A PROTOTYPE SOFTWARE TO SELECT AND CONSTRUCT CONTROL CHARTS FOR SHORT RUNS

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A PROTOTYPE SOFTWARE TO SELECT AND CONSTRUCT CONTROL CHARTS FOR SHORT RUNS

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ABSTRACT

A PROTOTYPE SOFTWARE TO SELECT AND CONSTRUCT CONTROL CHARTS FOR SHORT RUNS

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Small and Medium Sized Enterprises (SMEs) were founded to improve the activity and effectiveness of small industries, to provide economic and social needs of the country, to increase the competitive level of the country, and to establish integration in the industry. In today's competition conditions, SMEs should continuously improve themselves; otherwise, they could lose their market shares.

One of the major problems encountered in Turkish SMEs is poor quality activities; especially, not being able to exploit the Statistical Process Control (SPC) techniques. Production runs become shorter and shorter, and the product variety seems to be ever increasing, which cause short production runs. Using traditional control charts for short production runs can yield wrong and costly results. Instead of traditional control charts, short run charts such as Difference Charts (DNOM), Zed Charts, and Zed-Star Charts should be preferred.

For this purpose, software that not only constructs short run control charts but also implements charts by tests to solve the problems of SMEs is developed. A Control Chart Selection Wizard, which is capable of emulating human expertise in finding a suitable control chart according to the user response for different cases is developed and added as a subprogram.

Software was tested at Arçelik Dishwasher Plant in Ankara. The overall evaluation of the developed software, as regards the user, was satisfactory. The software can meet some requirements of the SMEs.

ÖZ

KISA SÜREÇLER İÇİN KONTROL DİAGRAMI SEÇEN VE OLUŞTURAN PROTOTİP BİR BİLGİSAYAR YAZILIMI GELİŞTİRİLMESİ

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Küçük ve Orta Büyüklükteki İşletmeler (KOBİ) küçük endüstrilerin etkinliğini ilerletebilmek, ülkenin ekonomik ve sosyal ihtiyaçlarını karşılayabilmek, ülkenin rekabet düzeyini yükseltebilmek ve endüstrideki entegrasyonu sağlayabilmek için kurulmuşlardır.Günümüzün rekabet koşullarında KOBİ'ler kendilerini sürekli geliştirmelidirler; aksi takdirde pazar paylarını kaybederler.

Türkiye'deki KOBİ'lerin karşılaştığı en önemli problemlerden biri düşük kaliteli uygulamalardır; özelliklede İstatistiksel Proses Kontrol (İPK) tekniklerinin yeteri kadar uygulanmamasıdır. Üretim süreçleri gün geçtikçe kısılmakta, üretim çeşitliliği gittikçe artarak kısa süreçli imalatlara neden olmaktadır. Kısa süreçli imalatlar için kullanılan geleneksel kontrol diagramları hatalı ve pahalı sonuçlara yol açabilir. Bunun yerine Fark Diagramları, Zed Diagramları, Zed-yıldız Diagramları gibi kısa süreçli diagramlar tercih edilmelidir.

Bu amaçla sadece kısa süreçli diagramları oluşturmakla kalmayan, bununla birlikte testleri uygulayarak KOBİ' nin sorunlarını çözmeyi hedefleyen bir yazılım oluşturulmuştur. Değişik vakalardaki kullanıcı cevaplarına göre, uygun kontrol diagramlarını bulabilmek için uzmandan daha iyi yetilere sahip Kontrol Diyagramları Seçme Sihirbazı geliştirilmiş ve alt program olarak eklenmiştir.

Yazılım Ankara'daki Arçelik Bulaşık Makinası Fabrikasında test edilmiştir. Geliştirilmiş yazılımın genel değerlendirilmesi kullanıcılara göre tatmin edicidir. Yazılım KOBİ'lerin bazı gereksinimlerini karşılayabilir.

Anahtar kelimeler: İstatistiksel Proses Kontrol, İPK, Kısa Süreç, Kısa Süreçli Kontrol Diyagramları.

To My Family

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LIST OF SYMBOLS AND/OR ABBREVIATIONS

A_2, A_3	Constants dependent upon sample size
B_3, B_4	Constants dependent upon sample size
C_p	Process capability index, a measure of spread
C_{pk}	Process capability index, a measure of position
d_2, d_4	Constants dependent upon sample size
D_3, D_4	Constants dependent upon sample size
LCL	Lower control limit of a control chart
LTL	Lower tolerance limit
m	Number of subgroups
n	Number of observed values in a sample or subgroup
$\overline{n}$	Average sample size
p	Proportion of non-conforming units in a sample
$\overline{p}$	Average proportion of non-conforming units in a series of samples (weighted by sample size)
R	Range of a set of numbers (difference of maximum and minimum)
$\overline{R}$	Average of several ranges
SMEs	Small and Medium Sized Enterprises
SPC	Statistical Process Control
TQM	Total Quality Management
u	Number of non-conformities per unit in a sample which may contain more than one unit
$\overline{u}$	Average number of non-conformities per unit in samples not necessarily of the same size
UCL	Upper control limit of a control chart
UTL	Upper tolerance limit

X	Observed value of some variable usually a quality characteristic. Specific values may be designated as X_i, X_2, ..., X_n
$\overline{X}$ (X-bar)	Arithmetic mean, average of set of values
$\overline{\overline{X}}$ (X-dbar)	Mean of several X-bar, often called a grand average
$\hat{\sigma}$	Estimated standard deviation
σ	Standard deviation of the population
μ	Arithmetic mean, the average of the population

CHAPTER 1

INTRODUCTION

1.1 Historical Background

The history of quality control is undoubtedly as old as industry itself. During the Middle Ages, quality was to a large extent controlled by the long periods of training required by the guilds. This training instilled pride in workers for the quality of a product.

The concept of specialization of labor was introduced during the Industrial Revolution. As a result, a worker no longer contributed the entire product, only to a portion. This change brought about a decline in workmanship. Since most products manufactured during that early period were not complicated, quality was not then greatly affected. In fact, because of improved productivity there was a decrease in cost, which resulted in lower customer expectations. As products became more complicated and jobs more specialized, it became necessary to inspect products after manufacture.

Frederick W. Taylor introduced some principles of scientific management as mass production industries began to develop prior to 1900. Taylor pioneered dividing work into tasks so that the product could be manufactured and assembled more easily. His work led to substantial improvements in productivity. Also, because of standardized production and assembly methods, the quality of manufactured goods was positively impacted as well. However, along with the standardization of work methods came the concept of work standards, which can be defined as standard time to accomplish the work, or a specified number of units that must be produced per period. Frank Gilbreth and others extended this concept to the study of motion and work design. Much of this had a positive impact on productivity, but it often de-emphasized the quality aspect of work. Furthermore, when carried to extremes, work standards had the risk of halting innovation and continuous improvement, which we recognize today as being a vital aspect of all work activities. [1]

In 1924, W. A. Shewhart of Bell Telephone Laboratories developed a statistical method for the control of product variables. This method which employed a chart is considered to be the beginning of statistical quality control. Later in the same decade, H. F. Dodge and H. G. Romig, both of Bell Telephone Laboratories, developed the area of acceptance sampling as a substitute for 100% inspection. [2]

The new technique was subsequently developed in various memoranda, articles, and lectures; and in 1931 Shewhart published a book on statistical quality control titled Economic Control of Quality of Manufactured Product [3]. This book set the subsequent applications of statistical process control.

World War Π saw a greatly expanded use and acceptance of statistical process control concepts in manufacturing industries. The eruption of the conflict in 1939 set the United States to think national defense and made way for enlargement of military personnel and material. The armed services began to enter the market as large consumers of American output and had an increasing influence on quality standards. One of the best known people working with the War Department was Dr. W. Edwards Deming. In 1938, Deming had persuaded Shewhart to give series of lectures at the graduate school of the United States Department of Agriculture. Deming later became one of the leading international quality consultants and the top Japanese individual and plant quality awards are called Deming awards. Until the end of World War Π many groups, and societies were formed for the improvement of the technology of quality

Wartime experience made it clear that statistical techniques were necessary to control and improve product quality. Recognition of the value of statistical quality control became apparent by 1942 and in 1944 Dr. Martin Brumbaugh got the idea of publishing a journal dedicated to scientific advances in quality control, which he called Industrial Quality Control.

Two years later, in 1946, The American Society for Quality was formed. This organization, through its publications, conferences, and training sessions, has promoted the use of quality control for all types of production and service. It offers a number of conferences, technical publications, and training programs in quality assurance. The 1950s and 1960s saw the emergence of reliability engineering, the introduction of several important textbooks on statistical quality control, and the viewpoint that quality is a way of managing the organization.

It is safe to say that a worldwide revolution is occurring that places the quality of goods and services at the focus of industrial activity. The revolution started in Japan after World War Π. Devastated by war, having little in the way of natural raw resources, owning a notorious reputation for poor quality of products, and being dependent for survival on its finished goods in a developing international marketplace, Japan chose the improvement of quality as its national goal for economic survival. It was a conscious policy mutually agreed on by the leaders of industry, government, academia, and finance, a union of national resources not yet seen in the Western world (United States, Canada, South America, and Western Europe).

As part of the postwar efforts of the United States to support rehabilitation and recovery in Japan, several U. S. experts were sent to help the Japanese change their attitudes about quality and management, learn new skills in manufacture, and acquire know-how in the application of statistical quality control methods. Among these experts were Dr. W. Edwards Deming, a lecturer on statistics and management, and Dr. Joseph M. Juran, a management consultant.

In 1950, W. Edwards Deming, who learned statistical quality control from Shewhart, gave a series of lectures on statistical methods to Japanese engineers and on quality responsibility to the CEOs of the largest organizations in Japan.

Joseph M. Juran made his first trip to Japan in 1954 and further emphasized management's responsibility to achieve quality. Using these concepts the Japanese set the quality standards for the rest of the world to follow.

In the same year, with the aim of improvement and simplicity to Shewhart's methods many attempts were made. A lot of literature has been published in the field and many variations of Shewhart's charts have been developed. The Cumulative Sum (CUSUM) and Exponentially Weighted Moving Average (EWMA) Charts are one of the popular ones. CUSUM chart was introduced by Page in 1954; it represented a fundamental change in the classical procedure by constructing control charts based on sums of observations rather than individual observations [4]. EWMA chart was first exposited by Roberts in 1959, which showed that EWMA is useful for detecting small shifts in the mean of a process [5].

In 1960, the first quality control circles were formed for the purpose of quality improvement. Simple statistical techniques were learned and applied by Japanese workers.

Now, more than a generation later, the world is noting the effects of Japan's dramatic industrial revolution. To say that Japanese products are a formidable force in the international marketplace today is to understate their impact on our lives.

By the late 1970s and early 1980s, U.S. managers were making frequent trips to Japan to learn about the Japanese miracle. These trips were not really necessary, they could have read the writings of Deming and Juran. Nevertheless, a quality renaissance began to occur in U.S. products and services. It became known nationally through a television program that the devastating effect of better Japanese products on the U.S. economy had as its driving force the use of statistical methods, American industrial leaders paid attention. The typically American response was to focus first on the specific technique that had a proven track record (statistical quality control), then later develop a comprehensive system needed to achieve the desired result (total quality management) and by the middle of 1980 the concepts of TQM were being publicized

In the late 1980s the automotive industry began to emphasize statistical process control (SPC). Suppliers and their suppliers were required to use these techniques. Other industries and the Department of Defense also implemented SPC. The Malcolm Baldrige National Quality Award was established and became the means to measure TQM. Genechi Taguchi introduced his concepts of parameter and tolerance design and brought about a resurgence of design of experiments (DOE) as a valuable quality improvement tool.

1.2 Scope of the Study

In short period of time, the manufacturing environment has undergone many significant changes since Dr. Walter Shewhart first developed control charts at Bell Labs (U.S.A.) back in 1923. For example, the increasing use of just-in-time (JIT) inventory systems demand small lot sizes with shorter production runs. This means more frequent machine changeovers or set-ups to accommodate many different part numbers (model number, color, etc.) with possibly different print specifications, all run across the same process. By their very nature, job shops have also had great difficulty in applying the powerful methods of statistical process control (SPC) to their processes because of limited lot sizes.

These short production runs cause problems when attempting to use the traditional Shewhart charts because there is never enough data to calculate control limits in a timely manner. Usually the run for a given part number is over before the limits can be calculated and drawn on the chart. This means the operator must wait until after the job is completed before he discovers whether the process was in or out of control.

The aim of this study was to examine control charts for variable data in short production runs that occur at job-shop manufacturing systems or SMEs. Instead of using traditional control charts, we can adapt control charts to short production runs. This adaptation would include; Difference Charts (DNOM), Zed Charts, Zed-Star Charts, and for sub grouped data; Difference Charts for sub grouped data, Zed-Bar Charts and lastly Zed-Bar-Star Chart.

For the purpose, a software was developed with Microsoft Visual Basic 6.0 that can construct short run control charts. The software has the ability of;

- Easy data input,
- Calculating plot points,
- Calculating centerlines, upper control limits, and lower control limits,
- Minimizing calculation errors,
- Estimating σ,
- Calculating process capabilities,
- Chart interpretation by using tests,
- Ability to take output of test results in to a Word Document
- Ability to take output of constructed chart in to a Excel Worksheet with calculated data,
- User friendly interface.

To store data Microsoft Access 2002 has employed. As a result, the users have the opportunity to use old data and reconstruct the control chart when needed.

The software has an advanced wizard system that could help the user to select the right control chart for a specific case. In response to the some questions and data input, the wizard could advice the proper control chart. The advanced wizard system was developed by using Expert System Builder 4.03 and could work with Visual Basic as a sub program.

The rest of the thesis is organized as follows;

- Chapter 2- SPC System and Basic Tools are explained, and statistical background is given.
- Chapter 3- SPC in Short Run, definition, where and when to use it, and data collection strategies are clarified,
- Chapter 4- Details of types of short run charts are explained and discussed,
- Chapter 5- Software developed for the proposed model is explained,
- Chapter 6- Results of the experimental verification of the proposed software, based on the data collected at Arçelik are presented,
- Chapter 7- Outcome of this work, related conclusions and extension of this work are discussed.

CHAPTER 2

SPC SYSTEM AND BASIC TOOLS

2.1 SPC System

2.1.1 Definition of Quality

The word "quality" is used by a lot of people in different contexts. In most companies it is recognized that quality of a service or a product is very important. However, it is very hard to make a perfect definition that discriminates products or services of bad quality from products or services of high quality. Various authors have attempted to formulate such a definition.

Shewhart argues that there are two aspects of quality. Firstly, there is an *objective* concept of quality, resulting in quantitatively measurable physical characteristics that are independent of a second, *subjective*, aspect of quality. The latter has to do with what we think, feel or sense. Shewhart recognizes that the subjective side of quality is commercially interesting, but that it is necessary to establish standards of quality in a quantitative (objective) manner. Deming [10] also stresses the subjective side of quality: "*Quality can be defined only in terms of the agent"*. Furthermore, he emphasizes that impressions of quality are not static. They change over time. This creates problems in defining quality, since it is difficult to translate future needs of the user into measurable characteristics.

In a case Crosby defines quality as "conformance to requirements" [19]. In this view, a product is of good quality if it meets its specifications. This definition encloses an important part of what customers perceive as "quality". A manufacturer will most certainly receive a lot of quality complaints if a large part of his production exceeds tolerances that were agreed upon with the customers. On the other hand, this definition is too narrow. For example, the specifications themselves are part of what is perceived as “quality”. A product that is produced in conformance with specifications that are not popular with customers will not be ranked as a high quality product.

In Juran and Gryna, a broader definition is given: “quality is fitness for use”. In this view, “quality" is defined as a relative notion. Different usages of the product will result in different requirements with regard to the product. For example, the requirements of a person looking for high quality jogging shoes will differ from the requirements of the same person looking for high quality elegant shoes. [6]

Montgomery considers “conformance to requirements” as one of two aspects of “fitness for use”. The other aspect is “quality of design”, which emphasizes the intentional design differences between types of a product. The conformance aspect is how well the product conforms to the specifications required by the design. [1]

Nowadays, these definitions of “quality” are labeled as traditional. It is recognized that the quality of a product or a service is not a single, identifiable characteristic. Garvin [7] distinguishes the following eight dimensions of quality, which, when taken together, incorporate more aspects than the traditional definitions of quality.

1. *Performance* is one of the traditional measures of quality. It refers to the basic functioning of a product. For example, for an automobile, performance would include acceleration, handling, cruising speed, and comfort;
2. *Features* that are added to the basic functioning of a product attribute to a higher quality;
3. *Reliability* is another traditional measure of quality. A reliable product rarely fails. This aspect, which is sometimes reformulated as being free of deficiencies, is a very important dimension of quality;

4. *Conformance* is related to reliability. It refers to the degree to which a product meets reestablished requirements. This dimension of quality is very important in situations where products are used as the components in a more complex assembly. Specifications on the individual components are usually expressed as a target and a tolerance. If each of the components is just slightly too big or too small, a tight fit is unlikely, and the final product may not perform as intended by the designer, or may wear out early;
5. *Durability* is a measure of product life, either economically (expected cost of repair exceeds current product value) or physically (repair is impossible). A product that lasts longer is usually viewed as being of higher quality;
6. *Serviceability* relates to the time and effort that is needed to repair a product. The breaking down of a product is usually viewed as an annoyance, but a prompt repair may relieve part of the irritation;
7. *Aesthetics* is a subjective dimension of quality. It refers to the look, feel, sound, taste or smell of a product. It is greatly influenced by the preferences of the individual customer. On this dimension of quality it is usually not possible to meet the needs of every customer;
8. *Perceived quality* is also a very subjective dimension. When customers do not have full information about a product they may base their quality image on past experiences, the reputation of the manufacturer, the quality of other products from the same manufacturer, or the name of the product.

Realizing that quality is not a one-dimensional characteristic of a product and that quality is determined at various levels in the production process. Garvin stresses that manufacturers should not strive to be first on all eight dimensions of quality. Rather, he should select a number of dimensions on which to compete.

Traditionally, the quality control departments in factories compete with regard to the conformance dimension of quality. It is their responsibility to ensure that requirements set on a quality characteristic are met. Such requirements are usually stated in the form of specification limits. All parts within limits are classified as conforming. The objective then is to produce zero defects. Sullivan argued that this conformance to specification limits approach effectively prevents ongoing quality improvement. As long as all outcomes of a production process are within specification limits, a process engineer would have great difficulty in convincing his plant manager to make any investment for the improvement of quality. Sullivan advocates defining quality as "*uniformity around the target*" [29]. In this more modern point of view, which was put forward by, among others, Deming and Taguchi, any deviation from target reduces reliability and increases costs, in the form of plant and customer loss. Operational objectives directed towards achieving ongoing quality improvement should not be stated in terms of specification limits such as zero defects. The attention for quality improvement will reduce as soon as the manufacturing process is able to produce sufficiently within specifications. A more continuous drive for ongoing quality improvement will be obtained if the aim is to reduce variation around the target.

This relation between "quality" and "variation" is summarized in the following phrase which can be found in Montgomery: [1]

"*Quality is inversely proportional to variability*".

This statement demonstrates the contribution of statistical methods to quality improvement projects. By acknowledging that variation is present in process outcomes, and that they are to some extent uncertain, it becomes necessary to employ methods which take uncertainty explicitly into account.

2.1.2 SPC System

Statistical methods play a vital role in the quality improvement process in manufacturing and service industries. Incapable and inconsistent processes make the best designs weak and make supplier quality assurance irrelevant.

Whatever process is being operated, it must be reliable and consistent. SPC can be used to achieve this objective. Therefore if a product is to meet customer requirements, generally it should be produced by a process that is stable or repeatable. More precisely, the process must be capable of operating with little variability around the target or nominal dimensions of the product's quality characteristics. Montgomery defines Statistical process control as;

"A powerful collection of problem solving tools useful achieving process stability and improving capability through the reduction of variability [1]."

SPC is a strategy for reducing variability, the cause of most quality problems; variation in products, in times of deliveries, in materials, in equipment and its use, in maintenance practices, in everything. Control by it self is not sufficient. Total Quality Management, like SPC, requires that the process should be improved continually by reducing its variability. Oakland J.S. and Follewell R.F. attach importance to this situation as asking a basic question;

"Could we do the job more consistently and on target (i.e. better)?" [8]

In the application of SPC there is often an emphasis on techniques rather than on the implied wider managerial strategies. SPC is not about plotting charts and pinning them to the walls of a plant or office; it must be a component part of a company wide adoption of total quality and act as the focal point of never ending improvement. Changing an organization's environment into one in which SPC can operate properly may take several years rather than months. For many companies SPC will bring a new approach, a new philosophy, but the importance of the statistical techniques should not be disguised. Simple presentation of data using diagrams, graphs and charts should become the means of communication concerning the state of control of processes.

A quality management system, based on the fact that many functions will share the responsibility for any particular process, provides an effective method of acquiring and maintaining desired quality standards. The Quality Department should not assume direct responsibility for quality but should support, advise and audit the work of the other functions, in much the same way as a financial auditor performs his duty without assuming responsibility for the profitability of the company.

In his book, *Right First Time*, Frank Price gives a systematic study of a process framework for thinking about quality in manufacturing through answering the questions: [9]

"Can we make it OK?" (Capability)
"Are we making it OK?" (Control)
"Have we made it OK?" (Quality Assurance)
"Could we make it better?" (Continuous Improvement)

According to Price, answers provide knowledge of the process capability and the sources of non conforming outputs. This information can then be fed back quickly to marketing, design, and the technology functions. Knowledge of the current state of a process also enables a more balanced judgment of equipment, both with regard to the tasks within its capability and its rational utilization.

If variability is great, it may be impossible to predict the value of a characteristic of any single item or at any point in time. Using statistical methods, however, it is possible to take full knowledge of the output and turn it into meaningful statements which may then be used to describe the process itself. Hence, statistically based process control procedures are designed to divert attention from individual pieces of data and focus it on the process as a whole. SPC techniques may be used to measure and control the degree of variation of any purchased materials, services, processes, and products and to compare this, if required, to previously agreed specifications. [8]

2.1.3 A Process In Control, Definition of Special and Common Causes

Quality improvement can be obtained by reduction of variability. The approach towards reduction of variability is based on the idea that the phenomena causing variation in process outcomes can be classified in two groups: *common causes of variation* and *special causes of variation*.

In all aspects of our lives, there is some variation that is considered to be normal or acceptable, and does not call for action. The underlying sources that are responsible for this type of variation were originally called *chance causes of variation* by Shewhart. Nowadays, the term *common causes* is used, a reformulation that is due to Deming.

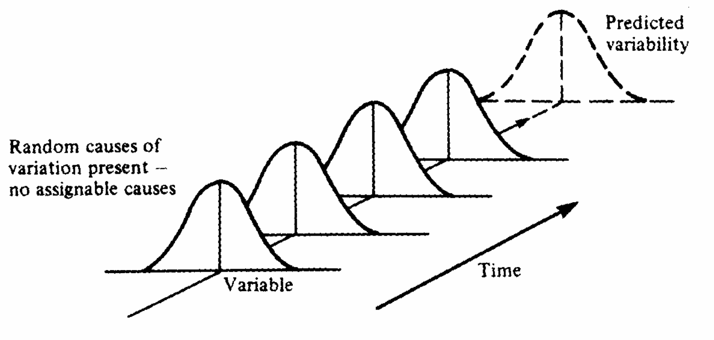
If the observed variability is such that it exceeds the boundaries of normal variation we are inclined to undertake action. The presence of something out of the ordinary, not within the class of common causes, is suspected. Such causes of variation belong to the class of *special causes* (in Shewhart's terminology: *assignable causes*).

In a manufacturing environment, it is in most cases, not difficult to visualize a large number of common causes, which causes variation in the outcomes. This variation is inherently part of the process, and is always present, from day to day, from hour to hour. Usually, it is not within the power of an operator to remove common causes of variation, such variation is left to chance. If it is necessary to remove common causes of variation, this requires in most cases a profound revision of the process, which is the responsibility of the owner of the process for example management.

Special causes of variation are not part of the process, and occur only accidentally. However, when a special cause of variation is present, it will have a large effect on the outcomes of the manufacturing process. If removal is possible, a special cause can usually be eliminated without revising the process. In many cases, an operator can be instructed to recognize and remove special causes of variation, thereby improving the quality of the outcomes of the process.

It is important to realize that the responsibility for reducing the effect of special causes of variation lies on a different management level than the reduction of common causes of variation. Eliminating the effect of special causes of variation can be delegated to operators, whereas reducing the effect of common causes of variation is the responsibility of the owner of the process. It is important for an operator to know whether or not special causes are present, so that he can undertake action to remove this cause of variation. But it is even more important to know when to leave the process alone when only common causes of variation are affecting the outcomes.

What happens in practice is that operators try to counteract the effect of common causes of variation as if it was a special cause of variation. In many cases, this will result in larger variation in the outcomes. This phenomenon of intervening in a stable process when it would have been better to do nothing is called *tamperin*g. It results in dissatisfaction, because of unsuccessful searches for special causes of variation, and in waste of time and money.



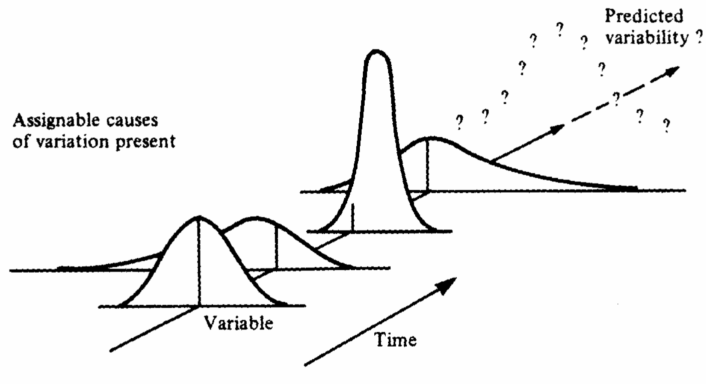


Figure 2.1: Random and Assignable causes of variation. (a) If only random causes of variation are present, the output from a process forms a distribution that is stable over time and is, therefore, predictable. (b) Conversely, if assignable causes of variation are present, the process output is not stable over time and is not predictable. [8]

It is therefore of critical importance to be able to distinguish situations where only common causes of variation affect the outcomes of a process, from situations where also special causes are present. If only common causes of variation are present, the manufacturing process is said to be statistically in control. This does not mean that there is no variation, or that there is small variation. It does mean that the outcomes are predictable, within statistical limits (see Figure 2.1)

2.1.4 Benefits of Control Charts

Control charts are one of the most important management control tools. They are important as cost controls and material controls. Modern computer technology has made it easy to implement control charts in any type of process, as data collection and analysis can be performed on a microcomputer or a local area network terminal in real time, online at the work center. Additional benefits of control chart can be listed as;

1. Control charts are proven technique for improving productivity. A successful control chart program will reduce scrap and rework, which are the primary productivity killers in any operation. If companies reduce scrap and rework, then productivity increases, cost decreases, and production capacity increases.

2. Control charts are effective in defect prevention. The control chart helps keep the process in control, which is consistent with the do it right the first time philosophy. It is never cheaper to sort out good units from bad units later on than it is to build it right initially.

3. Control charts prevent unnecessary process adjustment. A control chart can distinguish between background noise and abnormal variation. No other device including a human operator is as effective in making this distinction. If process control operators adjust the process based on periodic tests unrelated to a control chart program, they will often overreact to the background noise and make unneeded adjustments. These unnecessary adjustments can actually result in a deterioration of process performance.

4. Control chart provide diagnostic information. Frequently, the pattern points on the control chart will contain information of diagnostic value to

experienced operator or engineer. This information allows the implementation of a change in the process that improves its performance.

5. Control charts provide information about process capability. The control chart provides information about the value of important process parameters and their stability over time. This allows an estimate of process capability to be made. This information is of tremendous use to product and process designers.

In chapter 3, the advantages and disadvantages of specific control chart was discussed.

2.2 Normality Analysis

2.2.1 Population And Sample

A universe also called a population is a collection of all possible values. On the other hand, sample, is a subset of objects taken from the population. The purpose of sampling is to gain knowledge about the characteristics of the population from the information contained in a sample. If the sample is measured and used correctly, and if it is large enough, its average will almost always be close to the population average.

The concept of randomness is important in this situation. Randomness means that all members of the population have an equal chance of being chosen for the sample. Control charts use procedures that ensure this randomness. In statistical manner of speaking, a random sample is said to be nonbiased, while a nonrandom sample is said to be biased. Biased samples cannot be effectively used in normal curve calculations.

Characteristics of the population are called parameters while characteristics of samples are called statistics. All processes are populations, so process characteristics are parameters (that is why process characteristics are referred to as process parameters). Symbols are used to represent the more important characteristics. The population mean is called μ and the population standard deviation is called σ (the lower case Greek letter sigma). A sample mean, on the other hand, is called $\overline{X}$ (or X bar) and a sample standard deviation is called s. N is the number of items in the population where n is the number of items in the sample. During this thesis study these symbols were preferred.

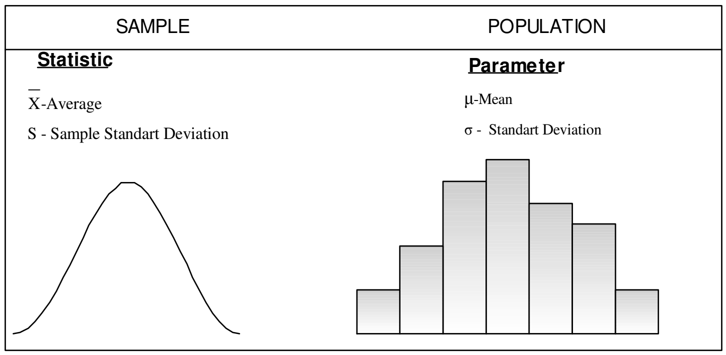


Figure2.2 Comparison of Sample and Population [2]

2.2.2 Central Tendency And Dispersion

The central tendency refers to the tendency of all measurements of the same characteristic to be the same, to be close to the center. Sometimes this tendency is strong with the values close to the center, while at other times this tendency is weak with the values far from the center. The mean, or arithmetic average, is the most important central tendency for statistics although there are others.

Dispersion refers to the tendency to be different. When this tendency is strong, the measurements are far from the center. When this tendency is weak, the measurements grouped about the central value. Obviously, these two measures (central tendency and dispersion) are opposite of each other. There are two main dispersion values the range and the standard deviation. Another measure of the dispersion, the variance, is just the square of the standard deviation.

When the distributions are normal, strong central tendencies and weak dispersions are characterized by high, peaked curves (and called leptokurtic). Weak central tendencies and strong dispersions are characterized by low, flat curves (and called platykurtic). Kurtic is a measure of peakedness.

2.2.3 Mean

The mean, or arithmetic average, is a central tendency. It is the average of all values, and is represented mathematically by the formulas given below;

<u>Population Mean</u>

$$\bar{\mu} = \frac{1}{N}\sum_{i=1}^{N} X_i \tag{2.1}$$

<u>Sample Mean</u>

$$\bar{X} = \frac{1}{n}\sum_{i=1}^{n} X_i \tag{2.2}$$

Where X_i values are the observations in the sample or in the population.

There are other central tendency values, but the mean is the most preferred one used in control charts. The other central values are rarely used.

2.2.4 The Range

The Range is a dispersion measurement, and it is defined as the distance from the smallest to the largest value. The formulation is,

<u>The Range</u>

$$R = H\text{-}L = X_H - X_L \tag{2.3}$$

Where R is the range, H is the high Value, L is the low value, and X is a measurement.

$\overline{R}$ represents the average range and calculated by,

The Average Range

$$\overline{R}=\sum\frac{R}{k} \quad \textit{Where k is the number of ranges} \tag{2.4}$$

2.2.5 The Standard Deviation

The variability in the sample data is measured by the sample variance. Sample variance is simply the sum of the squared deviations of each observation from the sample average $\overline{X}$, divided sample size mines one. If there is no variability in the sample then $S^2 = 0$. Generally the larger is the sample variance S^2, the greater is the variability in the data.

Sample Variance

$$S^2 = \frac{\sum_{i=1}^{n}(X_i-\overline{X})^2}{n-1} \tag{2.5}$$

This is often inconvenient and awkward to interpret, and so it is usually preferred to use the square root of the S^2, called sample standard deviation S, as a measure of variability.

The standard deviation is another important dispersion measure, and also can be defined as the average distance from the mean.

Population Standard Deviation

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N}(X_i-\mu)^2}{N}} \tag{2.6}$$

Sample Standard Deviation

$$S = \sqrt{\frac{\sum_{i=1}^{n}(X_i-\overline{X})^2}{n-1}} \qquad (2.7)$$

The standard deviation gives an accurate measure of spread, and it is difficult to calculate. Therefore in order to have some ease in calculations especially while in constructing control charts estimated standard deviation can be used.

Estimated standard deviation

$$\hat{\sigma}=\frac{\overline{R}}{d_2} \qquad (2.8)$$

$$\hat{\sigma}=\frac{\overline{s}}{c_4} \qquad (2.9)$$

Where d_2 and c_4 are constant factors depend to sample size n and given in the Appendix B. Generally equation (2.8) is preferable because of its simplicity.

2.2.6 Normal Distribution

One type of population that is quite common is called the normal curve, or Gaussian distribution. The normal curve is a symmetrical, unimodal, bell-shaped distribution with the mean, median, and mode having the same value. Symmetrical means that when the curve is folded along its center, the left side will exactly match the right side, the two forms (left and right side forms) will be the same, and one will exactly cover the other.

The normal distribution is used so much that we frequently employ a special notation, $X \sim N(\mu, \sigma^2)$, to imply that X is normally distributed with the mean μ and variance σ^2. The formula for normal distribution is defined as follows;

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2} \qquad -\infty < X < \infty \qquad (2.10)$$

Where the mean of the normal distribution is μ ($-\infty<\mu<\infty$) and, the variance is $\sigma^2>0$.

A population curve or distribution is developed from a frequency histogram. As the sample size of a histogram gets larger and larger, the cell interval gets smaller and smaller. When the sample size is quite large and the cell interval is very small, the histogram will take on the appearance of a smooth polygon or a curve representing the population.

The actual measurements are placed along the bottom or X-axis of a Cartesian coordinate system. The amount of each measurement (the number of times that particular measurement occurs) is measured by the height of the curve at that point (the Y-axis of a Cartesian coordinate graph). A normal curve can be thought of as representing a process and the area under the curve can be thought of as containing 100% of all items produced on that process. The area below a particular number, or above a particular number, can be thought of as a percent of items that measure above or below that particular value. In this way, the curve also represents probability, the probability that any one item will measure below, or above, a particular value.

Normal curves can be tall and narrow or low and flat, depending on the standard deviation (see Figure 2.4). There can be an infinite number of normal curves with the same shape but different centers (see Figure 2.3), and there can be an infinite number of normal curves with the same center but different shapes (see Figure 2.4).

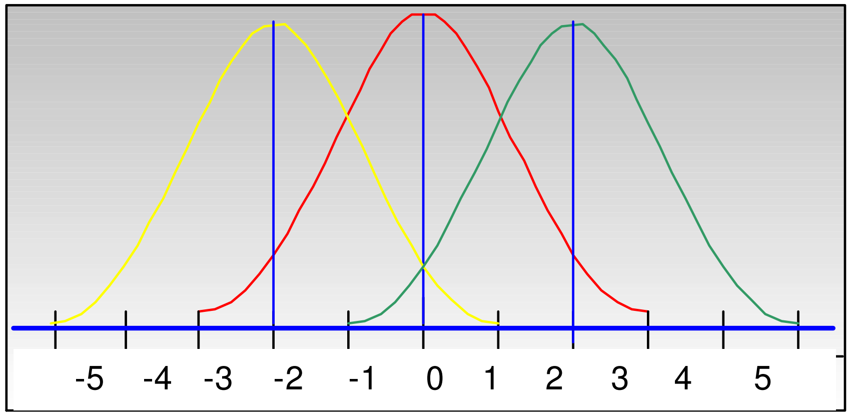


Figure 2.3: Normal curves with identical standard deviations but different means. [11]

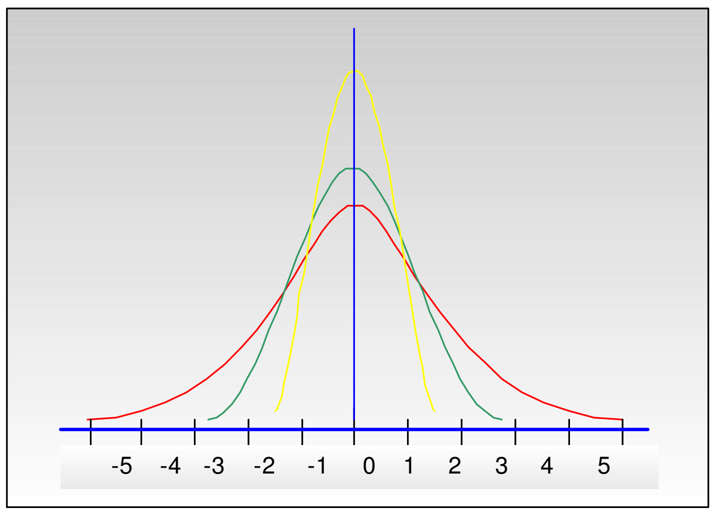


Figure 2.4: Normal curves with identical means but different standard deviations.

If a curve is not normal, it is usually skewed (having one tail longer than the other). Curves are considered to be positively skewed when the long tail is to the right, and negatively skewed when the long tail is to the left.

All normal distributions of continuous variables can be converted to the standardized normal distribution by using the standardized normal value, Z. It can be found by the formula;

$$Z = \frac{x - \mu}{\sigma} \tag{2.11}$$

Where Z is the number of standard deviations,

X_i is a specification, μ is the mean of the population distribution,

And σ (sigma) is the population standard deviation.

