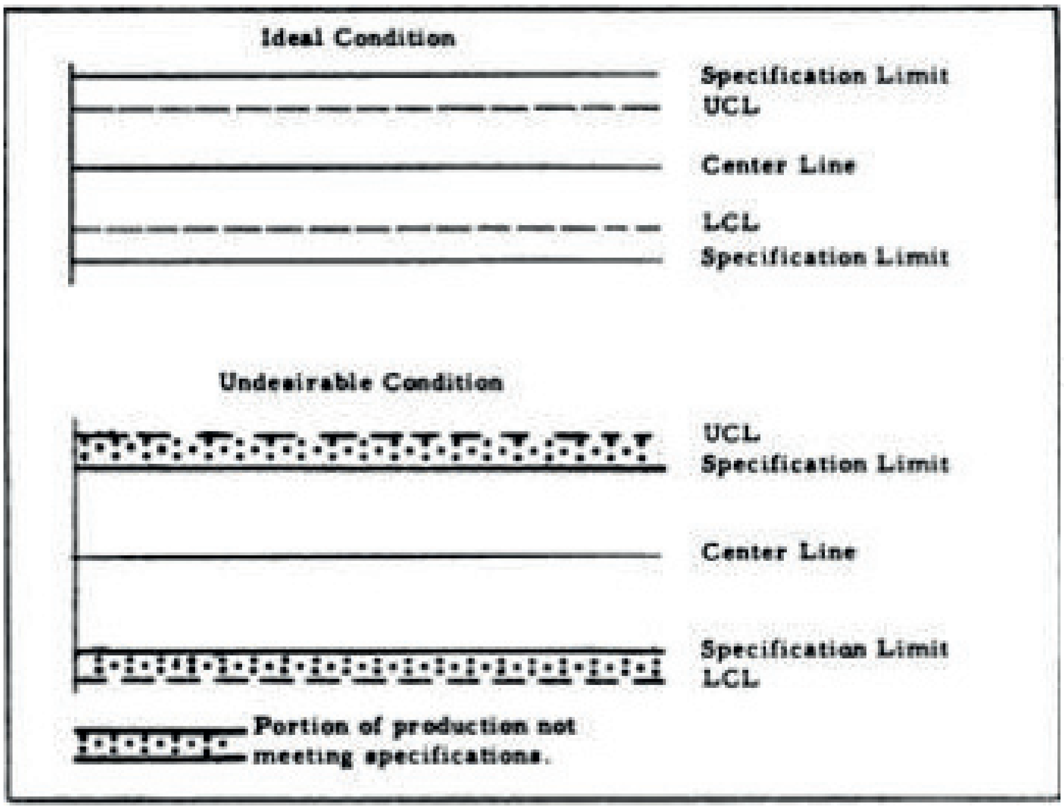

Figure 4. Placement of UCL and LCL according to specification limits.

condition because the product will be manufactured with a quality characteristic range that the client does not want, thus resulting in an inferior quality product.

3σ expansion means 6σ expansion from the UCL and LCL in total. From a normal distribution diagram, it is known that the area under the diagram corresponds to a 99.73% of probability. This means that the points used in the preparation of control charts will be included in the study with a 99.73% probability (**Figure 5**).

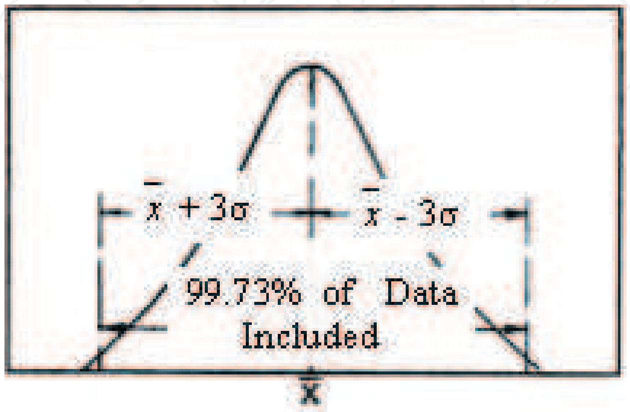

Figure 5. Representation of 99.73% probability.

Control charts are quality technique tools that may trigger an alarm. If a value exceeds the warning limit above or below, production may continue, but the reason for this variation must be investigated and corrective action must be taken.

In obtaining data from a process, sampling is performed by using small sample sizes. Concerning small samples, sensitivity of the control chart is increased by statistical methods, and the warning limit and the action limit are combined to be expressed as UCL and LCL. So, if a value gets close to one of these limits, it is understood that it is not needed to stop production but search for the reason of this variation and to correct it. Likewise, if a value crosses one of these limits, action has to be taken and production must be stopped before searching. Sensitivity, sample size, and sampling frequency (specific and equal time intervals) are important factors regarding the performance of the control chart. Sampling frequency must be in accordance with the production processes.

2.2. Types of control charts

Control charts have two main types according to the way the values used are obtained. Values can be obtained by measuring on a numerical scale, that is, counting, calculating, by using a testing instrument, or by deriving proportions of judgments. If they are conforming or nonconforming, one would look at their certain attributes they have to possess so as to express a case. If the values used are obtained by measuring, then they are called control charts for variables. If the values used are obtained by deriving proportions, then they are called control charts for attributes. These charts apply for different process-specific cases in processes, so that each can be evaluated on its own.

http://dx.doi.org/10.5772/intechopen.73237

Each type has different kinds of control charts particularly for the case studied. The most important kinds of control charts for variables are mainly

- Individual measurements control chart (x),
- Means control chart ($\overline{x}$),
- Ranges control chart (R),
- Standard deviation control chart (s).

Others are s^2 control chart, moving range control charts, and regression control chart. The main kinds of control charts for attributes are foremost p-, np-, u-, and c-control charts. Others are standardized control charts, g control charts, and h control charts.

There are control charts for special uses in literature which can be listed as cumulative sum control charts, moving average control chart, x-bar and R-control charts for short production runs, attributes control charts for short production runs, modified and acceptance control charts, group control charts for multiple-stream processes, chi-square control chart, difference control charts, control charts for contrasts, run sum and zone control charts, adaptive control charts, moving average control charts, residual control charts, control charts for six-sigma processes, acceptance control charts, T^2 control charts, Hotelling T^2 control charts, Exponentially Weighted Moving Average (EWMA) control charts, exponentially weight means square control charts, multivariate EWMA control charts, one-sided EWMA control charts, moving centerline EWMA control charts, and one-sided CUSUM control chart [7].

2.3. General guidelines to prepare control charts

Steps to prepare control charts in general are as follows:

1. Obtain a set of values;
2. Decide which kind of a control chart to prepare;
3. Do the needed calculations;
4. Draw the control chart;
5. Plot the values in Step 1 on the control chart;
6. Continue to plot the new values collected in due time on the chart;
7. Interpret the pattern occurring on the chart.

It is apparent from the last step, as the production proceeds, new values accumulate and these new values should be plotted on the same control chart with the UCL and LCL calculated from the first values of the same production. This procedure guarantees that the properties of the first products and the rest lie in the same control limits.

In the first preparation of the control chart, if an assignable cause is found in the data collected, that point is discarded and the trial control limits are recalculated, using only the remaining points.

2.4. Control charts for variables

Control charts for variables are widely used because they enable more effectual control and provide more information about the performance of the processes. These charts are preferred because they provide the user with an estimation of the central tendency and the distribution of the studied case [8]. The most commonly used ones as stated above are individual measurements control chart (x), means control chart ($\overline{x}$), ranges control chart (R), and standard deviation control chart (s).

2.4.1. Individual measurements control charts (X control charts)

Control charts prepared with individual measurements are called individual measurements control charts. These charts are used in cases where only one value measured on a numerical scale is to be defined, that is, counting, calculating, or with a testing instrument. Examples would be the number of workers for successive months, paid taxes over years (in economics), effective staple length for similar fiber batches, fiber fineness obtained from air flow principle (in textiles), etc. [9].

Preparation steps for an X control chart are:

1. There has to be at least 10 values, 20 is better, but if there is a large time gap between obtaining the values 8 serves as well;
2. Average value of X ($\overline{x}$) is calculated;
3. The absolute value of the differences between two consecutive values of X is called the moving range. Moving range (MR) is calculated and average of MR ($\overline{\text{MR}}$) is calculated;
4. UCL and LCL are calculated by $\overline{x} \pm 2.66\ \overline{\text{MR}}$ formula;
5. Control chart lines are drawn with the center line ($\overline{x}$), UCL, and LCL;
6. The values used in calculation are plotted on the chart;
7. The values coming up in due time are plotted on the same chart and interpreted as will be explained later.

An application of the X chart to yarn irregularity quality characteristic (U%) of the Kaynak Group Cotton Yarn Factory's regular measurements is given in **Figure 6** [10].

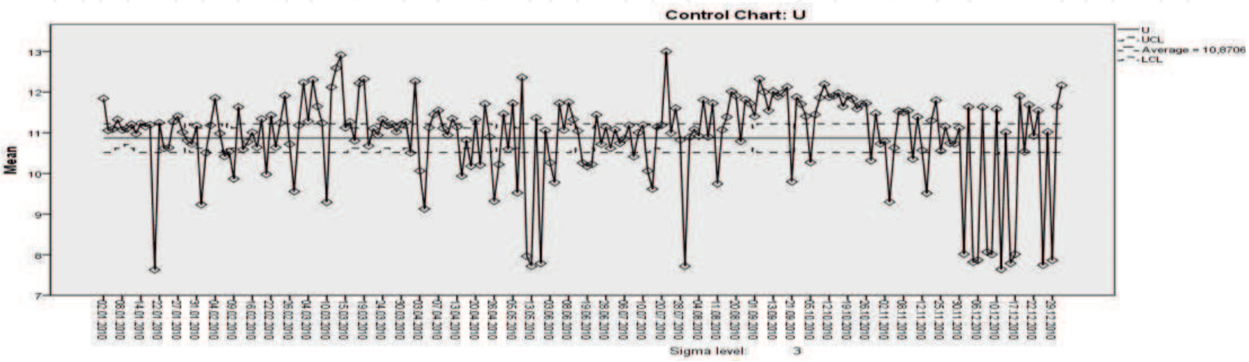

Figure 6. Application of X chart to yarn irregularity quality characteristic (U%) of the Kaynak group cotton yarn factory's regular measurements.

http://dx.doi.org/10.5772/intechopen.73237

2.4.2. Means control charts ($\bar{x}$) ($\bar{x}$ control charts)

When sampling is done, n-repeats are taken at once to analyze the case under study in specified intervals. Control charts prepared with the means of the samples taken at once are called means control charts. These charts are used in cases where repeated measurements on a numerical scale of small sample sizes are done. Sample size is usually 5. Means of the samples possess a normal distribution. The basis of this system depends on finding how close the means of the samples measured are to the nominal or average value. Examples would be yarn count, fabric weight per unit area (in textiles), etc.

Preparation steps for an X-bar ($\bar{x}$) control chart are:

1. There has to be at least 10 different repeated measurement groups of a sample size of 5; 12 is better, but it should never be 8;
2. Mean of sample size (usually 5) is calculated for each different repeated measurement group, where each mean of sample size is indicated as $\bar{x}$;
3. Range is the difference between the maximum and the minimum value in a sample (like size of 5). Range (R) for each sample size is calculated;
4. The averages of $\bar{x}$ ($\bar{\bar{x}}$) and R ($\bar{R}$) values are calculated;
5. UCL and LCL are calculated by $\bar{\bar{X}} \mp \bar{R}A_2$ formula. The constant A_2 is determined from the table in Appendix 1. The sample size is indicated in the column "n";
6. Control chart lines are drawn with the center line ($\bar{\bar{x}}$), UCL, and LCL;
7. The values calculated in Step 2 ($\bar{\bar{x}}$) are placed on the chart;
8. The values coming up in due time are plotted on the same chart and interpreted as will be explained later.

An application of $\bar{x}$ chart to yarn maximum breaking strength quality characteristic (gf) of the Kaynak Group Cotton Yarn Factory's regular measurements is given in **Figure 7**.

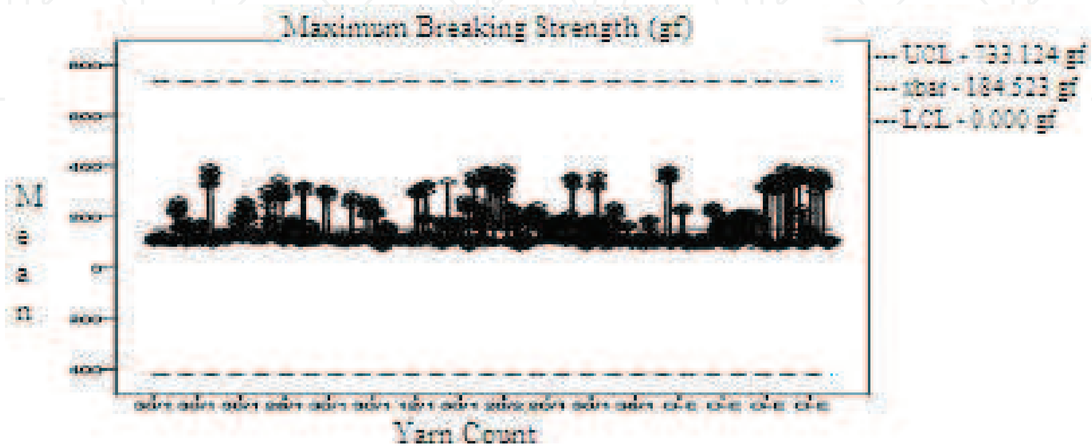

Figure 7. Application of $\bar{x}$ chart to yarn maximum breaking strength quality characteristic (gf) of the Kaynak group cotton yarn factory's regular measurements.

2.4.3. Ranges control charts (R) (R-control charts)

Control charts prepared with the range values are called range control charts. These charts are used together with means control charts ($\bar{x}$ charts). Some statistical information is lost, when small sample sizes (like 5 as stated above) are used and the mean of the values is used. The preparation of R chart becomes as such important in order to make the lost information somehow apparent. Ranges do not possess a normal distribution like the means of the samples. While a $\bar{x}$ control chart gives information about the behavior of the mean values of a sample, a R-control chart gives information about the differences in the samples.

The preparation steps for a R-control chart are:

1. The same R values obtained in Step 3 of $\bar{x}$ chart are used;
2. The same average of R ($\overline{R}$) in Step 4 of $\bar{x}$ chart is used;
3. The UCL is calculated by $D_4\,\overline{R}$ formula, and the LCL is calculated by $D_3\,\overline{R}$ formula. The constants D_4 and D_3 are determined from the table in Appendix 1. The sample size is indicated in the column "n";
4. Control chart lines are drawn with the center line ($\overline{R}$), UCL, and LCL;
5. The values used in Step 1 are plotted on the chart;
6. The values coming up in due time are plotted on the same chart and interpreted [9].

When interpreting the pattern occurring on the R-control chart, it is ideal when the points are located near to the LCL.

An application of R chart to yarn maximum breaking strength quality characteristic (gf) of the Kaynak Group Cotton Yarn Factory's regular measurements is given in **Figure 8**.

