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COLLEGE OF POST-GRADUATE STUDIES

Quality Control of Petroleum Products by using Statistical Quality Control (SQC) Charts

مراقبة جودة المنتجات البترولية باستخدام خرائط الرقابة الاحصائية

A THESIS SUBMITTED IN FULFILLMENT OF THE
REQUIREMENTS FOR THE PH.D IN STATISTICS

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﴿ بِسْمِ اللّهِ الرَّحْمَنِ الرَّحِيمِ ﴾

اقْرَأْ بِاسْمِ رَبِّكَ الَّذِي خَلَقَ ﴿١﴾ خَلَقَ الْإِنسَانَ مِنْ عَلَقٍ ﴿٢﴾ اقْرَأْ وَرَبُّكَ الْأَكْرَمُ ﴿٣﴾ الَّذِي عَلَّمَ بِالْقَلَمِ ﴿٤﴾ عَلَّمَ الْإِنسَانَ مَا لَمْ يَعْلَمْ ﴿٥﴾

صدق الله العظيم

سورة العلق الآيات (1–5)

DEDICATION

To the memory of my father, Elmahi Abd Elwahaab, who passed on a love of reading and respect for education.

To the person who learned me a lot
To the lovely lady
To my Mother

To my sister and brother
To my friend , Eman Mohammed

ACKNOWLEDGEMENTS

Firstly all thanks to ALLAH who gave me all this successes and, I truly thank my main supervisor Dr. Ahmed hamdi for his support, patience, encouragement and useful guidance.

All thanks to Dr. Saad AlDeen Mohammed. And also I thank Friend Eman for support.

I never forget to thank my family for their patience and encouragement ,during my study. Great thanks to all my friends for great help and support**.**

الخلاصة

تعد خرائط مراقبة الجودة اداة احصائية لمراقبة مدى مطابقة العملية الانتاجية للموصفات المحددة مسبقا واكتشاف مواطن الخلل والانحرافات غير المرغوب فيها في الاداء ومن ثم تحديد اسباب هذه الانحرافات و اتخاذ الاجراءات التصحيحية لضمان التحسين المستمر. تمثلت مشكلة الدراسة في تراجع جودة المنتجات النفطية واثره السلبي علي صحة الانسان و سلامة البئية , فالوقود الذي يحتوي علي الكبريت يؤثر في زيادة التلوث البيئي. هدفت هذه الدراسة الي تقييم جودة المنتجات النفطية (الديزل و البنزين) في مصفاة الخرطوم واستخدام خرائط الرقابة الاحصائية في ضبط جودة المنتجات النفطية. وكانت اهم الفرضيات استخدام الأساليب الإحصائية في الرقابة على جودة المنتجات النفطية أكثر فاعلية في كشف التغيرات في العملية الانتاجية من النظام المتبع لدى المصفاة. اعتمدت الدراسة علي المنهج التحليلي من خلال اخذ عينات متكررة من الانتاج و اعداد خريطة مراقبة جودة الانتاج للمتوسط باستخدام (R- bar , X- bar) و(X-bar , S)

خرجت الدراسة بنتائج كان اهمها : ان جودة منتج الديزل في مصفاة الخرطوم غير مطابق للمواصفات (كثافة الديزل و درجة الوميض) بينما الرقم السيتاني لمنتج الديزل مطابق للمواصفات. كما بينت اختبارات الرقابة الاحصائية لمنتج البنزين ان كثافة البنزين غير مطابقة للمواصفات. اوصت الدراسة بضرورة استخدام خرائط الرقابة الاحصائية لمراقبة جودة المنتجات النفطية بمصفاة الخرطوم وذلك لسهولة الاستخدام والدقة في اتخاذ القرار حول سير العملية الانتاجية وتدريب العاملين في مجال ضبط الجودة في المصفاة علي استخدام خرائط الرقابة الاحصائية ومراجعة وتحديث حدود مواصفات المنتجات النفطية بين الحين والاخر لتواكب التطورات العالمية .كما اوصت الباحثة بإجراء دراسة بعنوان استخدام 6 سيجما في ضبط جودة المنتجات النفطية لتكون امتدادا وتكملة لهذه الدراسة.