What this formula really does is to transform the process normal curve into a standard normal curve with the mean equal to zero and the standard deviation equal to one. The formula for the standardized normal curve is given below (see figure 2.5)

$$f(Z) = 0.3989 e^{-Z^2} 2 \tag{2.12}$$

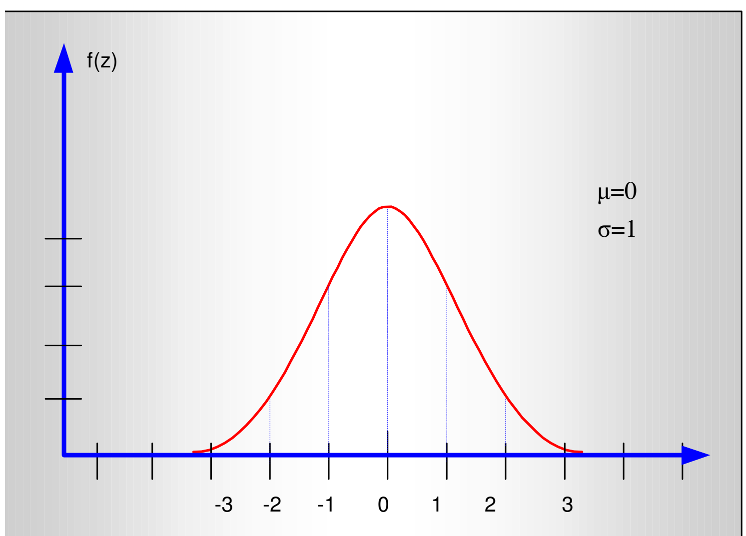


Figure 2.5: Standardized normal distribution with, X~N (0, 1) [2]

The percentage of items included between any two values can be determined by calculus. However, this is not necessary, since the areas under the curve for various Z values are given in Appendix C. Areas under the normal curve, is a left-reading table, which means that the given areas are for that portion of the curve from -∞ to a particular value, X_i.

All normal curves have the same percent of area when compared to the number of standard deviations (the Z score). For instance, the percent of area between ±1 standard deviations is always 68.26%. Between ±2 standard deviations, it is always 95.46%, and between ±3 standard deviations it is always about 99.73% (see Figure 2.6). These percentages are also shown as ratios (0.6826, 0.9546, and 0.9973) in the Appendix C.

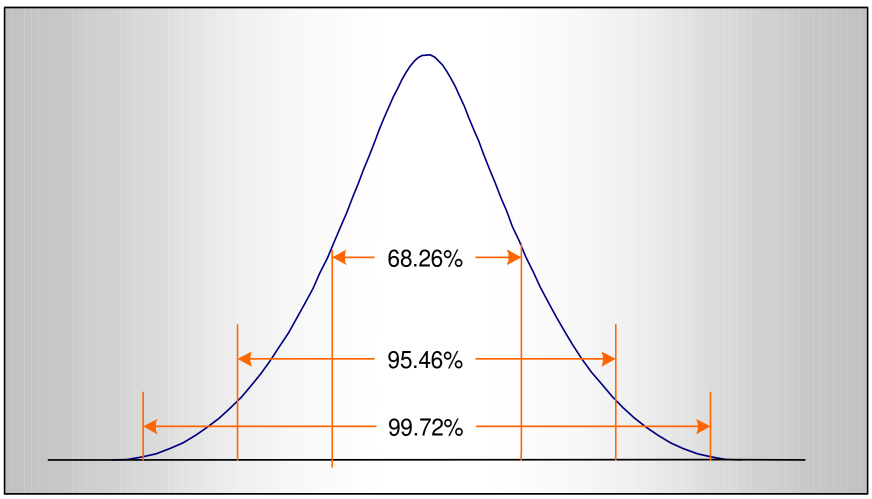


Figure 2.6: Percentage of items between 1, 2 and 3 standard deviations from the mean. [11]

2.2.7 Control Charts And The Normal Curve

The normal curve forms the theoretical foundation for all control charts. Variables charts use the normal curve direct, while attributes charts use the normal approximation to the binomial (p charts) and the normal approximation to the Poisson (u and c charts). However, all control charts use the normal curve theory.

Control charts are, essentially, just upended normal curves with the mean and ±3 standard deviation lines. The centerline of the control chart closely approximates the mean of the normal, and the upper and lower limit lines of the control chart closely approximate the ±3 standard deviations of the normal. This is shown in Figure 2.8 (although the curve itself is never shown on the chart). If the mean and limits have been properly determined, and if the process is in control, then 99.73% of all items produced will fall within these limits. Since there is such a small probability (0.27%) that an in-control process will produce product outside the limits, it is assumed that product measuring outside the limits has been caused by a process problem. Therefore, a search is started to find the cause, and to correct it.

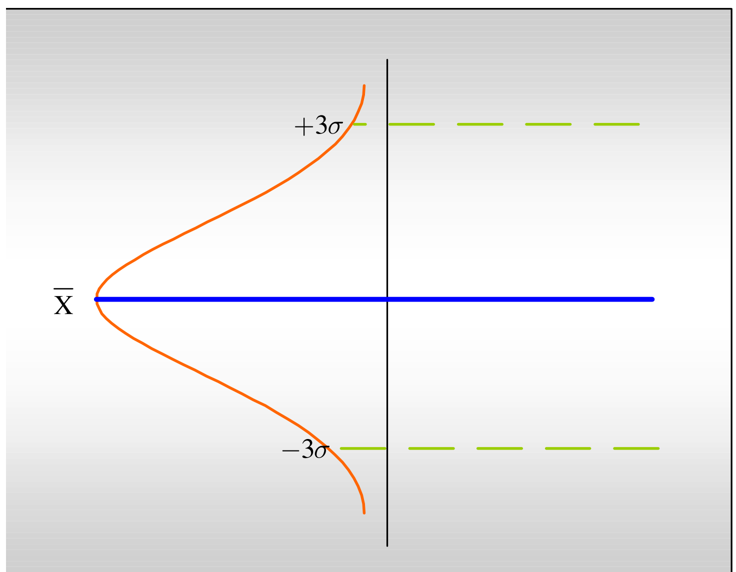


Figure 2.7 Curve illustrating the normal curve relationship to quality control charts. [11]

It is important, however, that the data plotted onto the control chart be normally distributed. Control charts (except the individuals chart) ensure this by the way the data is collected, by the way the data is plotted, and by the way the central value and chart limits are calculated.

However, the limit lines on the control chart are not specification limits. In fact, the control chart has nothing to do with specifications. It just shows what the process is capable of. Even if the specifications fall inside the control chart limits, bad parts can still be produced. Therefore, the specification limits must be compared with the control chart limits to see what the process can do with that product.

2.3 Basic Tools of SPC

SPC builds an environment in which all individuals in an organization desire continuous improvement in quality and productivity. This environment is best developed when management becomes involved in an on going quality improvement process. Once this environment is established, routine application of some quality tools becomes part of the usual manner of doing business, and the organization is well on its way to achieving its quality-improvement objectives.

In addition to the basic elements of a quality system, which will provide a framework for recording data, there exists a set of tools which may also be applied to interpret fully and derive maximum use of the data. The simple methods listed below will offer any organization means of collecting, presenting, and analyzing most of its data;

- Check Sheets
- Histograms or steam and leaf display
- Pareto Chart
- Cause and Effect Diagrams
- Defect Concentration Diagrams
- Scatter diagram
- Control chart

2.4 Control Chart Theory

A *variable* refers to a continuous characteristic like length, width, temperature, hardness, errors per page, etc., while an *attribute* is a discrete characteristic (number of items not in conformance to specifications). In quality control, variables are measured and attributes are counted. It is the actual measurements (actually, averages of subgroups of these measurements), or some coded variation of them that are plotted on the variables charts. In attributes charts, it is the average number of nonconformances, or nonconforming items, that are charted (in manufacturing, a nonconformance is called a defect while a nonconforming item is called a defective).

A control chart is a graphical display of a measure of a quality characteristic such as weight, length, temperature, waiting time, typing errors, etc. over time. The measurement of the characteristic is plotted on the vertical axis, with the sample number (also called subgroup or sub-sample) on the horizontal axis. Samples should be plotted as they are taken so that the plot shows progression, patterns, etc., over time. In this way, the operators, and any others that are involved, receive information about problems as they occur.

All control charts have a midpoint (or centerline) which corresponds to the process average and an upper and lower limit which correspond to ± three standard deviations ($\pm 3\sigma$) from this midpoint. Generally the central value is usually plotted as a horizontal solid line, and upper and lower control limits as horizontal dotted lines.

2.4.1 Traditional Attribute Charts and Their Usage

Three well-known, traditional control charts are;

- Individual X and Moving Range Chart
- X and Range Chart

- X and s Chart

These charts are the ones with which most of SPC users have preferred. They are also the backbone of all other control charts that was discussed during this thesis study. Traditional charts are most appropriately used in situations where the production runs are long and rarely changing, data are plentiful and inexpensive to gather, and there is only one characteristic to be evaluated. Traditional control charts were developed to be applied under these specific circumstances.

For each of the three traditional control charts, only one item defines their difference, subgroup size n. If the control chart user wishes to place a dot on the chart each time a measurement is taken, the individual X and moving range chart is appropriate. If user defines the subgroup size to be greater than one but less than ten, the $\overline{X}$ and range chart would be used. If enormous amounts of inexpensive data are gathered, proper subgroup size is ten or larger, and the $\overline{X}$ and s chart would be the chart to use.

Once the type of control chart is selected, the user generates a control chart for each quality characteristic. For example, if two different characteristics were of interest, the outside and inside diameters, the user would construct two separate charts for both characteristics.

After the subgroup size is defined and a control chart has been selected, one difficult issue is the management of the charts. In managing control charts, SPC users will be interested in identifying assignable causes and either eliminating them or add in them into the process. This is what is meant by process control, searching out reasons for changes in process performance and reacting to those changes. Control charts are a means for controlling the predictability and performance of characteristics from a process.

Process control using a control chart has two different stages;

- Establishing baseline data
- Control limits and maintaining the control chart.

For establishing baseline data and control limits firstly it is necessary to identify an appropriate control chart to use, define the subgroup size, and begin to gather data. Once 25 or more subgroups have been gathered, control limits can be calculated. If the chart shows a lack of control, then user should solve the problem, by identifying and then eliminating the assignable causes in the process. Once assignable causes have been eliminated, the revised control chart should be in control. This chart should then serve as the process' baseline.

The second step in using a control chart is to maintain it. After the baseline has been established, the chart user should take the baseline control limits and extend them into the future.

Extending control limits into the future allows one to judge subsequent data against the established baseline. For example new data added to the chart and a significant change occurred in the data, it will show up as au out of control signal. The next step would be for the chart user to identify the cause. In this situation it is important to understand that if the cause appeared is a common or special. If it is believed that cause appeared is a special (the try to counteract the effect of common causes of variation as if it was a special cause of variation is detailed discussed in section 2.1.3), than the chart user is not only to identify process problems, but also opportunities associated with this case by looking around and asking questions, shortly starts an investigation.

After the problem is solved, the chart user is now faced with the problem that the old baseline control limits are just old. They do not represent the current operation of the process. The control limits that have been extended into the future are no longer reflective of the current process performance, therefore new control limits should be calculated for the process.

Recalculation of control limits can be confusing when maintaining control charts. When to recalculate and when not to recalculate control limits is not always very clear. In his book, Understanding Statistical Process Control, Donald J. Wheeler writes;

"The revision of control limits should be considered only when there is reason to suspect that the current limits are not appropriate, the obvious time to consider a revision of the control limits is when the process has been changed." In other words, recalculating control limits should be done only when the current limits do not accurately reflect the present operation of the process.

Generally, control limit recalculation should be considered when all four of the following items are found to be true. [28]

1. The process has changed. (Indications of assignable causes, especially a shift, are present.)
2. The cause of the process change is known.
3. The process change is expected to continue.
4. There are enough data to recalculate (25 or more plot points).

The new control limits become the new baseline. Maintenance of the control chart should continue. Not only has a new baseline been established, but the old and new data can be used as proof of process improvement activities. The chart can be used as reinforcement to operators, managers, and engineers alike that hardware changes that have been implemented resulted in significant improvements to the process.

2.4.1.1 Individual X and Moving Range Chart

2.4.1.1.1 Description

The individual X chart, also called the IX, is used to monitor and detect changes in the process mean by evaluating the consistency of individual measurements of a single characteristic. Because the plot points represent individual measurements, the subgroup size is one. IX & MR charts are intended to be used to monitor characteristics where only one measurement can represent the process at a given period of time.

The moving range chart (also called an MR chart) is used to monitor and detect changes in the standard deviation of individual measurements from a process. The plot points represent the absolute difference between two consecutive individual measurements. Although not the same as standard deviation, the MR values can be used to estimate the process standard deviation.

2.4.1.1.2 Subgroup Size

For IX & MR chart subgroup size is constant and accepted as n=1. For each chart only one characteristic is observed therefore only one unit of measure is used. The measurements are assumed as normally distributed.

2.4.1.1.3 Calculating Plot Points

The moving range is calculated from two consecutive IX plot points by taking absolute difference, and each measurement are accepted as IX plot points.

$$\text{IX Plot Point} = X_i \tag{2.13}$$

$$\text{MR Plot Point} = \left| (\text{IX Plot Point})_i - (\text{IX Plot Point})_{i-1} \right| \tag{2.14}$$

2.4.1.1.4 Calculating Centerlines (CL)

For moving range chart and individual X chart, centerline is calculated as finding arithmetic average of MR plot points and IX plot points.

MR Chart Center line;

$$\overline{MR}=\frac{\sum_{i=2}^{k} MR_i}{k-1} \tag{2.15}$$

IX Chart Center line;

$$\overline{CL_{IX}}=\frac{\sum_{i=1}^{k} (\text{IX PlotPoint})_i}{k} \tag{2.16}$$

2.4.1.1.5 Calculating Control Limits

Control limits can be calculated as given in the below;

MR Chart Control Limits;

$$UCL_{MR}=D_4\times\overline{MR} \tag{2.17}$$

$$LCL_{MR}=D_3\times\overline{MR} \tag{2.18}$$

IX Chart Control Limits;

$$UCL_{IX}=CL_{IX}+A_2\times\overline{MR} \tag{2.19}$$

$$LCL_{IX}=CL_{IX}-A_2\times\overline{MR} \tag{2.20}$$

When the known constants A_2, D_4, and D_3 for subgroup size one is used, the formulations will be;

MR Chart Control Limits;

$$UCL_{MR} = 3.267\overline{MR} \tag{2.21}$$

$$LCL_{MR} = 0 \tag{2.22}$$

IX Chart Control Limits;

$$UCL_{IX} = CL_{IX} + 2.66\overline{MR} \tag{2.23}$$

$$LCL_{IX} = CL_{IX} - 2.66\overline{MR} \tag{2.24}$$

2.4.1.1.6 Advantages and Disadvantages

Advantages of IX and MR Chart are;

- Easy to understand.
- Only 25 or more individual measurements are necessary to estimate control limits.
- Minimal calculations are enough to construct the chart.

IX—MR Chart Disadvantages;

- Does not independently separate variation in the average from variation in the standard deviation.
- The histogram of the individual measurements must be approximately normal for the control limits to accurately represent $\pm 3\sigma$ limits.
- Not sensitive enough to quickly identify small changes in the process average or standard deviation.

2.4.1.2 X and Range Chart

2.4.1.2.1 Description

The chart is used to monitor and detect changes in the average of a single measured characteristic. The plot points represent subgroup averages. The subgroup size may range from two to nine, but users generally use subgroup sizes of three or five.

The range chart, also called R chart, is used to monitor and detect changes in the standard deviation of a single measured characteristic. The plot points represent subgroup ranges. Ranges are not the same as standard deviation, but when subgroup sizes are small for example less than ten ranges can be used to closely estimate within subgroup standard deviation.

2.4.1.2.2 Subgroup Size

Independent measurements are used to obtain subgroup size. For each chart sample size is constant and range from two to ten. Only one unit of measure is used.

2.4.1.2.3 Calculating Plot Points

For calculating $\overline{X}$ plot points, each subgroup average must be calculated, the result is denoted as $\overline{X}_i$.

$$\overline{X}_i = \frac{\sum_{i=1}^{n} X_i}{n} \tag{2.25}$$

Range of each subgroup can be found as the taking the difference between the largest and the smallest observations.

$$\text{R Plot Point} = \left| X_{max} - X_{min} \right| \tag{2.26}$$

2.4.1.2.4 Calculating Centerlines (CL)

To find centerline of range chart, user should calculate the average range and to find centerline of $\overline{\mathrm{X}}$ chart, it is necessary to calculate the average of $\overline{\mathrm{X}}$ plot points.

R Chart Center line;

$$\overline{R} = \frac{\sum_{i=1}^{k} R_i}{k} \tag{2.27}$$

X Chart Center line;

$$\mathrm{CL_X} = \frac{\sum_{i=1}^{k} (\mathrm{X\ PlotPoint})_i}{k} \tag{2.28}$$

2.4.1.2.5 Calculating Control Limits

The formulas for control limits are given below;

R Chart Control Limits;

$$\mathrm{UCL_R} = \mathrm{D_4} \times \overline{\mathrm{R}} \tag{2.29}$$

$$\mathrm{LCL_R} = \mathrm{D_3} \times \overline{\mathrm{R}} \tag{2.30}$$

X Chart Control Limits

$$\mathrm{UCL_X} = \mathrm{CL_X} + \mathrm{A_2} \times \overline{\mathrm{R}} \tag{2.31}$$

$$\mathrm{LCL_X} = \mathrm{CL_X} - \mathrm{A_2} \times \overline{\mathrm{R}} \tag{2.32}$$

2.4.1.2.6 Advantages and Disadvantages

$\overline{\mathrm{X}}$ and Range Chart Advantages are;

- Separates variation in the average from variation in the standard deviation.
- $\overline{\mathrm{X}}$ & R charts are the most widely recognized control charts.
- $\overline{\mathrm{X}}$ & R chart principles are used as the foundation for more advanced control charts.

$\overline{X}$ and Range Chart Disadvantages are;

- It is needed a separate $\overline{X}$ & R chart for each characteristic on each part number. This necessitates using multiple $\overline{X}$ & R charts in order to monitor a single part number with several key characteristics.

2.5 Process Capability and Performance Studies

Control charts are used to learn if the process is in control or not. Process control address stability and consistency, but control says nothing about acceptability. It is possible to have a stable, consistent process that produces 100 percent unacceptable outputs. The challenge, then, is not only to evaluate a process's stability, but also its capability and its acceptability. If a process is in control, then its behavior can be reliably compared to engineering tolerances. Therefore process capability can be defined as performance level of the process after it has been brought under statistical control.

Process capability studies are used to compare the natural variation of individual data values to engineering specifications (tolerances). Like its name, process capability studies only indicate what the process is capable of producing, not what it is actually producing.

Prior to performing a process capability study, following requirements should be met.

1. The process variability is stable.
2. The histogram of individual data values is approximately normal. One of his papers in Quality & Productivity Journal, Dr Mehernosh Kapadia discussed on the assumption that the underlying process distribution is approximately bell shaded or normal. Yet in some situations the underlying process distribution may not be normal. For example, flatness, pull strength, waiting time, etc., might naturally follow a skewed

distribution. For these cases, calculating Cpk the usual way might be misleading. Many researchers have contributed to this problem. [27]

3. The engineering tolerances are known.
4. The process standard deviation estimate is known.

2.5.1 Performing A Capable Process

Performing a process capability study means comparing a process natural variability against engineering tolerances to determine if the van ability is capable of fitting within the requirements (see Figure 2.8). When a process is not centered on a target, process capability studies do not always indicate the likelihood of producing nonconforming products, but they are a good gauge for how a process might perform.

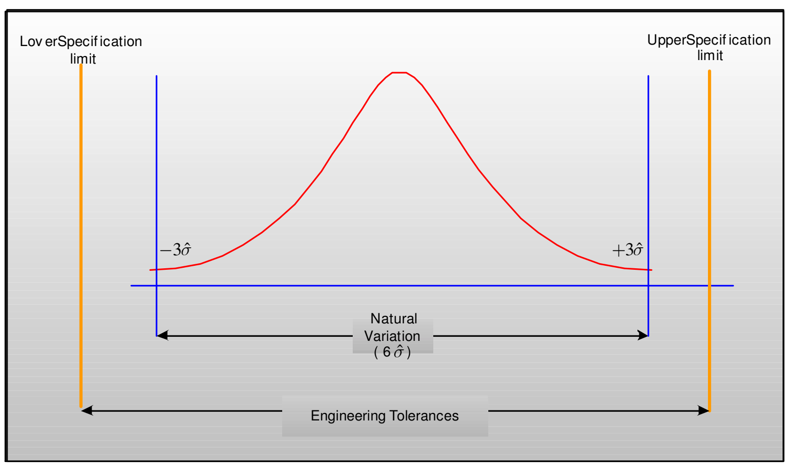


Figure 2.8: Comparison of the width of a normal curve to engineering tolerance, a process capability study. [26]

2.5.2 C_p Ratio

To numerically quantify the relationship between natural variability and engineering tolerance, C_p (Process Capability) ratio is used. The C_p ratio is a mathematical way to express Figure 2.8, relationship between a process' engineering tolerance and its natural variation. C_p is calculated by dividing the total engineering tolerance by the $6\hat{\sigma}$ spread of the normal curve.

$$Cp = \frac{USL - LSL}{6\hat{\sigma}} \tag{2.33}$$

Where USL is upper specification limit and LSL is lower specification limit.

Because of the nature of this calculation, it is desirable that the value of C_p be greater than 1. If C_p is greater than 1 it means that the natural variation is less than the engineering tolerance. In effect, a C_p greater than 1 indicates the process is capable of producing nearly 100 percent acceptable outputs. Figure 2.9 displays some general guidelines for interpreting the C_p index.

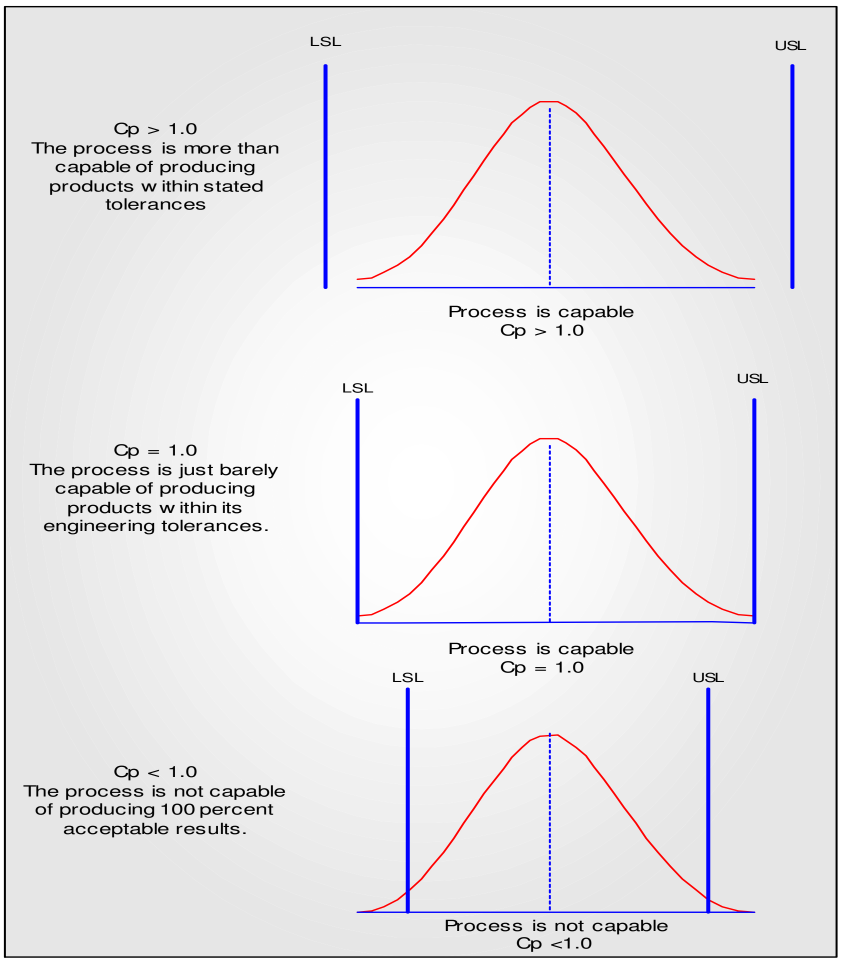


Figure2.9: Interpreting the Cp index, [15]

The process capability index is a powerful and useful communication tool. By using a single C_p value, user immediately knows how a process' natural variation compares to its engineering tolerances. C_p value also communicates information about the quality of a process. That is, C_p can be used to indicate how much product might be expected to fall outside engineering tolerances (see table 2.1).

2.5.3 C_{pk} Ratio

Even though C_p values can be instructive, they do not take into consideration the stability of the process average nor whether the overall process average is centered. A process is centered when the overall process average falls directly in the middle of two-sided engineering tolerances. Because the C_p index fails to address process centering or the lack thereof the C_{pk} process performance ratio was developed.

Unlike C_p values, C_{pk} ratios take into consideration the location of the overall average and, therefore, give a better indication of how the process is performing relative to upper and lower specification limits. C_{pk} is a unitless ratio that compares process statistics to engineering tolerances. Specifically, C_{pk} is a performance ratio that takes into account a process' variability and centering and compares them clearly to each of the upper and lower specifications. Also, the C_{pk} ratio focuses on the worst case scenario. That is, the reported C_{pk} value reflects the specification limit that resides closest to the process average.

To ensure that the C_{pk} values reported from a process performance study are reliable, user must ensure that the following requirements are met.

1. Both the process variability and average are stable (as indicated by an in-control X and MR chart, X and Range chart, or X and s chart).

2. The histogram of individual data values is approximately normal.
3. The engineering tolerances are known.
4. Reliable estimates of the process average and standard deviation are known.

Assuming that these requirements have been met, a reliable value can be calculated as (see also figure 2.10);

$$C_{pk} = MIN\left\{\frac{USL_i - \overline{\overline{X}}_i}{3\hat{\sigma}}, \frac{\overline{\overline{X}}_i - LSL_i}{3\hat{\sigma}}\right\} \tag{2.34}$$

- If $C_{pk} > 1$, then the process is more than capable of producing products within stated tolerances.
- If $C_{pk} = 1$, then the process is just barely capable of producing products within its engineering tolerances.
- If $C_{pk} < 1$, then the process is not capable of producing 100 percent acceptable products.
- If C_{pk} has a negative value, then the overall process average is outside of one of the specification limits.

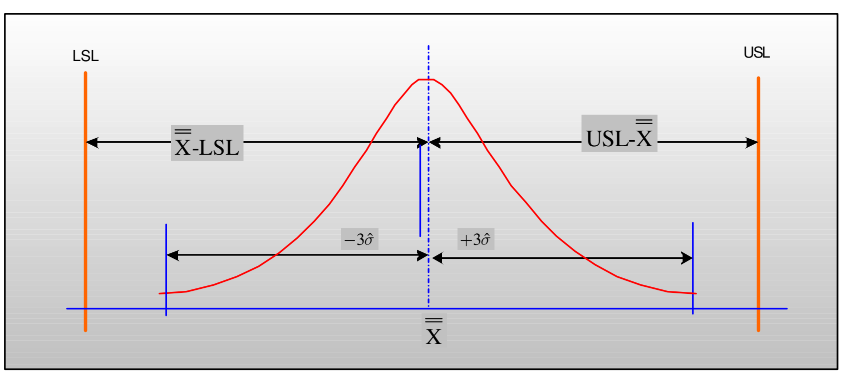


Figure 2.10: Illustration of C_{pk} formula.

Using process capability indices it is easy to forget how much of product is falling beyond specification, therefore Table 2.1 can be used to indicate C_{pk} fallout based on a centered process.

Table 2.1: Process fallout based on C_p values, and C_{pk} fallout based on a centered process. ppm= parts per million, ppb= parts per billion, (10,000 ppb=1) [15]

Calculated C_{pk} & C_p Ratio	**Predicted fallout (if Process is centered) (For $C_{p\&}$ $C_{pk)}$**	**Predicted fallout in each tail of bell curve (if Process is centered) (For $C_{pk)}$**
0.5	133,620 ppm	66,810 ppm
0.6	71,860	35,930
0.7	35,730	17,865
0.8	16,396	8,198
0.9	6,934	3,467
1.0	2,700	1,350
1.1	966	483
1.2	318	159
1.3	96	48
1.4	26	13
1.5	7	3
1.6	2	1
1.7	340 ppb	170 ppb
1.8	60	30
1.9	12	6
2.0	2	1

%)

2.5.4 Relation Between C_p and C_{pk}

C_p and C_{pk} are best used together to evaluate process performance and acceptability. Here are some general rules when eva1uatih C_p and C_{pk} together.

1. C_{pk} can be equal to but never larger than C_p
2. C_p and C_{pk} are equal only when the process is centered.

3. If C_p is larger than C_{pk} then the process is not centered.
4. If both C_p and C_{pk} are greater than 1, the process is capable and performing within tolerances.
5. If both C_p and C_{pk} are less than 1, the process is not capable and not performing within tolerances.
6. If C_p is greater than 1 and C_{pk} is less than one, the process is capable, not centered, and not performing within specifications.

The visual relationship between C_p and C_{pk} is illustrated in Figure 2.11

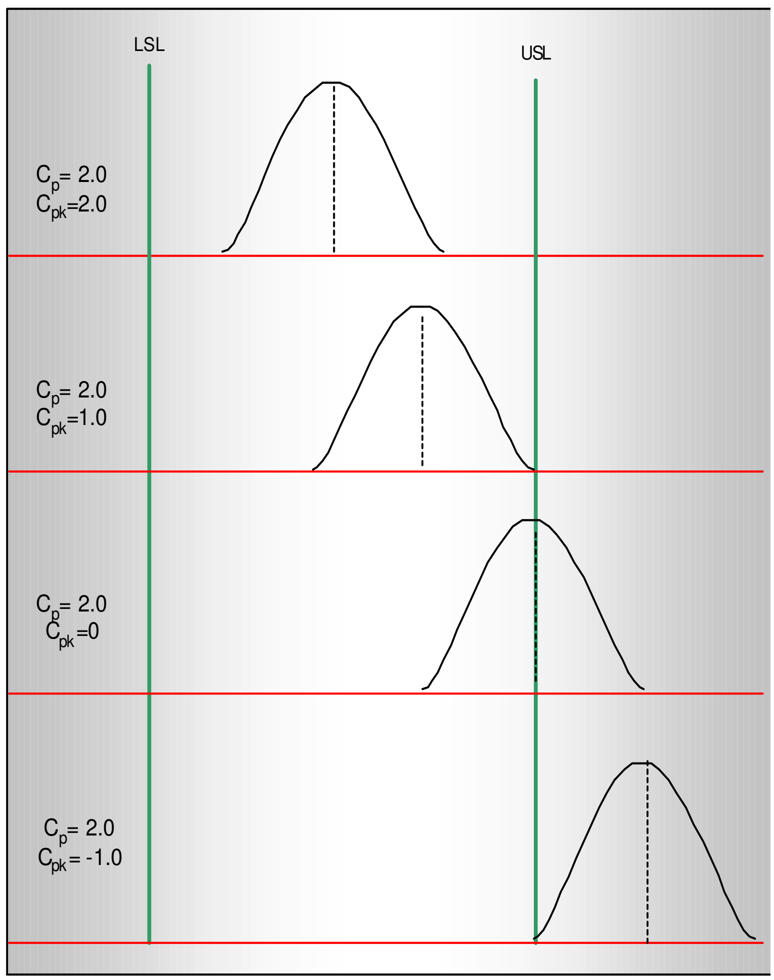


Figure 2.11: C_p and C_{pk} relationships

2.5.5 Advantages of a Controlled and Capable Process

Process capability analysis is a vital part of an overall quality improvement program. Some major benefits of a capable process can be summarized as;

- Process capability measurements allow summarizing process capability in terms of meaningful percentages and metrics.
- To predict the extent to which the process will be able to hold tolerance or customer requirements. Based on the law of probability, company can compute how often the process will meet the specification or the expectation of its customer.
- Knowing the capability of the processes, better quality performance requirements for new machines, parts and processes can be specified.
- Assists product developers and designers in selecting modifying a process.
- Reduces the variability in a manufacturing process.
- To set realistic cost effective part specifications based upon the customer's needs and the costs associated by the supplier at meeting those needs.
- To select between competing vendors.

2.6 Pattern Analysis

In his book, SPC for the Rest of Us, Hy Pitt defines control charts interpretation as both science and art. As a science, specific control chart patterns lead to rules that identify the presence of a special cause consistent with the probabilities that the plotting on the chart implies. The patterns can number from as few as one to as many as fourteen, depending on the level of sophistication desired. As an art, dependence on a skilled eye coupled with familiarity with the process can lead to interoperations that, although possibly correct, may not be convincing or persuasive [30].

The use of specific patterns and accompanying rules has distinct advantages by assuring reasonable uniformity in interpretation and decision making. But rules that are too numerous to remember may make them impractical to implement, may cause unnecessary confusion, or may result in automatic reactions to every wiggle on the control chart.

Several patterns or configurations of plotted points on a control chart exist that indicate the presence of a special cause. The patterns can generally be classified as outside control limits, runs, or trends. Each of these patterns is chosen because the probability is very small that it will occur when the process is supposed to be in statistical control. Then the question before is how many patterns should be looked for when interpreting the control chart in order to conclude that the process is not in statistical control and therefore warrants a search for a special cause? If it is chosen too few patterns, user may miss opportunities to search for a special cause when one is present. If it is chosen too many patterns, user may overreact or become confused, responding constantly to the chart's apparent signals.

Therefore there are several alternative sets of patterns or configurations proposed by various individuals and groups as criteria for the presence of a special cause. Some know ones are given below;

- Shewhart essentially used only one criterion as evidence that the process was not in statistical control, a single plotted point outside either control limit.
- Another popular set of tests for out of control conditions are the Western Electric Tests. Four basic rules are judged. The chart is divided into zones corresponding to the number of standard deviations of sample statistics [31].

- The adapted form of Western Electric tests are Nelson's eight tests for special causes that was proposed by Dr. Lloyd S. Nelson and published in 1984. [32]
- In a paper presented at the 4lst Annual Quality Congress of ASQC in Minneapolis, Alfred H. Jaehn introduced a simplified method for determining when a variables control chart for sample statistics signals a shift in the process and, therefore, the presence of a special cause. Using the Western Electric rules (now AT rules) for numbers of plotted points in runs, Jaehn assigned correspondingly weighted numerical scores to each of the zones. [33]
- Hy Pitt uses four patterns to test out of control conditions. These are chosen because they are easy to identify on a control chart, easy to remember and the probability of any one of them occurring when the process is supposed to be in statistical control is very small, therefore, the pattern constitutes strong evidence of the existence of a special cause. Since our target in this thesis study is job shops, and the test's simplicity and strong ability to determine out of control conditions, this test is preferred.

Four patterns used by Hy Pitt are;

1. A single point outside either control limits also called *freak* and showed in figure 2.12 (same as Shewhart's).

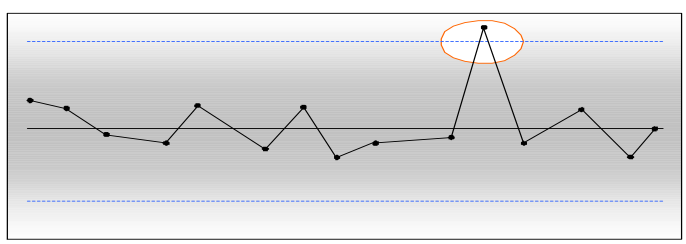


Figure 2.12: A freak

2. Eight points in a row on one side of the center line. The probability is $(0.5)^8 = 0.0039$, and this probability is considered small enough. This pattern is called a *run or shift* and illustrated in Fig. 2.13. These shifts may result from the introduction of new workers, methods, raw materia1s, or machines; a change in the inspection method or standards; or a change in the skill, attentiveness, or motivation of the operators; or a broken tool.

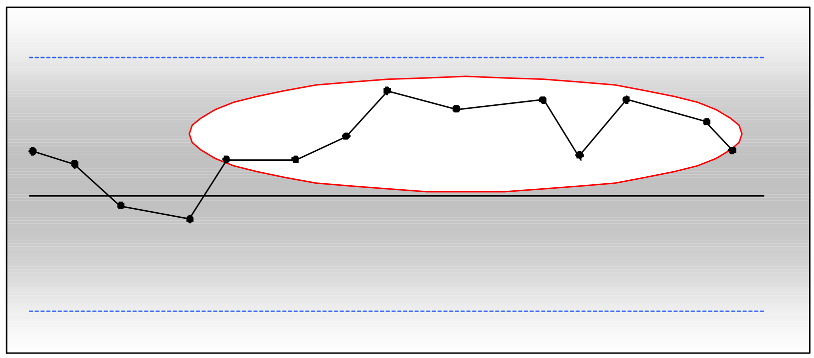


Figure 2.13: Run or Shift

3. Five or six points in a row all going in the same direction (up or down) and all on one side of the center line. The probability is more difficult to calculate, taking into account areas under different portions of the normal curve, but it is considered small. This pattern is called a *trend* and illustrated in figure2.14. Trends are usually due to a gradual wearing out or deterioration of a tool or some other critical process component. They can also result from human causes, such as operator fatigue or the presence of supervision. Change in coolant temperature or chip build upon work holding devices can also cause it. Finally, trends can result from seasonal influences, such as temperature. When trends are due to tool wear or other systematic causes of deterioration, this may be directly incorporated into the control chart model. However, it is important that a downward trend in arrange test can be occurred due to an improved operator skill, or better

maintenance intervals, or a gradual improvement in the uniformity of incoming material [13].

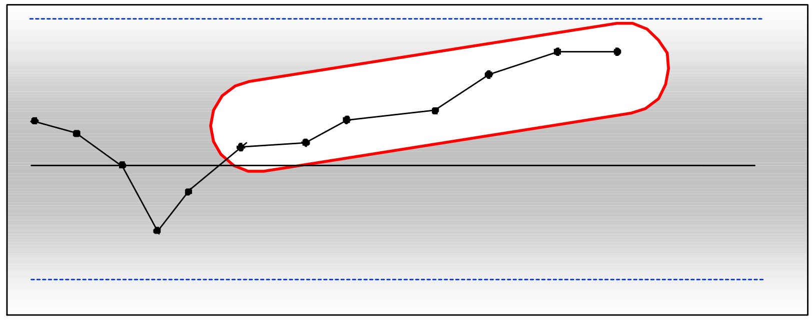


Figure 2.14: Trend

4. Two points in a row just inside a control limit. The area under a normal curve between two and three standard deviations on one side is 0.0214. The probability of two points in a row falling in this area is $(0.0214)^2 = 0.00046$, very small indeed and illustrated in Figure2.15.