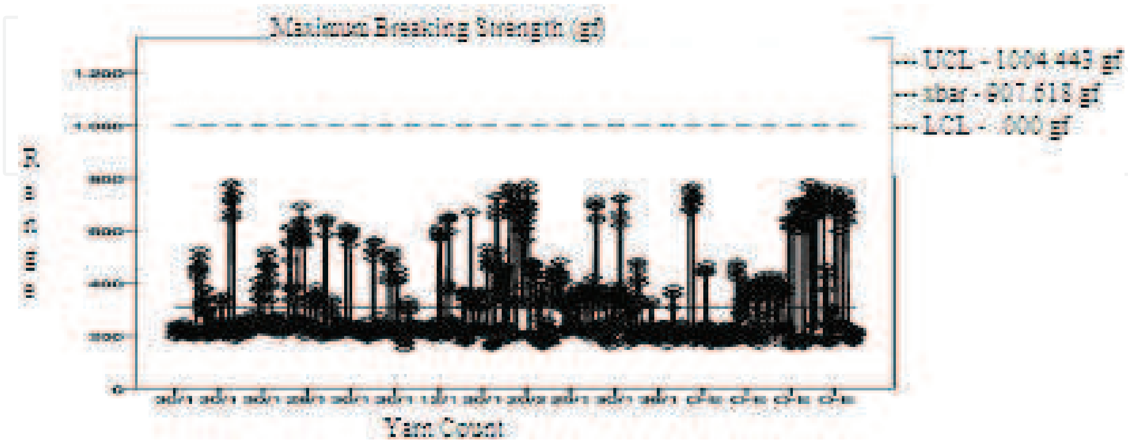

Figure 8. Application of R chart to yarn maximum breaking strength quality characteristic (gf) of the Kaynak group cotton yarn factory's regular measurements.

http://dx.doi.org/10.5772/intechopen.73237

2.4.4. Standard deviation control charts (s) (s-control charts)

Control charts prepared with the standard deviation values are called standard deviation control charts. These charts are used together with the means control charts ($\bar{x}$ charts). Some statistical information is lost when the mean of the values is used. When a sample size is large, it is preferred to use the s-control charts to make the lost information somehow apparent. Also, s charts are preferred to be used in cases, where there are missing data in the samples, in other words, the sample size varies. The s-control chart gives information about the overall variation of the values from the mean value of the samples.

It is suggested here to use $\bar{x}$, R, and s charts together so as to get a better understanding of the population that it is representing. Even the R chart and s charts have a similar pattern. In some cases, incidents are caught in the process which would alarm the user of an immediate problem. Range control chart shows the differences in individual measurements, but the s-control charts depict the general behavior of the distribution in the population. In a sample of values, with the same R, s may be high or low or vice versa. This means that R gives a specific interpretation of a case, but s gives a general interpretation about it.

The preparation steps for a s-control chart are similar with range control charts, that is, average value of s ($\bar{s}$) is used instead of $\overline{R}$. The UCL is calculated by the $B_4\,\bar{s}$ formula, and the LCL is calculated by the $B_3\,\bar{s}$ formula. The constants B_4 and B_3 are determined from the table in Appendix 1. The sample size is indicated in the column "n".

An application of the s chart to yarn maximum breaking strength quality characteristic (gf) of the Kaynak Group Cotton Yarn Factory's regular measurements is given in **Figure 9**.

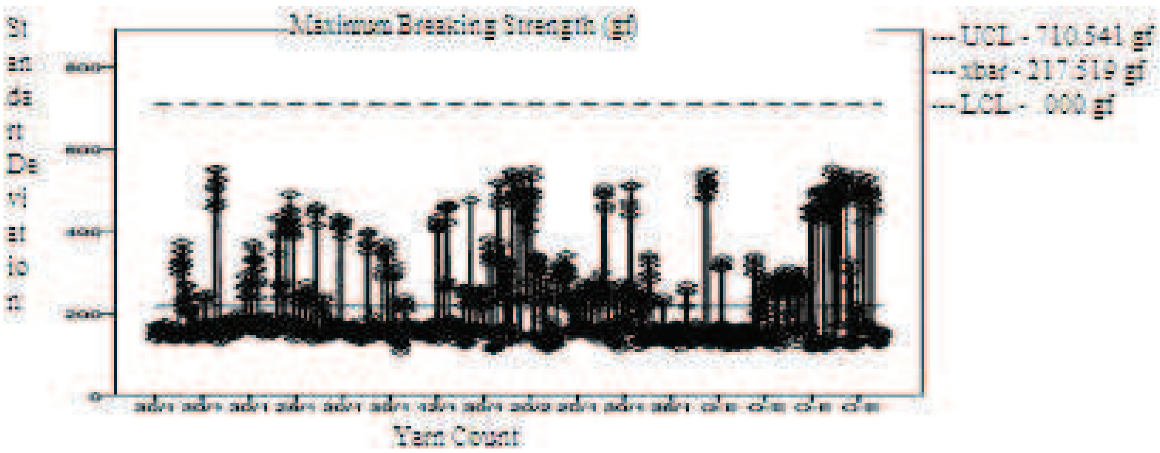

Figure 9. Application of s chart to yarn maximum breaking strength quality characteristic (gf) of the Kaynak group cotton yarn Factory's regular measurements.

2.5. Control charts for attributes

Control charts for attributes are used in cases, where the studied matter is not represented by measuring on a numerical scale but defined as a conforming (nondefective) or nonconforming (defective) to specifications. Then, different proportions suitable to each case are obtained, and control charts are drawn. The most commonly used ones as stated above are control chart for fraction nonconforming (p), control chart for the number of nonconforming items (np), control chart for conformities per unit (u), and control chart for nonconformities (c).

2.5.1. Control charts for fraction nonconforming (p) (p-control charts)

Control charts are developed by dividing the amount of nonconforming pieces to the total production amount are called p-control charts. The p-control charts possess binomial distribution. Since the total amount will be changing from one lot, batch, or party to the other, proportions are used to bring all to the same denominator. In the case where p charts will be used, 100% of the production must be controlled, otherwise the nonconformities which are not controlled may reach the end user. Examples would be the proportion of number of defective skirts to total produced skirts in 1 day, the proportion of number of defective yarn cones to total produced cones in one shift (in textiles), etc.

The preparation steps for a p-control chart are:

1. There has to be at least 10 values;

2. The proportions (p) are calculated by dividing the nonconformity amount to the total amount;

3. The average value of p ($\overline{p}$) is calculated;

4. The UCL and LCL are calculated by $\overline{p} \mp \sqrt{\frac{\overline{p}(1-\overline{p})}{n}}$ formula;

5. The control chart lines are drawn with the center line ($\overline{p}$), UCL, and LCL; and plotting is done as discussed above.

An application of the p chart to nonconforming pants in the Çağla Textile Ready-wear Factory's regular measurements is given in **Figure 10** [11].

2.5.2. Control charts for number of nonconforming items (np) (np-control charts)

Control charts prepared with the number of nonconforming items is called a np-control chart. A proportion is not done because the total production amount in these cases is the same in every day or shift, etc. There is no need to divide like in p-control charts every time. Examples would be the number of defective skirts in 1 day for a constant produced amount, the number of defective yarn cones in one shift for a constant produced amount (in textiles), etc.

The preparation steps for a np-control chart are similar with the p-control charts, that is, the average value of np ($n\overline{p}$) is used instead of $\overline{p}$, and the UCL and LCL are calculated by using the $n\overline{p} \mp 3\sqrt{n\overline{p}(1-\overline{p})}$ formula. $\overline{p}$ is obtained by dividing $n\overline{p}$ to the constant produced amount.

An application of the np chart to the nonconforming skirts in the Çağla Textile Ready-wear Factory's regular measurements is given in **Figure 11**.

http://dx.doi.org/10.5772/intechopen.73237

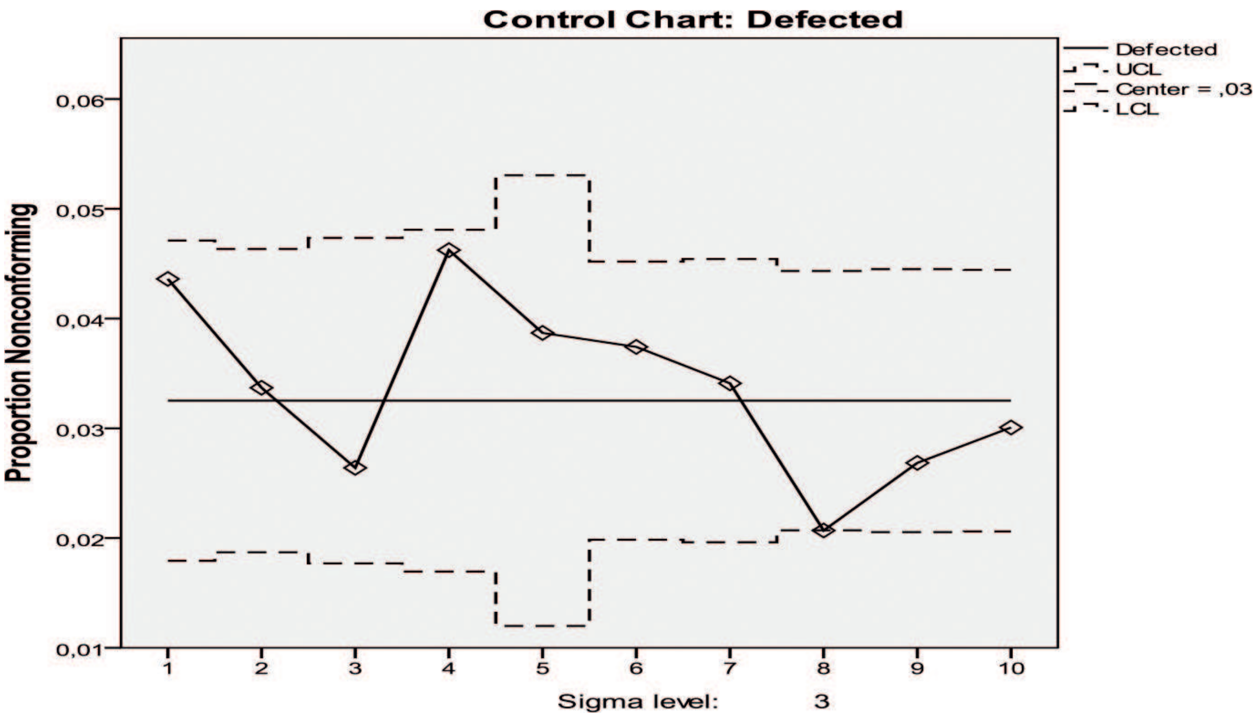

Figure 10. Application of p chart to nonconforming pants in the Çağla textile ready-wear Factory's regular measurements.

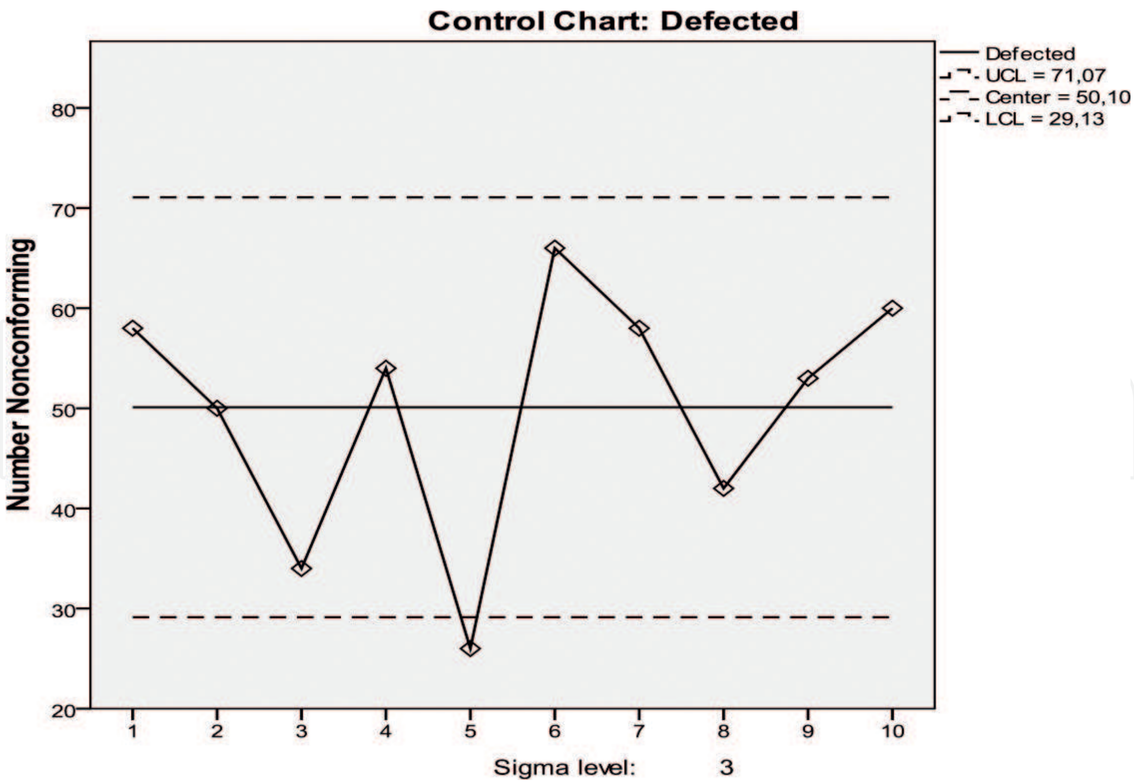

Figure 11. Application of np chart to nonconforming skirts in the Çağla textile ready-wear factory's regular measurements.

2.5.3. Control charts for conformities per unit (u) (u-control charts)

Control charts prepared with the number of nonconformities per unit are called u-control charts. The unit here is different from the production amount mentioned in the p- and np-charts, being changing or constant, respectively. The unit here is the restricting factor, where the main pronounced value is the nonconformity. A unit may be length, weight, etc. As such, it is mentioned as number of defects per unit length or number of conformities per unit weight, facilitating the status change of the unit.

The number of nonconformities is divided to the unit to find the "per unit" value of the defects to bring all to the same comparison ground. An example would be the number of defects per 100 m length of fabric (fixed width) (in textiles).

The preparation steps for a u- control chart are:

1. There has to be at least a set of 10 values;
2. The number of defects per unit is calculated for a specified unit for every value;
3. The average value of u ($\overline{u}$) is calculated;
4. The UCL and LCL are calculated by $\overline{u} \mp 3\sqrt{\frac{\overline{u}}{n}}$ formula;
5. The control chart lines are drawn with the center line ($\overline{u}$), UCL, and LCL; plotting the lines is done as depicted above.

When interpreting the pattern occurring on the u-control chart, it would be preferably when the points are located near to the LCL.

Applications of u charts to defects in fabrics of fixed width in the Özer Textile Weaving Factory's regular measurements are given in **Figure 12** [12].