ABSTRACT

Quality control chart is statistical tool to control production process according to specific specification . It also used to know defects and unneeded deviations in performance to know deviation causes and then make a decisions to ensure continuous improve. The research problem is the decline in the quality of petroleum products and its bad effect in human health and the environment .the fuel contains sulfur which increase pollution. The study aimed to evaluate petroleum products quality (diesel & gas oil) in Khartoum refinery using statistical control chart. The main hypotheses is using statistical control method in petroleum products quality more effective to know changes in production process compared to the current system . The study followed the statistical approach by taking frequent samples from products and prepare quality control chart for mean using (X- bar , R- bar)و (X-bar , S) . The result shows that the diesel quality in Khartoum refinery does not meet the specification by test diesel density and flash point . But the cetena number for diesel meet the specification. The statistical control tests show that the Gas Oil density does not , meet the specification . The study recommends using statistical control chart to control petroleum product quality in Khartoum refinery for its usability and accuracy in production decision making process Also it recommends training for people who work in refinery quality control to use statistical control chart and continuously update petroleum products specification limits to meet international development.

The researcher recommend a study in title the use of 6 Sigma to control the quality of petroleum products to be an extension for this study.

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1-1 Background:

The quality has become one of the basic conditions in marketing and applying the international standards or the quality specifications help any corporation to be in the global market and to gain the ability for competition.

Most of the companies and corporations depend on the final check to the products to know if the product has fulfilled all the qualities required or it needs redevelopment or to get rid of it because of the differences found in the treatment and need refinement and improvement.

Accordingly, statistical monitoring plans help to understand the differences associated with treatment or identifying the causative to lessen the differences between the quality attributes.

1-2 Research Problem:

The withdraw of the petrol products lead to high proportion of sulphur emission into the products which lead to emission of pollutants from exhaust gas which results from the combustion of gasoline or the diesel that directly affect the human health and also the cause of air pollution in cities and the appearance of mist which contains sulphur and affect negatively the age of the engines and contribute in increasing environmental pollution and the best petrol products characterized by less rate of sulphur emissions. It is mandatory to use the gasoline free from sulphur in America, Japan, Europe and Brazil.

1-3 Hypotheses of the study:

Using the statistical methods in censorship to the quality of kerosene which is more effective than the system used in refinery.

1-4 importance of the study:

The importance of the study derives from the importance of the statistical censorship to the production's quality and the extent of conformity to the retroactive production process specifications and discover the undesirable deviations in performance and then correct actions to avoid such problems in the future and to ensure continuous improvements.

Lies the importance of the study in:

1. Clarify the ways and styles of the statistics to the quality monitoring.

2. Contributing in upgrade the quality of petrol products in countries by producing petrol free of leads or free from even small quantities of sulfur to reach the international protection of the environment by introducing statistical methods to help in producing petrol which is international autotype.

1-5 Objectives of the study

2 To apply the ways of statistic for quality control to petroleum derivatives on Khartoum refinery.

3 To evaluate the quality of derivatives products on Khartoum refinery.

4 The research aims to assist the workers in the quality productive field to lead them doing the job perfectly and effectively.

1-6 Methodology of the study:

The research will follow the descriptive method in describing the study variables, tables, graphs and the analytical method to the data which is collected from the field and the case study. The information will be gathered from the first sources by taking samples from the production.

1-7 Limitation of the study:

Because of the multiplicity of oil derivatives and the large number of properties, the study will focus on the diesel production as a sample to the rest of oil derivatives and that because the important and plenty of using it in daily life. The study will be limited into:

1-8 Spatial border: Khartoum refinery.

1-9 Temporal border: cover the time from 3/6/2014 – 28/6/2014

1-10 Past Study:

1-10-1 **Multivariate quality control: Statistical performance and economic feasibility**

Khalidi, Mohammad Said Asem. Wichita State University, ProQuest Dissertations Publishing, 2007. 3311796.