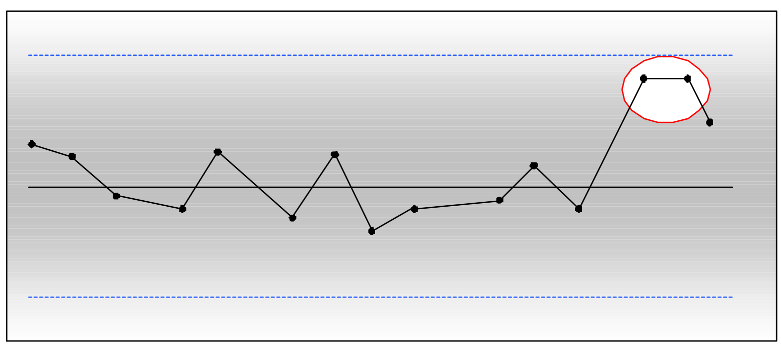


Figure 2.15: Two points in a row just inside a control limit

While interpreting patterns on the $\overline{X}$ chart, we must first determine whether or not the R chart is in control. Some assignable causes show up both $\overline{X}$ and R charts. If both the $\overline{X}$ and R chart exhibit a nonrandom pattern, the best strategy is to eliminate the R chart assignable causes first. In many cases, this will automatically eliminate the nonrandom pattern on the $\overline{X}$ chart. The user never attempts to interpret the $\overline{X}$ chart when the R chart indicates an out of control condition.

For all short-run target charts, interpretation of chart patterns does not change. The same types of patterns (runs, trends, and so on.) will be seen on a short run target chart as they might be seen on a traditional control chart. The primary difference is the range test that watches for high or low run patterns on the range chart immediately after a new part number has been set up and plotted. The major benefit is that every time the process goes out of control, and the assignable cause is removed, the reduced variability affects all part numbers that will be made on the process.

Standardized charts are little bit different when it comes to pattern ana1ysis.Since each and every plot point is standardized and could represent a different part number or different process altogether, specific patterns may not represent a continuous stream of variation as with traditional charts, therefore user could be more careful between different processes.

2.7 Data Collection Strategy

Once the decision has been made to use statistical tools, confusion is typically found around how data should be collected. Therefore, prior to the use of any statistical tool, one must develop a coherent data collection plan. This plan is called a data collection strategy.

Prior to developing a data collection strategy, questions such as these should be asked and answered.

- ✓ Should measurements be made?
- ✓ What should be measured?
- ✓ When should data be taken?

- ✓ How often should data be taken?
- ✓ Should the data be sub grouped and, if so, what should be the subgroup size?

Should Measurements Be Made?

Data collection costs money. Data should be collected when there is reasonable belief that doing so will benefit the organization. The information gained from the data should outweigh the money spent on collecting it. Only a small amount of data is initially required to confirm whether or not further data collection will be beneficial. There are four basic reasons for collecting data.

1. To comply with customer or industry requirements.
2. To learn an unknown. For example, an engineer may have a predicted estimate of a unit's performance based on preproduction calculations; however actual data are necessary to confirm the engineer's estimates.
3. To optimize. Exploratory measurements in the form of designed experiments, correlation studies, and regression analysis are all methods used to find optimal level is of process parameters.
4. For process control.

Ongoing data collection should be pursued only if it is a customer requirement or it continues to provide benefits to the organization.

Determining What to Measure

Before knowing what to measure, one must decide what needs to be learned. Answering the question, "What am I trying to learn?" should provide clarity to the question, "What do I measure?"

If fit problems are occurring during assembly, then data from mating surfaces should be collected. If surface durability for different conditions to be predicted, one should base the data collection on the surface area being processed. Once again, collecting data costs money. When process operators are collecting data, parts are either not being made or attention is being diverted away from manufacturing duties. Either way, there is a real or perceived cost of collecting data. These costs should be compared against the potential benefit (or detriment) of collecting the data (or not collecting it). In other words, use common sense when establishing data collection strategies.

When to collect data

Data should be collected at the earliest possible point where to the desired information to be learned can be gathered. If one desires to learn something about a characteristic fabricated on a grinding machine, data should be collected at the grinding operation. If one waits several operations after the fact before taking measurements, many opportunities to gain knowledge, for instance, about the grinding operation may be lost. Waiting until final inspection to take measurements regarding in process events is almost always too late to be of real-time benefit.

How Often to Collect Data

The frequency of data gathering depends on four factors.

1. The availability of data
2. The cost of gathering the data
3. The time interval between major process changes or adjustments
4. Process stability or uncertainty of process output

Take, for example, a process where there are many opportunities available to take data. Also, the data gathering is automated, and the cost of data acquisition is likely to be low. The 25 subgroups represent maybe only a few minutes worth of cure time. Within this period there are no major changes or adjustments made to the process, its materials, computer programming, staffing, and so on. Additionally, the $\overline{X}$ & R chart proved to be in control. With this information in mind, one could comfortably conclude that the process does not significantly change over the few minute intervals.

Because the process is quick stable, the frequency of data gathering could be decreased. That is, for the purpose of determining process control, taking a data reading in seconds may be overload. Generally, if a process does not change over some period of time, its frequency of data gathering can be reduced. The amount of decrease in frequency will depend on the comfort level of those working in the process as well as the risk, penalty, and/or costs involved in producing nonconforming product due to an undetected process change.

The key is to gather data frequently enough so that any important changes to the process are caught, but not so frequently that the data gathering it self is cost prohibitive. The question to be answered is, "How long can we go without sampling the process and still have confidence that the process is still consistent and that good product is still being produced?"

Sometimes, especially with new products or processes, time intervals between process changes are unknown. With new processes, one should generally take as much data as possible, even if one has to resort to gathering data on 100 percent of the products produced. In this way, process changes and their time intervals can be identified and the appropriate sampling frequency can be established.

Frequency of data collection is typically a trade-off between minimizing data collection cost and maximizing the probability of detecting process changes.

Once sampling frequency has been established, one must then consider the issue of sub grouping.

Determining Rational Subgroups

Generally, sub grouping strategies should be determined while keeping in mind these three important points.

1. Each subgroup should be as homogeneous as possible.
2. Each measurement in a subgroup must be independent of one another.
3. Using larger subgroups results in control charts that are more sensitive to shifts in the process mean.

The first point, each subgroup should be as homogeneous as possible, means that each subgroup should be composed of measurements that represent a similar time and place of manufacture. This usually means taking measurements of consecutively produced products at or from the same machine or location. Taking data in this manner ensures that the variation within the subgroup and between subgroup ranges can be fairly compared with one another. Given this sub grouping strategy, short term variability is illustrated by the range chart and longer-term process variability is illustrated by the X chart. [15]

The second point, each measurement in a subgroup must be independent of one another, means that one measurement in a subgroup should not be influenced by another.

The third point to keep in mind when sub grouping is using larger subgroups results in control charts that are more sensitive to shifts in the process mean. Generally, subgroup sizes (n) range from 1 to 10, and sometimes larger. Either way, the bigger the subgroup, the more sensitive the X chart is to changes in the average. However, there is a trade-off. As the subgroup size, n, increases, the range (since it only uses two data points in a subgroup, the largest and smallest values) becomes less efficient as an estimator of process variability. Typically, when n is 10 or larger, the sample standard deviation s is a better statistic to use in estimating process variability since all of the data points in the subgroup are used in the s calculation.

CHAPTER 3

SPC IN SHORT RUN

3.1 Short Run SPC

The purpose of statistical process control is to assist in the production of quality products and services. Since its initial concept in the 1920's, it has evolved to meet the changing needs of manufacturing. Today, the focus on SPC has diminished even more because customers have become more demanding. Not only do they want more features and options in their products, but customers also demand more product customization. More options and customizations have translated into an ever growing list of part numbers, manufacturing complexity, and a geometric progression of critical dimensions and characteristics requiring control. In short, the advent of small lot sizes, increased part complexity, and customization has made it exceedingly difficult to effectively use traditional SPC.

Traditional SPC charting does not work well with the short-run processes, and this situation creates disappointment for these manufacturers. This problem is understandable indeed; traditional charts are not designed to work with short production runs. Generally, SPC charts require a long, continuous and homogeneous process to be most effective, whereas most job-shop and companies practicing Just In Time (JIT) manufacturing have short production runs of many different products. This scenario creates legitimate problems for a JIT organization that desires to implement traditional SPC charts.

These short production runs cause problems when attempting to use the traditional Shewhart charts because there is never enough data to calculate control limits in a timely manner. Usually the run for a given part number is over before the limits can be calculated and drawn on the chart. This means the operator must wait until after the job is completed before he discovers whether the process was in or out of control.

Even when there is enough data for the first part number run, if a different part number is scheduled to be run on this equipment, a new chart must be started. Since most job shops have hundreds (if not thousands) of part numbers, a mountain of paperwork is created. The operator wastes valuable production time searching for the proper chart, thereby decreasing his efficiency. Maintaining all these separate charts, while valid for each individual part number, is not very effective in evaluating the continuous performance of the equipment over time.

SPC users provide solution to this vexing problem and cover other innovative methods that settle all the irregular problems associated with the use of traditional SPC charts. By utilizing special data transformation formulas, the short-run charts allow users to plot all the various part-number products to run through the process on a single control chart thus eliminating the need for hundreds of separate charts. Control limits can be determined sooner, and since all the data is now plotted on one chart, any time-related process changes can be more easily detected since all the data is plotted chronologically on the same chart. Furthermore, these methods reduce time consuming paper work, and increase the effectiveness of the process control.

Some short run definitions are;

- ❖ A “short run” is any situation where there is insufficient subgroup data for a given part number to calculate traditional Shewhart control limits in a timely manner. [14]

- ❖ Thomas Pyzdek describes a short runs as ones that get over fast. These may produce a large number of units, but the runs are short by the virtue of their high production rate. Small runs are defined as runs with small number of pieces. Again, these need not be short. A classic example stated is that of the Hubble Space Telescope program that produced only one piece but took 15 years to get it into orbit. [26]

- Gary K. Griffith defense short run problem is happened when insufficient or untimely data for control limits are occurred. [13]

- To Tyler Mangin, a production run that is not long enough to provide adequate data to construct a control chart is called short run. [50]

- Job-shops, JIT manufacturing and reduced inventory systems has led to shorter production runs with more frequent setup and that can cause short run problems which occurs when the size of historical data used to establish phase I, or trial control limit is too small.[16]

3.2 Previous Attempts to Monitor Short Runs

1. First and/or last piece inspection (risky).

Many companies measure only the first piece run off a new setup. If this piece is acceptable, the remainder is run with no more checks being made. This practice is risky since many process changes occur over time like tool wear, temperature changes, coolant deterioration, operator fatigue etc.

Sometimes the last piece is also measured, but if this one is good, all that is really known is that two good pieces were made. What if this last piece is bad? When did the process change? How many bad pieces were produced? It's too late to discover there was a problem after the run is over.

2. 100% inspection (costly).

Instead of checking only the first and last pieces of a run, all pieces could be inspected. This is usually a costly alternative and in cases where destructive testing is required, impossible.

Even if the measurement is inexpensive and non-destructive, 100% inspection is not totality effective. According to Davis Bothe it's only about 85% effective. This means if a defective plan is made, there is a 15% chance it will get through the 100% inspection check and end up in the hands of the customer. [14]

3. Separate control chart for each part number.

Separate charts needed due to control limits of traditional SPC charts. If either X-double bar and/or R changes from one part number to the next, then the limits change, requiring a different chart. Therefore extra efforts are necessary to hold the hundreds of control charts required for each operation, one for every different part number, this make SPC implementation messy and difficult to use.

3.3 When and Where to Use Short Run SPC

The result of these industry developments (as was discussed in section 3.1) has highlighted three primary limitations faced by those using traditional SPC techniques. These limitations can be listed as;

Limitation 1: The lot size is extremely small (only 1 to 15 pieces) or the lot size is large (more than 100 pieces) but very few samples could be collected during the run.

Traditional SPC techniques were developed to be applied to long, rarely changing production runs. To develop a control chart that accurately reflects process performance, one traditionally needs more than 25 data points (only for IX and MR chart, to obtain traditional $\overline{X}$ and R chart one will need more than

100 data points). If one wanted to develop a control chart to track the thickness of black paint car, no problem occurred. No problem because 15 or 25 cars might be painted in the blink of an eye. It would have been easy to develop a control chart because the opportunities for data collection would have been plentiful.

However, no auto manufacturer at present could dare offer a vehicle with only one color choice. In fact, the amount of customization and options made available by auto manufacturers are staggering. Short production runs and small batch sizes are what is needed to satisfy the customers' needs. Short production runs result in numerous process changes, which, in turn, translate into smaller amounts of data for a given production setup.

Consider a stamping operation carried on various parts with different part number. If the production rate is 1000 pieces per hour with samples taken at every half hour, and a part with a certain number is produced for only two hours, just four plot points are obtained. Obviously these are not enough to calculate traditional control limits. Though the lot size is large (more then 100 pieces) very few samples could be collected during the run.

At present a multitude of parts with different part numbers lot with varying batch sizes undergo nominally the same type of operation. One could appreciate the difficulties involved in developing at traditional control charts. After all, if one is going to make only a handful of parts, how can control chart development be justified, and even if it could be justified, how would it be done. These are indeed difficult questions to answer if one is armed only with traditional SPC techniques.

Limitation 2: Only one characteristic can be tracked per control chart

This is really not a limitation if few characteristics are to be controlled, because the number of charts required will be small.

To add to the problem, even the same characteristic on the same part might require separate charts. For example; take a twin spindle mill that is facing a stainless steel surface to a single specified thickness. If the left side of the part is milled by spindle A and the right side is milled by spindle B, one would need two separate control charts. The logic is simple, to try to identify assignable causes that might be present at one spindle but not at the other. Spindle A may have new inserts whereas spindle B's might be worn. Or, the coolant directed at the work piece under spindle A might have greater pressure than spindle B. The challenge is to determine what effect the different tools had on the thickness of the stainless steel part. In effect, the operator would want to ensure that the thickness is uniform across the piece. Therefore, a control chart would be developed to evaluate the consistency of the left side of the milled surface (milled by spindle A) and another chart would be required for the right side (milled by spindle B).

Multiple characteristics result in multiple charts, which translate into more work for the operator and less attention to his or her manufacturing duties. In brief, traditional SPC techniques are not very efficient when one needs to evaluate multiple characteristics.

Limitation 3: Even if part characteristics are Similar, other differences such as material type or specification limits necessitate separate control charts

We can take the example again, let's think a manufacturer is interested in developing a control chart for paint thickness of two types of paint: flat white and metallic green. We can take paint thickness measurements regardless of paint type and put them on one chart. However, each type of paint may have a different target specification for thickness. One may be required to be thicker or thinner than the other. So, one must set up two different control charts because of the difference in target paint thicknesses. One chart would be needed to track the thickness of the metallic green and another for the flat white; thus for instance, nine different paint colors would necessitate nine different control charts.

The three limitations discussed in the forgoing, have confused SPC implementers for years. For the reasons outlined, many people concluded that it is a waste of time to employ the traditional. The limitations here are not the result of the failure of traditional SPC techniques but rather the need for a different, nontraditional set of charting methods.

One only needs the right control chart technique to deal with the complex manufacturing realities of present marketplace. SPC can be effectively applied even with small lot sizes, complex parts, numerous part dimensions, and similar but different characteristics, as will be explained below.

To deal with limitation 1, one should use either “Control Charts for Small Lot Production Runs-The Short Run Charts” or **“**Control Charts for Similar Characteristics - The Nominal X&R”.

For limitation 2, “Charts for Multiple Characteristics-The Group Charts or Q charts can be used” however multiple characteristics are not included in this thesis study. But if the characteristics are similar “The Short Run Charts” can still address the situation.

To address limitation 3, even if part characteristics are similar, other differences such as material type or specification limits necessitate separate control charts, “Control Charts for Similar Characteristics— The Nominal X&R can be used.

CHAPTER 4

TYPES OF SHORT RUN CHARTS

4.1 Types of Short Run Charts

Short run SPC methods work on a variety of different part numbers, target dimensions, and part tolerances primarily due to the use of coded data (also known as pooling method). There are basically two methods for coding the measurements (data) from a process. These coding methods are;

- Control Charts for Similar Characteristics - The Nominal Charts (DNOM Charts or Target Charts)
  - Nominal IX & MR Charts
  - Nominal $\overline{X}$ & R Charts
- Control Charts for Small Lot Production Runs- The Short Run Charts (Standardized Charts)
  - Short Run IX & MR Chart or Zed* Charts.
  - Short Run $\overline{X}$ & R or (Z*- Sub)
  - Zed Charts or Z-Charts
  - Zed-Bar Charts or $\overline{Z}$ -Charts

These charts, as being the most known and popular ones, will be used a main model for this thesis study and they will be discussed detailed in the following section. They are preferred due to ease of use, and comfortable adaptability to job shops. However a variety of other approaches can be applied to the short run production environment. These methods can be shortly summarized as;

- The cusum and EWMA control chart can be applied to short production runs, because they have shorter average run length performance than Shewhart type charts, particularly in detecting small shifts. Furthermore, cusum and EWMA control charts are very effective with subgroups of size one, another potential advantage in the short run situation.

- Quesenberry has presented procedures for short run SPC using a transformation that is different from the standardized approach. He refers to these charts as Q-charts, and notes that they can be used for both short and long production runs. [17,18,19]

- Del Castillo and Montgomery have investigated the average run length performance of the Q chart for variables and show that in some cases ARL performance is inadequate. They suggest some modifications to the Q-chart procedure and some alternative methods based on the EWMA and a related technique called the Kalman filter that have better ARL performance than Q chart. [25]

- Crowder has also reported a short run procedure based on the Kalman filter. [24]

- Quesenberry reports some refinements to the use of Q charts that also enhance their performance in detecting process shifts. He also suggests that the probability that a shift is detected within a specific number of samples following its occurrence is a more appropriate measure of the performance of a short run SPC procedure than its average run length. [20,21,22,23]

From these, field of study can be figured out as;

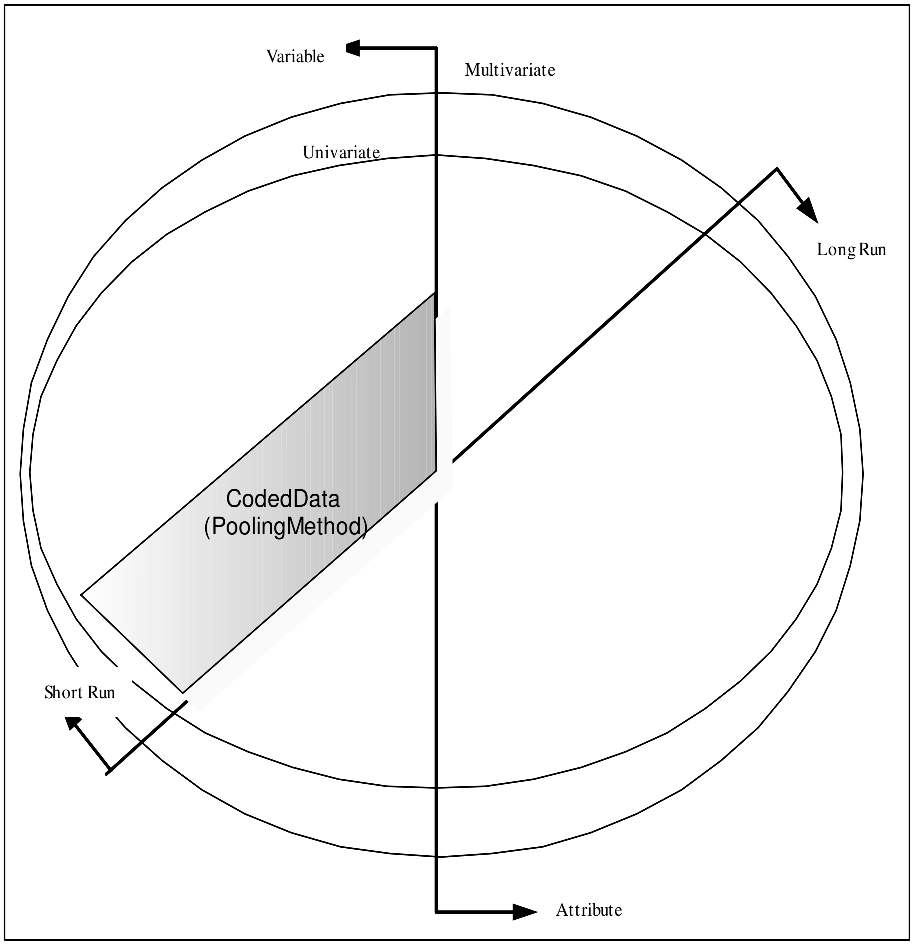


Figure 4.1: Field of study

4.2 Control Charts for Similar Characteristics - The Nominal X&R

The Nominal Charts are also known as names like; “Target Charts”, “Difference Charts” or “DNOM Charts”. In this section, two control charts will be covered. The Nominal Charts will help the SPC user deal with situations where;

- Similar characteristics with different dimensions,
- Small lot sizes,
- High product mix with low production volumes, are encountered,

When these specific conditions are encountered, the SPC user should benefit from using one or a combination of these charts

- Nominal IX & MR Charts.
- Nominal $\overline{X}$ & R Chart

Take, for example, three shafts with different diameters like in the figure 4.1. For someone familiar with only traditional control charts, this situation would require the use of three separate control charts. Separate traditional control charts would be required for each different shaft diameters because the averages and the scales on the X charts would be different. The setups would most likely be different, as would be the targets for the diameters of 500 mm, 350 mm and 650 mm. [15]

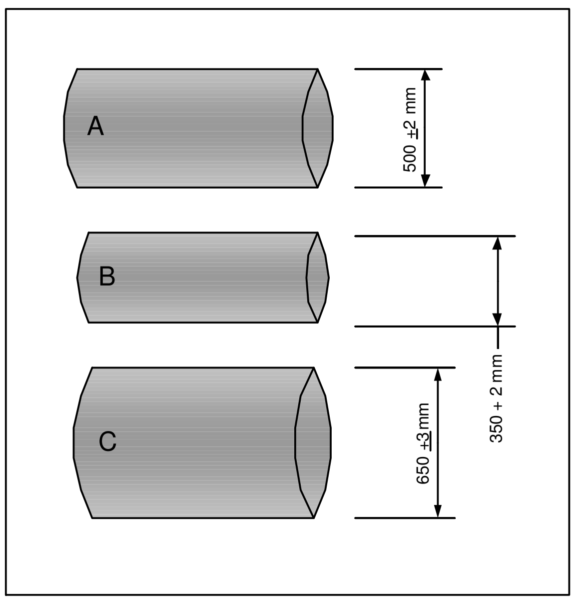


Figure 4.2: Three different size shafts [15]

However, what is similar is the process itself. The characteristics of interest (hole diameters) are also quite similar. Given these similarities, one may consider using a single target chart to track the consistency of both hole diameters.

The key to using nominal charts is to identify a target for each characteristic and then mathematically determine how far away the actual measurements fall from the target. In this way, the target becomes a common point from which many similar characteristics with different dimensions can be evaluated. The target value itself typically identified in one of three different ways.

1. Target defined as print spec nominal (the mid point in the engineering specification).
2. Target defined by the machinist or engineer. Because of manufacturing limitations or some other constraint, one may intentionally center the process at a value that is different than the specification midpoint.
3. Target defined as a value sufficiently far enough away from a maximum only or minimum only (unilateral) specification.

The deviations from target values are those that are used for plot ting on the Nominal $\overline{X}$ & R or Nominal IX & MR charts. They are coded values that represent the distance each measurement falls from its target.

4.2.1 Nominal IX & MR Charts

4.2.1.1 Description

The Nominal IX & MR Charts are used to monitor and detect changes in individual measurements of one characteristic at a time, but allows for several similar characteristics or more than one product to be plotted on the same chart.

It is known that only one part number can be plotted on the traditional IX & MR chart, but in most short run situations multiple part numbers are run over the process. Therefore the traditional IX & MR chart can be modified to allow different part numbers to be plotted on the same chart. This is accomplished by coding the measurements before they are plotted. The coding is the result of subtracting a target value from an actual measurement. Target values are typically, although not always, set at the desired centering of the process, usually specification nominal. Each distinct characteristic on the chart will have its own target value.

These charts are mostly used to monitor similar characteristics with different dimensions from processes where only one measurement represents the process at a given period of time or from processes that produce small numbers of the product or characteristic being evaluated. Examples include measurements from homogeneous batches like chemical concentrations or a dimensional feature with different nominal values from small lot sizes that are manufactured on the same machine.

The moving range chart, also called an MR chart, is used to monitor and detect changes in the variation from one individual measurement to the next. The plot points represent the absolute difference between two consecutive individual measurements. The MR chart is not affected by the target coding.

4.2.1.2 Subgroup Size

For short runs, the IX plot point is based on one measurement, the moving range is calculated from two consecutive IX plot points. The sample size is constant (n=1) and individual measurements are assumed to be normally distributed.

4.2.1.3 Calculating Plot Points

First the IX plot point is calculated by subtracting the nominal value from the individual piece measurement. Then the MR plot point is calculated by taking the absolute value of the difference between two consecutive IX plot points.

$$\text{IX Plot Point} = X_i - \text{Nominal} \tag{4.1}$$

$$\text{MR Plot Point} = \left| (\text{IX Plot Point})_i - (\text{IX Plot Point})_{i-1} \right| \tag{4.2}$$

The vertical lines in the MR formula means one take the absolute value of the difference between the plot points - the current (i) and the immediately previous one (i-1).

4.2.1.4 Calculating Centerlines (CL)

The IX and MR plot points from all part numbers are used to calculate the center lines. Since there is no MR for the first measurement recorded, the sum of the moving ranges is divided by k - 1 rather than k (k is the number of subgroups, and n is the size of appropriate subgroup). The number of measurements (k) used to calculate the center lines should be at least 15. Therefore;

MR Chart Center line;

$$\overline{MR} = \frac{\sum_{i=2}^{k} MR_i}{k-1} \tag{4.3}$$

Nominal IX Chart Center line;

$$\overline{CL}_{IX} = \frac{\sum_{i=1}^{k} (\text{IX PlotPoint})_i}{k} \tag{4.4}$$

4.2.1.5 Calculating Control Limits

The control limit formulations are given below;

MR Chart Control Limits;

$$UCL_{MR} = D_4 \times \overline{MR} \tag{4.5}$$

$$LCL_{MR} = D_3 \times \overline{MR} \tag{4.6}$$

Nominal IX Chart Control Limits;

$$UCL_{IX} = CL_{IX} + A_2 \times \overline{MR} \tag{4.7}$$

$$LCL_{IX} = CL_{IX} - A_2 \times \overline{MR} \tag{4.8}$$

However, the control limit factor D_3 is 0, and D_4 is 3.27 (the subgroup size for the moving range is 2). Also, A_2 (or E_2) factor is 2.66 for this chart. Then the formulations will be;

MR Chart Control Limits;

$$UCL_{MR} = 3.267\overline{MR} \tag{4.9}$$

$$LCL_{MR} = 0 \tag{4.10}$$

Nominal IX Chart Control Limits;

$$UCL_{IX} = CL_{IX} + 2.66\overline{MR} \tag{4.11}$$

$$LCL_{IX} = CL_{IX} - 2.66\overline{MR} \tag{4.12}$$

4.2.1.6 Assumptions

- The control limits for this chart assume the process output has a normal distribution. This assumption can be checked by plotting the measurements in a histogram, using normal probability paper or conducting a statistical goodness-of-fit test.
- The products must be similar.
- The materials must be similar. Two different types of materials, for instance, would probably have different causes for any one nonconformance problem.
- Only variables data can be used.

- Sample size must be constant (n=1) and in each subgroup only one kind of product must be used.

4.2.1.7 Calculating Process Capability & Performance Ratios

Before Process Capability calculations, standard deviation should be estimated, and for standard deviation the moving range chart for subgroups proved to be in control. From chapter 2, Equation 2.8, it is known that;

$$\hat{\sigma} = \frac{\overline{R}}{d_2} \qquad \textit{Where } d_2 \textit{ depends on } n$$

Because $\overline{MR}$ is used instead of $\overline{R}$ in Nominal IX & MR Chart, the estimation will be;

$$\hat{\sigma} = \frac{\overline{MR}}{d_2} \qquad \textit{Where } d_2 \textit{ depends on } n$$

For calculating process capability and performance ratios, it is important to establish the number of each unique part and/or characteristic that is used. And for each of it, Cp and Cpk values could be calculated. So that the formulations will be;

$$C_{Pi} = \frac{USL_i - LSL_i}{6\hat{\sigma}} \tag{4.13}$$

$$C_{Pki} = MIN\left\{\frac{USL_i - \overline{IX_i}}{3\hat{\sigma}}, \frac{\overline{IX_i} - LSL_i}{3\hat{\sigma}}\right\} \tag{4.14}$$

$$\text{Where } \overline{IX_i} = \frac{\sum_{i=1}^{k} (\text{IX PlotPoint})_i}{k} \tag{4.15}$$

4.2.1.8 Advantages And Disadvantages

Nominal IX&MR Chart Advantages;

- Multiple parts, specifications, or similar characteristics can be plotted on the same chart (provided they all have similar variability as exhibited by an in-control MR chart).
- C_p and C_{pk} can be calculated for each characteristic on the chart.
- Statistical control can be assessed for process and each unique part and/or characteristic on the chart.

Where as the disadvantages of Nominal IX & MR Chart Advantages;

- The moving range plot points are dependent on the individual X plot points. In other words, changes in the MR chart are directly related to changes from one individual measurement to the next.
- Variation in the individual measurements could be caused by a shift in the average or the inherent standard deviation of the process; however, the Nominal IX & MR Charts cannot efficiently separate the effects of the two.
- Reliable control limits require the distribution of the individual measurements to be approximately normal.
- The Nominal IX & MR Chart is not as sensitive to changes in the process average or standard deviation as would be The Nominal X & R.

4.2.2 Nominal $\overline{X}$ & R Charts

4.2.2.1 Description

The Nominal $\overline{X}$ & R Chart (Nominal X-bar Chart) is used to monitor and detect changes in the average of a single type of measured characteristic regardless of the part number. Therefore this method allows all part numbers run on a given process to be plotted on the same chart for the purpose of determining statistical control.

This is made possible by first coding the subgroup's average (actual measured readings) as a deviation from a common reference point, in this case the nominal print specification or called target point. Then the average and range of this coded data are calculated and plotted on Nominal $\overline{X}$ & R chart.

Target values are set at the desired centering of the process, which is typically, although not always specification nominal (the middle of two-sided specs). The part number can only be changed between subgroups values change when the respective part number changes. For example when the next scheduled part number is run, the target value for that part number is used to code the data in the same manner as for the first part number. By doing this, the zero point on the Nominal $\overline{X}$ & R chart scale represents the nominal value for all coded data, no matter which part number is being run.

The range chart, also called an R chart, is used to monitor and detect changes in the standard deviation of a single type of measured characteristic. The plot points represent subgroup ranges. Ranges are not the same as standard deviation, but when subgroup sizes are small (less than 10) ranges can be used to estimate within subgroup standard deviation. The range chart is not affected by the "deviation from target" data coding that takes place with the Nominal $\overline{X}$ Chart.

4.2.2.2 Subgroup Size

While constructing Nominal $\overline{X}$ & R chart it is recommended to use 2 to 5, usually 3 as a subgroup size. In "long run" situations, traditional $\overline{X}$ and R charts commonly use subgroup sizes of 4 or 5. Because of the small lot sizes and shorter running times associated with short runs, it is important to understand what is happening in the process before most of the run is over. Thus, smaller subgroup sizes like 2 or 3 are used for the short run SPC charts. During the sub grouping independent measurements must be made and the sample size must be constant. Also, it is important to use similar characteristics.

4.2.2.3 Calculating Plot Points

The range plot point is calculated in the same manner as for traditional range charts, the highest measurement in the subgroup minus the lowest.

$$R = X_{High} — X_{Low} \tag{4.16}$$

There are two ways for calculating the $\overline{X}$ plot points - the long method and the short-cut method. For a subgroup size n = 3 (X, represents the measurement of the i th piece);

<u>*The long method*;</u>

$$\sum_{i}^{n}(X_i\text{-Nominal})=(X_1\text{-Nominal})+(X_2\text{-Nominal})+(X_3\text{-Nominal})$$

$$\overline{X}\text{PlotPoint}=\frac{\sum_{i}^{n}(X_i\text{-Nominal})}{n}$$

<u>The Short-cut method; [14]</u>

$$\sum_{i}^{n}X_i=X_1+X_2+X_3$$

$$\overline{X}\text{PlotPoint}=\frac{\sum_{i}^{n} X_i}{n}-\text{Nominal} \tag{4.17}$$

4.2.2.4 Calculating Centerlines

The center lines for the Nominal Range chart and the Nominal $\overline{X}$ chart are calculated with these formulas, using the range and X-bar plot points from all part numbers run on this process (k is the number of plot points summed and recommended to use at least 15 *[14])*

Nominal Range chart Centerline;

$$\overline{R}=\frac{\sum_{i=1}^{k} R_i}{k} \tag{4.18}$$

Nominal X-Bar Chart Centerline;

$$CL_{\overline{X}}=\frac{\sum_{i=1}^{k} (\overline{X}\text{PlotPoint})_i}{k} \tag{4.19}$$

4.2.2.5 Calculating Control Limits

These formulas below to calculate the control limits (the control limit factors D_3 D_4 and A_2 can be found Appendix B - Factors For Control Charts) are given below.

Nominal Range Chart Control Limits;

$$UCL_R = D_4 \times \overline{R} \tag{4.20}$$

$$LCL_R = D_3 \times \overline{R} \tag{4.21}$$

<u>*Nominal X-Bar Chart Control Limits;*</u>

$$UCL_{\overline{X}} = CL_{\overline{X}} + A_2 \times \overline{R} \tag{4.22}$$

$$LCL_{\overline{X}} = CL_{\overline{X}} - A_2 \times \overline{R} \tag{4.23}$$

After the center lines and control limits are drawn on Nominal $\overline{X}$ & R chart, it can be interpreted in almost the same manner as a traditional X-bar and R chart.

4.2.2.6 Assumptions

The Nominal X-bar and R chart allow user to compute one set of control limits for all part numbers because it assumes the process variation (R-bar) of all part numbers is approximately equal. This is usually true if the five "M"s (manpower, machine, material, measurement, method) are similar for all part numbers run on the process.

If the process variation of one part number is more than 30% larger than the others, it cannot be plotted on the same Nominal X-bar and R chart. Because the control limits are dependent on R-bar, this part number would require significantly wider control limits than the others. If this happens, user must either plot this part number on its own separate chart, reduce its variation so it is similar to the others, or use some other short run technique not having this assumption.

To maintain constant control limits, the subgroup size (n) must also be constant for all subgroups of all part numbers because the control limit factors D_3, D_4 and A_2 are a function of n.

4.2.2.7 Calculating Process Capability & Performance Ratios

The average difference from target is not the same for each unique part and/or characteristic, so calculations for $\overline{\overline{X}}$ need to be done separately for each of it. To estimate the process average Equation (4.24) is used.

$$\overline{\overline{X}}_i = \frac{\sum \overline{X}_i}{k} \tag{4.24}$$

The estimation of standard deviation is;

$$\hat{\sigma} = \frac{\overline{R}}{d_2} \quad , \qquad \textit{Where } d_2 \textit{ depends on } n$$

And for each unique part and/or characteristic, Cp and Cpk values should be calculated. For calculation of Cp, Equation 4.9 is used;

$$C_{Pi} = \frac{USL_i - LSL_i}{6\hat{\sigma}} \tag{4.9}$$

$$C_{Pk,i} = MIN\left\{\frac{USL_i - \overline{\overline{X}}_i}{3\hat{\sigma}}, \frac{\overline{\overline{X}}_i - LSL_i}{3\hat{\sigma}}\right\} \tag{4.25}$$

4.2.2.8 Advantages And Disadvantages

Nominal $\overline{X}$ & R Chart Advantages;

- Multiple parts, specifications, or characteristics can be plotted on the same chart (provided they all exhibit similar variability).
- Data from gages that are zeroed out on their target values can be plotted directly on the Nominal X-Bar without further data coding or transformation.
- Statistical control can be assessed both for the process and each unique part and/or characteristic being made.

Nominal $\overline{X}$ & R Chart Disadvantages;

- Control limits are valid only when the $\overline{R}$'s from each part on the chart are similar. When they are not similar, the suspect part(s) must be monitored on a separate chart, or the data must be collectively evaluated on a short run chart.

4.3 Control Charts for Small Lot Production Runs- The Short Run Charts

4.3.1 General Principles and Definitions for Short Run Charts

These special control charts will help the SPC user manage situations where he or she encounters;

- Multiple characteristics
- Dissimilar characteristics and standard deviations
- Short production runs
- Limited quantities of data

In this section four more control charts will be covered, which are listed as;

- Short Run IX & MR Chart or Zed* Charts.
- Short Run $\overline{X}$ & R or (Z*- Sub)

Shor Run Charts

- Zed Charts or Z-Charts
- Zed-Bar Charts or $\overline{Z}$ -Charts

Zed Charts

A variation on the Short Run Chart is Zed Chart. Instead of dividing by sigma(X), the difference between the observed value and the target (Nominal) value is divided by appropriate average range. Short run charts and Zed Charts share common attributes and the derivation of zed charts is similar short run charts. Rather than repeating these commonalties between them, it will be covered once in this overview.

These control charts are designed to be useful with small lot production runs with limited amounts of data. Like the nominal (target) charts, data from different production lots are mathematically coded; however, the short run charts go one step further by converting the plot points into unitless ratios. This allows for the use of common control limits that can be used for multiple part numbers or different characteristics. When one thinks that one just doesn't have enough data to calculate meaningful control limits, one should then investigate the short run charts before giving up.

Short run control charts are based on traditional control charts. The two traditional or core variables control charts are;

- Individual X and Moving Range Chart
- X and Range Chart

These chart types are used to monitor the stability of a process' central tendency (average) and the variation (standard deviation) about that average. All short run charts in this section are derived from one of these two common traditional charts.