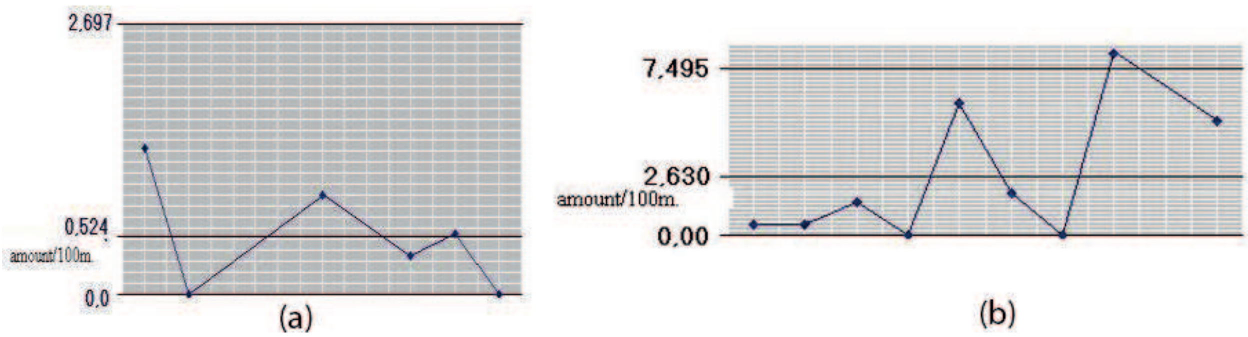

Figure 12. Application of u charts to defects in fabrics of fixed width in the Özer textile weaving factory's regular measurements. (a) Application of u chart to thin weft yarn defect calculated per 100 m. Of fabric (considered normal), (b) application of u chart to thick warp yarn defect calculated per 100 m of fabric (gives alarm).

2.5.4. Control chart for nonconformities (c) (c-control charts)

The control charts prepared with the number of nonconformities per constant unit are called c-control charts. The unit here is again the restricting factor, where the main pronounced value is

http://dx.doi.org/10.5772/intechopen.73237

the nonconformity. In these cases, the unit will be constant for all the data collected. There is no need to divide every time, since they are all on the same ground of comparison. Examples would be the imperfections (thick place in yarn, thin place in yarn, and neps) in yarn (number of an imperfection per 1 km. of yarn; in textiles).

The preparation steps for a c- control chart are similar with the u-control charts, that is, the average value of c ($\overline{c}$) is used instead of $\overline{p}$ and UCL and LCL are calculated by $\overline{c} \mp 3\sqrt{\overline{c}}$ formula.

The applications of c charts in the Gülçağ Textile Yarn Factory and the Yıldırımlar Printing & Dying Factory are given in **Figure 13**.

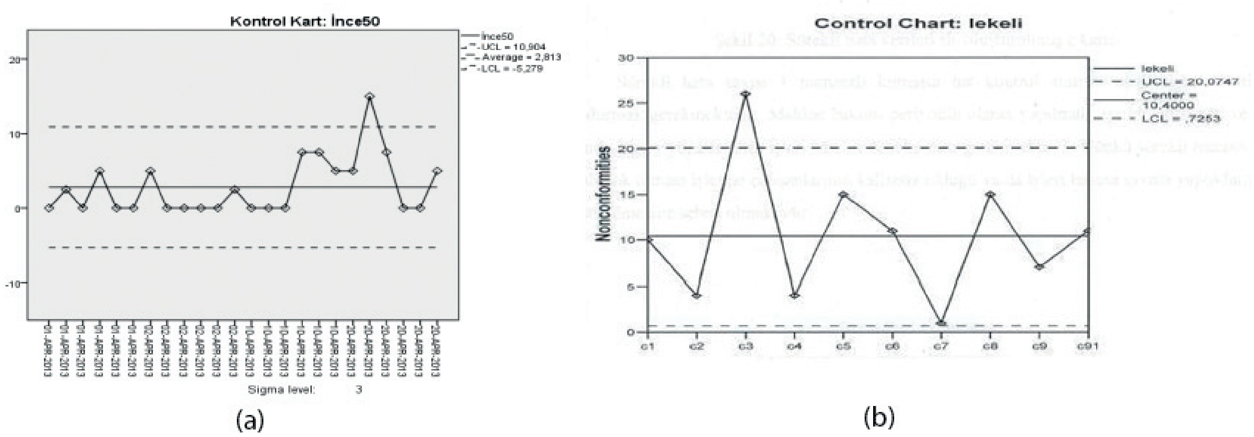

Figure 13. Application of a c chart. (a) Applications of c chart to thin place imperfection per 1 km, of yarn in the Gülçağ textile yarn Factory's regular measurements [13], (b) applications of c chart to spot defects per fixed fabric roll of 80 m. In the Yıldırımlar printing & dying factory's regular measurements [14].

3. Results and analysis

This chapter will detail and analyze industrial applications of control charts for variables and attributes.

3.1. Industrial applications of control charts for variables

Control charts are widely used in industry nowadays. The information obtained from them helps production to be monitored effectively. Some examples of control charts for variables taken from industry are given in **Figures 14–17**.

Individual measurements control charts for number of rolls of nonwoven fabric and daily production weight of Sarıkılıç Textile Nonwoven Factory are given in **Figures 14** and **15**, respectively. By observing mentioned figures, one might see that at the beginning, both the number of rolls and production weight are high, but toward the end, even the number of rolls are near to average and production weight is high. This is because the weight of the unit area of nonwoven fabric increased. This is a typical case seen in textile factories, and as such, it can be said that production is under control.

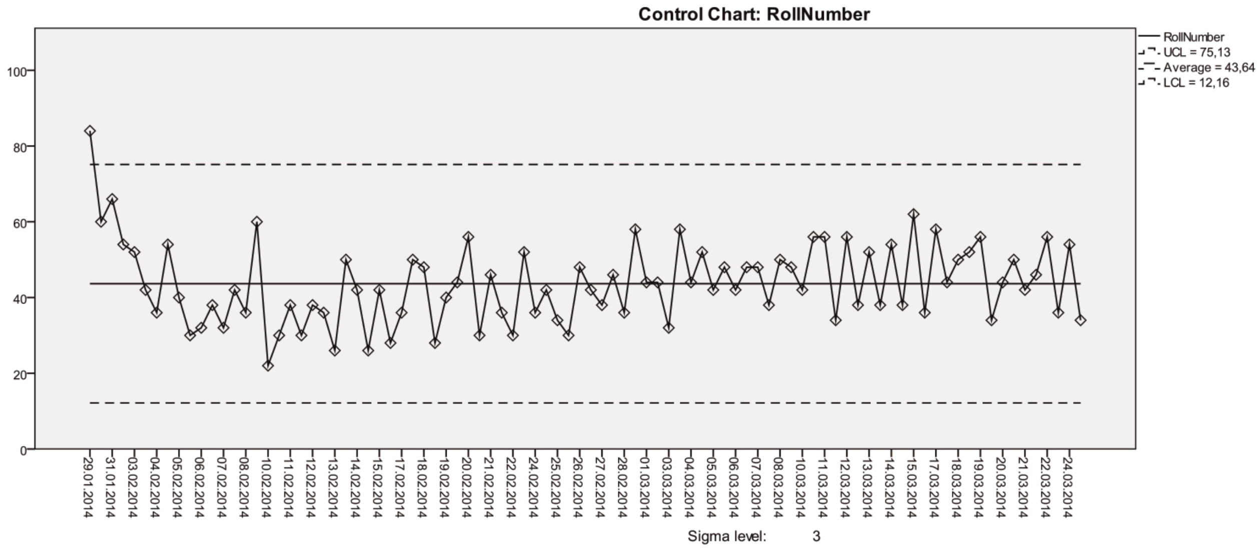

Figure 14. Individual measurements control chart for the number of rolls daily of Sarıkılıç.

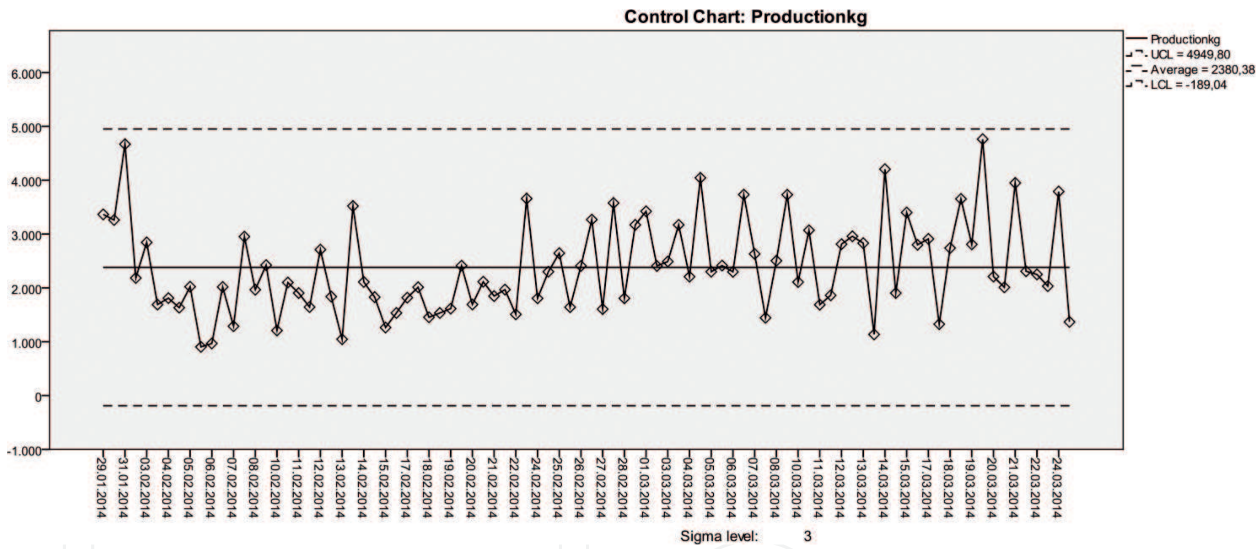

Figure 15. Individual measurements control chart for the production weight daily of Sarıkılıç textile nonwoven factory.

In **Figure 16**, the means control chart, ranges control chart, and standard deviation control chart are given for open-end yarns' hairiness values, which are supplied from Kaynak Group Yarn Factory. A closer look at the charts may reveal an improvement in hairiness values, as the production proceeded but for a short time. The factory searched for the reason of this improvement and found out that it was because of the better condition of air suction and applied that condition afterward.

In **Figure 17**, means control chart, ranges control chart, and standard deviation control chart are given for nonwoven thickness of nonwoven fabric values of the Sarıkılıç Textile Nonwoven Factory. It is seen in the charts that the thickness values have increased. The same applies to the range and standard deviation values too. The factory searched for the reason, and it was

http://dx.doi.org/10.5772/intechopen.73237

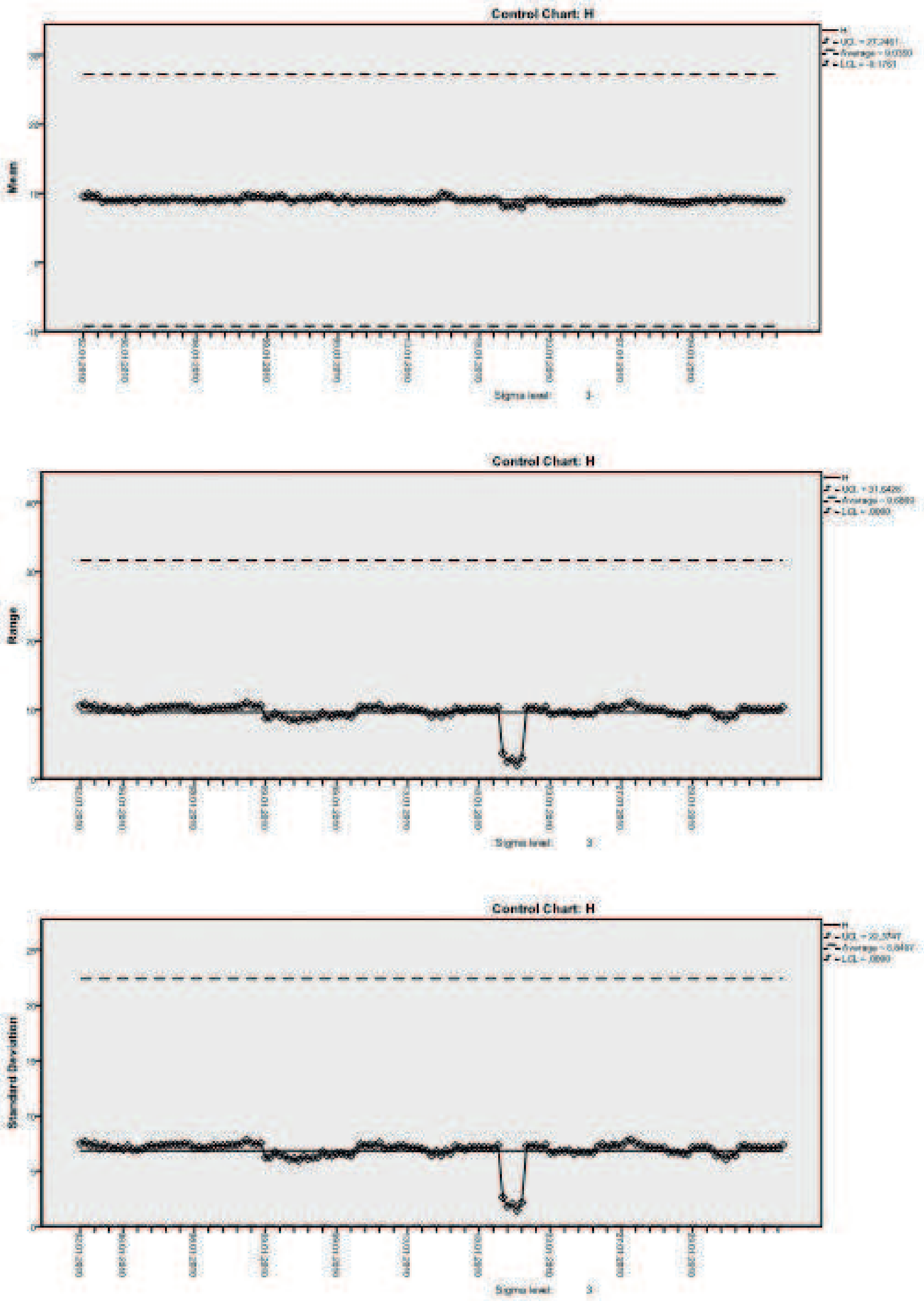

Figure 16. Means control chart, ranges control chart, and standard deviation control chart for open-end yarns' hairiness values of the Kaynak group yarn factory.