Shewhart control charts have been used to monitor uncorrelated quality characteristics. Advancement in manufacturing technology and increased complexity of products and systems raise the need to monitor correlated characteristics. This research is aimed at quantifying the statistical and economic consequences of utilizing the Hotelling's T 2 multivariate control chart as an alternative to the traditional Shewhart x chart. Consequently, there were two main objectives of this research. The first objective was to identify the levels of correlation between the charted variables where the statistical performance of the x chart deteriorates compared to that of an equivalent T 2 chart. The second objective was to assess the economic feasibility of utilizing a T2 chart as an alternative to the two x charts. Results indicated that the switch to multivariate T2 chart would result in economic savings under all levels of the process and chart variables considered. It is hoped that this research will encourage practitioners to implement appropriate multivariate statistical techniques in monitoring their processes.

1-10-2 Multivariate statistical quality control

Golnabi, Saeed. University of Cincinnati, ProQuest Dissertations Publishing, 1998. 9833691.

univariate quality control, the bar X-Charts and R-Charts and S-Charts have been useful to control the process parameters, (the process mean and process variability.) It would be very useful to have similar charts applied to the multivariate case. The existing methods do not provide all the information that a quality control practitioner would like to possess such as the indication of which variables are causing the process to be out of control. In this thesis there are two main subjects, concerned with the control of the process mean and the process variability respectively. The first subject is based on the adequate selection of the critical region. The process considered is assumed to be multivariate normal with parameters known from historical data or estimated from a large sample. We call this method, "Multivariate Shewhart Chart (MS Chart)", because it reduces to the Shewhart Chart when the process involves only one variable. The second subject concerns the control of the covariance structure, which is based on sample partial correlations. The procedures outlined have been illustrated with the help of simulated data and examples, which have been frequently used by other authors in this field.

1-10-3 Statistical properties of control charts for the mean

Capilla Roma, Carmen. Universidad Politecnica de Valencia (Spain), ProQuest Dissertations Publishing, 1991. 3122644.

Control charts are statistical methods widely applied to improve the quality and productivity of products and processes. In this research work we study the statistical properties of these procedures, with the aim of determining their optimal application to control the mean of a quality characteristic. The sampling frequency and size are analyzed, evaluating the performance of the control chart for the sample mean as a function of the sampling scheme under several out of control situations and process capabilities. The statistical properties of this chart are studied when supplementary runs rules are considered, and compared with the CUSUM chart and the sample means chart with only one out-of-control signal (a point outside the control limits). The statistical performance of the moving averages chart are determined as a function of the grouping size. The effectiveness of this chart is compared with that of the individuals chart, and CUSUM and

EWMA procedures. Finally, the effect of serial correlation on the statistical properties of all the control charts mentioned above, is analyzed.

1-10-4 The economic statistical design of variables control charts with an application to exponentially weighted moving average charts

Torng, Chau-Chen. Arizona State University, ProQuest Dissertations Publishing, 1992. 9223149.

The purpose of this research is to investigate the design of variables control charts from the economic and statistical viewpoint. A cost model is developed for the exponentially weighted moving average (EWMA) control charts based on Lorenzen and Vance's unified approach. Average run length (ARL) and average time to signal (ATS) are chosen as statistical constraints for the economic statistical design of EWMA charts. Comparisons between the economic designs of X-bar charts and EWMA charts based on cost and ARL criteria show no significant difference. It appears that an optimally designed EWMA chart is slightly better than an optimal X-bar chart. If a non-optimized X-bar chart is used, the difference will be much in favor of the EWMA chart. Sensitivity analysis shows that cost of the economic statistical design is more sensitive to the smaller out-of-control ATS bounds but relatively insensitive to the larger bounds. Adding additional constraints to the economic statistical designs does not significantly increase cost over the designs without additional constraints but ensures better protection against shifts other than the expected shift. In summary, economic statistical designs will probably be the best choice for the design of variables control charts in today's industry because they yield designs that are at least as good as statistical designs in terms of statistical properties but are also generally less costly. A protection over a wider range of shifts is another advantage of the economic statistical design.