Short run charts are designed to monitor characteristics with different feature sizes, units of measure, and different standard deviations all on the same control chart. Like nominal charts, short run charts require data to be mathematically coded. While only averages are coded on nominal charts the short run charts for example, requires coding of both subgroup average and range values.

Short run charts may be used to monitor all key characteristics on a part regardless of its feature type or differences in standard deviation or averages. For example a part's profile, hardness, and surface finish can all be tracked on the same short run chart. Also short run charts may be used to monitor a process' output regardless of the part number or feature type being produced. For example a five-axis milling machine will cut a multitude of different shaped parts and a single short run chart may be set up to monitor the milling machine's ability to hog, finish, drill, ream, and bore in the X, Y, and/or Z axis. Or a short run chart can even be used to track a part as it travels through its manufacturing operations. For example a part's key characteristics at each step of the manufacturing operation can be monitored on the same short run chart. That is, one short run chart could be used to track a part starting with pilot hole drilling, then to hogging, finishing, heat treating, straightening, anodizing, painting, curing, and finally part marking.

Short run charts are necessary when characteristics to be monitored on the same chart have different units of measure and/or have different standard deviations. A short run chart could be used to track taper in thousandths of an inch and Rockwell hardness on the same chart (different units), or to track drilled and reamed holes on the same chart (different standard deviations). [15].

As compared to using traditional control charts, using short run control charts will decrease the number of charts that must be managed, while allowing an increase in the number of characteristics that can be tracked.

4.3.1.1 Short Run Plot Points

Short run plot points are based on the traditional X and R plot points. In order to monitor dissimilar characteristics on the same chart, the plot points must be coded. This coding of data is what allows different units of measure and different product characteristics to be plotted on the same chart.

4.3.1.2 Plot Points for the Short Run Range Chart

Before coding, it is helpful to recall how control limits are calculated on the traditional range chart. Let's assume that for any individual range plot point falling between the control limits found like Equation 2.29 and 2.30 and it is said to be in control.

Upper and lower control limit formulas for traditional R chart.

$$UCL_R = D_4\overline{R} \tag{2.29}$$

$$LCL_R = D_3\overline{R} \tag{2.30}$$

A plot point is in control on an R chart when it falls between the control limits shown in Equation 4.22 Where R is the actual subgroup range value

Traditional R chart inequality.

$$UCL_R > R > LCL_R \quad \text{or} \quad D_4\overline{R} > R > D_3\overline{R} \tag{4.26}$$

To make the R chart plot points unitless ratios, the $\overline{R}$ must be eliminated from the inequality found in Equation 4.26. To eliminate $\overline{R}$ from the calculations without changing the inequality, simply all three terms in Equation 4.26 can be divided by $\overline{R}$.

$$\frac{D_4\overline{R}}{\overline{R}} > \frac{R}{\overline{R}} > \frac{D_3\overline{R}}{\overline{R}}$$

When $\overline{R}$'s are canceled, the result is found in Equation (4.27), in which The new plot point is defined as $\frac{R}{\overline{R}}$.

Coded plot point and control limits for short run R chart

$$D_4 > \frac{R}{\overline{R}} > D_3 \tag{4.27}$$

The $\overline{R}$ for a given process is the expected or "hoped for" average range, so it will renamed as target $\overline{R}$. Therefore, the short run range plot point is defined in Equation 4.28 as,

Short run range plot point formula

$$\text{Short run range plot point} = \frac{R}{Target\,\overline{R}} \tag{4.28}$$

The short run range plot point is the ratio between an actual subgroup range and an expected or target range. This plot point is a unitless ratio. Neither the chart nor its x-axis is constrained by limitations imposed by plotting data representing different units of measure.

4.3.1.2.1 What is Target $\overline{R}$?

Target $\overline{R}$ is the heart of the short run data transformation. It represents an estimated or expected range. There are five methods for estimating target R. Each is described now and listed from most desirable to least desirable.

1. *Use $\overline{R}$ from existing in-control range charts*: When using a traditional range control chart, the standard practice is to calculate the centerline and control limits after about 20 plot points. If the range chart is in control, the limits and centerline are extended into the future and used as baselines. New data are plotted against the established baselines. The limits are recalculated only when there has been a sustained change in the process. Therefore, the centerline on an existing in-control range chart can be used as the target R.

2. *Convert existing inspection sampling data into target $\overline{R}$:* If quality assurance personnel have recorded measurements from the characteristics that represent normal production output, the standard deviation of that data can be converted into a target R using the formula found in Equation 4.29.

Formula for calculating target R from a historical data set

$$Target\ \overline{R} = \left(\frac{d_2}{c_4}\right)s \qquad (4.29)$$

Where, c_4 is based upon the number of historical measurements, d_2 is based upon the anticipated subgroup size of the short run range control chart and s is the sample standard deviation of the historical data set.

3. *Use $\overline{R}$ from similar characteristics, parts, or process parameters:* If no control charts or quality records exist for a new characteristic to be controlled, but data from a similar characteristic exists, use methods 1 or 2 on the similar data to estimate an initial target $\overline{R}$ for the new characteristic.

4. *Investigate the capability of the process:* For example, ask the machinist what tolerance the lathe will hold. Suppose the response is, "It will hold ±0.001." Given this statement, one might assume that the machinist was describing the natural variability (the six sigma spread) of the machine's variability. Assuming this, the standard deviation can be estimated by dividing the total tolerance by six. In this example, the estimated standard deviation would be 0.002/6 = 0.00033. Then method two can be used to convert the estimated s into a target $\overline{R}$.

5. *Use engineering tolerance to establish initial target $\overline{R}$.* If there is no knowledge of the expected standard deviation of the characteristic, an initial target $\overline{R}$ can be taken from the engineering tolerance using one of the following formulas.

   a. For two-sided specifications, Equation 4.30 can be used

$$\text{Target } \overline{R} = \frac{d_2}{6}(\text{USL-LSL}) \qquad (4.30)$$

b. <u>For unilateral, or one-sided specifications, Equation 4.31 can be used</u>

$$Target\,\overline{R} = \frac{d_2}{3}(Specification\,limit - Target\,\overline{\overline{X}}) \qquad (4.31)$$

Note: Method 5 should be used with caution and with full knowledge that a target $\overline{R}$ based on engineering tolerance should not be used as a standard of statistical control. It can, however, be used as a temporary starting point. Once actual data become available, the target $\overline{R}$ should be updated to reflect the new information.

4.3.1.3 Plot Points for the Short Run $\overline{X}$ Chart

From Chapter 2, it is known that traditional $\overline{X}$ control limit formulas are;

<u>Upper and lower control limits for traditional control charts</u>

$$UCL_{\overline{X}} = \overline{\overline{X}} + A_2\overline{R} \qquad (2.31)$$

$$LCL_{\overline{X}} = \overline{\overline{X}} - A_2\overline{R} \qquad (2.32)$$

A plot point (an average) is in control when it falls between $\overline{X}$ chart control limits as defined in Equation 4.32.

<u>Traditional $\overline{X}$ chart inequality</u>

$$UCL_{\overline{X}} > \overline{X} > LCL_{\overline{X}} \quad \text{Or} \quad \overline{\overline{X}} + A_2\overline{R} > \overline{X} > \overline{\overline{X}} - A_2\overline{R} \qquad (4.32)$$

With the short run chart, both $\overline{\overline{X}}$ and $\overline{R}$ need to be removed from the inequality so that only A_2 remains. Doing this will result in a short run $\overline{X}$ chart whose control limits are $-A_2$ and $+A_2$. To do this without changing the inequality, one must first subtract from all three terms like in the Equation 4.33

Subtraction of $\overline{\overline{X}}$ *from traditional* $\overline{X}$ *chart inequality*

$$\left(\overline{\overline{X}} + A_2\overline{R}\right) - \overline{\overline{X}} > \overline{X} - \overline{\overline{X}} > \left(\overline{\overline{X}} - A_2\overline{R}\right) - \overline{\overline{X}} \tag{4.33}$$

And the result of Equation 4.33 will be,

$$A_2\overline{R} > \overline{X} - \overline{\overline{X}} > -A_2\overline{R}$$

Next, $\overline{R}$ must be eliminated from the inequality. This is done by dividing the inequality $\overline{R}$

Division of traditional X chart inequality by $\overline{R}$

$$\frac{A_2\overline{R}}{\overline{R}} > \frac{\overline{X}-\overline{\overline{X}}}{\overline{R}} > \frac{-A_2\overline{R}}{\overline{R}}$$

When user cancel the $\overline{R}$s produces, the result can be found in Equation 4.34.

Coded plot point and control limits for short run $\overline{X}$ *control chart*

$$+A_2 > \frac{\overline{X}-\overline{\overline{X}}}{\overline{R}} > -A_2 \tag{4.34}$$

As a result, the short run X plot point is shown in Equation 4.35

<u>Formula for the short run X plot point</u>

$$\text{Short run } \overline{\text{X}} \text{ plot point} = \frac{\overline{\text{X}}\text{-Target}\overline{\overline{\text{X}}}}{\text{Target}\overline{\text{R}}} \tag{4.35}$$

The short run $\overline{X}$ plot point is the ratio between a coded $\overline{X}$ (deviation from target $\overline{\overline{X}}$) and a target range (target $\overline{R}$).

Short run IX plot points using MR are calculated in a similar fashion as short run X plot points.

<u>*Formula for the short run IX chart plot point*</u>

$$\text{Short run individual X plot point} = \frac{IX - T\arg et\ \overline{\text{IX}}}{T\arg et\overline{MR}} \tag{4.36}$$

4.3.1.3.1 What is Target $\overline{\overline{X}}$?

Target $\overline{\overline{X}}$ is the targeted or expected average of a process parameter or characteristic. There are four ways to estimate target $\overline{\overline{X}}$, each numbered from most desirable to least desirable.

1. *Use $\overline{\overline{X}}$ from existing in-control $\overline{\overline{X}}$ charts*: When using a traditional $\overline{X}$ chart, the standard practice is to calculate the $\overline{X}$ and control limits after about 20 plot points. If the control chart is in control, the limits and centerline are used as baselines. They are extended into the future and current data are plotted against the established centerline and control limits. The limits are recalculated only when there has been a sustained change in the process. Therefore, the centerline on an existing in-control $\overline{X}$ chart can be used as the target $\overline{\overline{X}}$.

2. *Convert existing quality assurance sampling data into target X:* If quality assurance inspection data from the characteristic exist, and the data

represent normal production output, the average of that data can be used as the target $\overline{\overline{X}}$.

3. *Use $\overline{\overline{X}}$ from similar characteristics, parts, or process parameters:* If no control charts or quality records exist for the new characteristic to be controlled, but there exists charts or quality records from a similar characteristic, use methods 1 or 2 on the similar data to estimate an initial target $\overline{\overline{X}}$ for the new characteristic.

4. *Use engineering print nominal as target X:* If there is no knowledge of the expected centering of the characteristic to be monitored, initial target $\overline{\overline{X}}$ can be taken from engineering nominal (the midpoint between the USL and LSL). For unilateral tolerances, we can pick a target value sufficiently (preferably greater than three standard deviations) away from the specification to ensure minimal fallout.

4.3.2 Short Run Individual X and Moving Range Chart(Z* Chart or Z*&W)

4.3.2.1 Description

Only part numbers with similar R-bar values can be plotted on the Nominal IX & MR chart, but in many short run situations part numbers have significantly different amounts of variation. The Nominal IX & MR chart can be modified to handle this situation by coding the piece measurements for not only differences in centering (subtracting target $\overline{\overline{X}}$) but for differences in variation as well (dividing by target $\overline{R}$). The result of this modification is called the "Short Run IX & MR Chart" or "Zed* Charts".

The short run individual X chart is used to monitor and detect changes in individual measurements among characteristics of any type. The characteristics may have different nominals, different units of measure, and different standard deviations, but should be related enough to want to analyze them all on the same chart. The plot points represent individual measurements that are coded by subtracting a target $\overline{IX}$ (usually an engineering nominal value) from each measurement and then dividing the result by a target $\overline{MR}$. Each characteristic on the chart may have a unique target IX and target $\overline{MR}$.

These charts are mostly used to monitor characteristics where only one measurement is necessary to represent a process at a given period of time. Examples include accounting values, homogeneous batches such as concentration in a chemical bath, and characteristics that, due to the nature of the process, the sources of variation change significantly from one sampling opportunity to the next.

The short run moving range chart is used to monitor and detect changes in the standard deviations among characteristics of any type. The plot points on the short run moving range chart represent the absolute difference between consecutive coded short run IX chart plot points.

4.3.2.2 Subgroup Size

For short runs, the IX plot point is based on 1 measurement, the moving range value is calculated from the difference between 2 consecutive IX plot points. The sample size is assumed to be constant during the process.

4.3.2.3 Calculating Plot Points

The IX plot point is coded in a manner similar to the Short Run $\overline{X}$ plot point and given before in equation 4.36. Then the moving range plot point is calculated as done for the Target MR chart.

Formula for the short run IX chart plot point

$$\text{IX plot point} = \frac{\text{IX-Target } \overline{\text{IX}}}{\text{Target}\overline{\text{MR}}} \tag{4.36}$$

Formula for the MR Plot Point

$$\text{MR Plot Point} = \left| \left(IX \text{ Plot Point} \right)_i - \left(IX \text{ Plot Point} \right)_{i-1} \right| \tag{4.37}$$

4.3.2.4 Calculating Centerlines

With this method of coding for the subgroup ranges, the result can be plotted on the Short Run MR chart with a center line of 1. The center line of the Short Run IX chart is 0. Since these are constant values, they can be drawn on the chart before any subgroup data is collected.

MR Chart Center Line;

$$CL_{MR} = 1 \tag{4.38}$$

Short Run IX Chart Center Line;

$$CL_{IX} = 0 \tag{4.39}$$

4.3.2.5 Calculating Control Limits

This special coding method results in control limits for the plot points that are constant and independent of both $\overline{\overline{X}}$ and $\overline{R}$. The control limit factor D_3 is 0 and D_4 is 3.27 (remember, the subgroup size for the moving range is 2). The A_2 (or E_2) factor is 2.66.

MR Chart Control Limits;

$$UCL_{MR} = D_4 = 3.27 \tag{4.40}$$

$$LCL_{MR} = D_3 = 0 \tag{4.41}$$

Short Run IX Chart Control Limits;

$$UCL_{IX} = A_2 = +2.66 \tag{4.42}$$

$$LCL_{IX} = -A_2 = -2.66 \tag{4.43}$$

4.3.2.6 Assumptions

The major assumption, which is common for all IX charts, is that the process output must be normally distributed. This assumption can be checked by plotting the measurements in a histogram, using normal probability paper or conducting a statistical goodness-of-fit test. Also the sample size is constant during the process.

4.3.2.7 Calculating Process Capability & Performance Ratios

Estimates of the process average should be calculated separately for each characteristic or part on the short run IX and MR chart.

Estimate of average for type i

$$I\overline{X}_i = \frac{\sum IX_i}{k_i} \tag{4.44}$$

Estimates of $\hat{\sigma}$ are also calculated separately for each characteristic or location represented on short run IX and MR charts. The calculation of $\overline{MR}$ is

Calculation of the average moving range for type i

$$\overline{MR_i} = \frac{\sum MR_i}{k_i - 1} \tag{4.45}$$

Estimate of the process standard deviation for type i

$$\hat{\sigma}_i = \frac{\overline{MR_i}}{d_2} \tag{4.46}$$

Note: To ensure reliable estimates, k needs to be at least 15.

<u>Calculating Process Capability and Performance Ratios for type i</u>

$$C_{Pi} = \frac{USL_i - LSL_i}{6\hat{\sigma}_i} \tag{4.9}$$

$$C_{Pki} = MIN\left\{\frac{USL_i - \overline{IX}_i}{3\hat{\sigma}_i}, \frac{\overline{IX}_i - LSL_i}{3\hat{\sigma}_i}\right\} \tag{4.47}$$

4.3.2.8 Advantages and Disadvantages

Short Run IX & MR Chart Advantages can be listed as;

- Graphically illustrates the variation of multiple product or process characteristics on the same chart.
- Can chart process parameters that have changing target values.
- Characteristics from different parts with different means, different standard deviations, and different units of measure can be analyzed on the same chart.
- Pinpoints the characteristics that are in need of the most attention.
- Separates variation due to the process from variation that is product specific.

Short Run IX & MR Chart Disadvantages are;

- The MR chart is dependent upon consecutive IX chart plot p

- $\overline{IX}$, $\overline{MR}$, and estimates of $\hat{\sigma}$ must be calculated separately for each characteristic on the chart, as a result difficulties in calculation can be occurred.

4.3.3 Short Run $\overline{X}$ & R (Z*- Sub or $\overline{Z}^*$ & W)

4.3.3.1 Description

Nominal (Target charts) Charts assume the process output variation ($\overline{R}$) of all part numbers charted are similar, but in most manufacturing processes this is usually not true because of changes in material, tooling, or any of the other five "M"s. If the average range changes from part number to part number, then so do the control limits for the Nominal charts since they are a function of $\overline{R}$ (R-bar).

The coding methods used for these charts adjusted the data from different part numbers only for differences in where the process output should be centered. Part numbers with different R-bar values would have to be plotted on separate charts.

The short run X chart is used to monitor and detect changes in the averages among multiple characteristics of any type. The characteristics may have different nominals, different units of measure, and different standard deviations. However, all characteristics on the chart should be related enough to warrant analyzing them together. The plot points are coded by subtracting from each subgroup average its respective target $\overline{\overline{X}}$ (usually the engineering nominal value), and then dividing by its target $\overline{R}$. Each characteristic on the chart has its own unique target $\overline{\overline{X}}$ and target $\overline{R}$.

The short run range chart is used to monitor and detect changes in the standard deviations among multiple characteristics. The plot points are coded by dividing the subgroup range by its respective target $\overline{R}$.

4.3.3.2 Subgroup Size

For each characteristic, the number of measurements taken in a subgroup may range from two to nine, but users generally use subgroup sizes of three to five and mostly two. Constant sample size is assumed during the process.

4.3.3.3 Calculating Plot Points

As it is drive before, the coding formulas for this chart are slightly different. The plot point formulas of $\overline{X}$ and R are;

Short run range plot point formula

$$\text{Short run range plot point} = \frac{R}{Target\,\overline{\overline{R}}} \tag{4.28}$$

Formula for the short run X plot point

$$\text{Short run } \overline{\mathrm{X}} \text{ plot point } = \frac{\overline{X} - Target\,\overline{\overline{X}}}{Target\,\overline{R}} \tag{4.35}$$

4.3.3.4 Calculating Centerlines

With this method of coding for the subgroup ranges, the result can be plotted on the Short Run Range chart with a center line of 1. The center line of the Short Run X-bar chart is 0. Since these are constant values, they can be drawn on the chart before any subgroup data is collected.

R Chart Center Line;

$$CL_R = 1 \tag{4.38}$$

Short Run X-bar Chart Center Line;

$$CL_{\overline{X}} = 0 \tag{4.39}$$

4.3.3.5 Calculating Control Limits

This special coding method results in control limits for the plot points that are independent of both $\overline{\overline{X}}$ and $\overline{R}$. Now part numbers having significantly different output averages and variation can be plotted on the same chart. Notice that the limits are constants and do not need to be calculated. This means they can be drawn on the chart before any data is collected. When the plot points of the first subgroup are charted, one can tell immediately if the process is in or out of control.

R Chart Control Limits;

$$UCL_R = D_4 \tag{4.40}$$

$$LCL_R = D_3 \tag{4.41}$$

Short Run X-bar Chart Control Limits;

$$UCL_{\overline{X}} = +A_2 \tag{4.42}$$

$$LCL_{\overline{X}} = -A_2 \tag{4.43}$$

4.3.3.6 Assumptions

The subgroup size for all subgroups of all part numbers run on the process must be constant. This is because the control limits for the Short Run X-bar and R chart are just the control limit factors, which are a function of the subgroup size.

4.3.3.7 Calculating Process Capability & Performance Ratios

Estimates of the process average and $\hat{\sigma}$ should be calculated separately for each characteristic or part on Short Run $\overline{X}$ & R chart

Estimate of average for type i

$$\overline{\overline{X}}_i = \frac{\sum \overline{X}_i}{k_i} \tag{4.48}$$

Calculation of the average moving range for type i

$$\overline{R_i} = \frac{\sum R_i}{k_i} \tag{4.49}$$

Estimate of the process standard deviation for type i

$$\hat{\sigma}_i = \frac{\overline{R_i}}{d_2} \tag{4.50}$$

Calculating Process Capability and Performance Ratios for type i

$$C_{Pi} = \frac{USL_i - LSL_i}{6\hat{\sigma}_i} \tag{4.9}$$

$$C_{Pki} = MIN\left\{\frac{USL_i - \overline{\overline{X}}_i}{3\hat{\sigma}_i}, \frac{\overline{\overline{X}}_i - LSL_i}{3\hat{\sigma}_i}\right\} \tag{4.25}$$

4.3.3.8 Advantages And Disadvantages

Short Run X and Range Chart Advantages;

- Graphically illustrates the variation of multiple product or process characteristics on the same chart.

- Characteristics from different parts with different means, different standard deviations, and different units of measure can be analyzed on the same chart.
- Pinpoints the characteristics that are in need of the most attention.
- Separates variation due to changes in average from variation due to changes in the standard deviation.
- Separates process variation from product-specific variation.

Short Run X and Range Chart Disadvantages

- The use of negative numbers and unitless ratios may be confusing at first.
- $\overline{\overline{X}}$, $\overline{R}$, and the estimate of σ must be calculated separately for each characteristic on the chart.
- Proper chart analysis requires knowledge of how target values were derived.

4.3.4 Zed Charts

4.3.4.1 Definition

A variation on Short Run IX & R Chart (or Z*& W) is Zed Chart (also called a Z-Chart). Instead of dividing Target $\overline{MR}$, the difference between the observed value and the target value, is divided by the Sigma X (or simply σ). This made calculations little bit complex so that Short Run IX&R chart be mostly preferable and known one.

The Zed Chart makes allowances for different aim points at the same time that it makes allowances for different amounts of dispersion from product to product. In order to use a Zed Chart one will have to have both a Nominal Value and a σ value for each product. The Nominal Values may be either a target value or a grand average value. The σ values will have to be obtained from the Product Control Charts (The user is warned to avoid the use of a single s statistic in obtaining a σ value). The observed value for a given product will be transformed into a Zed value by first subtracting off the Nominal Value for that product and then by dividing this difference by the appropriate σ value for that product.

Point by point the Short run IX Chart and Zed Chart can look identical, but they will have different scales on the vertical axis. The user is free to choose either one. But it is also important not to confuse the two charts because they do have different limits.

4.3.4.2 Subgroup Size

For Zed (Z Charts) Charts, the moving range is calculated from two consecutive IX plot points. The sample size is constant (n=1) and individual measurements are assumed to be normally distributed.

4.3.4.3 Calculating Plot Points

First to calculate IX plot points, sigma (X) for each unique part and/or characteristic have to be calculated. (Look at Equation 4.52 and 4.53)

Then IX plot point is calculated by subtracting the nominal value from the individual piece measurement and dividing this difference to appropriate sigma X. The resulting value will be denoted by the symbol Z and will be plotted on the Zed Chart. (Equation 4.51)

Then the MR plot point is calculated by taking the absolute value of the difference between two consecutive IX plot points. (Equation 4.54) Traditionally this standardized range value is denoted by the symbol W.

The vertical lines in the MR formula means one take the absolute value of the difference between the plot points - the current (i) and the immediately previous one (i-1).

Z Chart plot point formula

$$Z_i = \frac{IX_i\text{-}TargetIX}{\sigma_{IX,i}} \tag{4.51}$$

Where

$$\sigma_{IX,i} = \overline{MR_i} / d_2 \tag{4.52}$$

$$\overline{MR_i} = \frac{\sum MR_i}{k_i - 1} \tag{4.53}$$

W Chart plot point formula

$$\text{W Plot Point} = \left| (IX \text{ Plot Point})_i - (IX \text{ Plot Point})_{i-1} \right| \tag{4.54}$$

Where i =2… k

4.3.4.4 Calculating Centerlines

W Chart Center Line;

$$CL_W = d_2 \tag{4.55}$$

$$CL_W = 1.128 \tag{4.56}$$

Z Chart Center Line;

$$CL_Z = 0 \tag{4.57}$$

4.3.4.5 Calculating Control Limits

W Chart Control Limits;

$$UCL_W = d_2 + 3d_3 \tag{4.58}$$

$$UCL_W = 3.686 \tag{4.59}$$

$$LCL_W = 0 \tag{4.60}$$

Z Chart Control Limits

$$UCL_X = +3 \tag{4.61}$$

$$LCL_X = -3 \tag{4.62}$$

4.3.4.6 Assumptions

The process output must be normally distributed. It can be checked by histogram, using normal probability paper or conducting a statistical goodness-of-fit test. Also the sample size is constant during the process.

4.3.4.7 Calculating Process Capability & Performance Ratios

Estimates of the process average and $\hat{\sigma}$ should be calculated separately for each characteristic or part on Short Run $\overline{X}$ & R chart

Estimate of average for type i

$$I\overline{X}_i = \frac{\sum IX_i}{k_i} \tag{4.48}$$

Calculation of the average moving range for type i

$$\overline{MR}_i = \frac{\sum MR_i}{k_i - 1} \tag{4.53}$$

Estimate of the process standard deviation for type i

$$\sigma_{IX,i} = \overline{MR}_i / d_2 \tag{4.52}$$

Calculating Process Capability and Performance Ratios for type i

For calculating process capability and performance ratios, it is important to establish the number of each unique part and/or characteristic. And for each of it, Cp and Cpk values have to be calculated. So that the formulations will be;

$$C_{Pi} = \frac{USL_i - LSL_i}{6\hat{\sigma}_{IX,i}} \tag{4.63}$$

$$C_{Pki} = MIN\left\{\frac{USL_i - \overline{IX}_i}{3\hat{\sigma}_{IX,i}}, \frac{\overline{IX}_i - LSL_i}{3\hat{\sigma}_{IX,i}}\right\} \tag{4.64}$$

4.3.4.8 Advantages And Disadvantages

Zed Chart advantages are;

- Graphically illustrates the variation of multiple product or process characteristics on the same chart.
- Can chart process parameters that have changing target values.
- Characteristics from different parts with different means, different standard deviations, and different units of measure can be analyzed on the same chart.
- Pinpoints the characteristics that are in need of the most attention.
- Separates variation due to the process from variation that is product specific.

Zed Chart Disadvantages are;

- The W chart is dependent upon consecutive IX chart plot p

- Estimates of $\hat{\sigma}$ must be calculated separately for each characteristic on the chart, for each plot point as a result difficulties in calculation occurred.

4.3.5 Zed-Bar Chart ($\overline{Z}$ & W Chart)

4.3.5.1 Description

The Zed-Bar Chart differs from the Zed Chart enough that the different name is helpful in avoiding confusion. In order to convert the Subgroup Averages and Subgroup Ranges into Zed-Bar and W values one will need:

- A Nominal Value for each product,
- A Sigma $\overline{X}$ value for each product (Equation 4.66 and 4.67)
- A Sigma(X) value for each product.(Equation 4.68 and 4.69)

When these three quantities for each product are obtained, the Subgroup Averages can be converted into Zed-Bar values.

4.3.5.2 Calculating Plot Points

Zed-Bar Chart plot point formula

$$\overline{Z}_i = \frac{\overline{X}_i - T\arg etX}{\sigma_{\overline{X}i}} \tag{4.65}$$

Where

$$\sigma_{\overline{X},i} = \overline{R}_i \Big/ \left(d_2\sqrt{n}\right) \tag{4.66}$$

$$\overline{R}_i = \frac{\sum R_i}{k_i} \tag{4.67}$$

W Chart plot point formula

$$\text{W Plot Point} = R \big/ \sigma_{X,i} \tag{4.68}$$

Where

$$\sigma_{X,i} = \overline{R}_i / d_2 \tag{4.69}$$

4.3.5.1 Calculating Centerlines

W Chart Center Line;

$$CL_W = d_2 \tag{4.55}$$

Z Chart Center Line;

$$CL_Z = 0 \tag{4.57}$$

4.3.5.2 Calculating Control Limits

W Chart Control Limits;

$$UCL_W = d_2 + 3d_3 \tag{4.58}$$

$$UCL_W = d_2 - 3d_3 \tag{4.60}$$

Z Chart Control Limits

$$UCL_X = +3 \tag{4.61}$$

$$LCL_X = -3 \tag{4.62}$$

4.3.5.3 Assumptions

The subgroup size for all subgroups of all part numbers run on the process must be constant. This is because the control limits for the W chart are just the control limit factors, which are a function of the subgroup size.

4.3.5.4 Calculating Process Capability & Performance Ratios

Estimates of the process average and $\hat{\sigma}$ should be calculated separately for each characteristic or part on Short Run $\overline{X}$ & R chart

<u>Estimate of average for type i</u>

$$\overline{X}_i = \frac{\sum X_i}{k_i} \tag{4.48}$$

<u>Calculation of the average moving range for type i</u>

$$\overline{R}_i = \frac{\sum R_i}{k_i} \tag{4.53}$$

<u>Estimate of the process standard deviation for type i</u>

$$\sigma_{X,i} = \overline{R}_i / d_2 \tag{4.52}$$

<u>Calculating Process Capability and Performance Ratios for type i</u>

$$C_{Pi} = \frac{USL_i - LSL_i}{6\hat{\sigma}_{X,i}} \tag{4.61}$$

$$C_{Pki} = MIN\left\{\frac{USL_i - \overline{X}_i}{3\hat{\sigma}_{X,i}}, \frac{\overline{X}_i - LSL_i}{3\hat{\sigma}_{X,i}}\right\} \tag{4.62}$$

4.3.5.5 Advantages And Disadvantages

Zed-sub Chart Advantages;

- Graphically illustrates the variation of multiple product or process characteristics on the same chart.
- Characteristics from different parts with different means, different standard deviations, and different units of measure can be analyzed on the same chart.
- Separates variation due to changes in average from variation due to changes in the standard deviation.
- Separates process variation from product-specific variation.

Zed-sub Chart Disadvantages;

- The estimate of σ and $\overline{\sigma}$ must be calculated separately for each characteristic on the chart.
- Calculations are difficult to obtain.

CHAPTER 5

SOFTWARE DEVEOPED FOR SHORT RUN SPC

5.1 The Need For Short Run SPC Software

The use of computer systems reduces the day-to-day workload of SPC reporting activities and allows production and quality control employees to concentrate on process and quality improvement activities. Thus, growing number of software organizations have begun to focus on applying the concepts of statistical process control to the software process.

Quality Progress provides a quality assurance (QA)/quality control (QC) directory every year. The 14th Annual QA/QC Software Directory lists 255 software programs [47]. Many of these software programs perform the fundamental SPC analyses, while others specialize in particular applications (e.g., gage capability). The prices of the software programs in the directory range anywhere from $500 to as much as $30,000 depending on the number of copies, customized modules, or PC network environment.

Though there are many SPC software packages, few of them include the Short Run SPC charts. For example, MINITAB, one of the best known software, only includes Zed Chart for short run productions. Some specialized software packages include short run charts but they are too costly to purchase or too complicated for intermediate users.

To be enabling the readers to appreciate the problems of software development for the SMEs, it will serve the purpose well to treat the pros and cons of expert systems in brief.

5.1.1 Definition of Expert Systems

It is not easy to give a precise definition of expert systems, because the concept of expert system is a changing one, therefore some known ones are;

- "An intelligent computer program that uses knowledge and inference procedures to solve problems that is difficult enough to require significant human expertise for their solution". [45]
- "Expert Systems are a class of computer programs that can advise, analyze, categorize, communicate, consult, design, diagnose, explain, explore, forecast, form concepts, identify, interpret, justify, learn, manage, monitor, plan, present, retrieve, schedule, test, and tutor. They address problems normally thought to require human specialists for their solution". [35]
- According to Michaelsen, expert systems defined as "A class of computer programs intended to serve as consultants for decision making. They address problems normally thought to require human specialists for their solution." [35]
- "Expert systems are computer systems encoded with human knowledge and expertise that solve problems at an expert level of performance in a specific problem area or domain." [36]
- Fotr defines expert systems as "Practical implementation of the research in one area of the artificial intelligence". [34]
- "An Expert System is a computer system which emulates the human decision-making ability of a human expert" [44]

- "An expert system is a computer program that represents and reasons with knowledge of some specialist subject with a view to solving problems or giving advice" [46]

5.1.2 The Advantages of Expert Systems

- *Permanence :* Expert systems do not forget, but human experts may
- *Reproducibility:* Many copies of an expert system can be made, but training new human experts is time-consuming and expensive
- If there is a maze of rules (e.g. tax and auditing), then the expert system can "unravel" the maze
- *Efficiency:* can increase throughput and decrease personnel costs. Although expert systems are expensive to build and maintain, they are inexpensive to operate. Development and maintenance costs can be spread over many users. The overall cost can be quite reasonable when compared to expensive and scarce human experts. Cost savings: Wages - (elimination of a room full of clerks) Other costs - (minimize loan loss)
- *Consistency:* With expert systems similar transactions handled in the same way. The system will make comparable recommendations for like situations.
- Humans are influenced by recently effects (most recent information having a disproportionate impact on judgment) primacy effects (early information dominates the judgment).
- *Documentation:* An expert system can provide permanent documentation of the decision process.
- *Completeness:* An expert system can review all the transactions, a human expert can only review a sample.
- *Timeliness:* Fraud and/or errors can be prevented. Information is available sooner for decision making.

- *Breadth:* The knowledge of multiple human experts can be combined to give a system more breadth that a single person is likely to achieve
- Reduce risk of doing business.
- Consistency of decision making.
- *Entry barriers:* Expert systems can help a firm create entry barriers for potential competitors.
- *Differentiation:* In some cases, an expert system can differentiate a product or can be related to the focus of the firm.
- Computer programs are best in those situations where there is a structure that is noted as previously existing or can be elicited.

5.1.3 Criticisms of Expert Systems

When the rule set for an expert system is written, the knowledge of humans is observed. Video tapes, interviews, protocol, and other techniques are used to try to capture the thought process of experts. A problem with expert systems is writing the rules themselves. Thought processes that are highly rule oriented are easier to write than ones that rely more on creativity or intuition. Another problem is that often experts themselves disagree. Different experts might take different courses of action or go through different thought processes when given the same problem to solve. Thus there is disagreement in the professional community about the validity of expert systems.

Expert systems are improving as technology advances. In the past, expert systems have received criticism and some negative publicity because of the failures that were highly publicized. Unfortunately, the successes are less publicized, because companies want to maintain their competitive edge. Expert systems are a great tool for companies especially, as depicted here, companies in finance. It is important for companies to remember, however, that humans should make the final decision, and not the computer. Humans still have the insight and intuition that computers are unable to possess for now, anyway.

5.1.4 SPC & Expert Systems

Quality control is a major component of any methods improvement program with the objective of minimizing losses due to rejection, scrap and reworked production. Statistical process control, which is a form of quality control, contributes to this objective by helping the company to understand its operations as a set of processes.

A process must be a value added activity with inputs and measurable outputs. In general, if the outputs cannot be measured they cannot be managed. Hence, quality or process engineer must be familiar with the available process measurements as well as ways of presenting the information gathered in a way that will communicate the state of the process to management and the personnel involved in the process. One method of doing this is the use of control charts.

Control charts are a very effective way of showing the capability and state of control of a process [37]. Some control charts can provide information on the process mean and variability while others provide information on the average number of defective items produced by the process [38]. There are more than thirty different types of control charts with variations depending on the application in which they are used. Each control chart type is designed to provide some information about the process. Out of these available charts, eight are commonly used (which were called traditional control charts) while the remaining are very specialized and rarely encountered.

5.1.5 Basic Structure of the Software

Deciding which type of control chart is appropriate for a specific process can be a difficult task requiring expertise that can be represented through an expert system. The basic purpose of the expert system in question is to provide a tool to assist the process or quality engineer in the selection of the best control chart for the given application.

There are several control charts applicable to each of the areas following selection among them depends on sample size *or* sample variability, amount of information available and type of information required from the chart, to name a few considerations.

As was mentioned, the aim of this wizard is to develop an expert system for control chart selection to use the right control chart for specific case. The expert system has three main goals; to offer to user guidance for selection of suitable control chart which is fitting special conditions of the analyzed process, easy data entrance with user friendly interface, quick and consistent solutions. During the consultation the knowledge based system asks questions to determine the type of data to be tracked, the resources available for chart calculation as well as the information needed from the control chart. Developed expert system then determines the best control chart for the situation along with any recommendations as to the best application of the suggested chart.