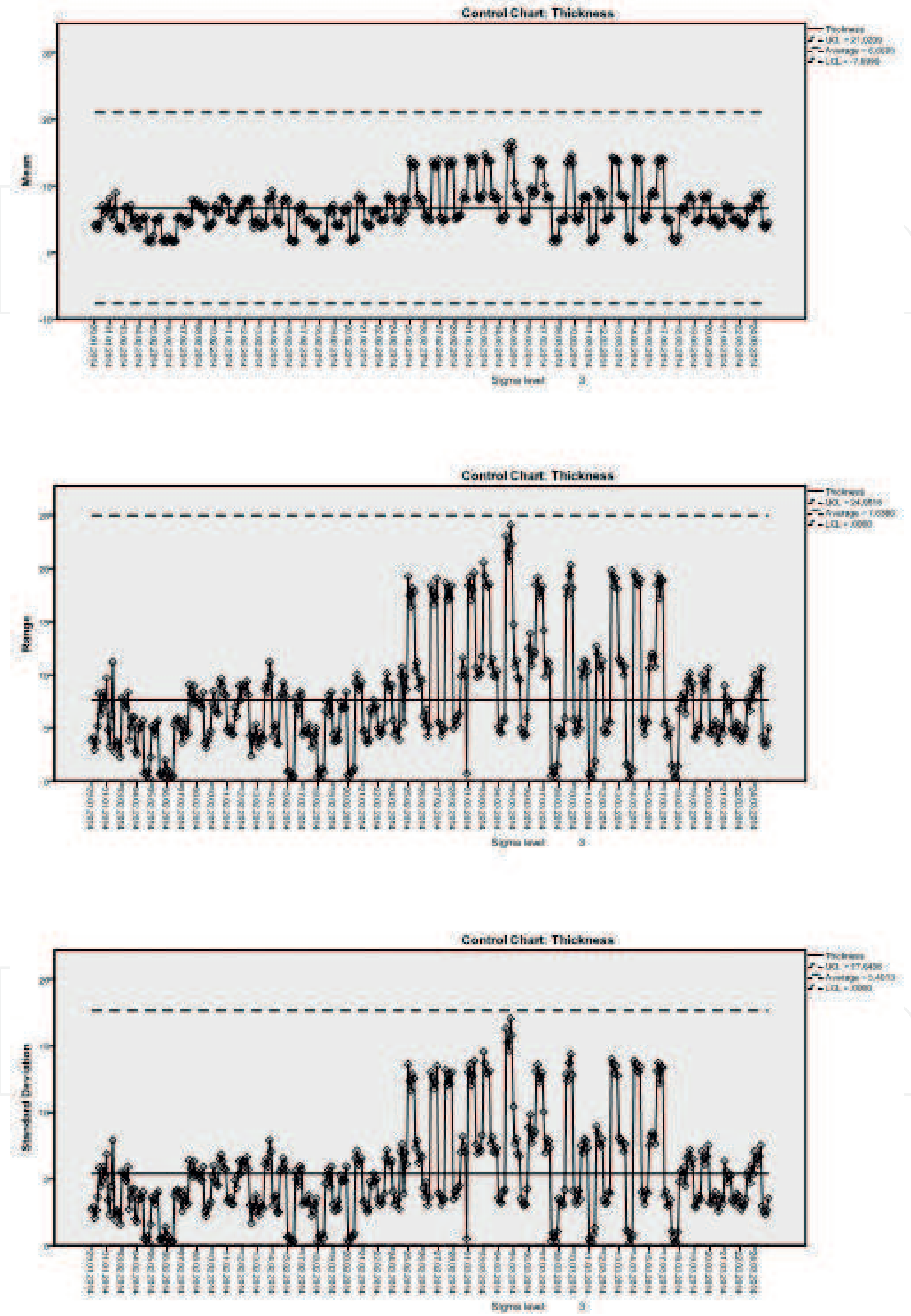

Figure 17. Means control chart, ranges control chart, and standard deviation control chart for nonwoven thickness values of the Sarıkılıç textile nonwoven factory.

http://dx.doi.org/10.5772/intechopen.73237

determined that different unit weights of nonwoven rolls were plotted on the same charts and were corrected.

3.2. Industrial applications of control charts for attributes

Some examples of control charts for attributes applied in industry are given in **Figures 18-21**.

In the Tekstüre Textile Socks Factory in İstanbul, there are nonconforming socks produced during manufacturing. A p-control chart for nonconforming socks in different amounts of production is given in **Figure 18**. As can be seen in the figure, there is an increase in nonconformities toward the end. The factory searched for the underlying reason and found out that new employees had not taken enough training regarding socks production. A np-control chart for nonconforming socks in constant amount of production is given in **Figure 19**. As depicted in the figure, there is a decrease in nonconformities toward the end. The factory searched for its reason and found out that new machines were bought, which had started production.

In the Ne-Ke Textile Weaving Factory, there is a double weft fault in weaving of bed placemats. A u-control chart for different lengths of fabric rolls is given in **Figure 20**. As seen in the figure,

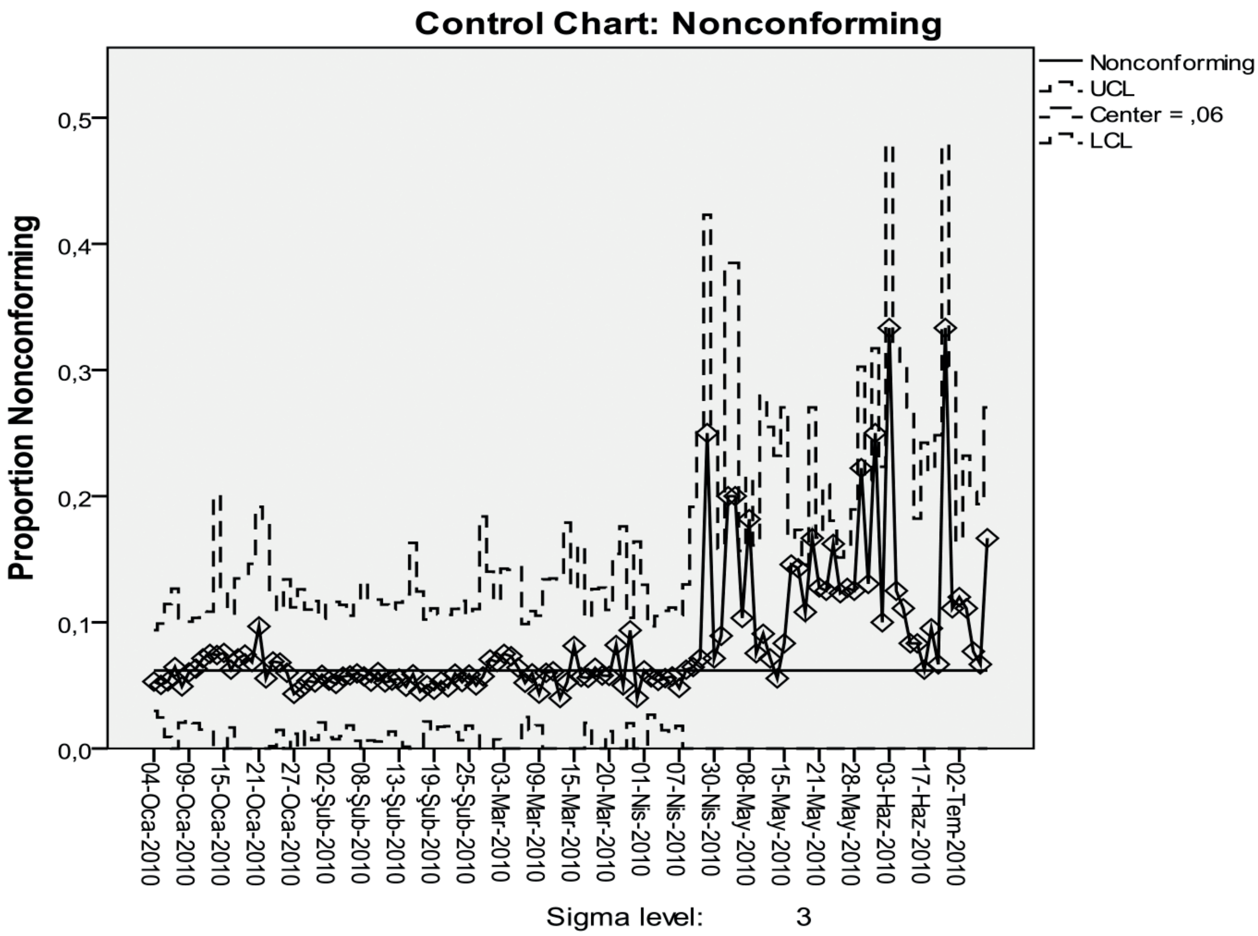

Figure 18. p control chart for nonconforming socks in different amounts of production in the Tekstüre textile socks factory.

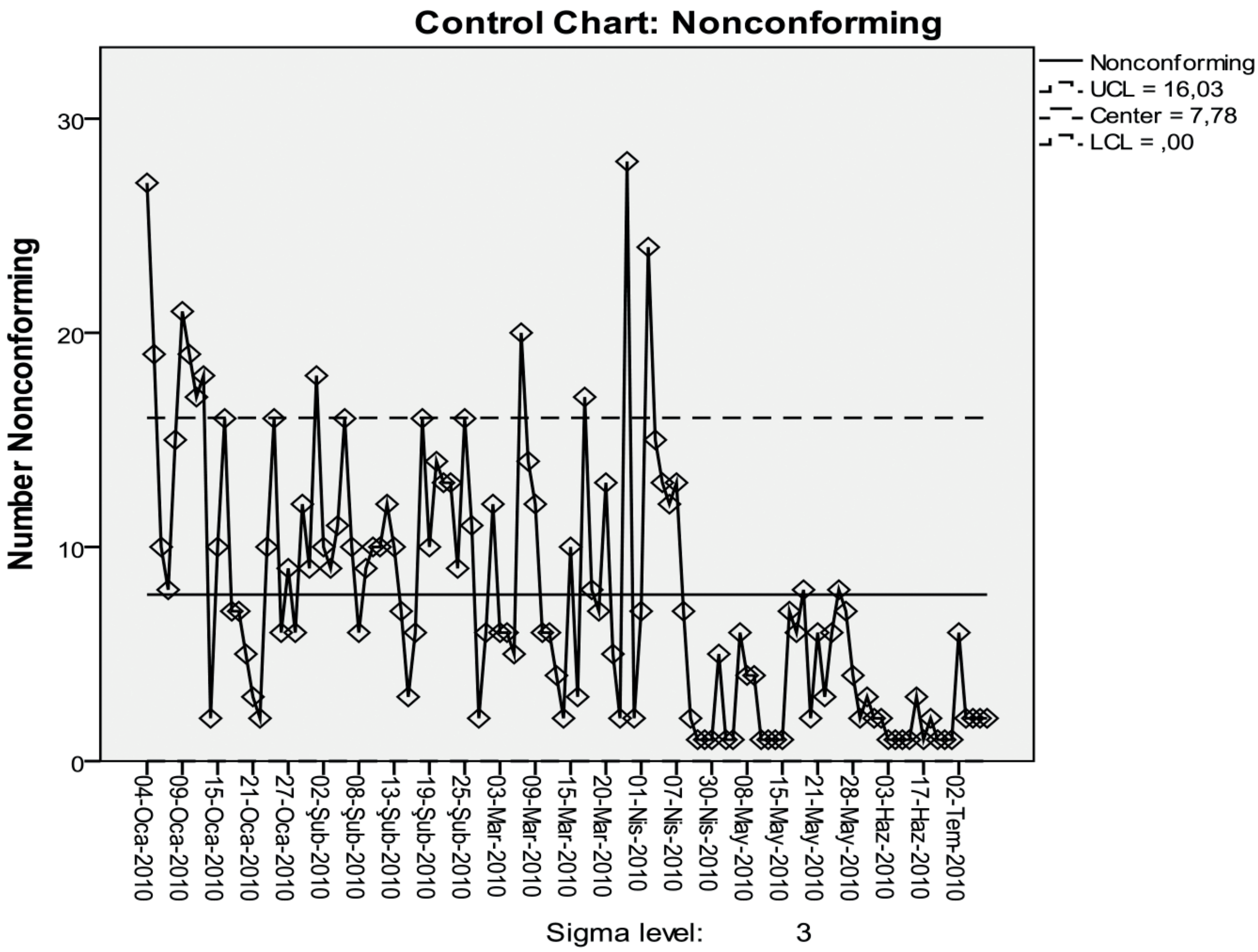

Figure 19. np-control chart for nonconforming socks in constant amount of production in the Tekstüre textile socks factory.

the pattern seemed normal, and the factory did not take any action for this case. In **Figure 21**, a c-control chart is given for the cracks occurred in the dying department of the Özer Textile Weaving Factory. By observing the corresponding figure, it can be seen that there is a sharp increase and then a fall. The factory searched for its reason and found that the worker had forgotten to add the anticrack chemical into the dying bath in the night shift and gave more training to the worker.

3.3. Special cases for control charts

Some special cases for control charts are listed below:

- The formulae for calculation of the UCL and LCL change in $\overline{x}$, R, and S charts, when standard values for μ and σ are known from past data
- If there are variable sample sizes, then the UCL and the LCL will be varying also and another approach to dealing with variable sample size is to use a “standardized” control chart

http://dx.doi.org/10.5772/intechopen.73237

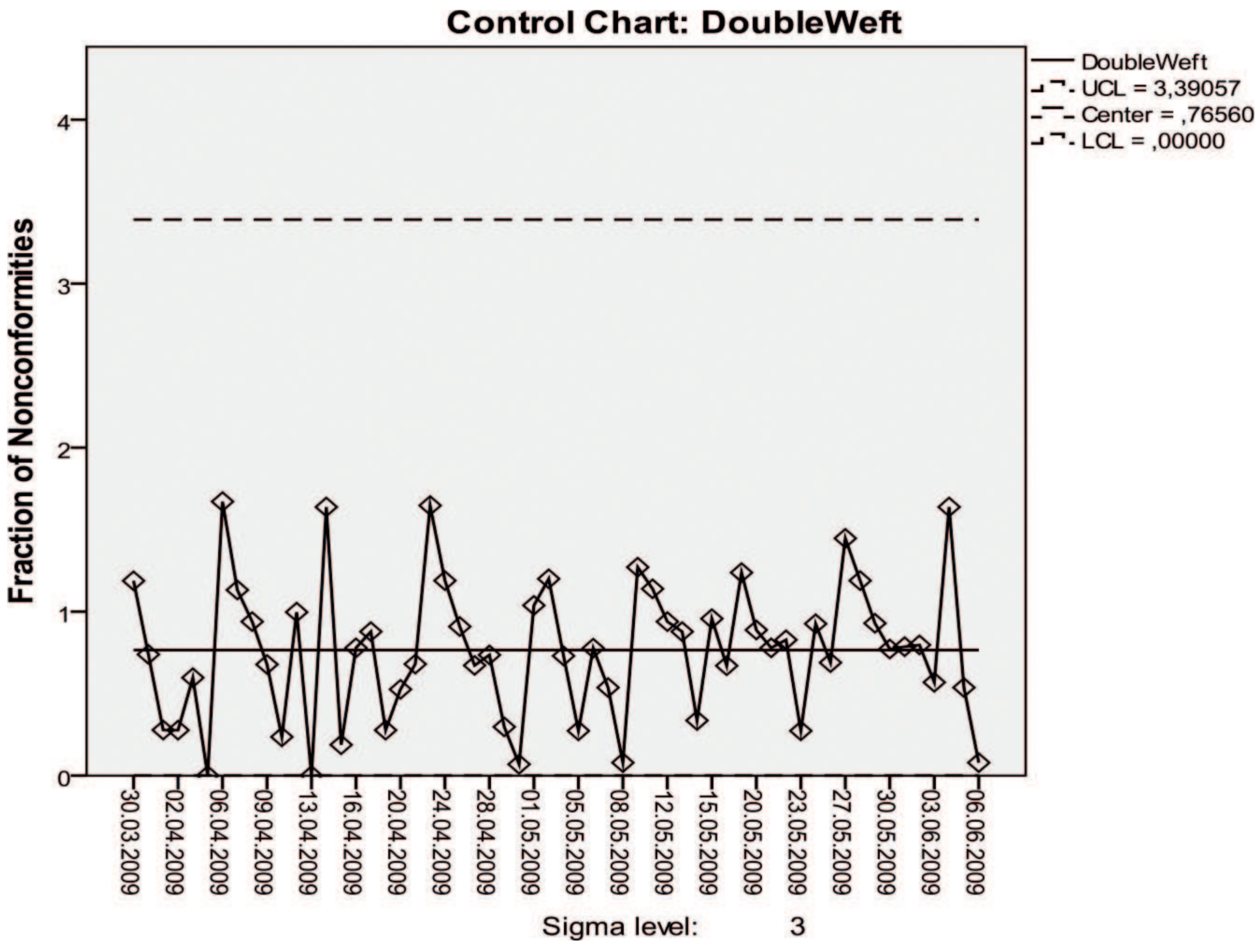

Figure 20. u-control chart for double weft fault in different lengths of fabric rolls in the Ne-Ke textile weaving factory.