1-10-5 EWMA control charts and extended EWMA control charts

Zhang, Ling Yun . The University of Regina (Canada), ProQuest Dissertations Publishing, 2002. NR04037.

In this thesis we study the well known exponentially weighted moving average (EWMA) technique when it is used to construct control charts. After a literature review, we concentrate on the following five topics: the average run length (ARL) unbiased property, one-sided EWMA charts for censored lifetime data, double exponentially weighted moving average (DEWMA) charts, m -fold EWMA charts, and EWMA charts for binomial data. Both analytic and numerical simulation methods are used to investigate the performance and design of the above new EWMA charts. We show that EWMA control charts are ARL-unbiased, that one-sided EWMA charts can monitor both decreases and increases in the process mean for censored lifetime data, while the Shewhart X-bar chart can only monitor decreases, that DEWMA charts can improve upon EWMA charts for variable data, that there may still be room for improvement if we use m -fold ($m > 2$) EWMA statistics to construct control charts, that the EWMA p control chart for attribute data with time-varying control limits dominates the Shewhart p chart, and that the DEWMA p chart also improves upon the EWMA p chart.

1-11 Data Analysis by SPSS:

For analyzing we use SPSS software to monitor the data by statistical quality control maps, two methods used(R-bar, R-bar) and (X-bar ,S-bar).

1-12 Thesis structure:

This thesis work will cover following chapters respectively:

Chapter one: Introduction: This chapter will start with some backgrounds about the work. It will continue by introducing research area, and continuously will explain the purpose of the thesis. Finally, it will describe delimitations and thesis structure.

Chapter Two: Theoretical Frame of References. In this chapter the start point is about some basic definitions. Then it will continue by introducing a SQC approach, addresses what has been written by quality control writers and previous studies

Chapter Three: Khartoum refinery, created, objectives, organization structure and quality of oil derivatives.

Chapter Four : Application Part ,Analysis and discussion. This chapter will begin by analyzing the result of investigation discussed in previous chapter. Accordingly, findings will be summarized, and problems found as a result of investigation will be clarified. In the next part of this chapter, recommendations and suggestions for improvement will be described. This part is based on what it has been discussed in theoretical frame of reference and analysis of findings.

Chapter Five: Conclusion and recommendations. This chapter will be consisting of conclusion of the whole work. Hereby, the whole work will be reviewed precisely and the final conclusion will be described at the end.

Chapter Two

Theoretical Frame

2-1 Introduction:

Quality can be defined in many ways, ranging from "satisfying customers' requirements" to "fitness for use" to "conformance to requirements." It is obvious that any definition of quality should include customers, satisfying who must be the primary goal of any business. Experience during the last two decades in the U.S. and world markets has clearly demonstrated that quality is one of the most important factors for business success and growth. Businesses achieving higher quality in their products enjoy significant advantage over their competition; hence, it is important that the personnel responsible for the design, development, and manufacture of products understand properly the concepts and techniques used to improve the quality of products. Statistical quality control provides the statistical techniques necessary to assure and improve the quality of products.

Most of the statistical quality control techniques used now have been developed during the last century. One of the most commonly used statistical tools, control charts, was introduced by Dr. Walter Shewarts in 1924 at Bell Laboratories. The acceptance sampling techniques were developed by Dr. H.F. Dodge and H. G. Romig in 1928, also at Bell Laboratories. The use of design of experiments developed by Dr. R.A. Fisher in the U.K. began in the 1930s. The end of World War II saw increased interest in quality, primarily among the industries in Japan, which were helped by Dr. W.E. Deming. Since the early 1980s, U.S. industries have strived to improve the quality of their products. They have been assisted in this endeavor by Dr. Genichi Taguchi, Philip Crosby, Dr. Deming, and Dr. Joseph M. Juran. Industry in the 1980s also benefited from the contributions of Dr. Taguchi to design of experiments, loss function, and robust design. The recent emphasis on teamwork in design has produced concurrent engineering. The standards for a quality system, ISO 9000, were introduced in the early mobile industries, resulting in QS-9000.[1] (M. Jeya Chandra 2001)