5.1.6 Control Chart Selection Tree and Previous Works

A prototype expert system for selecting control charts is developed by Cihan H. Dağlı and Richard Stacey in 1988. The structure of a prototype expert system provides support to the process or quality engineer in the selection of the proper type of control charts to use in tracking the state of the process. But only 14 charts are available and the software works in a DOS environment. [39]

D. T. Pham, E. Oztemel believed that the majority of available microcomputer packages for statistical process control are off-line programs which present information regarding quality in the form of control charts. The user has to interpret the charts to infer process and product quality. D. T. Pham, E. Oztemel describes XPC, an on-line expert system for SPC. The system produces mean and range charts and interprets them automatically. XPC consists of five main modules. The first module ascertains process parameters and constructs the charts. The second module performs capability analysis to ensure that these control charts are compatible with the process specifications. The third module interprets on-line data, detects possible out-of-control situations and suggests corrective actions. The fourth module updates the charts to improve process capability. The last module produces periodical reports. XPC is based on Leonardo, an expert system shell with a hybrid knowledge representation facility enabling the use of rules, rule sets, frames, procedures and classes. However, the software uses DOS work environment and can only interpret X Bar and R chart [42]

A. S. M. Masud, M. S. Thenappan said implementation of an effective quality management system requires the ready availability of expert statistical quality control practitioners. However, this expertise may be unavailable to many small and medium size manufacturing organizations. Knowledge-based systems (KBS) can be used to make SQC expertise easily available to these organizations. For that aim they develop software ASQC. It provide assistance in the selection and design of appropriate quality control charts, the process monitoring analyses and providing corrective advice based on the monitoring analyses results. The KBS runs on a microcomputer and has been developed using a commercially available development shell. However, number of control chart is limited and decision selection tree is given below; [43]

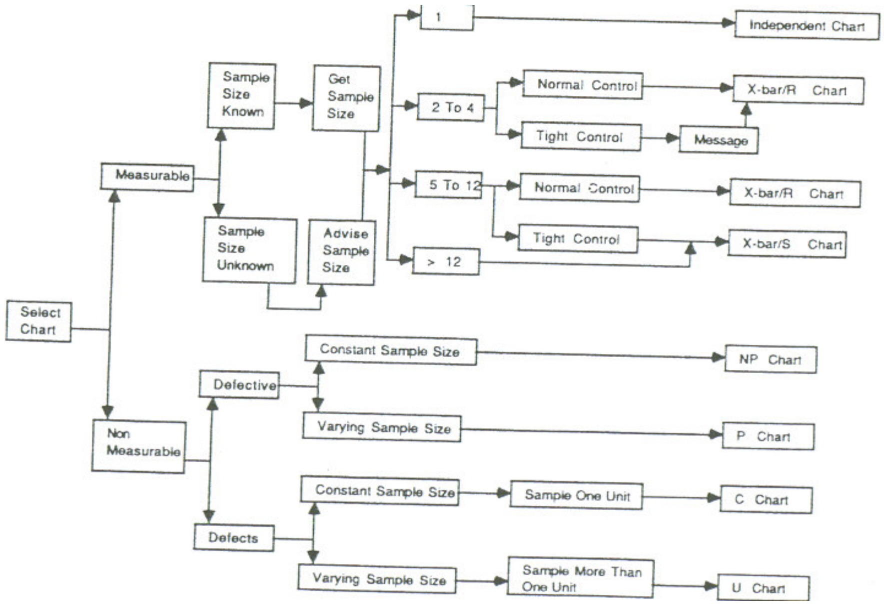


Figure 5.1: Control Chart Selection Heuristic Developed By A. S. M. Masud and M. S. Thenappan

In his study V. Deslandrest and H. Pierrev, have presented an expert advisory quality control system called SYSMIQ (SYSteme .pour la Maıtrise Intelligente de la Qualite, Le., intelligent system for quality control). The system provides expertise in the selection of quality methods and appropriate procedures. More than twenty five quality methods are available in the knowledge-base. It also provides assistance in the implementation of these tools on the shop floor, in order to control manufacturing processes. As a result, SYSMIQ greatly facilitates the diffusion of quality techniques and skills through people daily faced with quality problems, and thereby contribute to the success of the implementation of total quality control concepts, however short run charts are not available in SYSMIQ. [41]

An advisory System for control Chart Selection is presented by Alexander and Jagannathan. System is not only used to advise the suitable control chart but also to construct and interpret it. Charts available in the system are; X Bar & Range Chart, Individual X & Moving Range Chart, Cusum Chart ,EWMA Chart, Np Chart, P Chart, U Chart, C Chart Modified X bar & R Chart, Geometric Moving Average Chart. Explanation facility is not available. [44]

Montgomery gives a practical guide for statistical process chart selection in the entrance of his book Introduction to Statistical Process Control. Short run control charts are not available in the tree. Detailed picture of it is given below; [1]

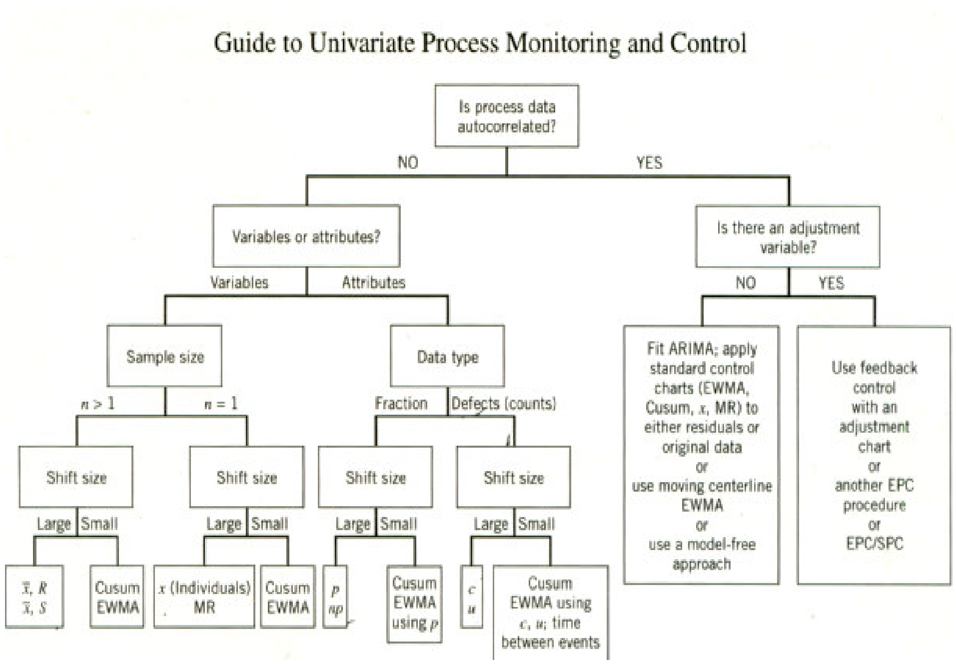


Figure 5.2: Montgomery's guide for control chart selection.

Malak developed a chart selection expert system called CSES. For its initial version twenty six charts are available. Multivariate charts and charts for auto correlated data and short run charts have not considered in the system. KAPPA has been chosen for the CSES development. Explanation facility is available. [40]

Bothe presented an application decision chart to resolve many of the problems associated with applying SPC to short production runs when dealing with attribute data. It help user for selecting the proper short run chart when working with attribute data. [14]

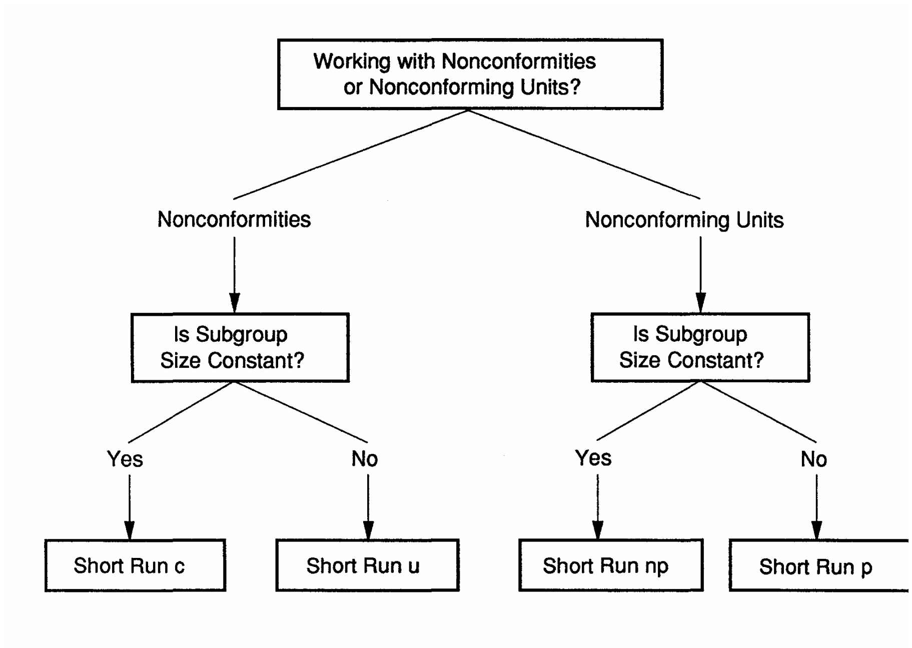


Figure 5.3: Decision Tree for Short Run Variable Data [14]

In their book, Innovative Control Charting - Practical SPC Solutions for Today's Manufacturing Environment, Wise and Fair, recommend control chart decision tree used to determine which control chart is appropriate for short run variable data. The tree is given below; [15]

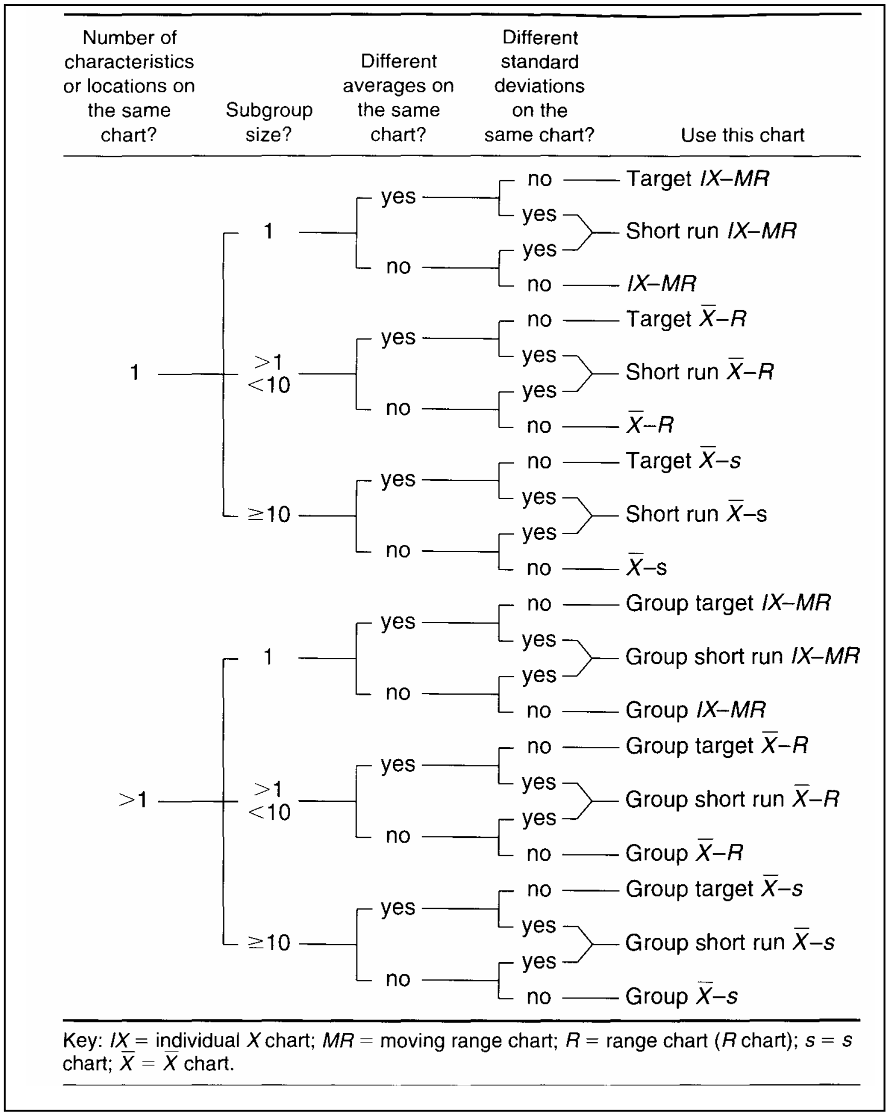


Figure5.4: Control Chart Selection Tree for Short Run Variable Data [15]

To form our expert system, all these previous works were tried to combine and a detailed control chart selection tree was performed in the Appendix A2. However this version was only a prototype. Some additional questions like; autocorrelation or not, inspection cost versus manufacturing cost, skill level of the operator high or not, type of data distribution (Normal, Binomial, or Poisson…?) can be asked and added to control chart selection tree. To facilitate the wizard for SME workers, these subjects did not added to the prototype. As a future work or improved versions of the expert system, these subjects can be added to the software.

5.1.7 The Software "Expert System Builder"

To perform our control chart selection expert system, the "Expert System Builder (built4.2.2)" was used. "Expert System Builder" is a program intended to simplify the development of practical fuzzy expert systems that can be used in the day-to-day decision making processes of most organizations. The resultant system can be deployed locally or it can be deployed onto the Internet with JavaESB.

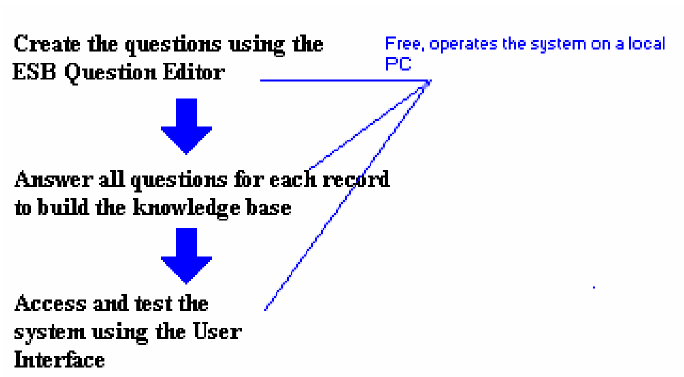


Figure5.5: Order of operations.

The standard system, currently ESB4.2, is PC based and provides the means to develop knowledge based system that can be operated on a Windows PC (95, 98, Me, 2000 and XP). The system comprises three programs: namely the Question Editor**,** Knowledge Acquisition and User Interface programs. Together, these allow non-programmers to develop their own expert or knowledge based computer systems. The order of operations can be seen in Figure: 5.5. Each of these programs is described below.

5.1.8 The ESB Question Editor

The ESB Question Editor is the program used to start developing the system. It is used to build a bank of questions, and the series of associated responses, upon which the complete system is developed. The questions developed here form the backbone of the complete system. Dependencies between questions are set-up such that one question is only asked if the responses given previously deem so. Questions are assigned an importance so that key questions have a greater effect on the final outcome. Questions can be expanded upon by linking the question to a URL on the Internet or local machine. The questions determined for our control chart selection is given below;

1. Would you like to get information about Statistical Process Control and its principles?

    - No, continue without information.
    - Yes, I am quite sure about SPC.
2. Define the number of subgroups (k) you will use.
    - Between 25 and 100.
    - More than 100.
3. Is the measurement to be taken on the sample a destructive measurement?
    - Normal.
    - A destructive measurement, samples can be damaged.
4. Dou you want your chart to be sensitive enough to detect small shifts?
    - Not necessary.
    - Sensitive to small shifts.
5. Define type of your data for short run charts.
    - Variable.
    - Attribute.
6. Define type of your data.
    - Variable.
    - Attribute.
7. Is your non measurable data, defects (counts) or defectives (fractions)?
    - Defects (counts).
    - Defectives (fractions).
8. Is your subgroup size, n, constant or varying?

- Constant.
- Varying.

9. How many characteristics are to be monitored on the same chart?
    - One.
    - More than one.
10. What is the subgroup size (n)?
    - One (n=1).
    - Greater than one but less than ten (1<n<10).
    - Greater than or equal to ten (n=10 or n>10).
11. Are the characteristics with different averages going to be evaluated on the same chart?
    - Yes¸ different averages on the same chart.
    - No.
12. Is the variation between different characteristics is similar or not?
    - Similar (R bars with in 30%).
    - Not similar (R bars out of 30%).
13. Define type of your data to detect small shifts
    - Measurable (Variable).
    - Non measurable (Attribute).
14. Is your non measurable data to detect small shifts defects (counts) or defectives (fractions)?
    - Defects (counts).
    - Defectives (fractions).
15. Is your subgroup size, n, for small shifts constant or varying?
    - Constant.
    - Varying.
16. Is your non measurable data, defects (counts) or defectives (fractions) for short runs?
    - Defects (counts).
    - Defectives (fractions).
17. Is your subgroup size, n, for short runs constant or varying?
    - Constant.

- Varying.

5.1.9 The ESB Knowledge Acquisition Program

The second in the series, the Knowledge Acquisition program, is used to populate the knowledge base of the system. The system developer enters records into the system and assigns a weighting to each of the options associated with each question in the system for the new record. That is to say some options on a particular question will add to the probability of the record being the correct answer whilst other will detract from it. These weightings are then used by the User Interface program, together with the user's actual responses, to determine which records to recommend. Records used in our expert system are given below;

- Short Run Individual X And Moving Range Chart
- Zed And W Chart
- Individual X And Moving Range Chart
- Target Individual X And Moving Range Chart
- Short Run X Bar And Range Chart
- Target X Bar And Range Chart
- Zed Bar And W Chart
- Short Run X Bar And S Chart
- Group Target Individual X And Moving Range Chart
- Group Short Run Individual X And Moving Range Chart
- Group Individual X And Moving Range Chart
- Group Short Run X Bar And Range Chart
- Group X Bar And Range Chart
- Group Target X Bar And S Chart
- Group Short Run X Bar And S Chart
- Group X Bar And S Chart
- Cusum Chart
- EWMA Chart
- Short Run Np Chart

- Short Run P Chart
- Cusum Np Chart
- Cusum U Chart
- EWMA U Chart
- Cusum C Chart
- EWMA C Chart
- Short Run U Chart
- Short Run C Chart
- X Bar And S Chart
- Np Chart
- P Chart
- U Chart
- C Chart
- Target X Bar And S Chart
- X Bar And Range Chart
- Group Target X Bar And Range Chart
- EWMA Np Chart
- Cusum P Chart
- EWMA P Chart
- Information About SPC

Records are described by linking the record to a URL on the Internet or local machine. This allows a user to be directed to the recommendation of the system with ease. The example of it can be seen in example case study at chapter 6. For initial version of the system thirty nine charts available in the record, however multivariate charts and charts for auto correlated data have not considered in the system.

5.1.10 The ESB User Interface Program

The User Interface collates all of the information entered in the above two programs and presents the user with a set of questions to answer. Using the user inputs, the knowledge base of information entered with the knowledge acquisition program and its own inference engine the system uses “fuzzy logic” to determine the records that best suit the data entered by the user. This is presented as an ordered table with the best at the top and the worst at the bottom. The picture and text descriptions of each record can be displayed at the click of a button.

5.2 Basic Requirements As Regards The User

The aim of this thesis is to supplement the activities of SMEs, who have limited resources. The software developed meets the following essential requirements;

- *User friendly*: The developed software is easy to learn, and use, while providing error free data entry, highly visual user interface, and easy to interpret outputs.
- *In Turkish:* Most of the Turkish SME employees have problems in understanding and using software which is in English. None of the existing software has Turkish language version or component available.
- *Compatibility with other softwares*: The developed software is compatible with other software programs for data import and export purposes and compatible with any existing program. Microsoft’s Visual Basic was chosen as program language.
- *Perform statistical operations*: Software provides the short run control charts. The software, constructs plot points, centerlines, upper control limits, lower control limits, and process capabilities. Minimizes calculation errors, estimates σ. Interpret chart by using tests, take output of test results in to a Word Document. Take output of constructed chart in to an Excel Worksheet. All these are achieved with a user friendly interface and easy data entrance.

- *Flexibility for future expansion:* The software developed as flexible as to expand in the future. All the charts are coded in different forms; therefore new charts can be self-trained. Because all the data are coded in Access, other SPC applications can be applied to the software like histogram.
- *Training:* Technical support and help programs are included in the software. By reading these, user can be trained. Also control chart selection wizard help users to select the proper chart for the specific case. Selecting the right chart is one of the major problems that SPC users mostly encounter.

5.3 Components of the Software

The components of the software can be outlined below and explained in detail in chapter.

- New project (as “Yeni Proje”)
- Open Project (as “Proje Aç”)
- Delete Project (as“Proje Sil”)
- Control Chart Selection Wizard (as “Diagram Sihirbazı”)
- Parameters (as “Parametreler”)
- Help (as“Yardım”)
- Select Control Chart (as“Diagram Seç”)
- Option (as “Tercihler”)
- Construct Chart (as“Chart Çiz”)
- Tests (as “Testler”)
- Output (as “Yazdır”)

5.3.1 Data Storage Structure

Microsoft Hierarchical FlexGrid (MSHFlexGrid) is employed for data input by the user. It controls displays, operates on tabular data, and allows complete flexibility to sort, merge, and format tables containing strings and pictures. The Row and Col properties specify the current cell in an MSHFlexGrid. User can enter data by a user friendly interface like an Excel worksheet. To store the data, Microsoft Access 2002 is chosen. Access was preferred because of compatibility with Microsoft Visual Basic.

A table is a collection of data about a specific topic, such as products or part number. To store data, a separate table for each topic is used. This results in a more efficient database and fewer data-entry errors.

The tables used in the data base and the relations between them can be seen in the Figure 5.6.

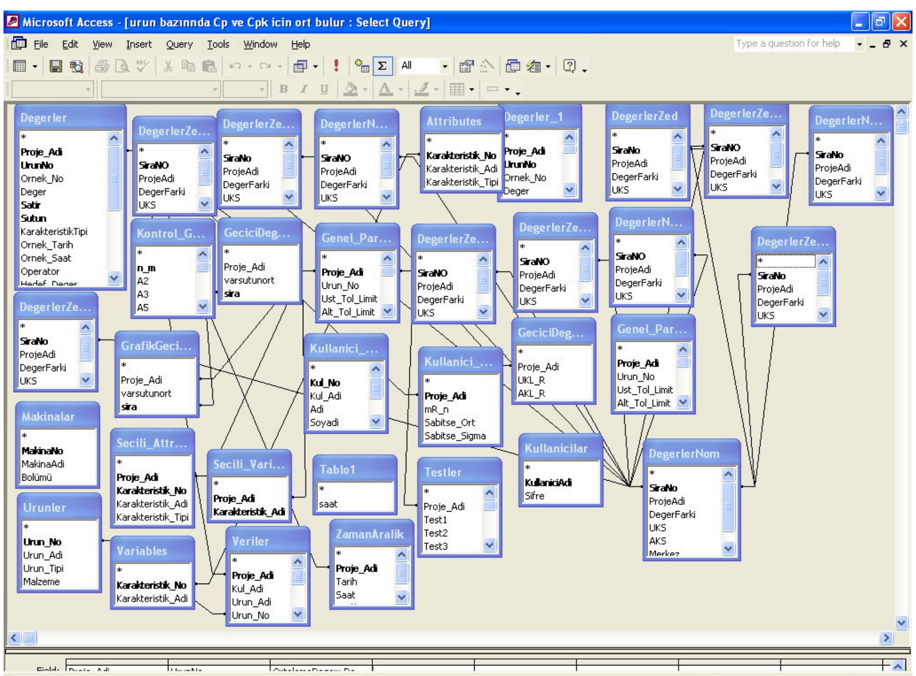


Figure 5.6: Tables used in the database

Queries are used to view, change, and analyze data for the software. There are several types of queries mostly preferred which are Select and SQL query.

An SQL query is a query created by using a Structured Query Language (SQL) statement that can be used to query, update, and manage relational database. When a query is created in query Design view, Access constructs the equivalent SQL statements behind the scenes for user. In fact, most query properties in the property sheet in query Design view have equivalent clauses and options available in SQL view. These statements are frequently used in the software. For Example by SQL statement given below is used to take the distinct records ("degerler", "hedef değer and "ürün no" ordered by "ürün no") from "Degerler" table where target value is different than zero and project name is called" Deneme Z sub group", from the database.

SELECT DISTINCT Degerler.Proje_Adi, Degerler.UrunNo, Degerler.Hedef_Deger

FROM Degerler

WHERE Degerler.Hedef_Deger<>0 And Degerler.Proje_Adi='Deneme Z sub_group'

ORDER BY urunno

5.3.1.1 Opening New Project, Opening Existing Project and Deleting Project

After the enterance animation (Appendix A1, Figure A1.1), and login(Appendix A1, Figure A1.2), the first form seen is called Main Menu (Appendix A1, Figure A1.3).

The first three option is used for data storage structure. First option, called "Yeni Proje", is used for opening a new project. Project name is primary key of the database therefore, to use software user firstly have to open a new project. After option “Yeni Proje” is selected and button “Tamam” is pressed, form in the Figure A1.4 becomes visible. From that form information’s like; Project name, User name, Process Name, Sub Group Size, Time interval for acceptance sampling and characteristic names are gathered.

If an existing project is wanted to examine, option “Proje Aç” should be used and to delete an existing project, option “Proje Sil” can be used.

5.3.2 Defining Parameters

When option “Parametreler” is selected and button “Tamam” is pressed, then Figure A1.13 becomes visible. This form has four main functions; defining products, characteristics, passwords, and machines. All the parameters are added to the software by this menu. For example under products menu, all the products used in the projects are available. By adding new option, new product names can be added to the software or by deleting option an existing unused product names can be deleted. In addition to these by updating option, existing product names can be updated. These options are valid for the other three functions.

5.3.3 Construction of Short Run Control Charts

First thing to construct the chart is to calculate the values of the charts like Centerline, Control Limits, X and R plot points. Because each chart has its own formulations, for each one different form and methodologies are used.

As it is stated before, the data collected from the user was stored in Access in “Degerler” table. For each of short run chart necessary data are called by an SQL statement. For example to calculate X Nominal value for X Nominal-Sub Chart, it is necessary to calculate the average of each Subgroup. Then for each product this average is subtracted from its target value and attached to a temporary database. The code of this operation is given below, for other calculations similar codes are used.

```
sqlstr = "SELECT Degerler.UrunNo, Degerler.Sutun, Avg(Degerler.Deger) AS OrtalamaDeger"
sqlstr = sqlstr & " FROM Degerler GROUP BY Degerler.Proje_Adi,Degerler.Sutun,Degerler.UrunNo "
sqlstr = sqlstr & " HAVING Degerler.Proje_Adi='" & varprojeadi & "' order by sutun"
adogecici.RecordSource = sqlstr .
adogecici.Refresh
```

The essential values, calculated for each chart are written to MSFlex grid component. It is the selected because of being flexible for data entrance and having a user friendly interface like an Excel Worksheet. By this interface user have better observation and interpretation ability. (See Figure A1.8) MSChart component of Visual Basic is used to graphically displays data. The MSChart supports true three and two dimensional representation for all major chart types and data grid population via random data and data arrays. The MSChart control is associated with a data grid (DataGrid object). This data grid is a table that holds the data being charted. The data grid can also include labels used to identify series and categories on the chart. The person who designs the chart application fills the data grid with information by inserting data or by importing data from a spreadsheet or array.

5.3.4 Interpretation of Control Charts

To interpret control charts four rules are used which was given in chapter 2.6. Each rule works as different subprograms. All the rules are applied for X and R chart. They are applied, as if they are selected in options menu. An example code is given in Appendix D.1.

Rules are coded as flexible as short run users can prefer. For example in Test 1, it is interrogated if a single point outside either three sigmas limits or not. From options menu, user can change this three sigma limit as two or one sigma limits. In such a case the software will detect the points that are outside the two or one sigma limits. To prevent users overlooks options form always become visible after selecting a chart type. This approach is applied for all tests. (See FigureA1.10: Output of Chart Interpretation, Figure A1.9: Chart Interpretation, Figure A1.7: Preferences)

When all the tests are applied and unusual points are founded, the users have the opportunity to take the output of the test as a Microsoft Word Document.

5.3.5 Output of the Software

The output of the tests is written to a Microsoft Word Document as explained in the previous topic.

To take the output of constructed chart Microsoft Excel Worksheet is preferred, because Microsoft Visual Basic is poor when it is tried to take the output of a form. All the calculated plot points and control limits for each chart is recorded in Access in tables. By using these data and Excel Chart Wizard the output of the each chart obtained again. (See Figure A1.10: Output of Chart Interpretation and Figure A1.11: Output of Chart Construction)

5.3.6 Help

One of the most important components of softwares is their technical support power. For our software it is Help files. Help files are created by Windows Help Designer/HTML Edition version 3.8.7 which is a 32-bit application for creating HTML Help files. Windows Help Designer/HTML is an executable program designed to help users create help systems using source files based on Hypertext Markup Language (HTML). It is designed for authors or developers who create content for software programs intranets, extranets, or for the Internet. With its easy-to-use interface, WHD HTML Help allows us to organize the different files that make up the content of our help system into a single project (.hhp) file. To access the help files users only have to press the "Yardim" button in the forms (See Appendix A1.3: Main Menu). Help files of the software created in Turkish to be more understandable and trainer. The help files of the Wizard are created in English, because Wizard is created by software called Expert System Builder, which has not Turkish Language support.

CHAPTER 6

EXPERIMENTAL VERIFICATON

6.1 Introduction of Company

The software developed and the feasibility of the employing short run SPCs were tested at the Ankara plant of Arçelik. Quality is predominantly important for Arçelik and Arçelik is the winner of the EFQM quality award in the year 2000.it can be said that the software developed went through rigorous testing at Arçelik Plant and was subjected to expert criticisms.

The proposed program of investigation and the basic features and requirements of software were initially discussed with the experts of the Plant. As a result, the most suitable process for experimental verification was determined to be welded construction group ("kaynaklı yapı grubu").

In Arçelik, manufacturing of dishwashers are started in 1985 at Çayırova. The construction of Arçelik Dishwasher Plant, new factory of company, had started in 1992 and finished in eleven months in Ankara. Manufacturing in the company started in 1993. Now with 109 thousand square meters open-land and factory with thirty two thousand square meters area, company keeps on its manufacturing with high technology at international standards. With the introduction of ancestry products, company form its product family. In year 2003, Arçelik managed to produce 400 thousand high quality products and import fifty five different countries which most of it was a member of European Union. Company deserve EFQM Quality award in year 2000.

6.2 Trial Run of Short Run SPC Software

6.2.1 Selecting The Critical Points

Manufacturing of welded construction group is one of the most critical operations in the company, because; all the parts are assembled onto that part. A faulty “group” on that part can cause greater problems; even leading to the scrap of dishwasher. For example; a deviation of 579.4mm ± 0.5 (in part no 1897500300) can cause a fitting problem of the door of the dishwasher.

It will shed light on the points to follow if the past of the existing practice is briefly mentioned: Forty two critical measurements were being taken from the welded construction group. Because each of the measurement had different target, each needed different quality control chart. This caused confusion and cause difficulties not only in calculation and construction of control charts but also in interpretation of process; not to mention lots of paper work. Eventually managing forty-two different charts led to the users giving up using quality control charts. At present, only the row data is collected and compared against the specifications without charting. If the data collected is different from the specifications, the quality inspector warns the engineer and foreman of the welded construction group department to investigate the cause and to remedy the fault.

By this method, out of control conditions can be determined. But to determine the trends, shifts or randomness tests would be difficult. In this manner, the problem is corrected after it has occurred or has just occurred. Thus, determination of the unusual events depends on the skill of the quality control group.

It was proposed to employ short run charts in conjunction with the usual practice in order to determine the process.

For experimental investigation, parts with number, 18975002, 18975005, and 18975006, were chosen. These parts had critical dimensions K02, K05 and K06 as shown in the Figure 6.1 and 6.2. Number of critical dimensions could have been increased. However it was initially limited for better observation.

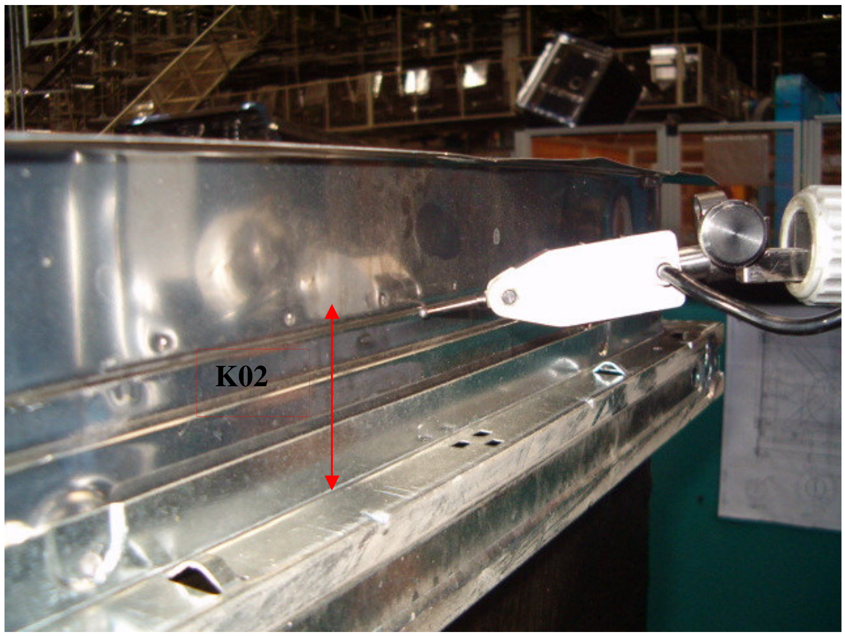


Figure 6.1: Critical dimension K02 (Part No: 18975002). Recorded = Measured = 40.85 mm.

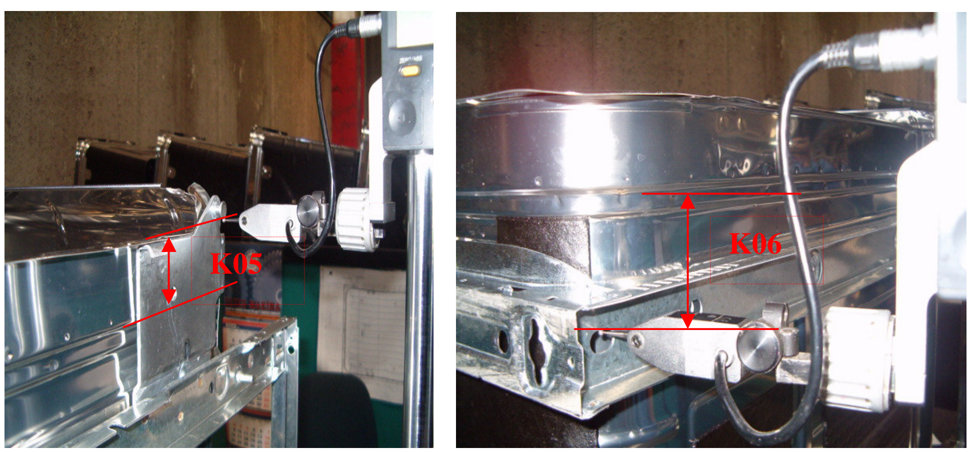


Figure 6.2: Critical dimensions K05 (18975005) and K06 (18975006). For K05, Recorded (55.43mm) = Measured (50.03 mm) + 5.4 mm (r) and for K06, Recorded (62.43 mm) = Measured (57.43 mm) + 5 mm (r)

6.2.2 Data Collection Strategy

Subgroup size was selected as three and the data was gathered during three shifts. The collected data is given in Table 6.1

Table 6.1: Data collected for measurement 18975002, 18975005 and 18975006

Sample Group	Date	18975002	18975005	18975006
1	24.05.2004	41.18	56.05	61.95
1	24.05.2004	41.26	55.75	62.04
1	24.05.2004	41.41	55.9	61.82
2	25.05.2004	41.52	55.6	61.75
2	25.05.2004	41.40	55.8	61.96
2	25.05.2004	41.44	55.65	62.13
3	26.05.2004	41.39	55.92	61.92
3	26.05.2004	41.60	56.17	62.04
3	26.05.2004	41.64	55.68	62.08
4	27.05.2004	41.47	55.72	61.64
4	27.05.2004	41.33	55.76	61.82
4	27.05.2004	41.33	55.97	61.83
5	28.05.2004	41.34	56.32	62
5	28.05.2004	41.58	55.74	62.03
5	28.05.2004	41.85	55.88	61.71
6	29.05.2004	41.22	56.08	62.09
6	29.05.2004	41.55	55.75	61.97
6	29.05.2004	41.42	56.4	62.19
7	30.05.2004	41.63	55.99	62.09
7	30.05.2004	41.42	56.09	61.81
7	30.05.2004	41.34	55.9	61.84
8	31.05.2004	41.69	55.93	61.83
8	31.05.2004	41.46	55.6	62.11
8	31.05.2004	41.63	55.88	61.96
9	01.06.2004	41.40	56.07	61.6
9	01.06.2004	41.55	56.02	62.2
9	01.06.2004	41.51	55.99	61.9
10	02.06.2004	41.33	55.81	62.16
10	02.06.2004	41.37	56.07	62.2
10	02.06.2004	41.39	55.91	62.11
11	03.06.2004	41.52	56.3	62.12
11	03.06.2004	41.52	56.03	62.16
11	03.06.2004	41.22	56.17	62.3
12	04.06.2004	41.54	55.97	61.95
12	04.06.2004	41.37	56.15	62.01
12	04.06.2004	41.20	56.1	62.03
13	05.06.2004	41.42	56.21	62.36

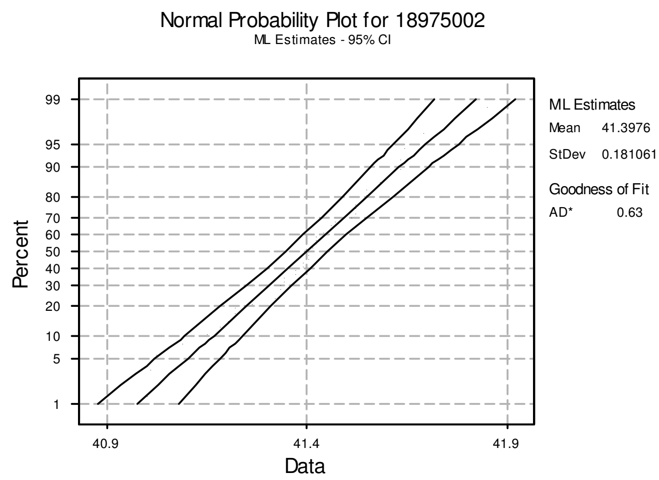
13	05.06.2004	41.40	56.15	62.03
13	05.06.2004	41.02	55.87	62.33
14	06.06.2004	41.32	55.85	61.9
14	06.06.2004	41. 45	56.1	62.22
14	06.06.2004	41.46	56.25	62.11
15	07.06.2004	41.01	56.04	62.2
15	07.06.2004	41.15	56.17	62.51
15	07.06.2004	41.09	55.87	62.3

6.2.3 Normality Test of Data

It is important to check the normality assumption when using the control charts. Because control charts are very sensitive to non-normality especially individual charts. A simple way to do this is with the normal probability plot or histogram.

Probability plot is used to assess whether normal distribution fits the data. Graphical output consists of a single probability plot. If the points in a probability plot are within the confidence intervals, it can be judged that the fit of normal distribution is a good one. Usually, points outside the confidence limits occur mostly in the tails. For small probabilities, points above the upper confidence limit indicate that there are more data in the left tail than one would expect. For large probabilities, points below the lower limit indicate that there are more data in the right tail than one would expect. The opposite conditions imply less data than expected.