- There can be subgroups for a case studied in the control chart. An example would be individual machines producing the same lot, yarn producing machines or fabric producing machines. In this case, there may be different control charts to control every machine under control even if they produce the same lot
- Process capability analysis can be done using a control chart
- There may be variable sample sizes on control charts
- There may be variable sampling interval on control charts

The details for these special cases are not included here.

3.4. Interpretation of control charts

The distribution of the points on a control chart is important, and the patterns occurring on the control chart have to be examined and interpreted. Since the values distribute at a distance around the mean value and support visually the variation in the spread of the test results, they provide useful information about the process so as to make modifications in order to reduce variability. For interpreting the control charts, the principles of the control charts have to be

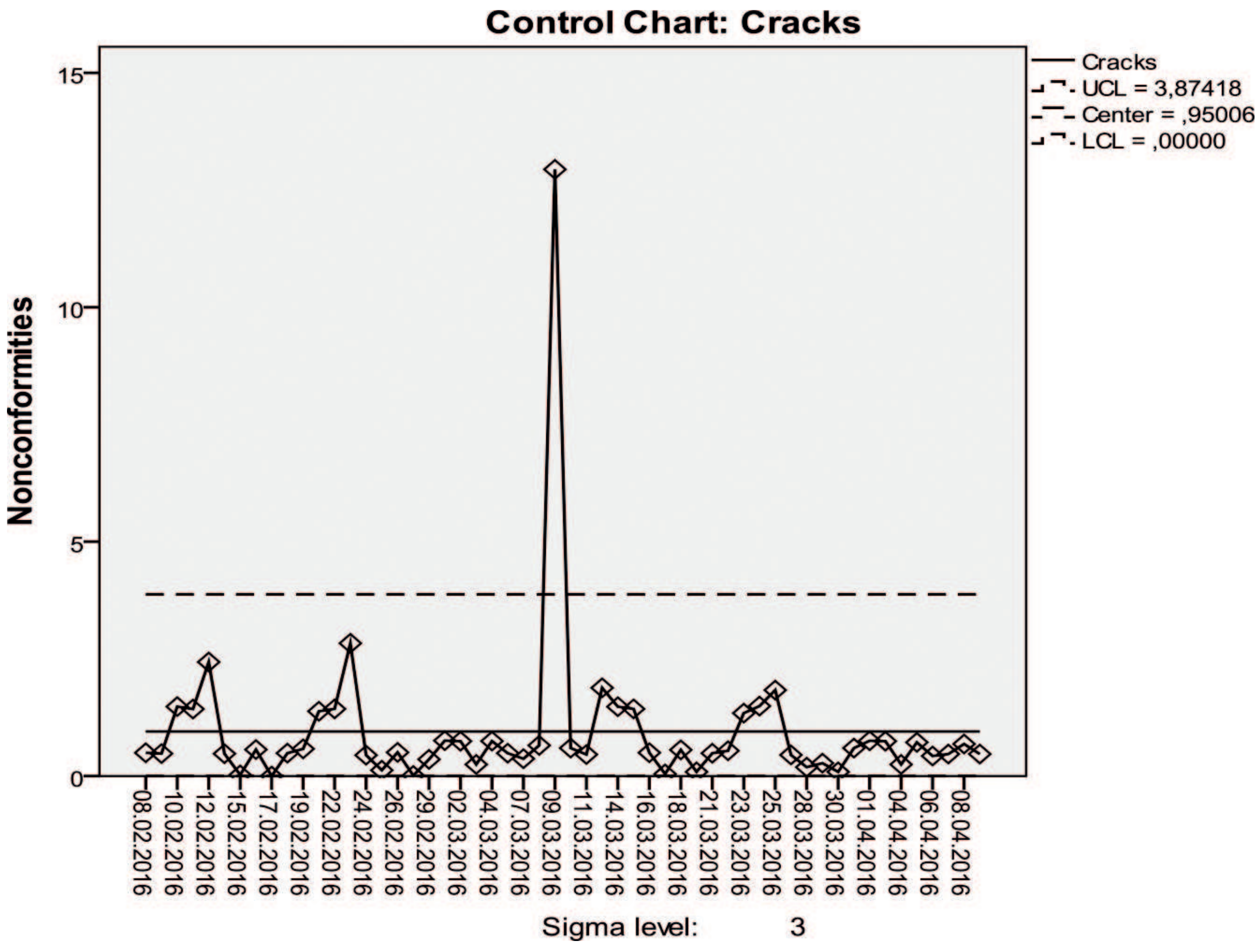

Figure 21. c-control chart for cracks in dying department of the Özer textile weaving factory.

known, and their users must be familiar with the process. It is the author's view that during the interpretation of control charts, not only statistics but also experience and common sense have to be combined with it. If there is a run toward the warning limit, this may suggest that a change has to be made. On the other hand, a similar run would also mean that a change in time may prevent the next item from lying outside the limits. This has to be evaluated for every occasion on its own.

Two examples of a typical control chart where production is under control or a normal behavior is noticed is seen in **Figure 22**.

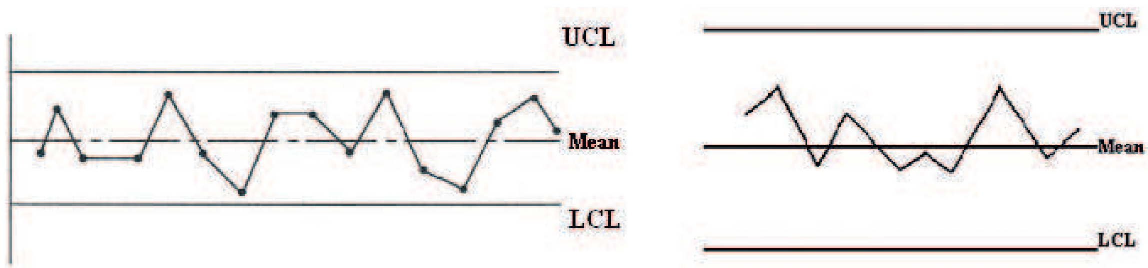

Figure 22. Two examples of a typical control chart.

The main interpretation of control charts is that all the points should lie in between the UCL and LCL. If sample points fall in between the control limits in a continued production, then the process is in control, and as such, no action has to be taken. If a point falls out of them, then the process is out-of-control, and further investigative and corrective action ought to be taken. If, however, points get close to the UCL and LCL's, one has to search for the root of the problem and solve it without stopping production. If on the other hand, points cross the UCL and LCL's, production must be stopped and the problem must be investigated and solved. Faulty production is worse than no production.

On the other hand, even if none of the points lie out of the control limits, this does not mean that the chance factor had played a role. All the points on the control chart may lie in between the UCL and LCL's like a typical chart in **Figure 22**, but this does not mean that production is under control. Incidentally, they may well be out-of-control soon. The reason for this is the pattern occurring on the control chart. Patterns give information about the condition of the process, and their early identification may trigger the alarm for the user to investigate their causes and to prevent any faults before they occur. Patterns having deviations from normal behavior are indicators of raw material, machine (setting, adjustment, tool abrasion, and systematic causes of deterioration) or measuring method, human, and environmental factors starting to change the quality characteristic of the product. To interpret control charts, every cause has to be studied one by one and investigated and corrective action ought to be taken.

$\bar{x}$ and R charts are interpreted together. If the underlying distribution is normal, then the two charts are statistically independent, and their joint consideration gives the user more information about the process. If there is an assignable cause in the process, it will show itself in both of them. If the underlying distribution is not normal, this nonnormality effects the $\bar{x}$ and R charts, leading corrective action not to be taken on time. As such, normality tests have to be done at the beginning. $\bar{x}$ and s charts are also interpreted together.

3.5. Patterns occurring on control charts

Cyclic patterns: Two examples of control charts showing a cyclic pattern are given in **Figure 23**. An $\bar{x}$ control chart having a cyclic pattern between the UCL and LCL may result from systematic environmental changes, such as temperature or heat or stress buildup, raw material

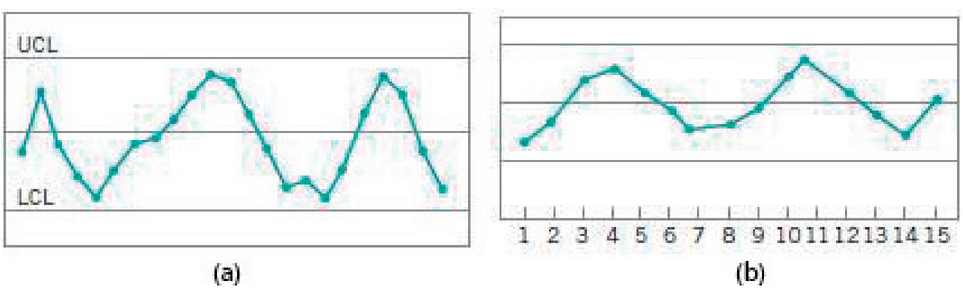

Figure 23. Two examples of control charts showing a cyclic pattern.

deliveries, operator fatigue, regular rotation of operators and/or machines, and fluctuation in voltage or pressure. An R-control chart having a cyclic pattern may result from maintenance schedules, fatigue, or tool wear. It is clear that the process is not out-of-control, but elimination or reduction of the source of variability will improve the product.

Mixture: An example of a control chart showing a mixture pattern is given in **Figure 24**. In a mixture pattern, the plotted points gather around the UCL and LCL, but few points fall near the center line. In this outline, there are two or more overlapping distributions generating the process output. An $\bar{x}$ control chart having a mixture pattern may be the result of "over-control," where process adjustments are done too often, or if many machines do the same production, but are adjusted wrongly.

Shift in process level: An example of a control chart showing a shift in process level pattern is given in **Figure 25**. An $\bar{x}$ control chart having a shift in process level pattern may result from introduction of new workers, methods, raw material, machine, change in the inspection method or standards, change in the either skill, attentiveness, or motivation of the operators.

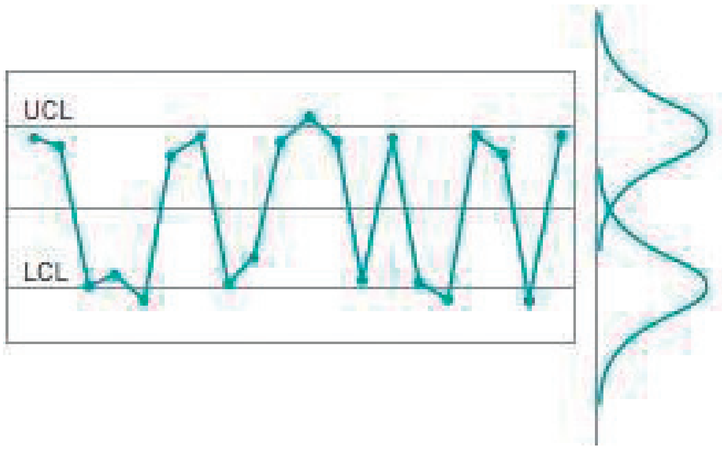

Figure 24. Example of a control chart showing a mixture pattern.

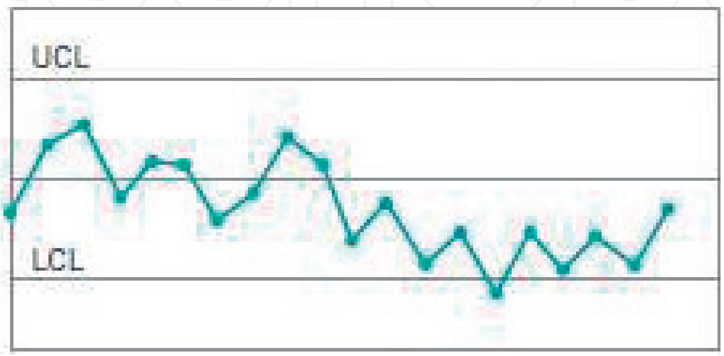

Figure 25. Example of a control chart showing a shift in process level pattern.

http://dx.doi.org/10.5772/intechopen.73237

Trend: An example of a control chart showing a trend pattern is given in **Figure 26**. In a trend pattern, the plotted points continuously move in one direction. An $\bar{x}$ control chart having a trend pattern may result from gradual wearing or deterioration of a tool or component, human causes, such as operator fatigue or the presence of supervision, and seasonal influences like temperature.

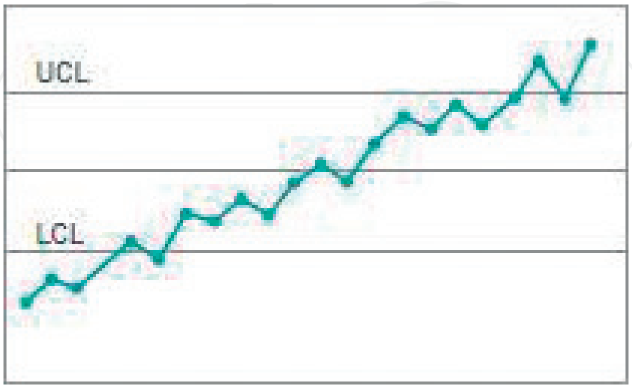

Figure 26. Example of a control chart showing a trend pattern.

Stratification: An example of a control chart showing a stratification pattern is given in **Figure 27**. In a stratification pattern, the plotted points tend to cluster around the center line, and there is a lack of natural variability in the pattern. An $\bar{x}$ control chart having a stratification pattern may result from incorrect calculation of the control limits, or if there are subgroups, several different underlying distributions might be collected in the sampling process.

Approaching LCL: An example of a control chart showing an approach to LCL pattern is given in **Figure 28**. A p-control chart having an approach to LCL pattern may represent a real improvement in process quality. But, downward shifts are not always attributable to improved quality. This is due to the fact that errors in the inspection process may be resulting from inadequately trained or inexperienced inspectors or from improperly calibrated test and inspection equipment during that particular shift. Besides, inspection may pass nonconforming units owing to a lack in training. The same interpretation is valid for np-control charts also.