2-2 Role of Control Charts:

No two products are exactly alike. This is so because the process that produces these products has many causes of variability. Many of these are common causes. They are a part of the normal operation of the process and produce product variation that is stable and predictable over time . Others are special causes. They are not a part of the normal operation of the process. When they occur, they cause the product variation to become unstable and unpredictable over time. To achieve product uniformity, it is necessary to either reduce the special and common causes of variation or reduce their effects on product variability. Reducing common causes or their effects requires product and process redesign, whereas reducing special causes requires action to ensure that the process

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[1] M. Jeya Chandra, (2001) Statistical Quality Control , by CRC Press LLC

operates in the way it is intended to. Thus, the corrective actions for the two ways to improve the process are fundamentally different. Confusion between common and special causes of variation is expensive and leads to counterproductive corrective actions. Shewhart developed control charts as a graphical method to distinguish between common and special causes of variation. This development brought about a new way of thinking regarding variation and improvements (Shewhart). The old way of thinking was to classify variation as either meeting specifications or not meeting specifications. Thus, a product was either good (met specifications) or bad (did not meet specifications). A report was either on time or not on time. This thinking led to a strategy of detection, in which the product was inspected and reinspected in an attempt to sort good products from bad products. This strategy is wasteful because it permits resources to be invested in unacceptable products and services. Furthermore, by defining quality as meeting specifications, it permits complacence by not requiring continuous improvement toward meeting the ideal product targets. A better approach is to avoid the production of bad products in the first place by a strategy of prevention. This prevention strategy is based upon an understanding of the process, the causes of variability, and the nature of actions necessary to reduce

variation and achieve consistent, on-target performance. The Process. A process is a way of doing things. All products and services are a result of some process. As shown in Figure 2.1, a process includes the entire combination of customers, suppliers, and producers, involving people, machines, materials, methods, and environment that work together to produce a product or service. Process quality is measured by the degree to which the process output is exactly as desired by the customers, namely by the degree to which product and service performance characteristics are consistently on target. The performance characteristics and their targets are selected on the basis of customer expectations. The process output is not consistently on target because the process is affected by many causes of variation. A product varies because of people (operators, training, and experience), machines(machine-to-machine)

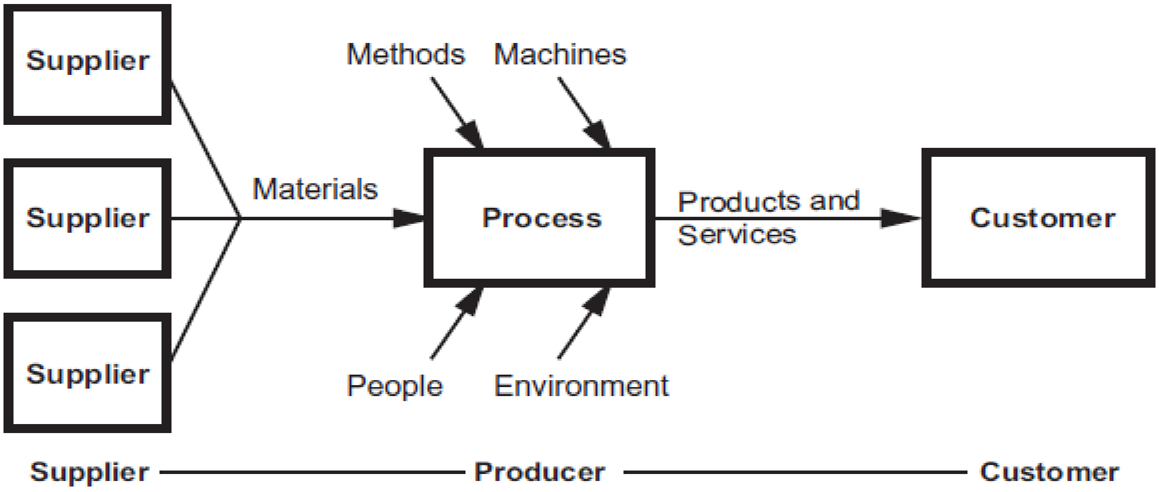

Figure 2-1 The process.