The normal probability plot and the histogram of the data collected from K02, K05, K06 dimensions are given in Figures 6.3-5.



Descriptive Statistics: 18975002

Variable	N	Mean	Median	TrMean	StDev	SE Mean
18975002	45	41.398	41.400	41.399	0.183	0.027

Variable	Minimum	Maximum	Q1	Q3
18975002	41.000	41.850	41.325	41.520

Histogram (with Normal Curve) of 18975002

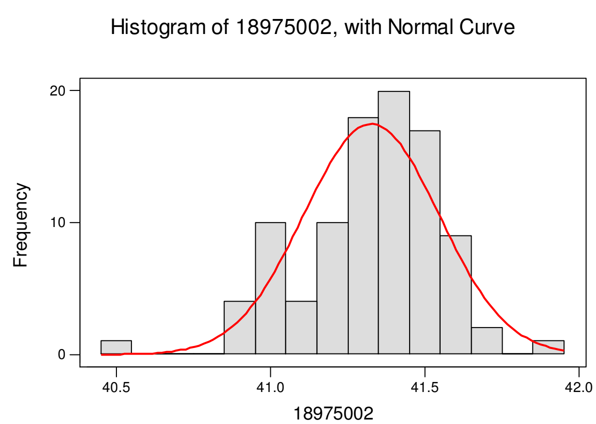
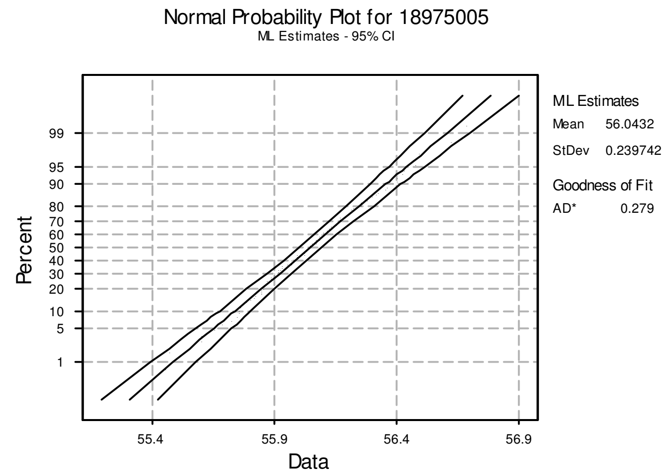


Figure 6.3: The normal probability plot and histogram output of Minitab for data 18975002



Descriptive Statistics: 18975005

Variable	N	Mean	Median	TrMean	StDev	SE Mean
18975005	45	55.970	55.970	55.969	0.195	0.029

Variable	Minimum	Maximum	Q1	Q3
18975005	55.600	56.400	55.830	56.100

Histogram (with Normal Curve) of 18975005

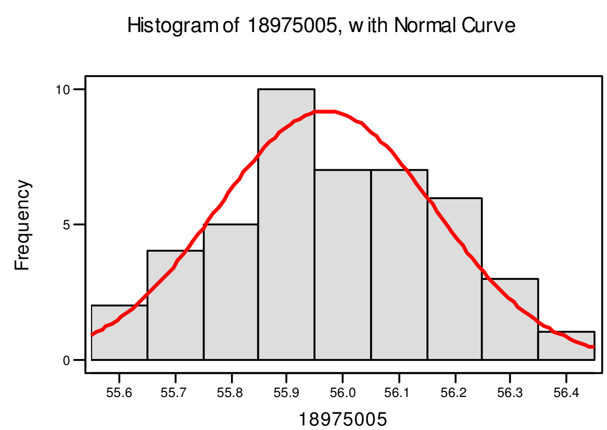
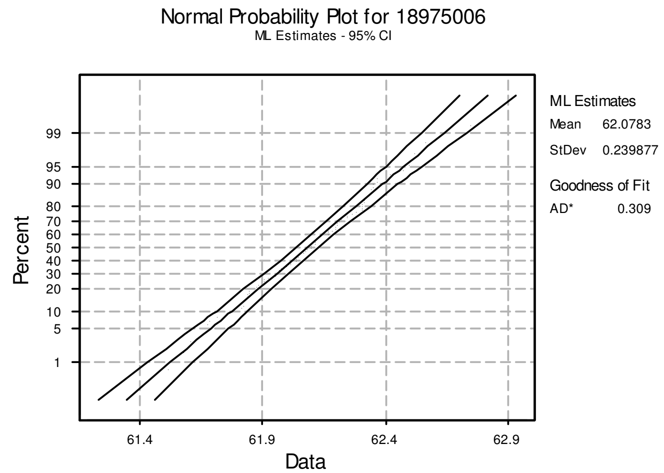


Figure 6.4: The normal probability plot and histogram output of Minitab for data 18975005



Descriptive Statistics: 18975006

Variable	N	Mean	Median	TrMean	StDev	SE Mean
18975006	45	62.029	62.030	62.029	0.194	0.029

Variable	Minimum	Maximum	Q1	Q3
18975006	61.600	62.510	61.900	62.160

Histogram (with Normal Curve) of 18975006

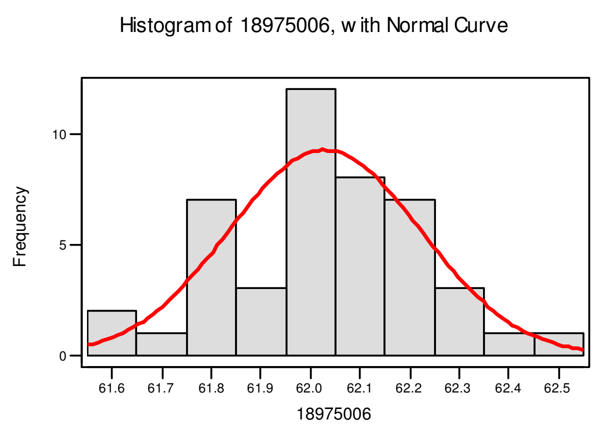


Figure 6.5: The normal probability plot and histogram output of Minitab for data 18975006

It can be seen form the figures that probability plots are within the confidence intervals. Normality assumption is further substantiated by the histograms.

6.2.4 Which Chart To use: Control Chart Wizard

There are more than thirty different types of control charts with variations depending on the application in which they are used. Each control chart type is designed to provide some information about the process. Out of these available charts, eight are commonly used (which we called traditional control charts) while the remaining are very specialized and rarely encountered like short run charts.

Deciding which control chart type is appropriate for a specific process can be a difficult task requiring expertise. The basic purpose of wizard is; to provide a tool to assist the process or quality engineer in the selection of the best control chart for the given application with easy data entrance, user friendly interface, and quick, consistent solutions.

To open wizard, “Diagram Sihirbazı” option must be selected and “Tamam” button must be pressed (see Figure 6.6). The next step is to open questions for control chart selection. To do this load questions button or Ctrl+ O short cut can be used. The name of the file is SPC Chart Selection Questions.qst. (see Figure 6.7)

First Question is asked to understand whether the user is familiar with SPC principles. This question is the one which is asked for every record. (see Figure 6.8)

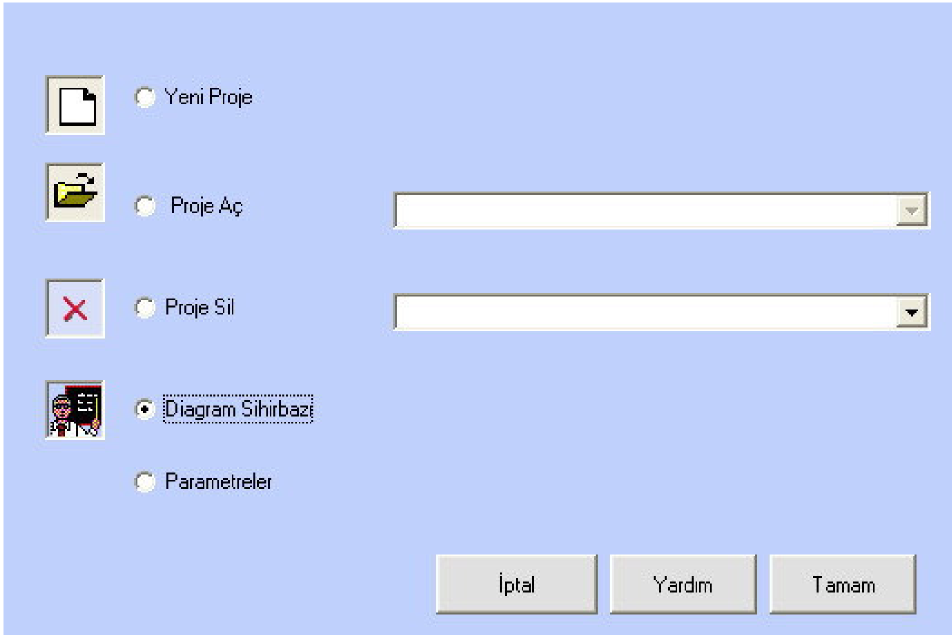


Figure 6.6: Opening of Chart Selection Wizard.

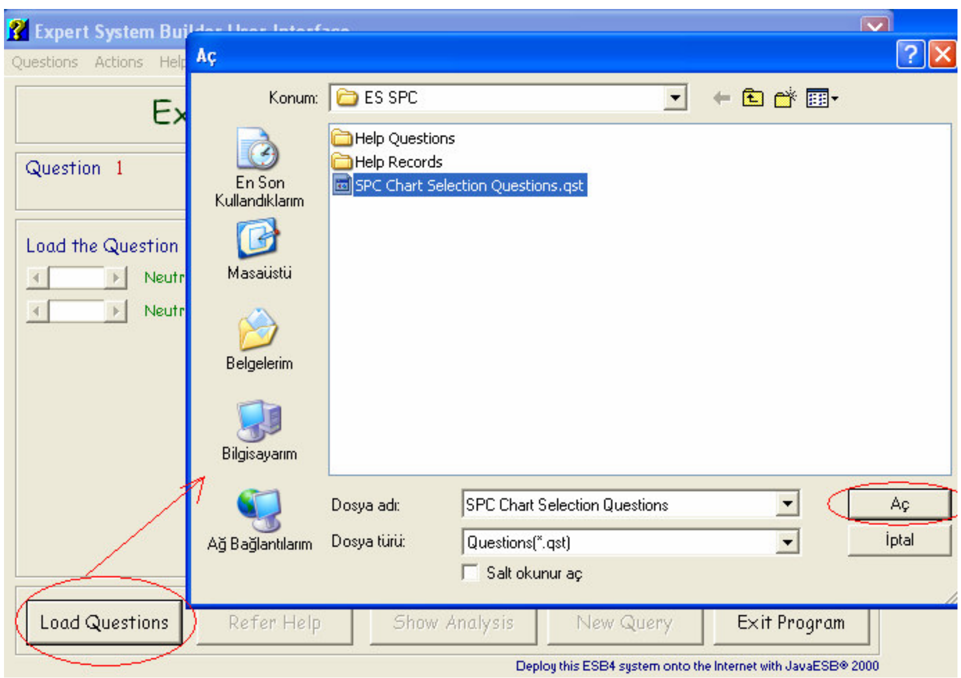


Figure 6.7: Opening SPC Chart Selection Questions.qst

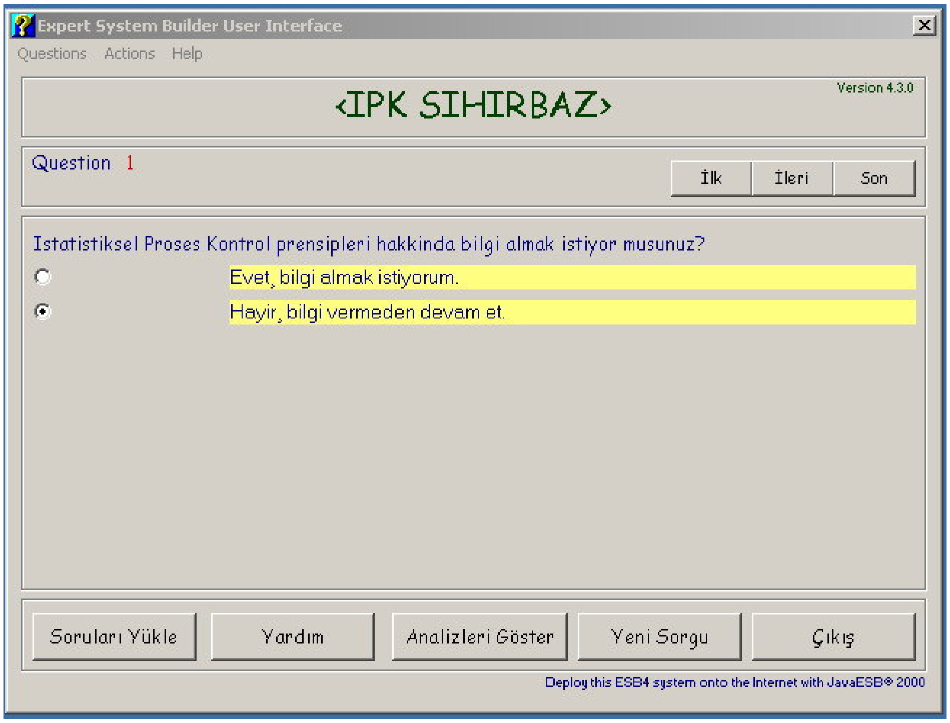


Figure 6.8: SPC Principles

The second question in figure 6.9 is asked to understand whether the case is a short run case or not. In literature, if the number of subgroup is not sufficient for traditional control charting, short run SPC charts are recommended. In this case study, seventy five data (less than) for three different measurements were collected. Therefore we selected option 1 (see Figure 6.9). If help button is pressed, an internet explorer page be appeared; that express the nature and aim of question and description of short run SPC. (see Figure 6.10).

Question in Figure 6.11 is asked to determine the sensitivity required detect small shifts in the process; If the answer is yes the software automatically refers to CUSUM and EWMA charts. Since in this investigation we were not interested in detecting small shifts so option 1 one was selected. (see Figure 6.11)

Question in Figure 6.12 is asked to understand whether the attribute data is defective or defect. All of our measurements are variable.

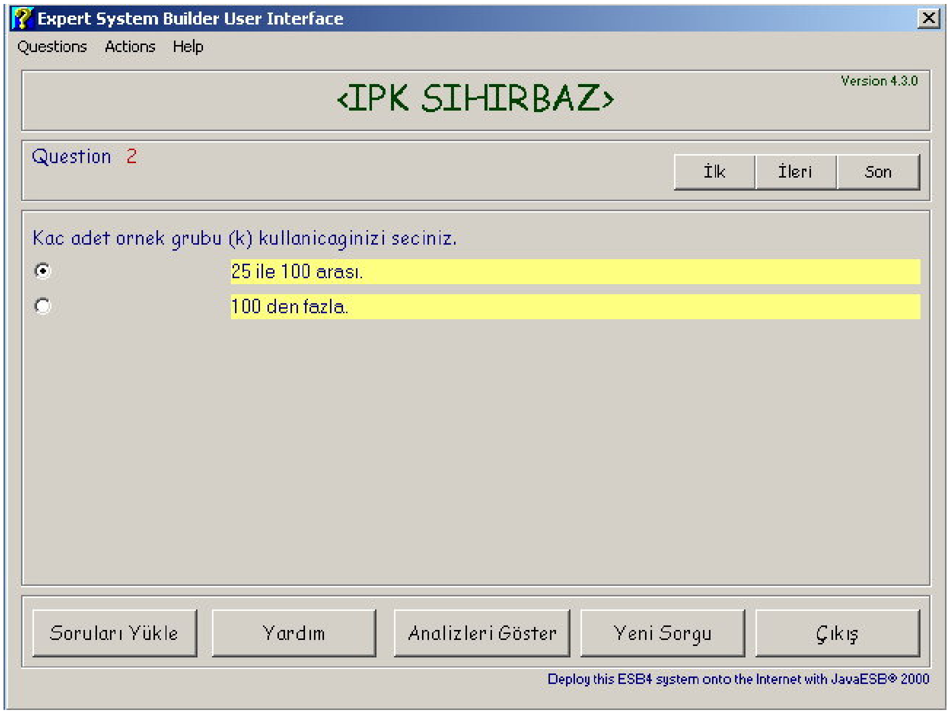


Figure 6.9: Number of subgroups

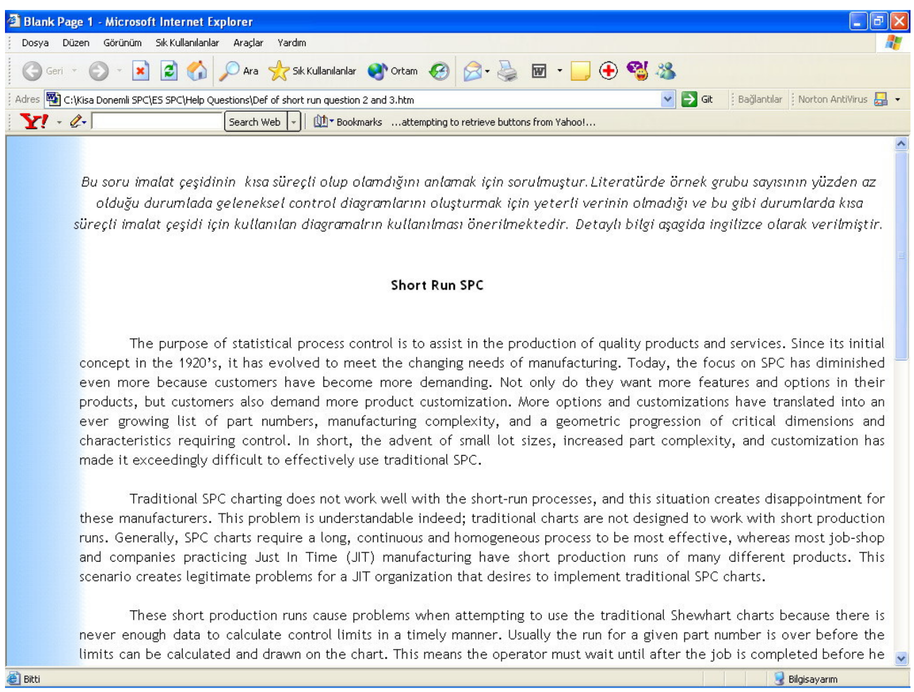


Figure 6.10: Definition for Short Runs

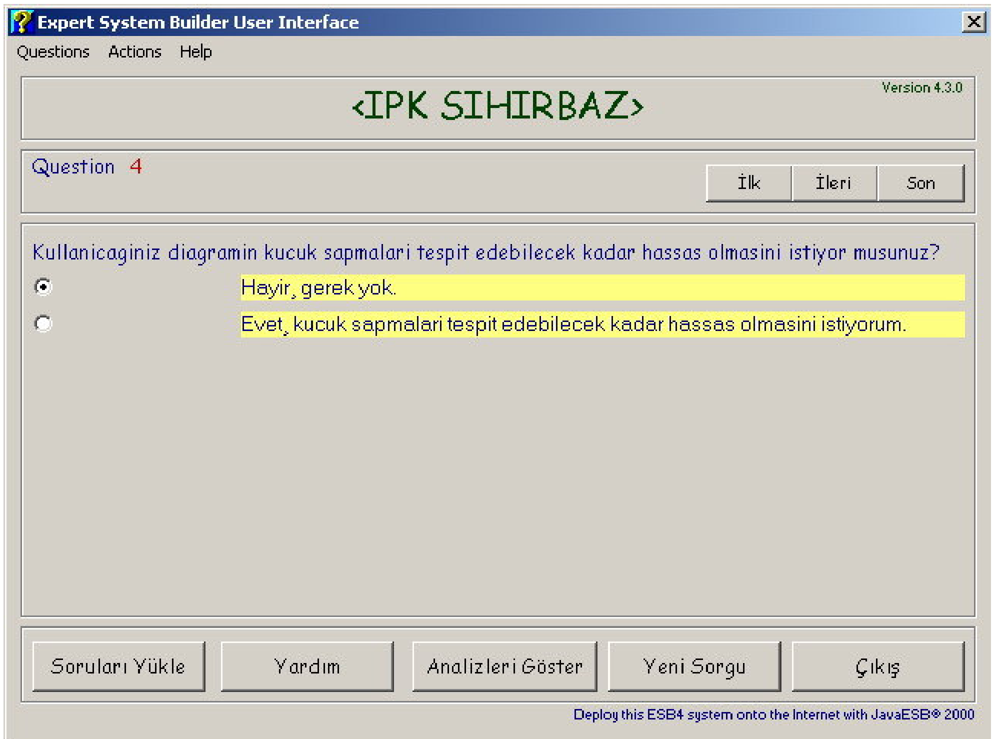


Figure 6.11: Sensitivity to shifts

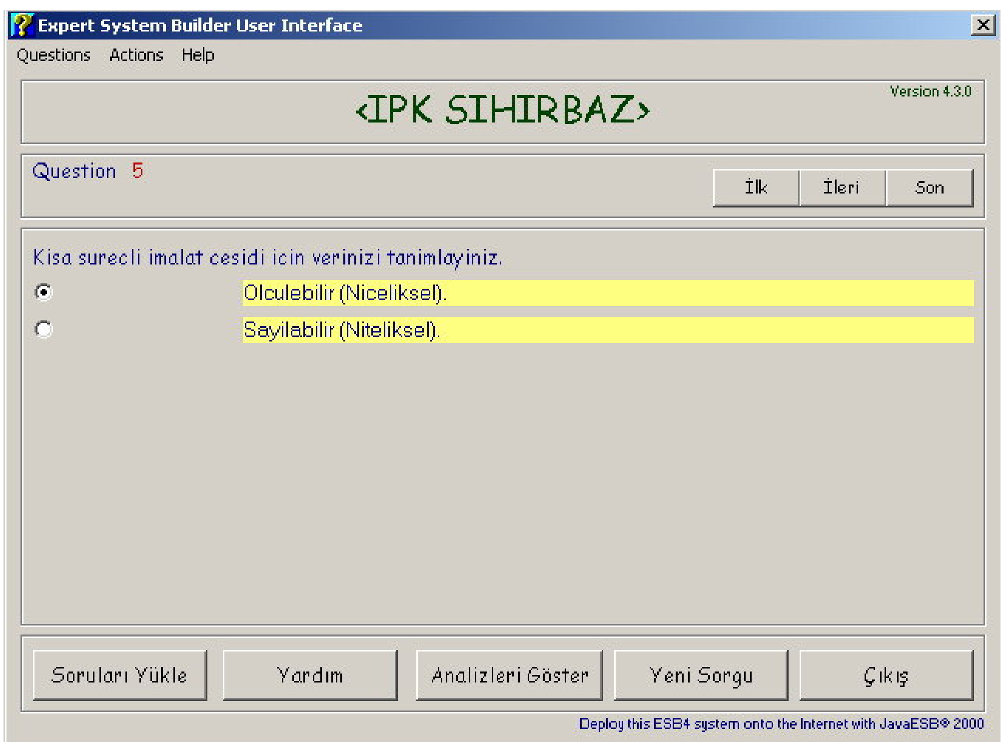


Figure 6.12: Variable or Attribute data

The question in Figure 6.13 is asked whether one characteristic or multiple characteristics, are on the plotted on the same chart. In manufacturing of welded construction group only one characteristic (length) was enough.

The question in Figure 6.14 is asked to understand the sample size of the subgroups. We used three as sample size; as a result option two was selected.

The user could see different averages on the same chart by responding to the question in Figure 6.15 Different averages can not been examined in traditional charts however it is possible to observe them in Target (Nominal) and Short Run charts. In our numerical example, we have the data of three different measurements with different averages. Therefore we selected the option one..

Last question is asked to determine whether the suitable chart is Short Run Chart or Target Chart (see Figure 6.16). When using target control chart, the variability of each part should be representative of the others; otherwise Short Run charts are recommended. To achieve this Range test must be performed. The results of the range test obtained from the production run in Arçelik are presented in Figure 6.17. It can be seen from the figure that all sets of data have passed the test. Thus the software automatically points out the most suitable chart to be employed as shown in Figure 6.18.

If range test cannot be performed, then the user has to make an assumption about the similarity of data. If no knowledge exists about the similarity it is more advisable to assume them to be similar. A rough test of similarity can be made as follows: If the standard deviation of a suspect characteristic is more than 30 percent different from the average standard deviation (or range) of the other parts on the chart. (note that this 30 percent difference is an estimate and should serve only as a rule of thumb), then dissimilarity exists. For more accurate results, other statistical methods, such as the F-test or Kruskal-Wallis test are also used to detect differences in standard deviations.

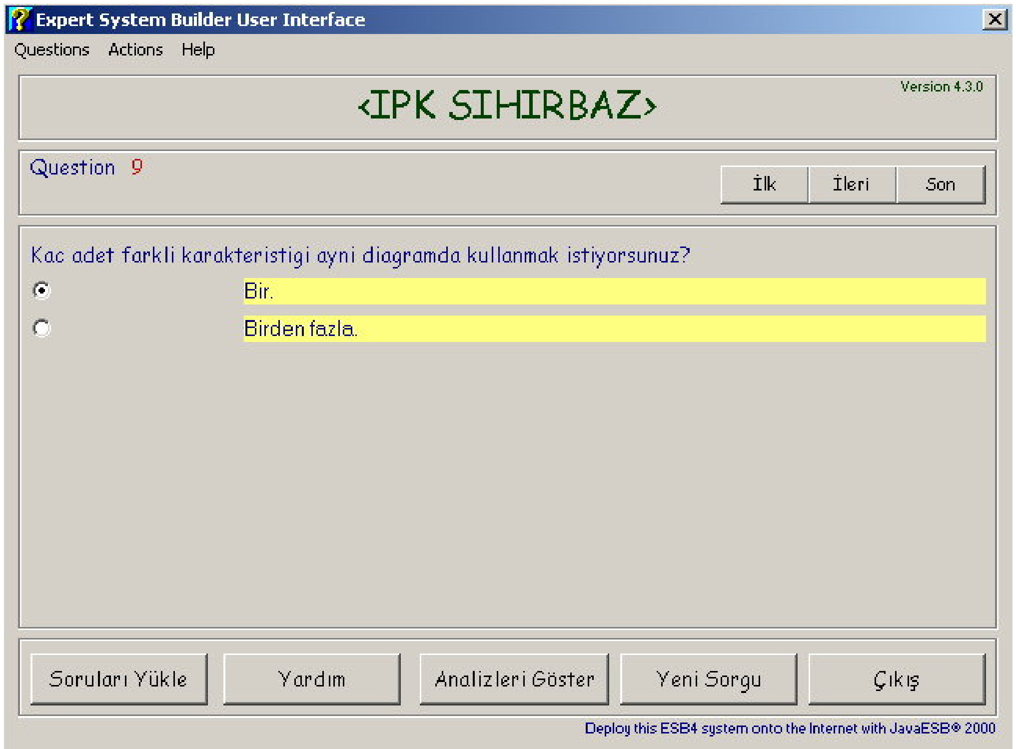


Figure 6.13: Number of Characteristics

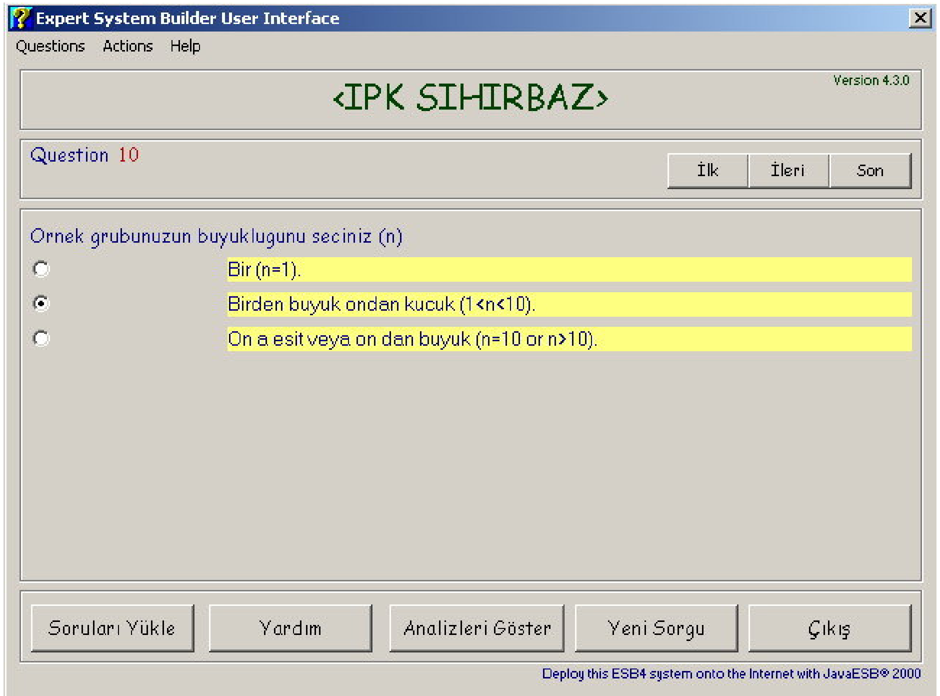


Figure 6.14: Subgroup Size

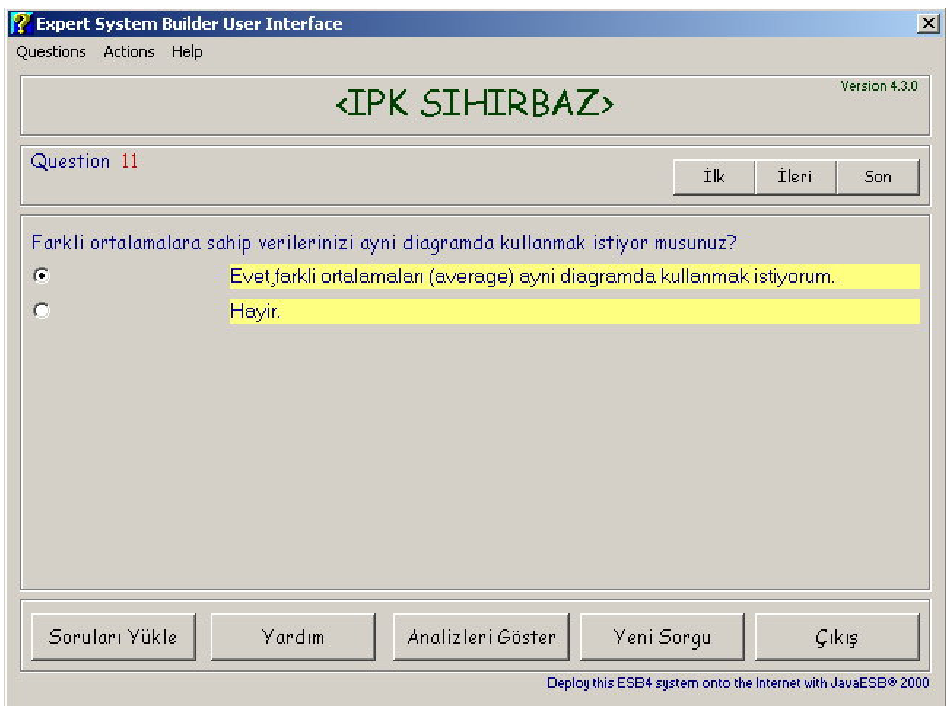


Figure 6.15: Different averages on the same chart or not

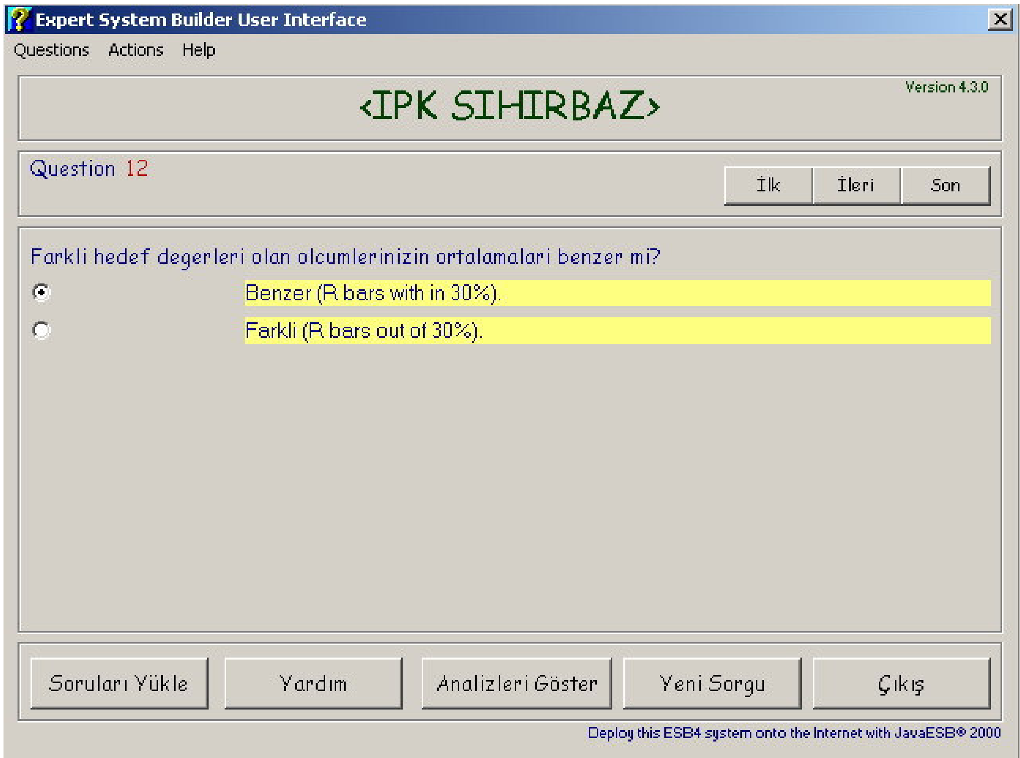
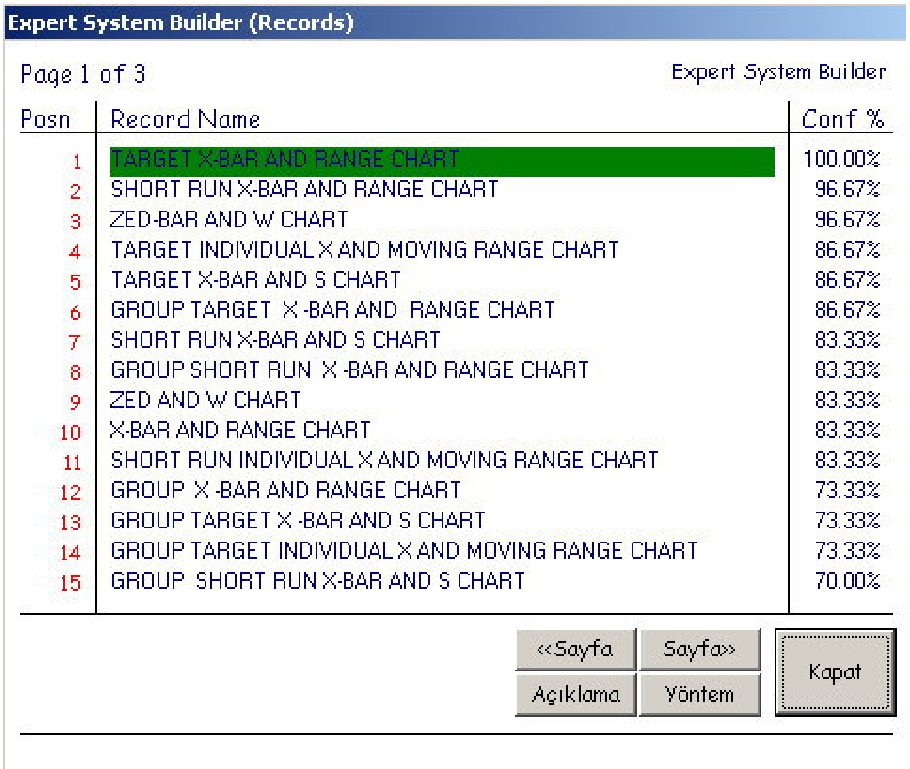


Figure 6.16: Similarity

Yetenek İndisi

	750002	750005	750006
HD	41.5	55.9	62.1
ÜTL	42	56.4	62.6
ATL	42	55.4	61.6
Cp	0	1.024	1.024
Cpk	1.214	0.882	0.879
R_ü	0.241	0.321	0.264
R_tc	0.275	0.275	0.275
R_ü	0.875	1.165	0.958
R_tc	1.142	0.857	1.042
R_T	Başarılı	Başarılı	Başarılı

Figure 6.17: The Result of Range Test



Expert System Builder (Records)

Page 1 of 3 Expert System Builder

Posn	Record Name	Conf %
1	TARGET X-BAR AND RANGE CHART	100.00%
2	SHORT RUN X-BAR AND RANGE CHART	96.67%
3	ZED-BAR AND W CHART	96.67%
4	TARGET INDIVIDUAL X AND MOVING RANGE CHART	86.67%
5	TARGET X-BAR AND S CHART	86.67%
6	GROUP TARGET X -BAR AND RANGE CHART	86.67%
7	SHORT RUN X-BAR AND S CHART	83.33%
8	GROUP SHORT RUN X -BAR AND RANGE CHART	83.33%
9	ZED AND W CHART	83.33%
10	X-BAR AND RANGE CHART	83.33%
11	SHORT RUN INDIVIDUAL X AND MOVING RANGE CHART	83.33%
12	GROUP X -BAR AND RANGE CHART	73.33%
13	GROUP TARGET X -BAR AND S CHART	73.33%
14	GROUP TARGET INDIVIDUAL X AND MOVING RANGE CHART	73.33%
15	GROUP SHORT RUN X-BAR AND S CHART	70.00%

Figure 6.18: Suggested Control Charts

After the question in Figure 6.16 is answered, wizard stops asking further questions. Following this stage, the wizard displays, by default, all the charts, in other words all the records, with certain confidence levels assigned to all. A screen-print is shown in figure; it is seen that Control Selection Wizard recommends a control chart with 100% confidence level for the above situation (Figure 6.18). If it is selected the below screen print will be appear which describes Nominal X Bar and Range Chart, its subgroup size, and give formulations. (Figure 6.19)

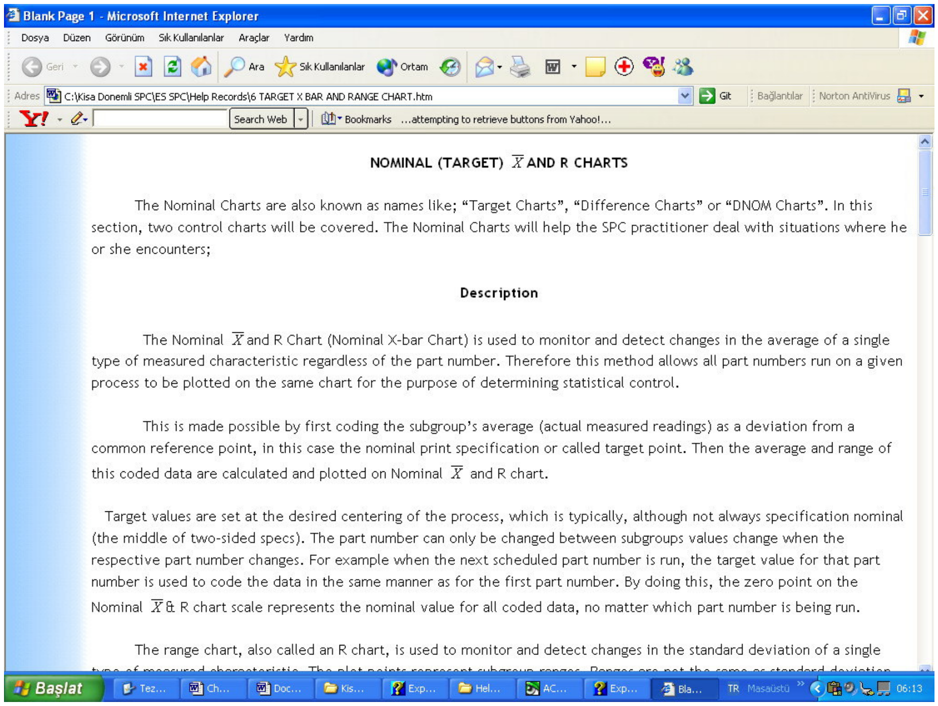


Figure 6.19: Description of Nominal X Bar and Range Chart

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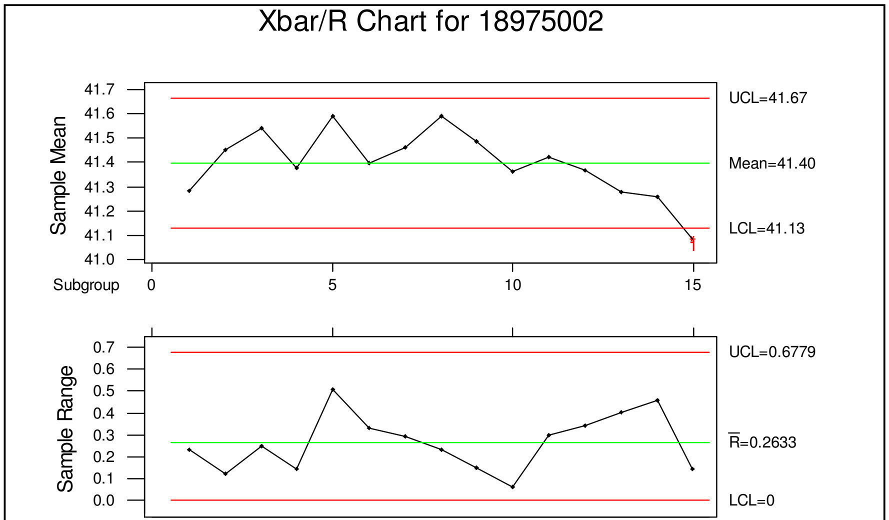
Interpretation of Data with Traditional Control Charts

Control chart selection wizard advised to use X Nominal Bar and Range Chart. However, to compare the performance short run charts with traditional charts and to see the performance of short run charts, it was decided to construct traditional charts from the same data.