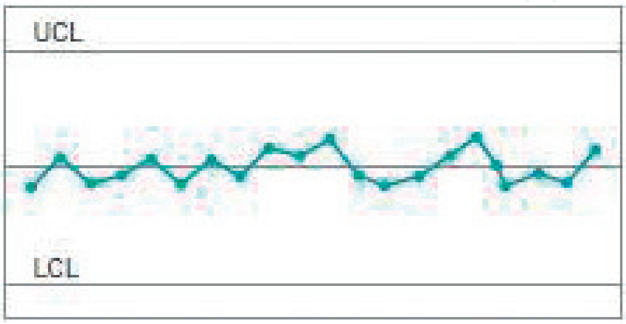

Figure 27. Example of a control chart showing a stratification pattern.

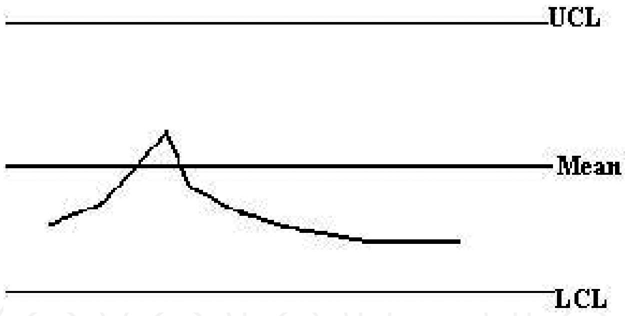

Figure 28. Example of a control chart showing an approach to LCL pattern.

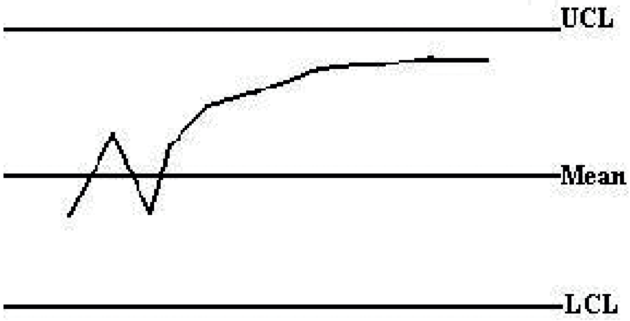

Figure 29. Example of a control chart showing an approach to UCL or LCL pattern.

Approaching UCL or LCL: An example of a control chart showing an approach to UCL or LCL pattern is given in **Figure 29**. A c-control chart having approaching the UCL line may be because of temperature control and an approach to the LCL may be due to inspection error.

3.6. Categorical guidelines other than patterns

Some definitive guidelines are developed to interpret control charts. Keeping in mind that the main principle is none of the points should cross UCL or LCL, the developed standards can be grouped as follows showing that process is out-of-control:

Point/Points crossing the control limits: Examples of control charts showing point/points crossing the control limits are given in **Figure 30**. If there is an assignable cause in the $\bar{x}$ control chart, this is related with either raw material, erratic method, or human error. The latter may be attributable to either changes in raw material lot, changes in microstructure, changes in measuring and control methods, changes in machine adjustments, or wrong reading by the

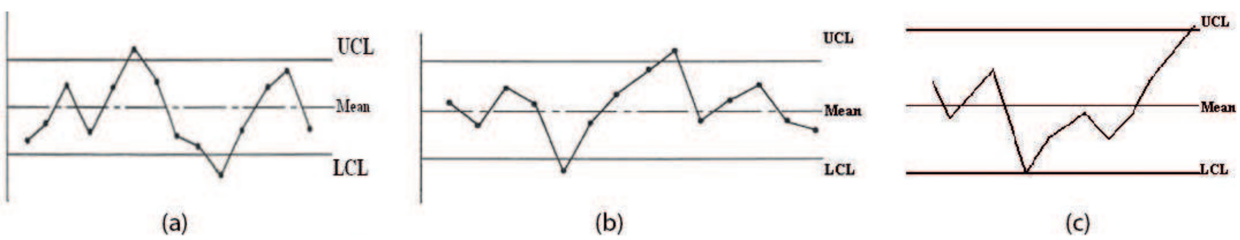

Figure 30. Examples of control charts showing point/points crossing the control limits.

http://dx.doi.org/10.5772/intechopen.73237

operator. If there is an assignable cause in the R-control chart, this is related with either machine or measuring instruments. Some noteworthy cases are, say, not calibrated measuring instruments, showing as such a low sensitivity value, the systematic causes of deterioration of production machines, as well as low machine maintenance. If there are points lying out of the control limits in both the $\overline{x}$ and R chart, this means that the calculation of the UCL and LCL would have been either wrong, or that the points were placed erratically. In addition to this, the process would have been out-of-control, the measuring system might have changed, or the measuring instrument may not be working properly. If one or more points fall sharp beyond or get close to the UCL or LCL, this is evidence that the process is out-of-control. A detailed investigation of the current circumstance has to be done, and corrective action has to be taken.

Many points very near to the control limits: An example of a control chart showing many points that are very near to the control limits is given in **Figure 31**. This pattern may be toward UCL or LCL.

Points gather around a value: An example of a control chart showing points gathering around a value is given in **Figure 32**.

Consecutive points: All the consecutive seven points which are placed on one side of the center line is given in **Figure 33**. About 10 out of 11 consecutive points that are placed on one side of the center line is shown in **Figure 34**.

This expression can be widened as 12 out of 14 consecutive points, 14 out of 17 consecutive points, 16 out of 20 consecutive points, and 19 out of 25 consecutive points (**Figure 35**) are placed on one side of the center line. They all indicate very nonrandom appearance and an out-of-control production.

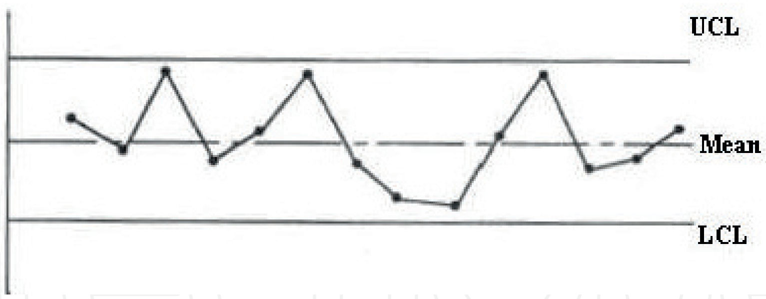

Figure 31. Example of a control chart showing many points that are very near to the control limits.

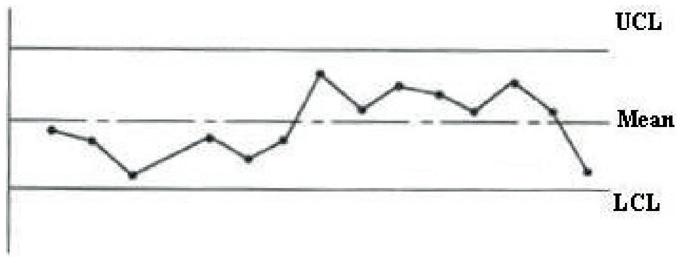

Figure 32. Example of a control chart showing points gathering around a value.

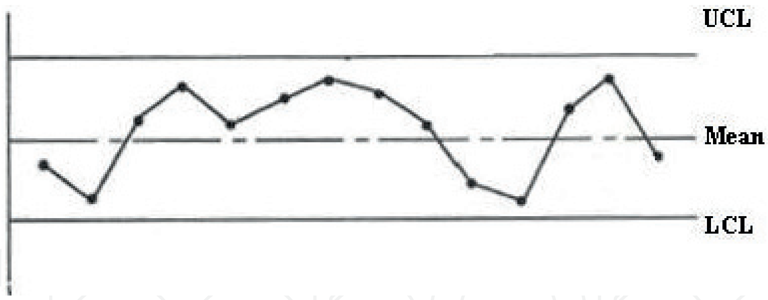

Figure 33. All of the consecutive 7 points are placed on one side of the center line.

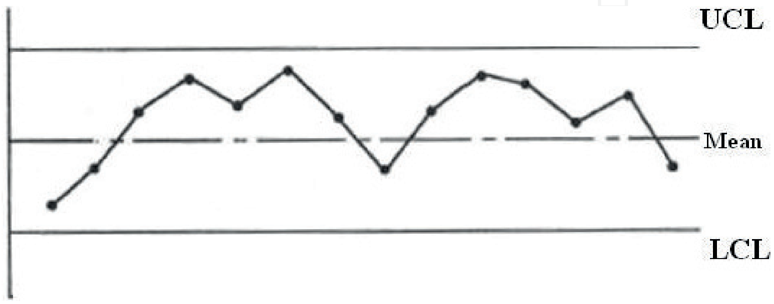

Figure 34. 10 out of 11 consecutive points that are placed on one side of the center line.

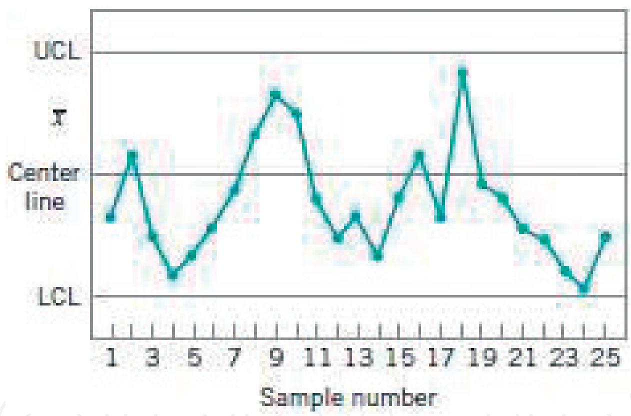

Figure 35. 19 out of 25 consecutive points are placed on one side of the center line.

Runs: Average run length is the average number of points that must be plotted assignable before it can be said that it is an out-of-control condition. They describe the performance of the control charts. Some examples are:

A run of 2 points out of 3 near the control limits is given in **Figure 36**.

Others may be a run of 4 points out of 5 at a 1σ distance from the center line, a run of 8 points lie at one side of the center line, and a run of 7 points rises or falls (**Figure 37**).

The placement of the points according to the center line is also important. 2/3 of the points have to lie between the inner 1/3 distance between the UCL and LCL's and 1/3 of the points

http://dx.doi.org/10.5772/intechopen.73237

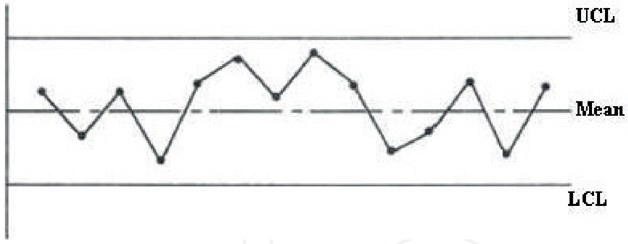

Figure 36. A run of 2 points out of 3 is near the control limits.

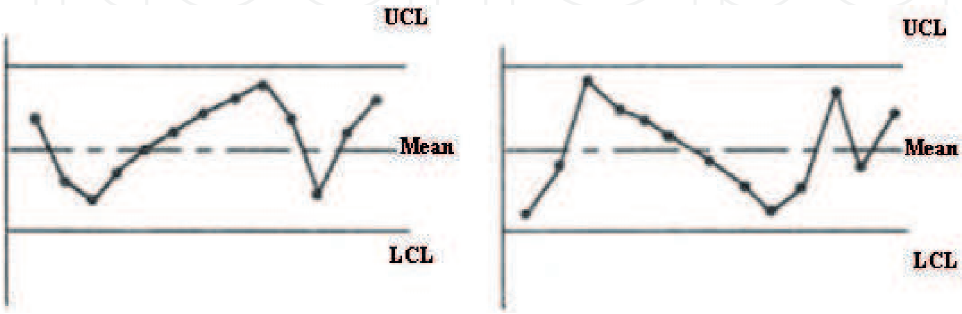

Figure 37. A run of 7 points rises or falls.

have to lie between the outer 2/3 distance between the limits. If more or less of the 2/3 of points lie near the center line, then this means either the limits were calculated wrong or the points are placed erratically on the chart, successive measurements may have been from different parties in production but located on the same chart by fault, or the machine adjustments have changed but the control operator was not aware of it and located the points on the same chart by fault instead of preparing a new chart.

Examples of less than 2/3 of points lie in the middle 1/3 of the control limits are given in **Figure 38**.

An example of clear shifts for different periods is given in **Figure 39**. The reason for these shifts would be that the process is changing periodically, and so, different limits have to be calculated for different periods. Another reason would be that the lot had been changed, but the person in charge is not aware of it and continues to plot two different lots on the same chart rather than preparing a new one for the new lot.

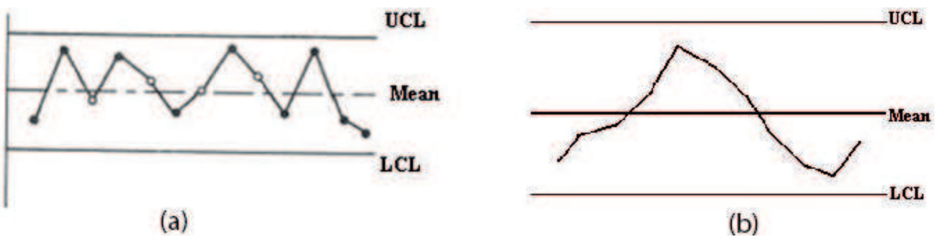

Figure 38. Less than 2/3 of points lie in the middle 1/3 of the control limits.

Figure 39. Example of clear shifts for different periods.

4. Discussion

A number of researches have been performed on the topic of control charts. Indeed, the majority of studied works emphasize the early prediction of defects and on different areas like poultry, health, etc., other than manufacturing which is the main area these are used. A short survey of new developments in control charts is given below.

There are some statistics software packages which also include preparations of control charts like SPSS, MATLAB, STATISTICA, etc. These software packages utilize the usage of control charts in companies, service, and official applications. With the help of computers, much of the work done by hand is performed very quickly, and results are obtained right away. The results are interpretated fast, and corrective action is taken to increase efficiency and profit in the enterprise. Furthermore, new techniques like artificial neural networks are applied in modern quality control methods and techniques.

4.1. Research on control charts done in Turkey

The authors use Shewhart control charts to maintain the quality of raisins (dried grapes) and dried figs within acceptable limits and make it possible to readjust storage conditions, if the acceptable limits should be violated. This occurs since the Shewhart control charts they use are constructed by using the Hunter *Lab* color scale parameters to assure maintenance of the color and flavor of raisins and dried figs during storage in modified atmosphere packages, vacuum packages, or nylon bags. Changing the storage conditions after the fruits have deteriorated cannot improve quality because deterioration of raisins or figs is irreversible. In the early stages of storage, violation of the control limits will warn the operators, and the storage conditions will be improved [15].

The authors used the program which was designed by Montgomery to prevent errors and wastage of resources during sampling process in order to determine the economic design of parameters. The economical design of Shewhart control charts improves the principle of balancing between control efficiency and its costs. They did an application in a fruit soda producing factory. It is worth noting at this point that although staff was trained about total quality control, they were not adequately trained in statistical quality control. After the work of the authors, with this program and by paying attention to the lost functions and unit costs, design parameters, sample size, sampling interval, and the control limits were determined, resulting in a reduction of errors [16].

It is the author's view that coal properties are variable even within a single coal seam due to coalification history, mining method, etc. To control the variability of coal quality is important from the points of efficiency and production costs of power plants. These are negatively affected by nonconsistent coal characteristics such as calorific value, moisture content, and ash content and profitability of the coal producer. Variations in coal properties of the Tuncbilek Power Plant were studied by means of control charts, and process capability analysis of the statistical quality control methods was found to be very high. The latter showed variation within short intervals and away from contract specifications. It was suggested that the coal should be blended to reduce the variability in coal characteristics before selling to power plants, so that the efficiency of the power plant and the income of the coal producer can be increased [17].