From Figure 6.20, it can be examined that an out of control point is exists in subgroup fifteen. No other unusual pattern is observed.



Test Results of 18975002

Xbar/R Chart: 18975002

Xbar/R for 18975002

Test Results for Xbar Chart

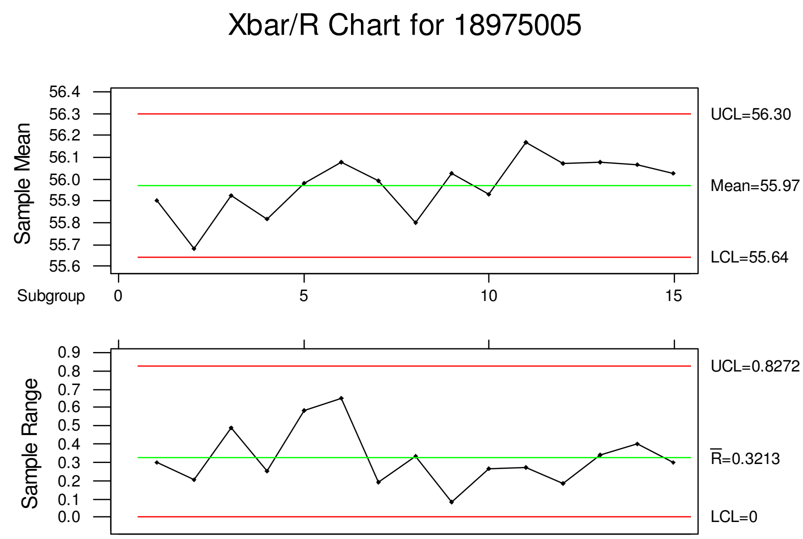
TEST 1. One point more than 3.00 sigmas from center line.

Test Failed at points: 15

Test Results for R Chart

Figure 6.20: Construction and interpretation of X Bar & Range Chart for measurement 18975002

When Figure 6.21 is examined, it is seen that the process is in control.



Test Results of 18975005

Xbar/R Chart: 18975005

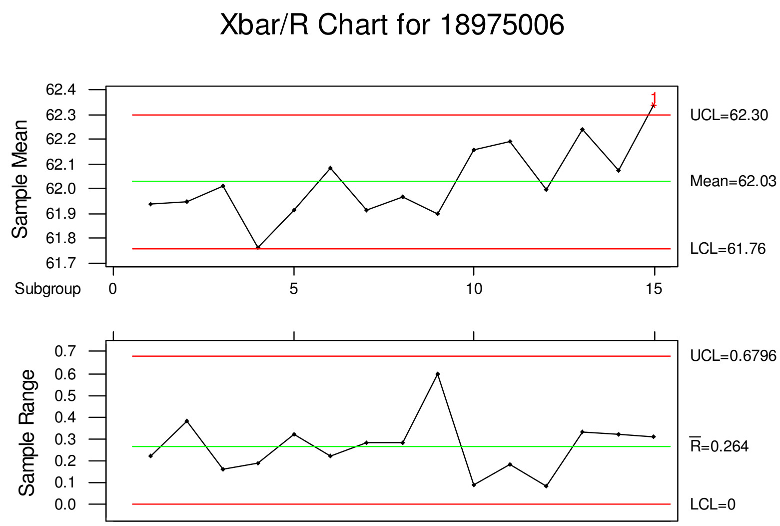
Xbar/R for 18975005

Test Results for Xbar Chart

Test Results for R Chart

Figure 6.21: Construction and interpretation of X Bar & Range Chart for measurement 18975005

In Figure 6.22, again an out of control position exists in X chart in subgroup fifteen.



Test Results of 18975006

Xbar/R Chart: 18975006

Xbar/R for 18975006

Test Results for Xbar Chart

TEST 1. One point more than 3.00 sigmas from center line.

Test Failed at points: 15

Test Results for R Chart

Figure6.22: Construction and interpretation of X Bar & Range Chart for measurement 18975006

6.2.5 Comparison of Data with Short Run Control Charts

As the acid test of the feasibility of employing should run SPC; the data obtained were plotted as Nominal X bar and Range Chart, as suggested by the wizard. Three different measurements are plotted in one chart as in Figure 6.23, which is a feature of the software. Output of the software is given below; (see Table 6.2)

Table 6.2: Calculation of R Nominal and X Nominal data

	Örn1	Örn2	Örn3	Örn4	Örn5
Operatör					
Zaman	11.04.2004 - 12:35	11.04.2004 - 15:10	11.04.2004 - 17:45	11.04.2004 - 20:20	11.04.2004 - 22:55
Ürün No	189750002-1	189750005-1	189750006-1	189750002-1	189750005-1
Veri	41.18	56.05	61.95	41.52	55.6
Veri	41.26	55.75	62.04	41.4	55.8
Veri	41.41	55.9	61.82	41.44	55.65
Ortalama	41.283	55.9	61.936	41.453	55.683
HedefDeğer	41.5	55.9	62.1	41.5	55.9
XNominalVeri	-0.216	-1.3E-06	-0.163	-0.04666	-0.216
RNominalVeri	0.229	0.299	0.22	0.119	0.2

Örn6	Örn7	Örn8	Örn9	Örn10	Örn11	Örn12
12.04.2004 - 1:30	12.04.2004 - 4:05	12.04.2004 - 6:40	12.04.2004 - 9:15	12.04.2004 - 11:50	12.04.2004 - 14:25	12.04.2004 - 17:00
189750006-1	189750002-1	189750005-1	189750006-1	189750002-1	189750005-1	189750006-1
61.75	41.39	55.92	61.92	41.47	55.72	61.64
61.96	41.6	56.17	62.04	41.33	55.76	61.82
62.13	41.64	55.68	62.08	41.33	55.97	61.83
61.946	41.543	55.923	62.013	41.376	55.816	61.763
62.1	41.5	55.9	62.1	41.5	55.9	62.1
-0.153	0.043	0.02333	-0.08666	-0.123	-0.08333	-0.336
0.38	0.25	0.489	0.16	0.139	0.25	0.19

Örn13	Örn14	Örn15	Örn16	Örn17	Örn18	Örn19
12.04.2004 - 19:35	12.04.2004 - 22:10	13.04.2004 - 00:45	13.04.2004 - 3:20	13.04.2004 - 5:55	13.04.2004 - 8:30	13.04.2004 - 11:05
189750002-1	189750005-1	189750006-1	189750002-1	189750005-1	189750006-1	189750002-1
41.34	56.32	62	41.22	56.08	62.09	41.63
41.58	55.74	62.03	41.55	55.75	61.97	41.42

41.85	55.88	61.71	41.42	56.4	62.19	41.34
41.59	55.98	61.913	41.396	56.076	62.083	41.463
41.5	55.9	62.1	41.5	55.9	62.1	41.5
0.09	0.07999	-0.186	-0.103	0.176	-0.016	-0.03666
0.509	0.579	0.319	0.329	0.65	0.219	0.29

Örn20	Örn21	Örn22	Örn23	Örn24	Örn25	Örn26
13.04.2004 - 13:40	13.04.2004 - 16:15	13.04.2004 - 18:50	13.04.2004 - 21:25	14.04.2004 - 00:00	14.04.2004 - 2:35	14.04.2004 - 5:10
189750005-1	189750006-1	189750002-1	189750005-1	189750006-1	189750002-1	189750005-1
55.99	62.09	41.69	55.93	61.83	41.4	56.07
56.09	61.81	41.46	55.6	62.11	41.55	56.02
55.9	61.84	41.63	55.88	61.96	41.51	55.99
55.993	61.913	41.593	55.803	61.966	41.486	56.026
55.9	62.1	41.5	55.9	62.1	41.5	55.9
0.09333	-0.186	0.09333	-0.09666	-0.133	-0.013	0.126
0.189	0.279	0.229	0.33	0.279	0.149	0.07999

Örn27	Örn28	Örn29	Örn30	Örn31	Örn32	Örn33
14.04.2004 - 7:45	14.04.2004 - 10:20	14.04.2004 - 12:55	14.04.2004 - 15:30	14.04.2004 - 18:05	14.04.2004 - 20:40	14.04.2004 - 23:15
189750006-1	189750002-1	189750005-1	189750006-1	189750002-1	189750005-1	189750006-1
61.6	41.33	55.81	62.16	41.52	56.3	62.12
62.2	41.37	56.07	62.2	41.52	56.03	62.16
61.9	41.39	55.91	62.11	41.22	56.17	62.3
61.9	41.363	55.93	62.156	41.42	56.166	62.193
62.1	41.5	55.9	62.1	41.5	55.9	62.1
-0.199	-0.136	0.029	0.056	-0.07999	0.266	0.09333
0.6	0.059	0.259	0.09	0.299	0.27	0.18

Örn34	Örn35	Örn36	Örn37	Örn38	Örn39	Örn40
15.04.2004 - 1:50	15.04.2004 - 4:25	15.04.2004 - 7:00	15.04.2004 - 9:35	15.04.2004 - 12:10	15.04.2004 - 14:45	15.04.2004 - 17:20

189750002-1	189750005-1	189750006-1	189750002-1	189750005-1	189750006-1	189750002-1
41.54	55.97	61.95	41.42	56.21	62.36	41.32
41.37	56.15	62.01	41.4	56.15	62.03	41.45
41.2	56.1	62.03	41.02	55.87	62.33	-0.09
41.37	56.073	61.996	41.28	56.076	62.24	41.409
41.5	55.9	62.1	41.5	55.9	62.1	41.5
-0.129	0.173	-0.103	-0.219	0.176	0.14	
0.34	0.18	0.07999	0.399	0.34	0.33	0.139

Table 6.2: Calculation of R Nominal and X Nominal data

Örn41	Örn42	Örn43	Örn44	Örn45
15.04.2004 - 19:55	15.04.2004 - 22:30	16.04.2004 - 1:05	16.04.2004 - 3:40	16.04.2004 - 6:15
189750005-1	189750006-1	189750002-1	189750005-1	189750006-1
55.85	61.9	41.01	56.04	62.2
56.1	62.22	41.15	56.17	62.51
56.25	62.11	41.09	55.87	62.3
56.066	62.076	41.083	56.026	62.336
55.9	62.1	41.5	55.9	62.1
0.166	-0.02333	-0.416	0.126	0.236
0.4	0.319	0.14	0.299	0.309

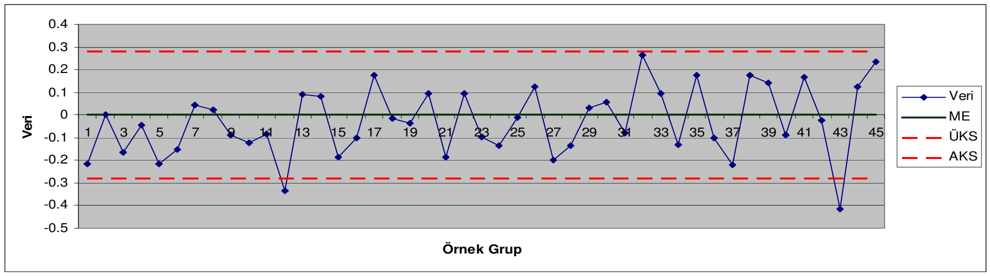
Table 6.3: Calculation of Cp and Cpk Value

Yetenek İndisi			
	189750002	189750005	189750006
HD	41.5	55.9	62.1
ÜTL	42	56.4	62.6
ATL	40	55.4	61.6
Cp	2.049	1.024	1.024
Cpk	1.214	0.882	0.879

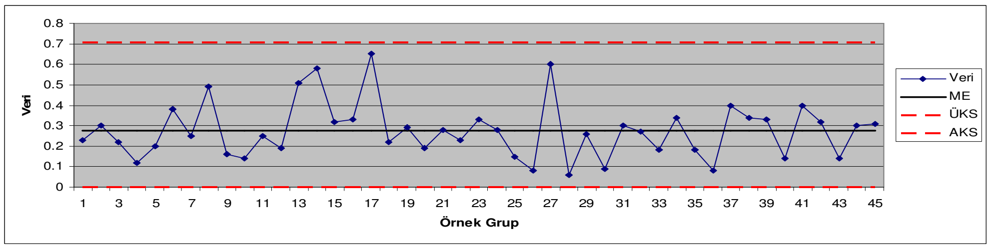
Table 6.4: Calculation of UCL and LCL

X-Nominal	
ME	0
ÜKS	0.281
AKS	-0.281

R-Nominal	
ME	0.275333
ÜKS	0.708
AKS	0



X Nominal



R Nominal

Figure 6.23: Nominal X Bar and Range Chart

Test Results of 18975002, 18975005& 18975006

KYG 29.06.2004

Test 1: Bir nokta K sigma degeri kadar merkez doğrusundan uzakta olursa

Test 1 X Diyagramı İçin Başarısız. Aşağıdaki noktalar K sigma değeri kadar Merkez eğrisinden uzakta: 12.(-0.3366648) 43.(-0.4166667)

Test 1 R Diyagramı İçin Başarısız. Aşağıdaki noktalar K sigma değeri kadar Merkez eğrisinden uzakta:

Test 2: Bir sıradaki K adet nokta merkez doğrusunun aynı tarafında olursa

Test 2 X Diyagramı İçin Aşağıdaki Noktalarda Başarısız:

Test 2 R Diyagramı İçin Aşağıdaki Noktalarda Başarısız:

Test 3: Bir sıradaki K adet noktanın artan veya azalan eğimi varsa.

Test 3 X Diyagramı İçin Aşağıdaki Noktalarda Başarısız:

Test 4: K noktadan K-1 tanesi merkez eğrisinden 2 sigma mesafeden daha uzakta olursa (aynı tarafta)

Test 4 X Diyagramı İçin Başarısız. K adet noktanın K-1 tanesi merkez eğrisinden 2 sigma değeri kadar uzakta:

Test 4 R Diyagramı İçin Başarısız. K adet noktanın K-1 tanesi merkez eğrisinden 2 sigma değeri kadar uzakta:

Figure 6.24: Test Results of Nominal X Bar and Range Chart

Now it’s possible to investigate our points which we found with tests;

12.(-0.3366648) and 43.(-0.4166667)

	Örn12	Örn43
Operatör		
Zaman	12.04.2004 - 17:00	16.04.2004 - 1:05
Ürün No	189750006-1	189750002-1
Veri	61.64	41.01
Veri	61.82	41.15
Veri	61.83	41.09
Ortalama	61.763	41.083
HedefDeğer	62.1	41.5
XNominalVeri	-0.336	-0.416
RNominalVeri	0.19	0.14

Figure 6.25: Results for subgroup 12 & 43

It is seen that X nominal value for “Orn12” and “Orn43” is under the lower control limit.

6.2.6 Discussion

When the results are compared:

- On the traditional chart, subgroup 4 of part 18975006 is below the lower control limit. This subgroup corresponds to the subgroup 12 of the short run SPC chart. Referring to Figure 6.23, point 12 is below the lower control limit.
- On the traditional chart, subgroup 15 of part 18975002 is below the lower control limit. This subgroup corresponds to the subgroup 43 of the short run SPC chart. Referring to Figure 6.23, point 43 is below the lower control limit.

- Traditional range charts are in control and so is the short run SPC R chart of Figure 6.23.

Clearly, the two results are in full agreement and the software developed in the context of this thesis meets the requirements.

It is worth mentioning some of the changes made during testing at Arçelik:

While testing the software it was noticed that the users had problems in selecting the right control chart for a specific case. Although the software had the capability, based on range test, to select between Nominal charts and Zed charts; this however was not sufficient for there are other charts that too have to be considered. Therefore a prototype expert system, (called Control Chart Selection Wizard) which was capable of emulating human expertise in finding a suitable control chart according to the user response for different cases, was developed and added as a subprogram. It is user-friendly and reduces errors in selecting appropriate chart; thus providing the knowledge and expert opinion for quick and qualified selection of the control chart. This prototype system can act either as an intelligent integrator for statistical based quality control software packages or a stand alone system.

Another improvement that was made during verification was, to further facilitate the use of the program. A help function was added to the software, which answered quarries in the face of a difficulty or problem. Help files were created by employing Windows Help Designer/HTML Edition version 3.8.7.

Finally, it is well worth considering some adverse opinions on the use of short run SPC charts.

Quesenberry criticized coded short run charts by claming that if enough data are indeed available, the traditional charts are sufficient [21]. Though this statement is valid, it does not rub the advantages offered by the short run SPC methods. Firstly, if a new part is to be produced, there will not be any prior information or sufficient data related to the product or process. Secondly, by using coding method, it is possible to construct one chart for different parts of similar characteristics, instead of using more than one chart. Because of this usage advantage, coded methods also called pooling method.

Işık said that in order to use the same control limits, the sample size of all parts should be equal, otherwise it is needed to determine A_2, D_3, and D_4 values for different sample sizes complicated the chart using [16]. However this is true for traditional charting methods and most of the short run control charting methods.

Another disagreement is with the use of target or nominal values instead of actual ones, because when a signal is received via DNOM chart, one can not be sure that process is really out of control, or the nominal or target value selected is a wrong one. According to the Quesenberry, using a target or nominal specification values is a serious mistake that is in kind the same as using specification limits for control limits. [17]. Selecting the target points is very critical for short run charts and detailed discussed in Chapter 4.2 and Chapter 4.3.1.2.1

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

7.1 Conclusions

For all countries, especially for developing ones, SMEs play vital role in fulfilling the economic and social needs of the country. According to the general industry survey made in 1992, %99.6 of the existing employees in Turkey work in SMEs and % 0.2 work in medium sized enterprises (See Table F1 in Appendix E) [48].

One of the major problems encountered in Turkish SMEs is poor quality activities; especially, not being able to exploit the SPC techniques. This work, in this context, is therefore both of academic and practical value.

Production speed and flexibility are essential to maintain a competitive edge. As a result, production runs become shorter and shorter, and the product variety seems to be ever increasing. In fact, the survival is dependent on being able to switch from one order to another, which is generally not in large quantities. Thus, as was discussed, this is an impediment to use of traditional SPC techniques.

As was discussed in the foregoing, one of the common and most important problems of the SMEs is the lack of resources. With this fact in mind, user friendly software was developed that not only constructs short run control charts but also implements charts by tests. The software is in Turkish, aimed at meeting the needs of the industry.

Software was tested at Arçelik Dishwasher Plant in Ankara. Data was gathered for three weeks from the production line and short run control charts were constructed. The results were cross checked by hand calculations and were in perfect agreement with the computer results.

The efficiency of the control charts produced by the software developed, were tested by plotting traditional charts with the same data. The results were perfectly in agreement.

The overall evaluation of the developed software, as regards the user, was systems observed to be satisfactory. One of the ailments of expert systems is the questions which are not logical or not really needed. This causes confusion and bewilderment. The experience and the comments of the users were favorable in this context.

In conclusion, the software meets the requirements of the SMEs in all respects. However, the following extensions would be or both academic and practical value.

7.2 Recommendations For Future Work

Future work regarding to the software can be listed as;

- In this thesis study only short run attribute charts that uses coded (or pooling) method were studied. However there are other types of short run charts like; Group Charts, Q Charts, and for attribute data; short run c, short run u, short run p, and short run np (these charts are also called standardized attribute charts in the literature) charts. In addition to these, in his book, *Introduction to Statistical Process Control*, Montgomery said that the cusum and EWMA charts have potential application to short production runs, because they have shorter average run length performance than Shewhart- type charts, particularly in detecting small shifts. As most production runs in short run environment will not, by definition, consist of many units, the rapid shift detection capability of those charts would be useful. Besides cusum and EWMA charts are very effective with subgroup of size one, another potential advantage in the short run situation. [1]. These charts are not available in the software, and as a future work by adding these charts software can return to an entirely software for short production runs. As well adding attribute charts made software favorable for companies work in service sector. While development stage, software formed as a way that all these charts can be added in the future.

- In the software, four patterns used by Hy Pitt are studied which were detailed described in Chapter 2.6. Nelson's eight tests or other special tests can be added to the "tests menu". Also when out of control positions are determined, some visual animations and alarm signals which make out of control case clear can be added to the software. These can be developed by flash animation and integrated to the graphics.

- Rounding is automatically made after three decimal digits. This feature can be made optional for users.

- Internet and Ethernet options can be added to the software. On line version of the software can be developed.

- In addition to Help and Wizard, the software can be improved by educational videos. Due to fact that visual education is still an effective technique, users can be adapted to the SPC concepts and software easily.

- Wizard of the software was developed with Expert System Builder version 4.4.2. The program selected since having ready shells for rules and user friendly interface but this version is too limited in defining rules usually expressed in the form of IF/THEN when combined either by AND or by OR statements. Also the user can not take a print out for report screen. Lastly by this version we have ability to see the recommended chart and description of it but it would be better if it is connected with our software for constructing control charts. Instead of this software, wizard and rules can be developed in Visual Basic in order to eliminate problems.

- To increase the efficiency and usage of software other SPC tools like; Check Sheets, Histogram, Pareto Chart, Cause and Effect Diagram, Defect Concentration Diagram, and Normality Test can be added to the software.

- Finally, the translation of the explanations and definitions English would be a very useful addition.

The following are the recommendations for further work:

- Trial run of the software was made in Arçelik Dishwasher Plant. Arçelik was selected because of being encouraging to innovative approaches. However the company cannot be regarded as small or medium sized manufacturing. Hence, it will be worthwhile to test the software in the SMEs.

- The wizard of the software should have to be tested by experts.

- Whilst applying test runs in Arçelik, it was seen that most of the time in SPC applications was spent for the sampling operations. Foremen take the measurements and then enter these to record sheets, which are finally entered to a computer. Unnecessarily repetitive activities are not only time consuming but are also prone to errors. Enquiring the possibility of linking the electronic measuring gauges with the computer, would be of practical interest.

- To use Short Run SPC charts it was assumed that data are distributed normally. Some innovative approaches or improvements in formulas can be made by statisticians for non normal distributed data.

- Performance of short run charts for different subgroup sizes is worth studying. Because, when the subgroup size decreases, efficiency of control charts decreases.