The authors obtained the control limits of $\overline{x}$ and R-control charts for skewed distributions by considering the classic, the weighted variance (WV), the weighted standard deviations (WSD), and the skewness correction (SC) methods. They compared these methods by using Monte Carlo simulation, Type I risk probabilities with respect to different subgroup sizes for skewed distributions, which are Weibull, gamma, and log-normal. They concluded that Type I risk of SC method is less than that of other methods, the Type I risks of Shewhart, WV, WSD, and SC $\bar{X}$ charts are comparable when the distribution is approximately symmetric, and the SC R chart has a smaller Type I risk [18].

It is worth noting however that statistical quality control charts (SQCCs) are widely used in manufacturing processes so as to keep fluctuations within the acceptable limits; nonetheless, no application is done to weight management studies. In this paper, the author proves that using the mean Body Mass Index (BMI) values as the only indicator to assess the weight status of populations might be misleading in clinical weight management studies. For healthy aging, the author suggests to introduce a powerful tool, SQCCs, to keep fluctuations in BMIs within acceptable limits in a given population and makes a cross-sectional design. The distributions of individual BMIs and the pattern of BMI which change by age were studied using X charts, tolerance charts, and a capability analysis was performed. It is concluded by the author that the mean BMI increased in both genders by age as seen in **Figure 40**. Likewise, the individual weights were out-of-control limits, the mean BMI values were within the limits, and although the number of overweight individuals was greater in some groups, their mean BMIs were lower compared to the groups with fewer overweight individuals. Capability tests concluded that each group, even the groups with a mean BMI in the normal weight ranges and also the groups which are referred as being "under control" according to the X charts, was not within the so-called energy balance ($Cp < 1$ and $Cp_k < 1$). The results suggest that by using the mean BMIs as the only indicator might be misleading in weight management studies. This work introduces SQCCs as a potential tool for clinical nutrition studies to maintain the fluctuations of individual BMIs within acceptable limits for healthy aging populations [19].

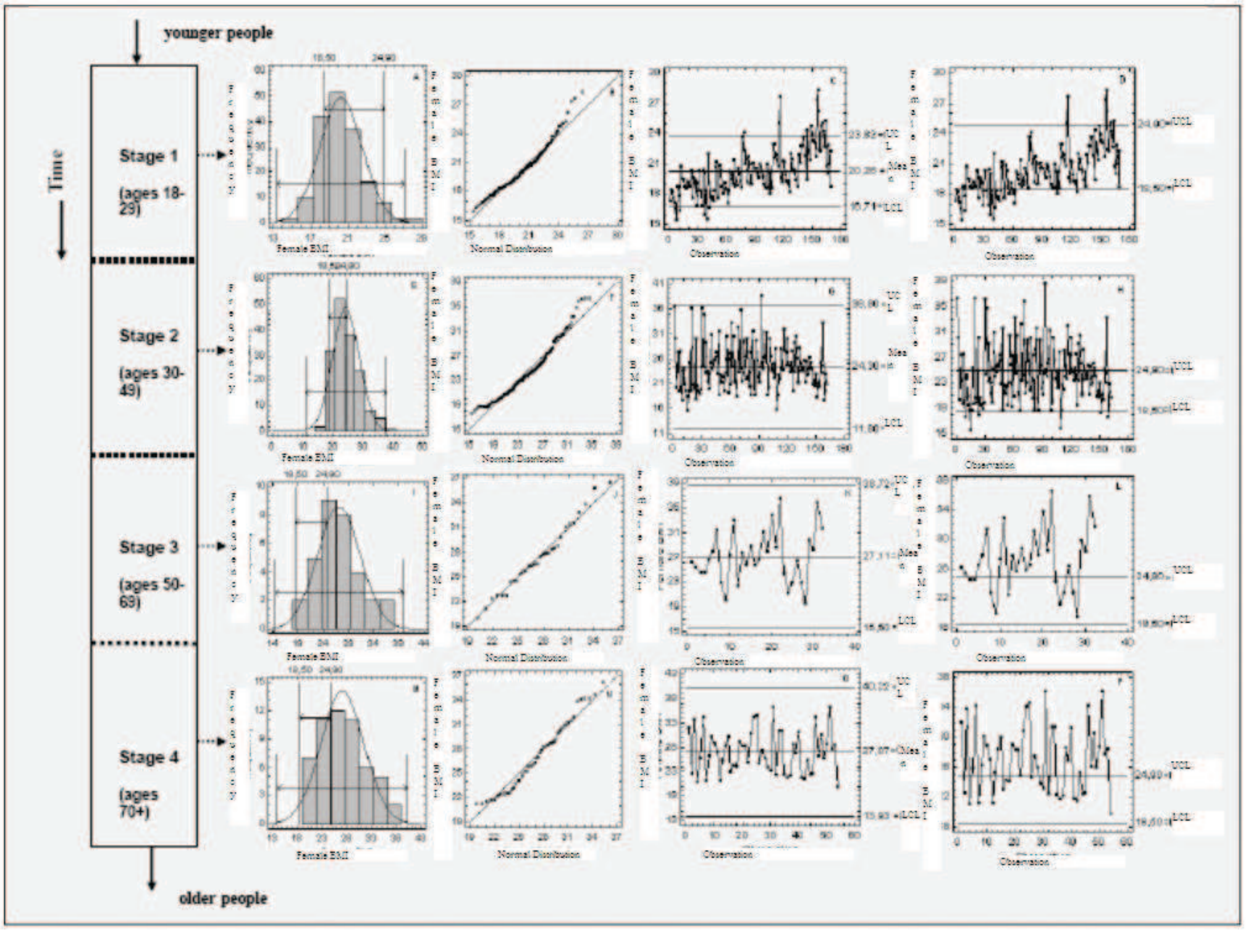

Figure 40. Mean BMI increase in females by age.

The authors constructed modified Shewhart charts incorporating weight loss, Haugh units and yolk index for storage of untreated, soda lime, water glass, or oil coated and thermostabilized eggs. The data obtained showed differences between particular treatments. Control charts derived from them illustrate that maintenance lies within the limits of the inevitable quality loss, and this comes from the storage of eggs. Knowing the trends made it possible to readjust the storage conditions so as to prolong the period before the violation of acceptable limits [20].

In determining the quality of the egg shell, broken or cracked eggs are important factors. The manufacturers need control charts throughout production to keep the number of broken or cracked eggs under control. The authors in this paper used p-control charts prepared with 52 weeks data in poultry business. They used three methods to draw control charts and concluded that the process was not under control because the number of broken or cracked eggs often crossed the upper control limit [21].

4.2. Research on control charts done in Greece

When the vector of means of several quality characteristics are monitored, the most widely used multivariate control chart is the Hotelling's χ2 control chart, which is a Shewhart-type control chart, and it is relatively insensitive to detect small magnitude shifts quickly. The authors study the performance of the Hotelling's $\chi 2$ control chart supplemented with a r-out-of-m runs rule. Their new control chart exhibits an improved performance over other competitive runs rules based control charts [22].

When the quality characteristics cannot be measured on a continuous scale, attribute control charts are very useful for monitoring different processes. Some cases involve the monitoring of multiple attributes simultaneously. This leads to multinomial and multiattribute quality control methods, which are better than the simultaneous use of multiple uniattribute methods. The authors equally studied research previously conducted on multiattribute quality control, regarding the design, performance, and applications of multiattribute control charts (MACCs), as well as multiattribute sampling plans. They also reviewed comparisons of the MACCs, as well as MADM research. They also emphasized the need of neural networks, the design of artificial neural network in attributes monitoring for an out-of-control signal, the detection of the magnitude of the shifts in parameters, the determination of the shape of the membership functions in linguistic terms, the appropriate degree of fuzziness of the membership functions, the exact relationship between the degree of fuzziness and sensitivity of control charts, and in nonhomogenous cases, where the distribution is no longer binomial what the properties of the process p chart should and as such may form a subject for further investigation [23].

The authors have examined the problem of the statistical and economics-based design of fully adaptive Shewhart control charts for monitoring finite-horizon processes, where the production horizon for a specific product can be limited to a few hours or shifts. They propose a Markov chain model to design a fully adaptive Shewhart control chart for such cases. Their Markov chain model allows the exact computation of several statistical performance metrics, as well as the expected cost of the monitoring and operation process for any adaptive Shewhart control chart with an unknown but finite number of inspections. The implementation of the Vp X chart in short runs shows the production of a finite batch of products. They also support two models, namely one that is economics based and one that is aimed for the statistical design. These charts can also be used to optimize the performance of any adaptive control chart (VSSI, VSI, VSS, and Vp) in a finite-horizon context. They derived some properties of the economics-based model, which facilitates economic optimization and CUSUM adaptive control charts can also be developed [24].

The authors presented the economic design of $\overline{x}$ control charts for monitoring a critical stage of the main production process at a ceramic tiles manufacturer in Greece. They developed two types of $\overline{x}$ charts:

- A Shewhart-type chart with fixed parameters and,
- An adaptive chart with variable sampling intervals and/or sample size.

They aimed to improve the statistical control scheme employed for monitoring quality characteristics and minimize the relevant costs. They also tested and confirmed the applicability of the theoretical models supporting the economic design of control charts with fixed and variable parameters and evaluated the economic benefits of moving from the broadly used static charts to the application of the more flexible and effective adaptive control charts. They concluded that by re-designing the currently employed Shewhart chart using economic criteria, the quality-related cost is expected to decrease by approximately 50% without increasing the implementation complexity.It is the author's view that by monitoring the process by means of an adaptive $\bar{x}$ chart with variable sampling intervals will increase the expected cost savings by about 10% compared with the economically designed Shewhart chart at the expense of some implementation difficulty [25].

The author studied the factors that affect the Brix value and the volatile acidity of the final product in the bio-production of grape molasses, considering the ground used for cultivation and the variety of grapes. The author applied off-line statistical quality control techniques and discussed the outcomes in detail, concluding that Corinthian and Camborne varieties of grapes seemed to lead to the optimum result because the Brix value is optimum and grape molasses, while Phocean and Corinthian varieties of grapes were the best choices in order to decrease their volatile acidity, and mountain ground was better [26].

The author indicates that Statistical Process Control procedures are based on the assumption that the process subject to monitoring consists of independent observations. Many nonindustrial processes besides chemical processes exhibit autocorrelation, where the assumption is not valid. The author has developed a methodology for monitoring autocorrelated processes. The main idea here is to compare the performance of the time series model against an alternative which works with departures from it. A phase II control procedure is proposed, which is a time-varying auto-regressive (AR) model for autocorrelated and locally stationary processes. That model is optimized during phase I, and as a result, the model describes the process accurately. The phase II control procedure is based on a comparison of the current time series model with the alternative model which is measuring deviations from it, using Bayes factors where its threshold rules enable a binomial-type control procedure. This model can equally be used in local nonstationarities via the dynamic evolution of the AR coefficients, and so it describes stable and nonstable processes. In particular, this method can be used in nonindustrial process monitoring, where nonstable or nonstationary processes are typical (finance, environmentrics, etc.). Temperature measurements at two different stages in the manufacturing of a plastic mold are used as data sets [27].

In statistical quality control, control charts are the most widely used and are regarded as an effective tool. This work presented recent developments in the design of the adaptive control charts, especially in univariate control charts because they allow some of their parameters to change during production. They also act as an extension of the study of Tagaras. Based on performed literature review, it may be stated that the adaptive control charts may result to faster detection of a process shift and thus may contribute to improving overall economic performance. However, they are harder to administer, and their application may run up against technical difficulties. The design parameters which are the sample size, the sampling interval, and the control limit coefficient can be changed in adaptive control charts, while warning limits are added and improvements are gained. This study has equally shown that the more parameters are adaptive, the more improvement is obtained, hence, making the implementation of the control chart more difficult. The performance measures of the adaptive control charts which are derived from the Markov chain approach are discussed in this paper. The authors are interested in monitoring the process dispersion instead of the process mean. They indicate that in the S or R chart and the conforming run length chart, modification can be applied in order to detect variance shifts, and these shifts prove to detect increase in σ better than the decrease and are useful to monitor both the process mean and the process variance shift. It is the author's view that users may misuse the cause-selecting chart in production steps because of unsatisfactory training, and this may lead to unnecessary adjustment that could increase the variability and as such the cost of the products. In view of the above, the dependent processes can be extended to the VP charts as well as to multiple process steps, multiple assignable causes, and dependent assignable causes. EWMA and the CUSUM charts are more effective than the standard Shewhart charts because they take into account both the present and previous samples. The adaptive control charts for attributes are also studied in this paper, and it is shown that by adding the adaptive feature, the detection ability of the charts is increased [28].

4.3. Research on control charts done in Bulgaria

In today's world, the pursuit of high quality production is one of the main topics. The need for use of the specific software products so as to control the production process quality is the result of the variety and complexity of the production characteristics. SPSS is the most widely used software, which provides increased deliverables for a basic quality control analysis. A critical review of SPSS quality control functions and features is done, which contributes to enhanced quality management. It is worth mentioning at this point though, that aforementioned software package is facing competition from Minitab and Statistica to name but a few. In the future, it is hoped to find a universal all-in-one tool for the data processing without any insufficiencies concerning quality control functions and statistical analyses [29].

4.4. Research on control charts done in China

Performed literature research indicates that pattern recognition technology is used to automatically judge the changing modes of control chart, which reveal potential problems. They propose a neural network-numerical fitting (NN-NF) model to recognize different control chart patterns with the purpose of improving the recognition rate and the efficiency of control chart patterns. They first use a back propagation (BP) network and then Monte Carlo simulation to generate training and testing of the data samples. If the control chart patterns are recognized with the general run rules, the abnormal report is directly generated, if not, the NN-NF model is activated. Training time of their NN-NF model is less, and the recognition rate is also improved [30].

In addition to the above, a skewness correction (SC) method is proposed for constructing the $\overline{X}$ and R-control charts. The latter are adjustments of the conventional Shewhart control charts for skewed process distributions. Their asymmetric control limits are based on the degree of skewness estimated from the subgroups, and no parameter assumptions are made on the form of process distribution. The new developed charts are compared with the Shewhart charts and weighted variance (WV) control charts. It is concluded that when the process distribution is in the proximity of a Weibull, log-normal, Burr, or binomial family, performed simulation showed that the SC control charts had a Type I risk closer to 0.27% of the normal case. Also, in the case where the process distribution is exponential with a known mean, both the control limits and the Type I risk, as well as the Type II risk of the SC charts, are closer to those of the exact $\overline{X}$ and R charts than those of the WV and Shewhart charts [31].