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APPENDIX A

SHORT RUN SPC SOFTWARE

A.1 Screenshot of the Short Run SPC Software

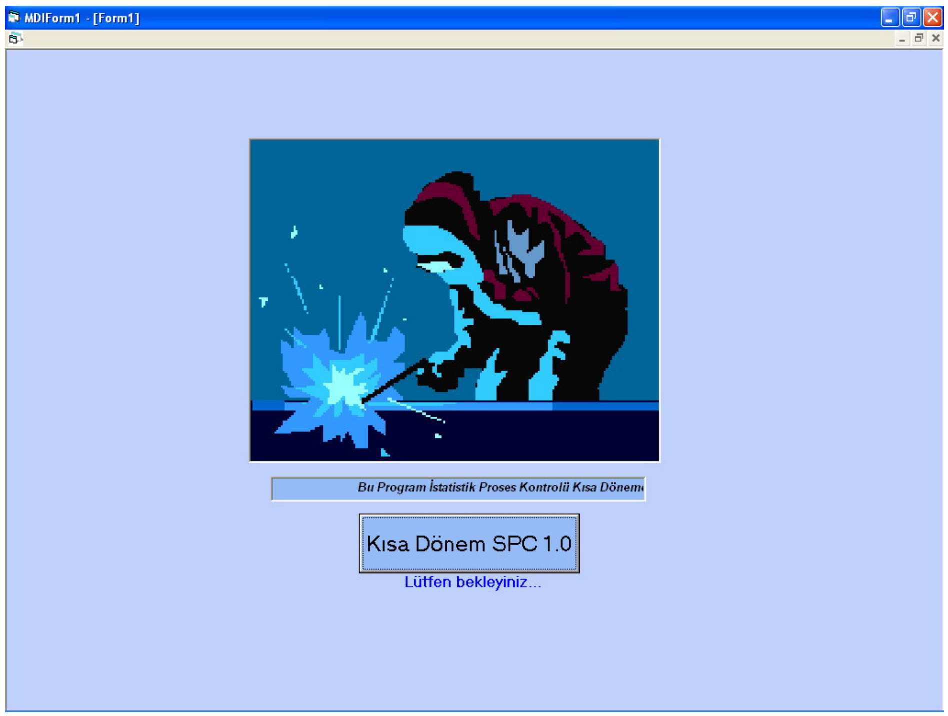


Figure A1.1: Entrance

Figure A1.2: Login

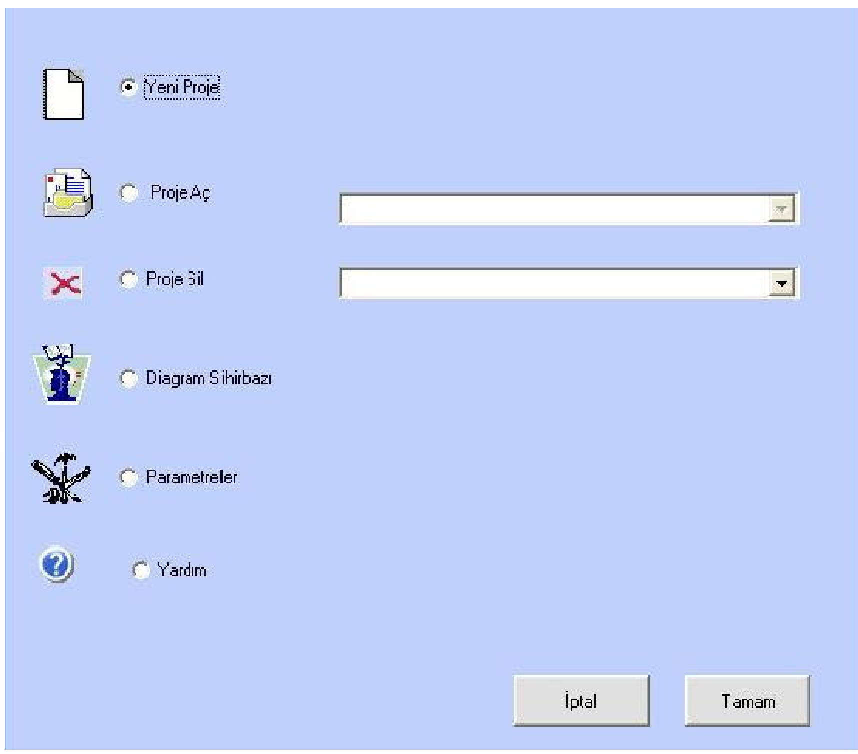


Figure A1.3: Main Menu

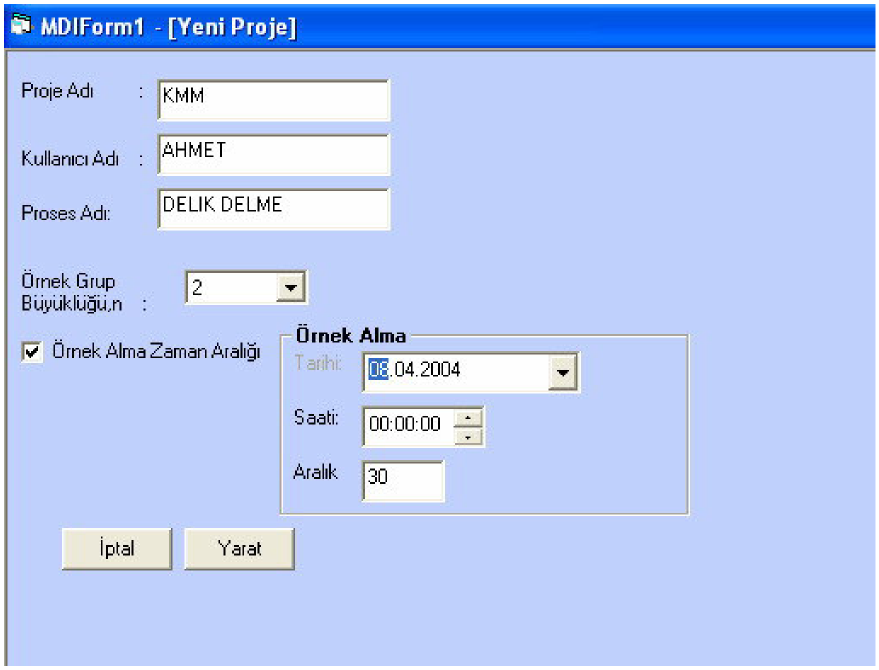


Figure A1.4: New Project

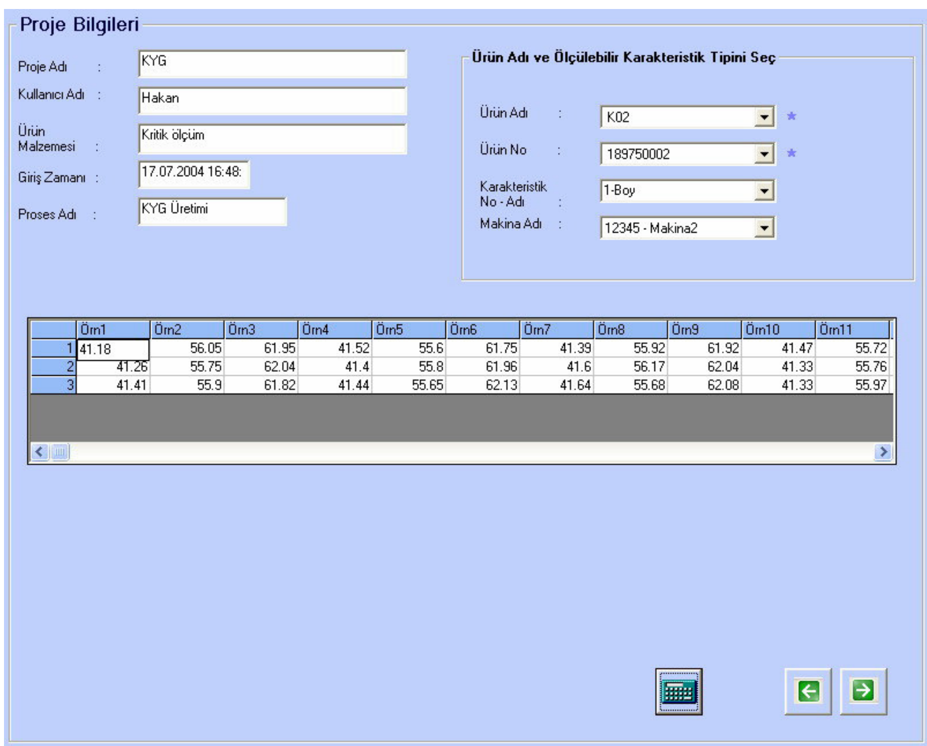


Figure A1.5: Data Entrance

Figure A1.6: Intermediate Menu

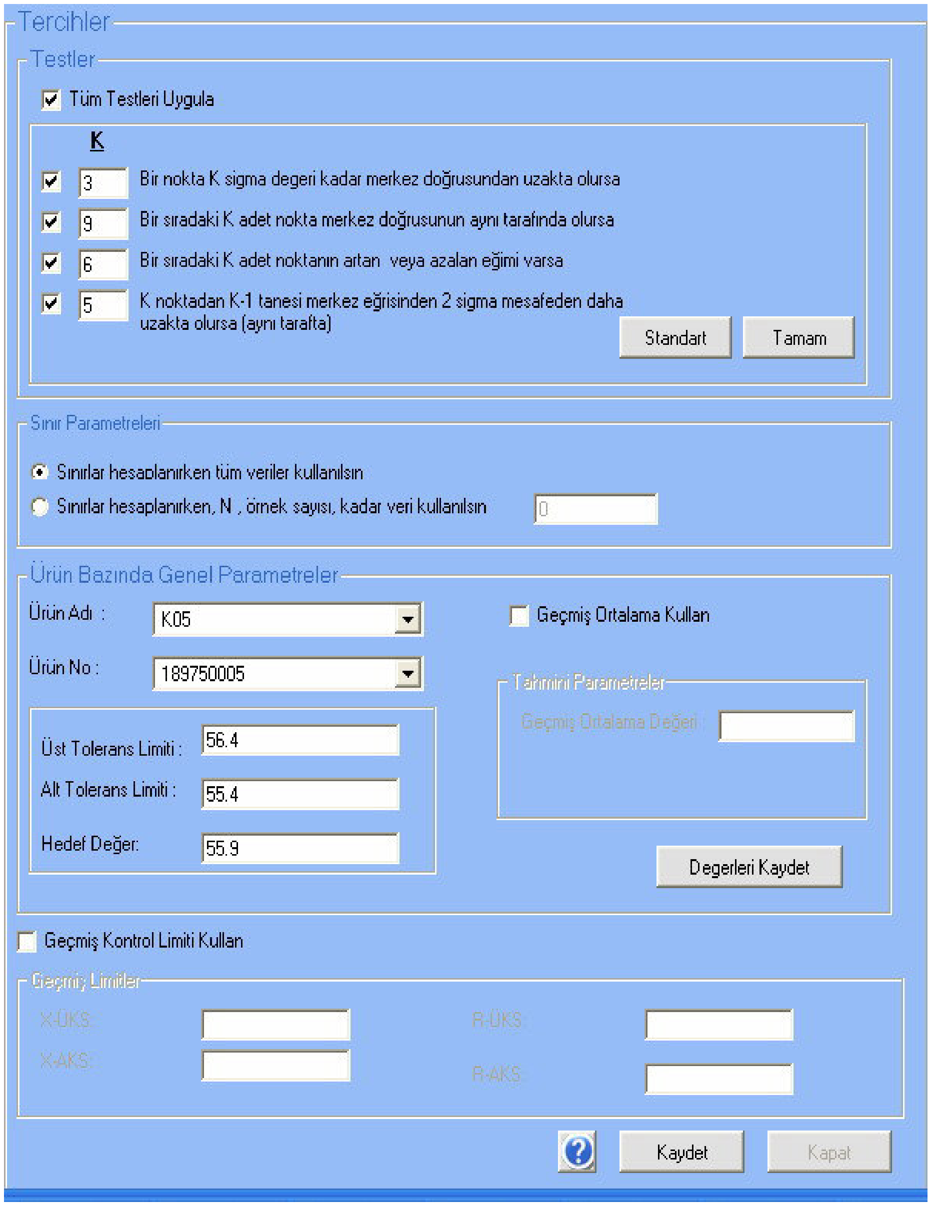


Figure A1.7: Preferences

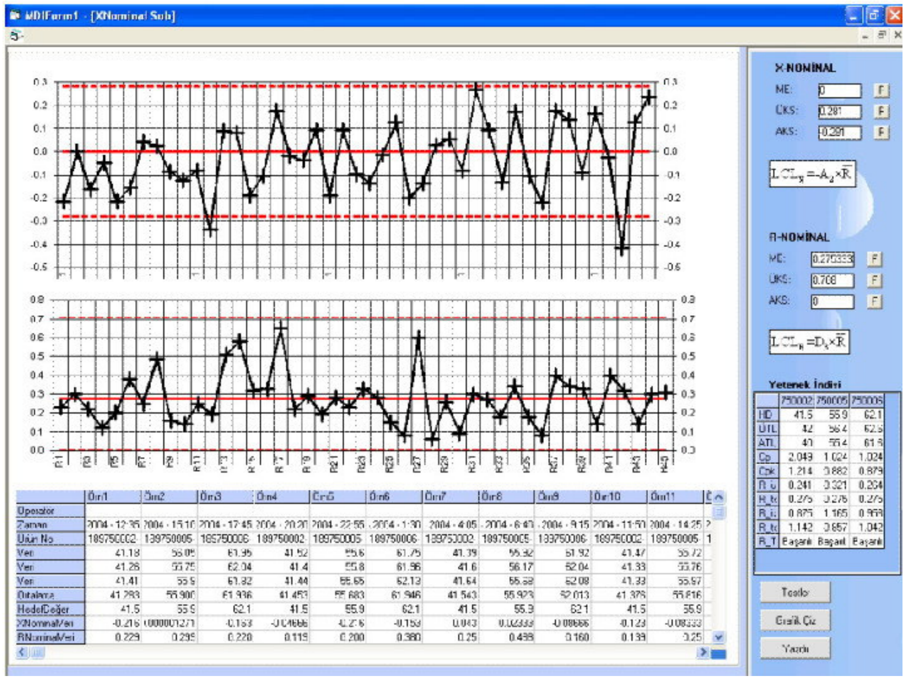


Figure A1.8: Chart Construction

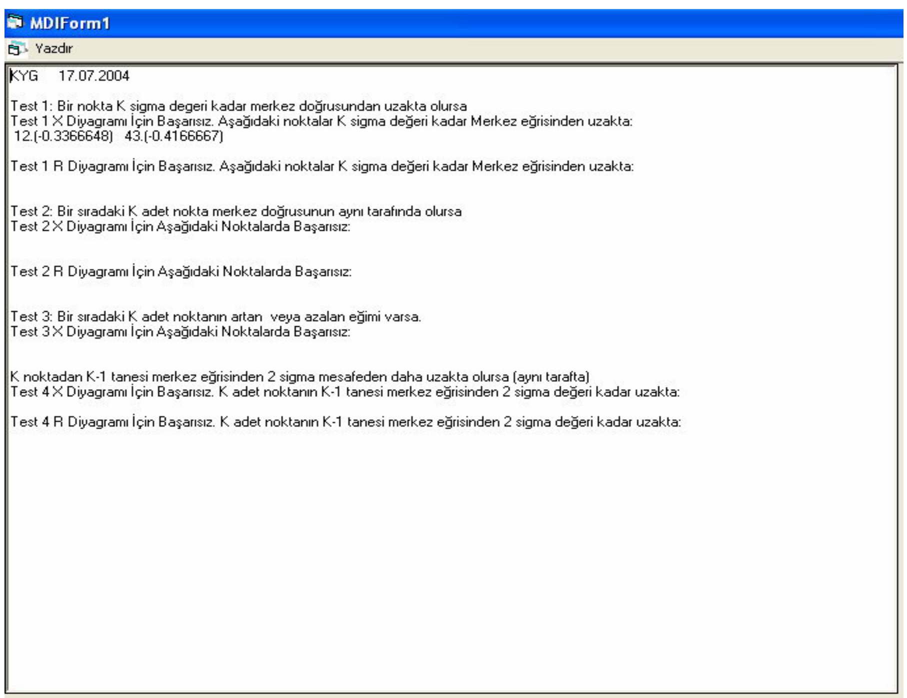


Figure A1.9: Chart Interpretation

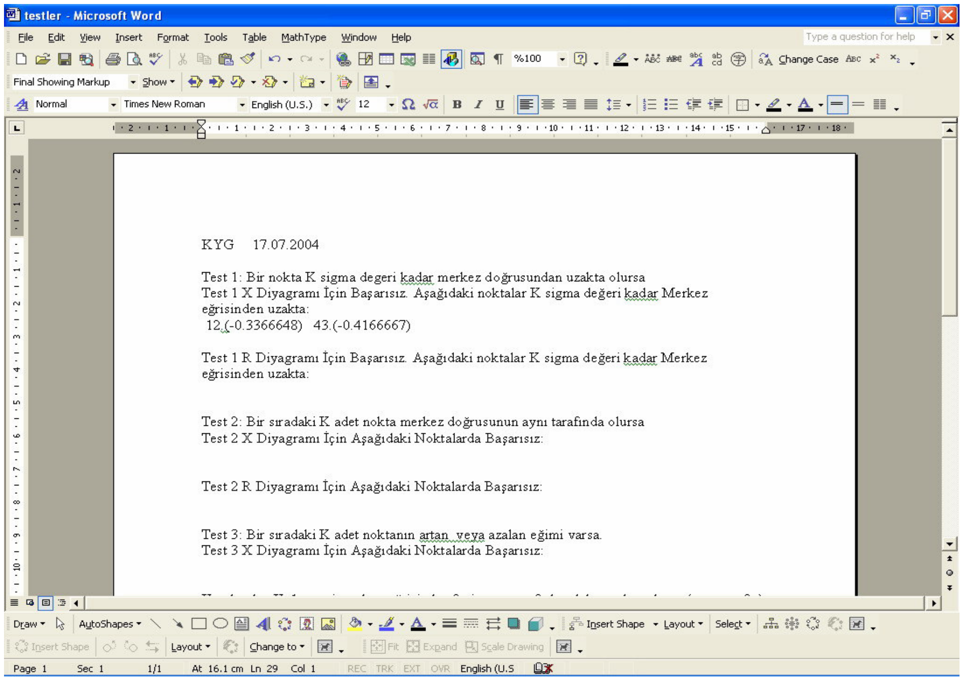


Figure A1.10: Output of Chart Interpretation

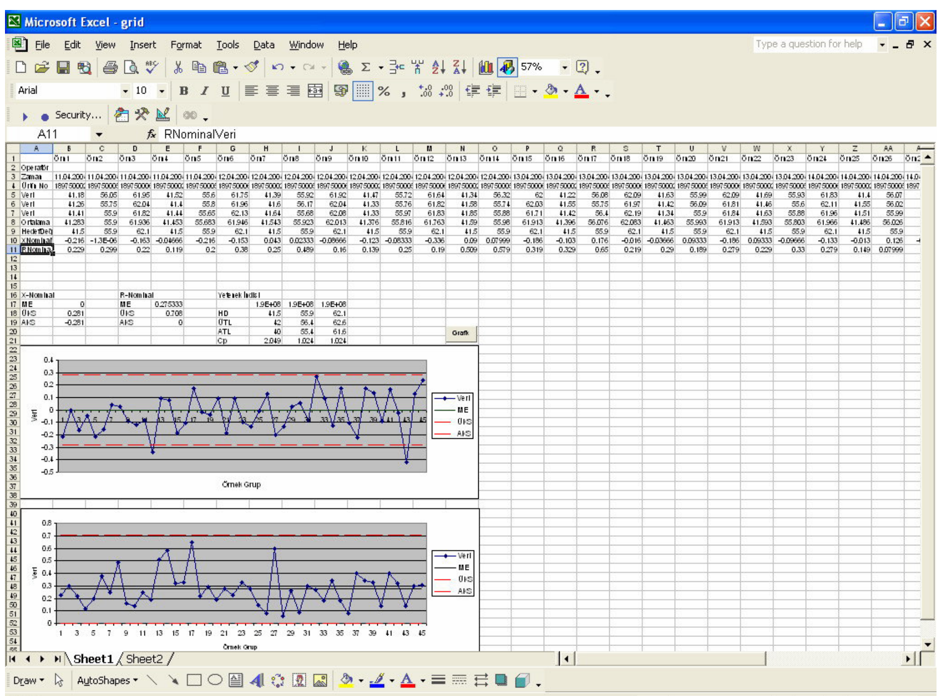


Figure A1.11: Output of Chart Construction

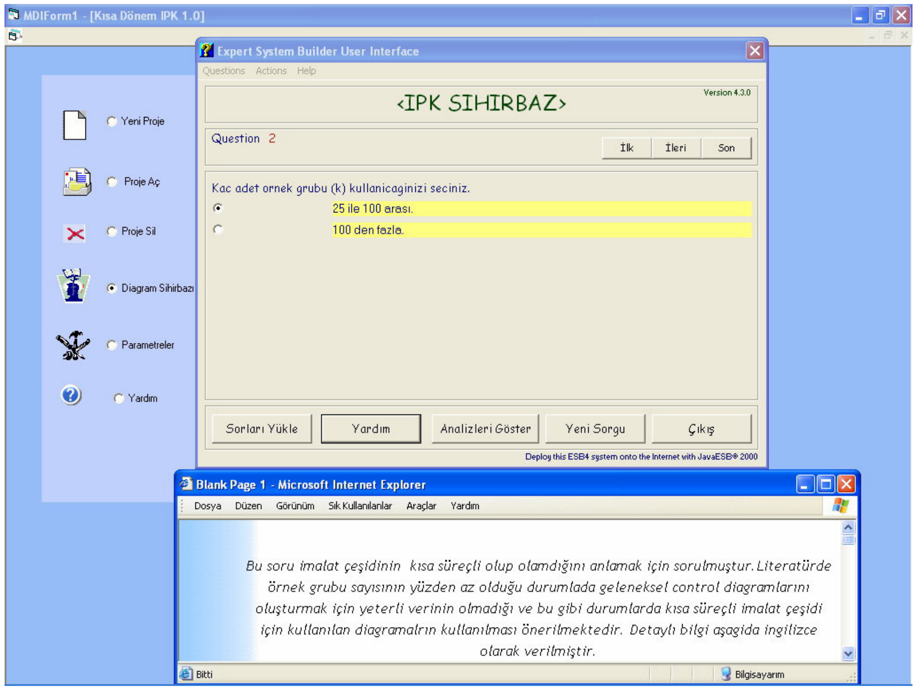


Figure A1.12: Control Chart Wizard

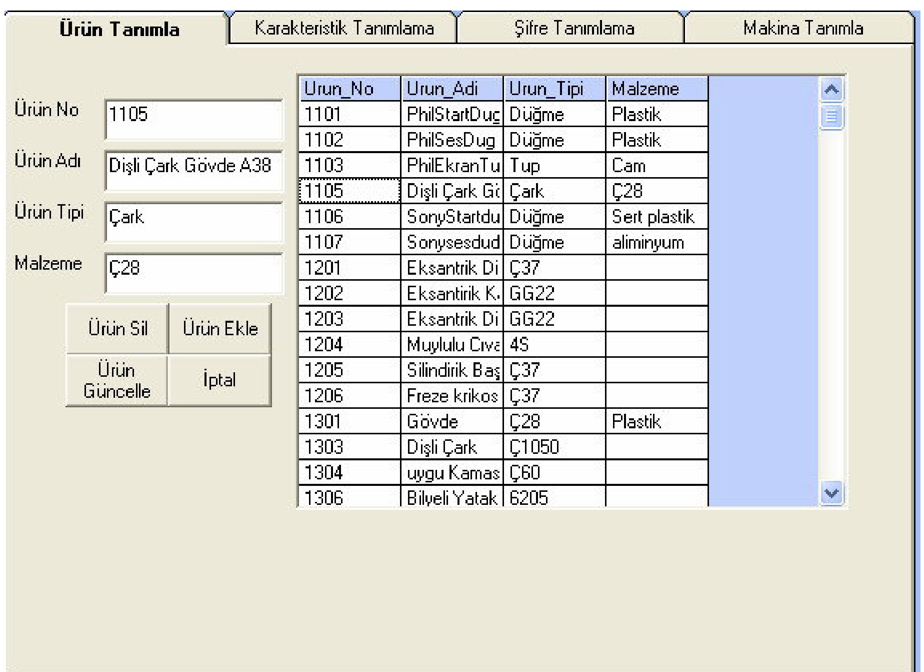


Figure A1.13: Parameters- “Urun Tanımlama”

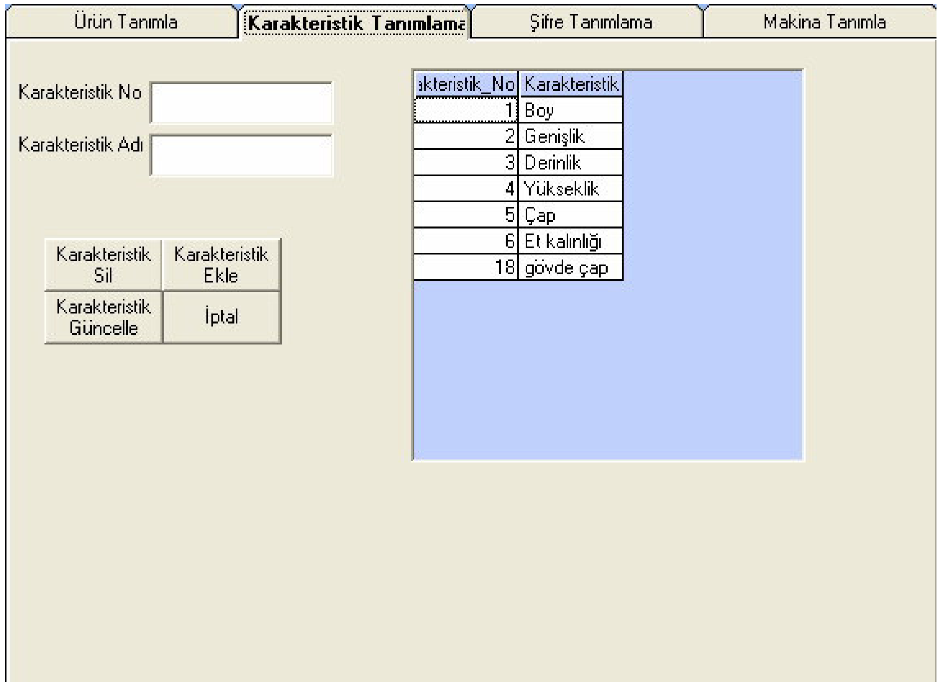


Figure A1.14: Parameters- “Karakteristik Tanımlama”

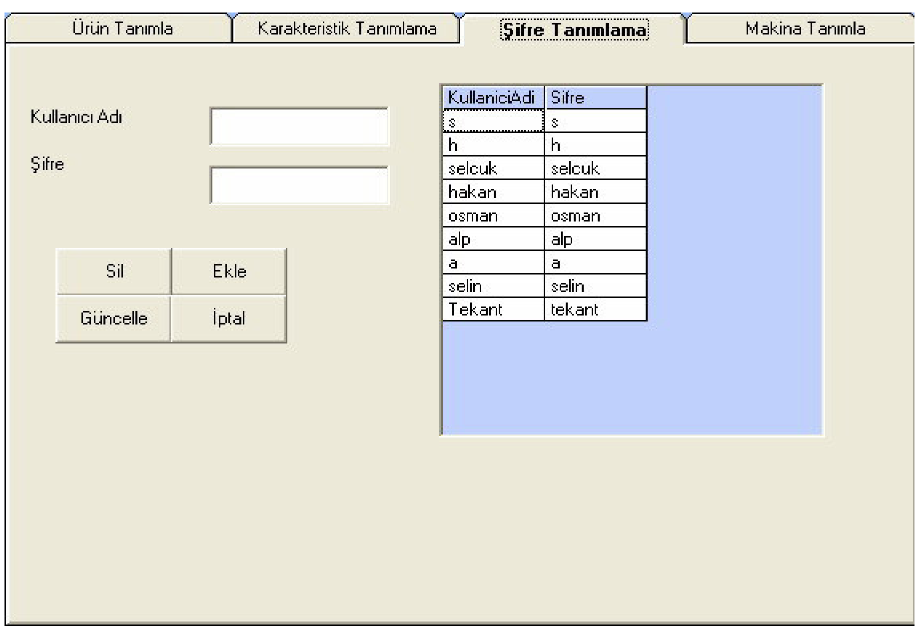


Figure A1.15: Parameters- “Şifre Tanımlama”

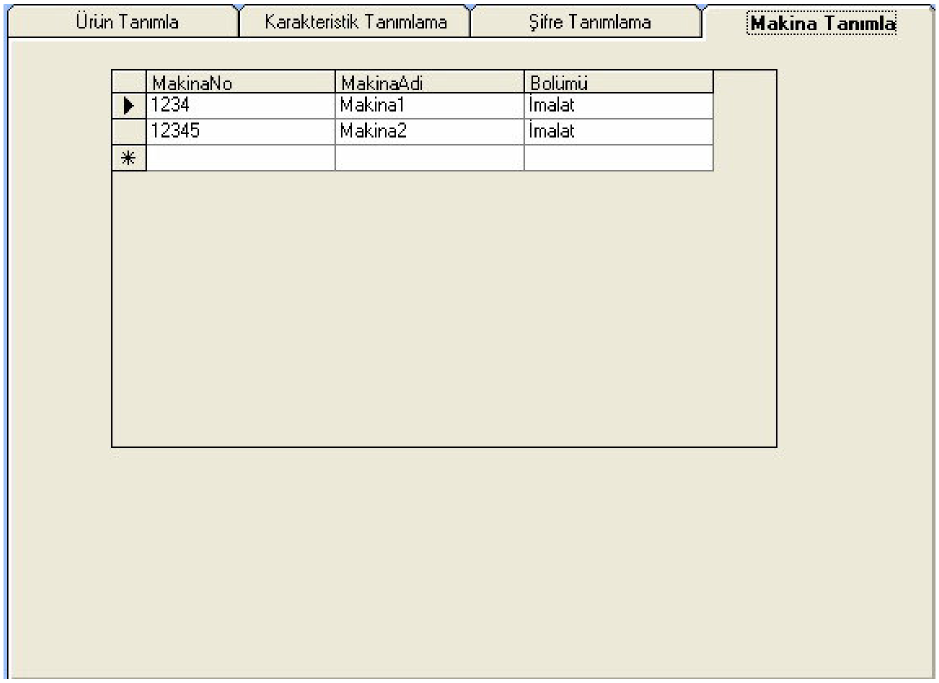
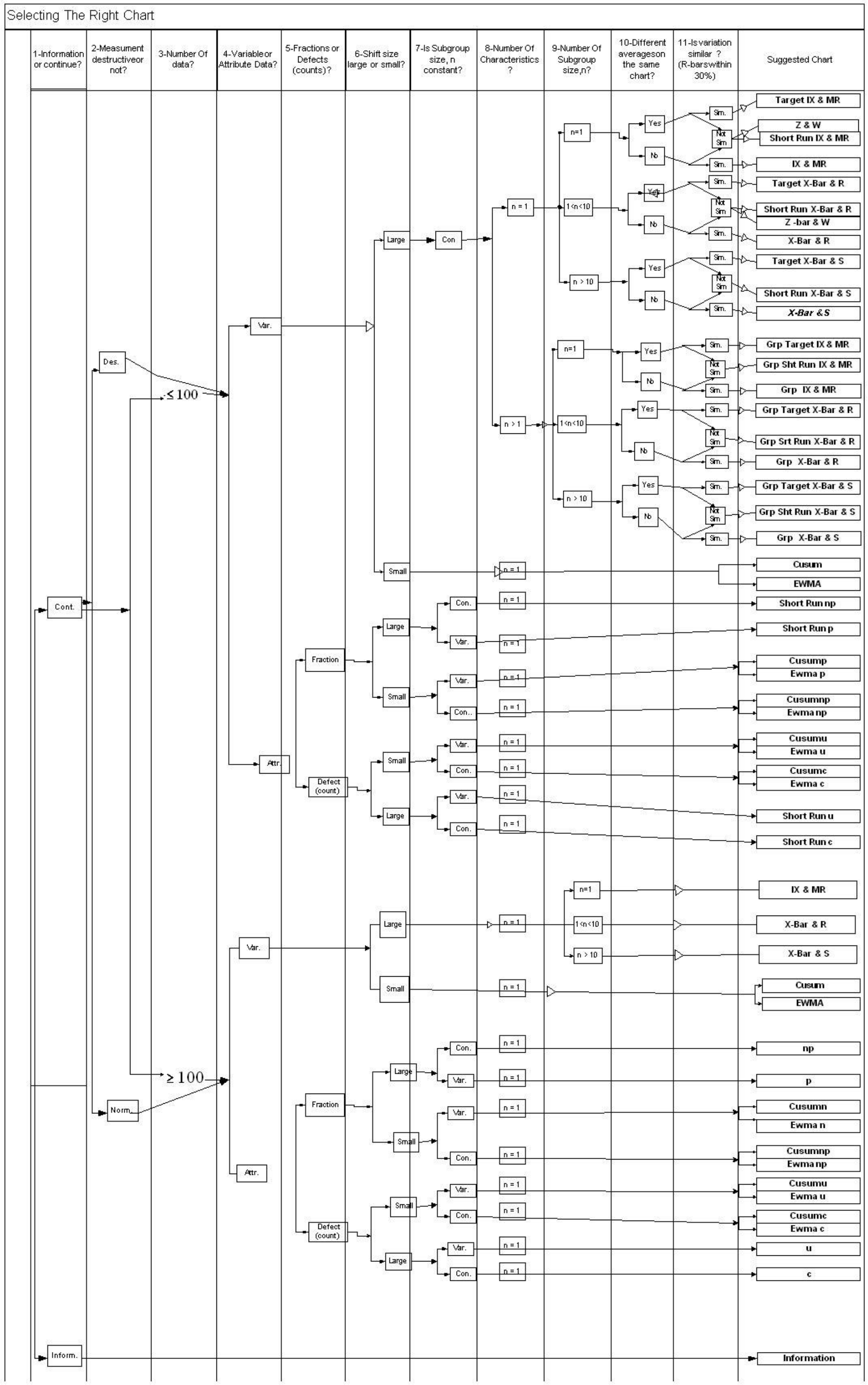


Figure A1.16: Parameters- "Makina Tanımlama"

A.2 Control Chart Selection Tree



A.3 Installation of the Software

Installing the software and running it on any computer with Windows® (*95, 98 second edition, ME, NT, 2000, XP*) operating system and that has a CD-Drive is very easy. The steps to follow are described below;

1- Insert the CD to the CD drive of the computer
2- Double click “Kisa Donemli IPK Setup.exe
3- Follow the instructions,
4- By default this folder will be; “C:\Kisa Donemli SPC, don’t change the path.
5- Open the CD and then the folder “ESB”; double click “Setup.exe”
6- Follow the on-screen messages and install ESB software on the computer

**: When the ESB software is loaded and run for the first time on any computer, it will be fully functional for the 30 days of evaluation period. The software should be purchased to be used after this time period at the internet address: www.esbuilder.com

APPENDIX B
FACTORS FOR CONTROL CHARTS

Table B1: Factors for Control Charts

$\bar{X}$ and range control charts				
n	A_2	D_3	D_4	d_2
1	2.660	0	3.267	1.128
2	1.880	0	3.267	1.128
3	1.023	0	2.574	1.693
4	0.729	0	2.282	2.059
5	0.577	0	2.114	2.326
6	0.483	0	2.004	2.534
7	0.419	0.076	1.924	2.704
8	0.373	0.136	1.864	2.847
9	0.337	0.184	1.816	2.970
10	0.308	0.223	1.777	3.078
11	0.285	0.256	1.744	3.173
12	0.266	0.283	1.717	3.258

Table B1: Factors for Control Charts (Continue) Source: American Society for Testing and Materials. Table adapted from ASTM-STP 15D.

n	A_3	B_3	B_4	C_4
6	1.287	0.030	1.970	0.9515
7	1.182	0.118	1.882	0.9594
8	1.099	0.185	1.815	0.9650
9	1.032	0.239	1.761	0.9693
10	0.975	0.284	1.716	0.9727
11	0.927	0.321	1.679	0.9754
12	0.886	0.354	1.646	0.9776
13	0.850	0.382	1.618	0.9794
14	0.817	0.406	1.594	0.9810
15	0.789	0.428	1.572	0.9823
16	0.763	0.448	1.552	0.9835
17	0.739	0.466	1.534	0.9845
18	0.718	0.482	1.518	0.9854
19	0.698	0.497	1.503	0.9862
20	0.680	0.510	1.490	0.9869
21	0.663	0.523	1.477	0.9876
22	0.647	0.534	1.466	0.9882
23	0.633	0.545	1.455	0.9887
24	0.619	0.555	1.445	0.9892
25	0.606	0.565	1.435	0.9896

APPENDIX C

AREA UNDER NORMAL CURVE

Table C: Area Under Normal Curve [11]

(Proportion of Total Area Under the Curve From − ∞ to Designated Z Value)

Z	0.09	0.08	0.07	0.06	0.05	0.04	0.03	0.02	0.01	0.00
-3.5	0.00017	0.00017	0.00018	0.00019	0.00019	0.00020	0.00021	0.00022	0.00022	0.00023
-3.4	0.00024	0.00025	0.00026	0.00027	0.00028	0.00029	0.00030	0.00031	0.00033	0.00034
-3.3	0.00035	0.00036	0.00038	0.00039	0.00040	0.00042	0.00043	0.00045	0.00047	0.00048
-3.2	0.00050	0.00052	0.00054	0.00056	0.00058	0.00060	0.00062	0.00064	0.00066	0.00069
-3.1	0.00071	0.00074	0.00076	0.00079	0.00082	0.00085	0.00087	0.00090	0.00094	0.00097
-3.0	0.00100	0.00104	0.00107	0.00111	0.00114	0.00118	0.00122	0.00126	0.00131	0.00135
-2.9	0.0014	0.0014	0.0015	0.0015	0.0016	0.0016	0.0017	0.0017	0.0018	0.0019
-2.8	0.0019	0.0020	0.0021	0.0021	0.0022	0.0023	0.0023	0.0024	0.0025	0.0026
-2.7	0.0026	0.0027	0.0028	0.0029	0.0030	0.0031	0.0032	0.0033	0.0034	0.0035
-2.6	0.0036	0.0037	0.0038	0.0039	0.0040	0.0041	0.0043	0.0044	0.0045	0.0047
-2.5	0.0048	0.0049	0.0051	0.0052	0.0054	0.0055	0.0057	0.0059	0.0060	0.0062
-2.4	0.0064	0.0066	0.0068	0.0069	0.0071	0.0073	0.0075	0.0078	0.0080	0.0082
-2.3	0.0084	0.0087	0.0089	0.0091	0.0094	0.0096	0.0099	0.0102	0.0104	0.0107
-2.2	0.0110	0.0113	0.0116	0.0119	0.0122	0.0125	0.0129	0.0132	0.0136	0.0139
-2.1	0.0143	0.0146	0.0150	0.0154	0.0158	0.0162	0.0166	0.0170	0.0174	0.0179
-2.0	0.0183	0.0188	0.0192	0.0197	0.0202	0.0207	0.0212	0.0217	0.0222	0.0228
-1.9	0.0233	0.0239	0.0244	0.0250	0.0256	0.0262	0.0268	0.0274	0.0281	0.0287
-1.8	0.0294	0.0301	0.0307	0.0314	0.0322	0.0329	0.0336	0.0344	0.0351	0.0359
-1.7	0.0367	0.0375	0.0384	0.0392	0.0401	0.0409	0.0418	0.0427	0.0436	0.0446
-1.6	0.0455	0.0465	0.0475	0.0485	0.0495	0.0505	0.0516	0.0526	0.0537	0.0548
-1.5	0.0559	0.0571	0.0582	0.0594	0.0606	0.0618	0.0630	0.0643	0.0655	0.0668
-1.4	0.0681	0.0694	0.0708	0.0721	0.0735	0.0749	0.0764	0.0778	0.0793	0.0808
-1.3	0.0823	0.0838	0.0853	0.0869	0.0885	0.0901	0.0918	0.0934	0.0951	0.0968
-1.2	0.0985	0.1003	0.1020	0.1038	0.1057	0.1075	0.1093	0.1112	0.1131	0.1151
-1.1	0.1170	0.1190	0.1210	0.1230	0.1251	0.1271	0.1292	0.1314	0.1335	0.1357
-1.0	0.1379	0.1401	0.1423	0.1446	0.1469	0.1492	0.1515	0.1539	0.1562	0.1587
-0.9	0.1611	0.1635	0.1660	0.1685	0.1711	0.1736	0.1762	0.1788	0.1814	0.1841
-0.8	0.1867	0.1894	0.1922	0.1949	0.1977	0.2005	0.2033	0.2061	0.2090	0.2119
-0.7	0.2148	0.2177	0.2207	0.2236	0.2266	0.2297	0.2327	0.2358	0.2389	0.2420
-0.6	0.2451	0.2483	0.2514	0.2546	0.2578	0.2611	0.2643	0.2676	0.2709	0.2743
-0.5	0.2776	0.2810	0.2843	0.2877	0.2912	0.2946	0.2981	0.3015	0.3050	0.3085
-0.4	0.3121	0.3156	0.3192	0.3228	0.3264	0.3300	0.3336	0.3372	0.3409	0.3446
-0.3	0.3483	0.3520	0.3557	0.3594	0.3632	0.3669	0.3707	0.3745	0.3783	0.3821
-0.2	0.3859	0.3897	0.3936	0.3974	0.4013	0.4052	0.4090	0.4129	0.4168	0.4207
-0.1	0.4247	0.4286	0.4325	0.4364	0.4404	0.4443	0.4483	0.4522	0.4562	0.4602
-0.0	0.4641	0.4681	0.4721	0.4761	0.4801	0.4840	0.4880	0.4920	0.4960	0.5000

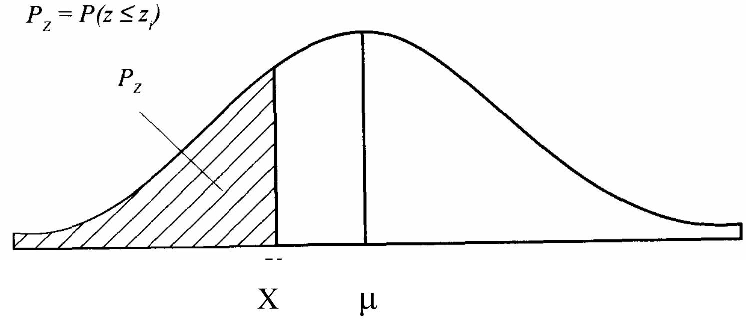
(Continued)

Z	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
+0.0	0.5000	0.5040	0.5080	0.5120	0.5160	0.5199	0.5239	0.5279	0.5139	0.5359
+0.1	0.5398	0.5438	0.5478	0.5517	0.5557	0.5596	0.5636	0.5675	0.5714	0.5753
+0.2	0.5793	0.5832	0.5871	0.5910	0.5948	0.5987	0.6026	0.6064	0.6103	0.6141
+0.3	0.6179	0.6217	0.6255	0.6293	0.6331	0.6368	0.6406	0.6443	0.6480	0.6517
+0.4	0.6554	0.6591	0.6628	0.6664	0.6700	0.6736	0.6772	0.6808	0.6844	0.6879
+0.5	0.6915	0.6950	0.6985	0.7019	0.7054	0.7088	0.7123	0.7157	0.7190	0.7224
+0.6	0.7257	0.7291	0.7324	0.7357	0.7389	0.7422	0.7454	0.7486	0.7517	0.7549
+0.7	0.7580	0.7611	0.7642	0.7673	0.7704	0.7734	0.7764	0.7794	0.7823	0.7852
+0.8	0.7881	0.7910	0.7939	0.7967	0.7995	0.8023	0.8051	0.8079	0.8106	0.8133
+0.9	0.8159	0.8186	0.8212	0.8238	0.8264	0.8289	0.8315	0.8340	0.8365	0.8389
+1.0	0.8413	0.8438	0.8461	0.8485	0.8508	0.8531	0.8554	0.8577	0.8599	0.8621
+1.1	0.8643	0.8665	0.8686	0.8708	0.8729	0.8749	0.8770	0.8790	0.8810	0.8830
+1.2	0.8849	0.8869	0.8888	0.8907	0.8925	0.8944	0.8962	0.8980	0.8997	0.9015
+1.3	0.9032	0.9049	0.9066	0.9082	0.9099	0.9115	0.9131	0.9147	0.9162	0.9177
+1.4	0.9192	0.9207	0.9222	0.9236	0.9251	0.9265	0.9279	0.9292	0.9306	0.9319
+1.5	0.9332	0.9345	0.9357	0.9370	0.9382	0.9394	0.9406	0.9418	0.9429	0.9441
+1.6	0.9452	0.9463	0.9474	0.9484	0.9495	0.9505	0.9515	0.9525	0.9535	0.9545
+1.7	0.9554	0.9564	0.9573	0.9582	0.9591	0.9599	0.9608	0.9616	0.9625	0.9633
+1.8	0.9641	0.9649	0.9656	0.9664	0.9671	0.9678	0.9686	0.9693	0.9699	0.9706
+1.9	0.9713	0.9719	0.9726	0.9732	0.9738	0.9744	0.9750	0.9756	0.9761	0.9767
+2.0	0.9773	0.9778	0.9783	0.9788	0.9793	0.9798	0.9803	0.9808	0.9812	0.9817
+2.1	0.9821	0.9826	0.9830	0.9834	0.9838	0.9842	0.9846	0.9850	0.9854	0.9857
+2.2	0.9861	0.9864	0.9868	0.9871	0.9875	0.9878	0.9881	0.9884	0.9887	0.9890
+2.3	0.9893	0.9896	0.9898	0.9901	0.9904	0.9906	0.9909	0.9911	0.9913	0.9916
+2.4	0.9918	0.9920	0.9922	0.9925	0.9927	0.9929	0.9931	0.9932	0.9934	0.9936
+2.5	0.9938	0.9940	0.9941	0.9943	0.9945	0.9946	0.9948	0.9949	0.9951	0.9952
+2.6	0.9953	0.9955	0.9956	0.9957	0.9959	0.9960	0.9961	0.9962	0.9963	0.9964
+2.7	0.9965	0.9966	0.9967	0.9968	0.9969	0.9970	0.9971	039972	0.9973	0.9974
+2.8	0.9974	0.9975	0.9976	0.9977	0.9977	0.9978	0.9979	0.9979	0.9980	0.9981
+2.9	0.9981	0.9982	0.9983	0.9983	0.9984	0.9984	0.9985	0.9985	0.9986	0.9986
+3.0	0.99865	0.99869	0.99874	0.99878	0.99882	0.99886	0.99889	0.99893	0.99896	0.99900
+3.1	0.99903	0.99906	0.99910	0.99913	0.99915	0.99918	0.99921	0.99924	0.99926	0.99929
+3.2	0.99931	0.99934	0.99936	0.99938	0.99940	0.99942	0.99944	0.99946	0.99948	0.99950
+3.3	0.99952	0.99953	0.99955	0.99957	0.99958	0.99960	0.99961	0.99962	0.99964	0.99965
+3.4	0.99966	0.99967	0.99969	0.99970	0.99971	0.99972	0.99973	0.99974	0.99975	0.99976
+3.5	0.99977	0.99978	0.99978	0.99979	0.99980	0.99981	0.99981	0.99982	0.99983	0.99983

$z = (x_i - \mu)/\sigma$

$P_S = P(z \leq z_i)$

$P_Z = P(z \leq z_i)$



APPENDIX D

SAMPLE CODE

D.1 Sample code of Test1 for X chart

```
'X İçin
sqlstr = "select * from " & varTabloAdiX
adotest.RecordSource = sqlstr
adotest.Refresh

'If varTestler(0) <> "" Then
varUKSMEFarki = adotest.Recordset.Fields("Merkez").Value +
(((adotest.Recordset.Fields("UKS").Value -
adotest.Recordset.Fields("Merkez").Value) / 3) * Val(varTestler(0)))
varAKSMEFarki = adotest.Recordset.Fields("Merkez").Value -
(((adotest.Recordset.Fields("Merkez").Value -
adotest.Recordset.Fields("AKS").Value) / 3) * Val(varTestler(0)))
varSiraNo = 1

txttum.Text = txttum.Text & Chr(13)
txttum.Text = txttum.Text & "Test 1: Bir nokta K sigma degeri kadar
merkez doğrusundan uzakta olursa" & Chr(13)
txttum.Text = txttum.Text & "Test 1 X Diyagramı İçin Başarısız.
Aşağıdaki noktalar K sigma değeri kadar Merkez eğrisinden uzakta:"
& Chr(13)
Do While Not adotest.Recordset.EOF
If adotest.Recordset.Fields("degerfarki").Value > varUKSMEFarki
Then
VarHataForTest1(varSiraNo) =
adotest.Recordset.Fields("degerfarki").Value
```

```
txttum.Text = txttum.Text & " " & varSiraNo & "." & "(" &
VarHataForTest1(varSiraNo) & ") " '& Chr(13)
End If

If adotest.Recordset.Fields("degerfarki").Value < varAKSMEFarki
Then
VarHataForTest1(varSiraNo) =
adotest.Recordset.Fields("degerfarki").Value

txttum.Text = txttum.Text & " " & varSiraNo & "." & "(" &
VarHataForTest1(varSiraNo) & ") " '& Chr(13)
End If
varSiraNo = varSiraNo + 1
adotest.Recordset.MoveNext
Loop
txttum.Text = txttum.Text & Chr(13) & Chr(13)
'End If
```

APPENDIX E

TABLES AND FIGURES

Table F1: Role of small and medium sized manufactures in economy for different countries [51]

Ülkeler	Tüm İşletmeler İçindeki Yeri	Toplam İstihdamdaki Yeri	Toplam Yatırımlar İçindeki Yeri	Katma Değer İçindeki Yeri	Toplam İhracat İçindeki Yeri
ABD	97.2	58	38	43	32
Almanya	99	64	44	49	31
Japonya	99.4	81.4	40	52	38
İngiltere	96	36	29.5	25	22
Fransa	99	67	45	54	26
İtalya	98	83	52	47	-
Hollanda	98	57	45	32	38
Hindistan	98.6	63	27.8	50	40
G.Kore	98.8	59	35	35	20
Tayland	98	64	-	47	50
Singapur	97	44	27	43	10
Türkiye	99.2	53	26.5	38	8