4.5. Research on control charts done in Tunisia

This paper emphasizes that control chart pattern recognition (CCPR) is a important task in statistical process control (SPC). Abnormal patterns in control charts can be associated with certain assignable cause adversely affecting the process stability. Work is aimed at reviewing and analyzing research on CCPR. In conjunction with this, a new conceptual classification scheme emerges, based on a content analysis method, so as to classify past and current developments in CCPR research done in more than 120 papers within the period 1991–2010. It was found that most of the CCPR studies dealt with independently and identically distributed process data; some recent studies pertaining to the identification of mean shifts or/and variance shifts of a multivariate process were based on innovative techniques. It is worth mentioning at this point though that there is an increase in the percentage of studies that address concurrent pattern identification as well as in Artificial Neural Network (ANN) approaches for improving the recognition of pattern together with hybrid, modular, and integrated ANN recognizer designs. The latter may be combined with decision tree learning, particle swarm optimization, etc. There are two main categories of performance criteria used to evaluate CCPR approaches: statistical criteria that are related to two conventional average run length (ARL) measures and recognition-accuracy criteria, which are not based on these ARL measures mainly for ANN-based approaches. Performance criteria with ARL measures are insufficient and inappropriate in the case of concurrent pattern identification. The authors also discuss some future research directions and their perspectives [32].

5. Conclusion and further work

Control charts are important tools of statistical quality control that enhance quality. Quality improvement methods like flow diagrams, cause-and-effect (fishbone) diagrams, check sheets, histograms, scatter plots, and Pareto diagrams have also been applied so as to fulfill the needs of consumers with the desired properties and the least possible defects in the output, while maximizing producers' profit. There are natural variations in production but also assignable causes which are not a part of chance but may be attributable to a number of internal and/or external factors like raw material, machine setting (or adjustment, tool abrasion, systematic causes of deterioration) or measuring method, human, and environmental effects.

This paper provided a qualitative and quantitative insight into the use of only the control charts. Based on a number of industrial cases, it showed that the implementation of control charts can indeed contribute to defects minimization and, hence, reduce warranty and other costs.

Control charts mainly used are control charts for variables, that is, individual measurements control chart (x), means control chart ($\overline{x}$), ranges control chart (R) and standard deviation control chart (s), and control charts for attributes, that is, control chart for fraction nonconforming (p), control chart for the number of nonconforming items (np), control chart for conformities per unit (u), and control chart for nonconformities (c). Sensitivity, sample size, and sampling frequency (specific and equal time intervals) are important effectors on the performance of the control chart. Upper and lower control limits are calculated by using different equations for each control chart. Points are plotted on the charts, and they have to be in between the UCL and LCL for a normal production. This, however, is not deemed to be enough to keep production under control. The pattern made by the points on the chart needs to be interpreted. Corrective actions are taken to keep production under control and bring the points back in between the control limits for the product to be at tolerable distance to the specified nominal values. The performance of a control chart is precise, even if it is the result of small sample sizes in production for tests done everyday.

The case studies presented herein showcase that control charts result in higher production efficiency and are as such used widely in industry. This work has equally highlighted performed research in the area of control charts. Indeed, research on control charts is done on a global basis, and from the findings discussed in this work, statistical methods and techniques are further empowered by the use of computer technology and, in particular, dynamic software packages and artificial neural networks, to name a few. In view of the above, it may be stated that Statistics may further assist its users by refined and selected methods to improve quality in a modern way besides control charts.

Acknowledgements

The author kindly exhibits her deep regards to Kaynak Group Cotton Yarn Factory, Çağla Textile Ready-wear Factory, Özer Textile Weaving Factory, Gülçağ Textile Yarn Factory, Sarıkılıç Textile Nonwoven Factory, Yıldırımlar Printing & Dying Factory, and Ne-Ke Textile Weaving Factory which are located in Uşak and Teksüre Textile Socks Factory which is located in İstanbul-Turkey.

Appendix 1 [7]

Factors for Constructing Variables Control Charts

Observations in Sample, n	Chart for Averages: Factors for Control Limits			Chart for Averages: Factors for Center Line		Chart for Standard Deviations: Factors for Control Limits				Factors for Center Line		Chart for Ranges: Factors for Control Limits				
	A	A_2	A_3	c_4	$1/c_4$	B_3	B_4	B_5	B_6	d_2	$1/d_2$	d_3	D_1	D_2	D_3	D_4
2	2.121	1.880	2.659	0.7979	1.2533	0	3.267	0	2.606	1.128	0.8865	0.853	0	3.686	0	3.267
3	1.732	1.023	1.954	0.8862	1.1284	0	2.568	0	2.276	1.693	0.5907	0.888	0	4.358	0	2.574
4	1.500	0.729	1.628	0.9213	1.0854	0	2.266	0	2.088	2.059	0.4857	0.880	0	4.698	0	2.282
5	1.342	0.577	1.427	0.9400	1.0638	0	2.089	0	1.964	2.326	0.4299	0.864	0	4.918	0	2.114
6	1.225	0.483	1.287	0.9515	1.0510	0.030	1.970	0.029	1.874	2.534	0.3946	0.848	0	5.078	0	2.004
7	1.134	0.419	1.182	0.9594	1.0423	0.118	1.882	0.113	1.806	2.704	0.3698	0.833	0.204	5.204	0.076	1.924
8	1.061	0.373	1.099	0.9650	1.0363	0.185	1.815	0.179	1.751	2.847	0.3512	0.820	0.388	5.306	0.136	1.864
9	1.000	0.337	1.032	0.9693	1.0317	0.239	1.761	0.232	1.707	2.970	0.3367	0.808	0.547	5.393	0.184	1.816
10	0.949	0.308	0.975	0.9727	1.0281	0.284	1.716	0.276	1.669	3.078	0.3249	0.797	0.687	5.469	0.223	1.777
11	0.905	0.285	0.927	0.9754	1.0252	0.321	1.679	0.313	1.637	3.173	0.3152	0.787	0.811	5.535	0.256	1.744
12	0.866	0.266	0.886	0.9776	1.0229	0.354	1.646	0.346	1.610	3.258	0.3069	0.778	0.922	5.594	0.283	1.717
13	0.832	0.249	0.850	0.9794	1.0210	0.382	1.618	0.374	1.585	3.336	0.2998	0.770	1.025	5.647	0.307	1.693
14	0.802	0.235	0.817	0.9810	1.0194	0.406	1.594	0.399	1.563	3.407	0.2935	0.763	1.118	5.696	0.328	1.672
15	0.775	0.223	0.789	0.9823	1.0180	0.428	1.572	0.421	1.544	3.472	0.2880	0.756	1.203	5.741	0.347	1.653
16	0.750	0.212	0.763	0.9835	1.0168	0.448	1.552	0.440	1.526	3.532	0.2831	0.750	1.282	5.782	0.363	1.637
17	0.728	0.203	0.739	0.9845	1.0157	0.466	1.534	0.458	1.511	3.588	0.2787	0.744	1.356	5.820	0.378	1.622
18	0.707	0.194	0.718	0.9854	1.0148	0.482	1.518	0.475	1.496	3.640	0.2747	0.739	1.424	5.856	0.391	1.608
19	0.688	0.187	0.698	0.9862	1.0140	0.497	1.503	0.490	1.483	3.689	0.2711	0.734	1.487	5.891	0.403	1.597
20	0.671	0.180	0.680	0.9869	1.0133	0.510	1.490	0.504	1.470	3.735	0.2677	0.729	1.549	5.921	0.415	1.585
21	0.655	0.173	0.663	0.9876	1.0126	0.523	1.477	0.516	1.459	3.778	0.2647	0.724	1.605	5.951	0.425	1.575
22	0.640	0.167	0.647	0.9882	1.0119	0.534	1.466	0.528	1.448	3.819	0.2618	0.720	1.659	5.979	0.434	1.566
23	0.626	0.162	0.633	0.9887	1.0114	0.545	1.455	0.539	1.438	3.858	0.2592	0.716	1.710	6.006	0.443	1.557
24	0.612	0.157	0.619	0.9892	1.0109	0.555	1.445	0.549	1.429	3.895	0.2567	0.712	1.759	6.031	0.451	1.548
25	0.600	0.153	0.606	0.9896	1.0105	0.565	1.435	0.559	1.420	3.931	0.2544	0.708	1.806	6.056	0.459	1.541

For $n > 25$.

$$A = \frac{3}{\sqrt{n}} \qquad A_3 = \frac{3}{c_4\sqrt{n}} \qquad c_4 \cong \frac{4(n-1)}{4n-3}$$

$$B_3 = 1 - \frac{3}{c_4\sqrt{2(n-1)}} \qquad B_4 = 1 + \frac{3}{c_4\sqrt{2(n-1)}}$$

$$B_5 = c_4 - \frac{3}{\sqrt{2(n-1)}} \qquad B_6 = c_4 + \frac{3}{\sqrt{2(n-1)}}$$

Author details

Nefise Gönül Şengöz

Address all correspondence to: nefisegonul.sengoz@usak.edu.tr

Textile Engineering Department, Engineering Faculty, Uşak University, Uşak, Turkey

References

[1] Atilla A. Exercises on ISO 9001 Quality Insurance System (ISO 9001) Kalite Güvence Sisteminin Örnekleri. İstanbul: Çağlayan Publications (Kitabevi); 1996. 412 pp

[2] Booth JE. Principles of Textile Testing An Introduction to Physical Methods of Testing Textile Fibers, Yarns and Fabrics. London: Newnes-Butterworths; 1969. 583 pp

[3] Kothari VK. Testing and quality management. In: Progress in Textiles : Science and Technology. Vol. 1. New Delhi: IFAL Publications; 1999. 543 pp

[4] Grover EB, Hamby DS. Handbook of Textile Testing and Quality Control. New York: Textile Book Publishers, Inc; 1960. 614 pp

[5] Kobu B. Management of Production (Üretim Yönetimi). 17th ed. Istanbul: Beta Publications (Yayınevi); 2014. 639 pp

[6] Başer G. Quality Control (Kalite Kontrolu). İstanbul: Çağlayan Publications (Kitabevi); 1972. 90 pp

[7] Montgomery DC. Introduction to Statistical Quality Control. 4th ed. New York: John Wiley & Sons, Inc.; 2001. 796 pp

[8] Statistical Quality Control (İstatistiksel Kalite Kontrol). Ankara: Turkish Statistics Institution (Türkiye Istatistik Kurumu); 2011. 48 pp

[9] Gönül Şengöz N, editor. Quality control. In: Lecture Notes of Assist. Uşak: Uşak University; 2012

[10] Akkuş R, Özcan G. "Improvement of Quality Control System of a Textile Company Using Regular Measurements in the Factory (Fabrikanın Üretim Verileri ile Kalite Kontrol Sisteminin Geliştirilmesi Çalışmaları)" (Established in Kaynak Group Cotton Yarn Factory in Uşak), Bachelor Thesis granted by TUBITAK (The Scientific and Technological Research Council of Turkey), Uşak University-Turkey; 2014. 125 pp. Supervisor: Assist. Prof.Dr.N.Gönül Şengöz

[11] Kalafatçı İN, Efendi N. Quality Control in Ready-wear Production (Konfeksiyonda Kalite Kontrol). (Established in Çağla Textile Ready-wear Factory in Uşak), Bachelor Thesis, Uşak University-Turkey; 2012. 128 pp. Supervisor: Assist.Prof.Dr.N.Gönül Şengöz

[12] Kırbıyıkoğlu B. Practice of Quality Control Charts in a Weaving Factory (Bir Dokuma İşletmesinde Kalite Kartları Uygulaması). (Established in Özer Textile Weaving Factory in Uşak), Bachelor Thesis, Uşak University-Turkey; 2004. 73 pp. Supervisor: Assist.Prof.Dr. N.Gönül Şengöz

[13] Dağcı ÇG. Practice of Quality Control Methods on Yarn Characteristics (Kalite Kontrol Yöntemlerinin İplik Özellikleri Üzerine Uygulanması). (Established in Gülçağ Textile Yarn Factory in Uşak), Bachelor Thesis, Uşak University – Turkey; 2013. 76 pp. Supervisor: Assist.Prof.Dr.N.Gönül Şengöz

[14] Gürarslan A, Erol R. Practice of Six-sigma Quality Management System in a Printing Factory (Altı Sigma Kalite Yönetiminin Baskı Fabrikasına Uygulanması). (Established in Yıldırımlar Printing & Dying Factory in Uşak), Bachelor Thesis, Uşak University-Turkey; 2007. 77 pp., Supervisor: Assist.Prof.Dr.N.Gönül Şengöz

[15] Özilgen M, Şumnu G, Emir H, Emir F. Quality control charts for storage of raisins and dried figs. Zeitschrift für Lebensmitteluntersuchung und -Forschung A. 1997;**204**(1):56-59

[16] Firuzan AR, Ayvaz YY. An Application About The Selection of Design Parameters at The SHEWHART Control Charts. Admistration and Economy Celal Bayar University Press (Yönetim ve Ekonomi Celal Bayar Üniversitesi Yayınları), 2005;**12**(1):1-9

[17] Elevli S. Coal quality control with control charts. Coal Preparation. 2010;**26**(4):181-199

[18] Karagöz D, Hamurkaroğlu C. Control charts for skewed distributions: Weibull, gamma, and lognormal. Metodoloˇski zvezki. 2012;**9**(2):95-106

[19] Ozilgen S. Statistical quality control charts: New tools for studying the body mass index of populations from the young to the elderly. The Journal of Nutrition, Health & Aging. 2011;**15**(5):333-339

[20] Kahraman-Doğan H, Bayındırlı L, Özilgen M. Quality control charts for storage of eggs. TOC. 1994;**17**(6):495-501

[21] Güney MÇ, Kayaalp GT. Determination of egg shell quality with P control charts in poultry. Turkish Journal of Agriculture - Food Science and Technology (TURJAF). 2016; **4**(7):588-591

[22] Rakitzis AC, Antzoulakos DL. Chi-square control charts with runs rules. Methodology and Computing in Applied Probability. 2011;**13**:657-669

[23] Topalidou E, Psarakis S. Review of multinomial and multiattribute quality control charts. Quality and Reliability Engineering International. 2009;**25**:773-804

[24] Nenes G, Castagliola P, Celano G. Economic and statistical design of Vp control charts for finite-horizon processes. IISE Transactions. 2017;**49**(1):110-125

[25] Nikolaidis Y, Rigas G, Tagaras G. Using economically designed Shewhart and adaptive . Xbar charts for monitoring the quality of tiles. Quality and Reliability Engineering International. 2007;**23**:233-245

[26] Triantafyllou IS. Off-line quality control in bioproducts processing: A case study in Greece. Open Journal of Statistics. 2016;**6**:229-238

[27] Triantafyllopoulos K, Bersimis S. Phase II control charts for autocorrelated processes. Quality Technology & Quantitative Management. 2016;**13**(1):88-108

[28] Psarakis S. Adaptive Control Charts: Recent Developments and Extensions. Wiley Online Library, Special Issue Article; 2015. pp. 1265-1280

[29] Naidenov A. Using SPSS for process quality control – A critical review, ICAICTSEE Conference Paper; 2013

[30] Jiang P, Liu D, Zeng Z. Recognizing control chart patterns with neural network and numerical fitting. Journal of Intelligent Manufacturing. 2009;**20**:625-635

[31] Chan LK, Cui HJ. Skewness correction X and R charts for skewed distributions. TOC. 2003;**50**(6):555-573

[32] Hachicha W, Ghorbel A. A Survey of control-chart pattern-recognition literature (1991-2010) based on a new conceptual classification scheme. Journal of Computers and Industrial Engineering. 2012;**63**(1):204-222

IntechOpen