Statistical Methods for Six Sigma by Anand M. Joglekar
ISBN 0-471-20342-4

Differences , wear, and maintenance), methods (temperature control) , materials (lot-to-lot and within-lot differences), and environment (ambient temperature and humidity). The time to place a purchase order varies due to people performing the various steps, availability of people, the accuracy of the original request, the reliability of equipment used, and the procedures followed. The collected data additionally vary due to the variability of the measurement system. These causes of variation can be classified as common and special causes. Common Causes of Variation. These causes of variation are a part of the normal operation of the process and are constantly present. Their effect manifests itself in short-term variability. They are usually large in number and the effect of any one of the causes is relatively small. Some examples are the small changes in process factors, raw materials, ambient conditions, and measurements that occur constantly. Due to the central limit theorem, the cumulative effect of common causes is variation

in output characteristic that is usually normally distributed and is stable and repeatable over time. In this situation, shown in Figure 3.2, the process is said to be in a state of statistical control or in control or stable, and the output of the process is predictable within limits. A stable process has constant mean, standard deviation, and distribution over time. Special Causes of Variation. These refer to causes of variation that are either not always present or are not always present to the same degree. They produce a large change in the output characteristic. Their effect manifests itself in the long term by making the long-term variability larger than the short-term variability. Special causes occur due to the introduction of a new cause that was previously absent or be-

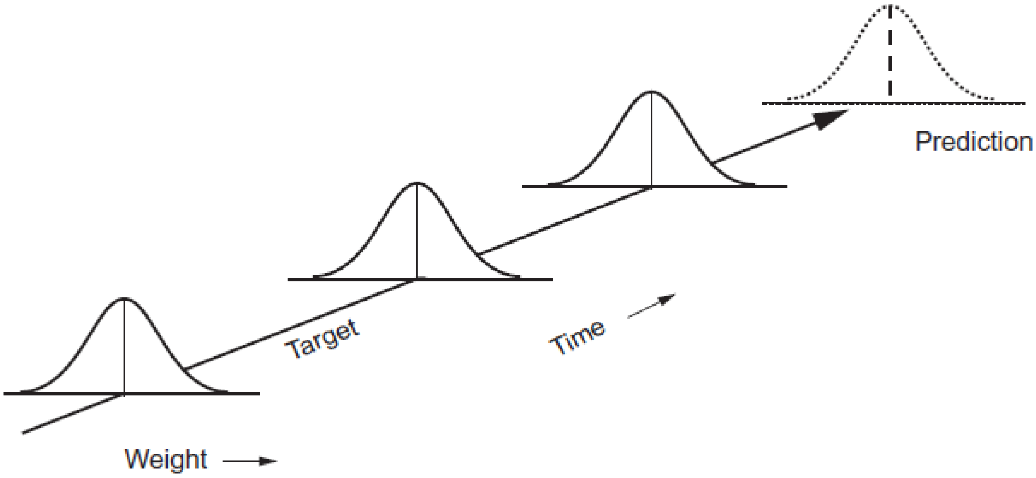

Figure 2-2 Common cause variation.

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cause of a larger than usual change in a key common cause. Use of the wrong ingredient, wrong process setting, or an untrained operator are examples of special causes. When they occur, they cause an unpredicted change in the mean, variance, or shape of the distribution of output characteristic, as shown in Figure 2.3. Therefore, predictions regarding the future distribution of output characteristics cannot be made. The process is said to be out of control or unstable.

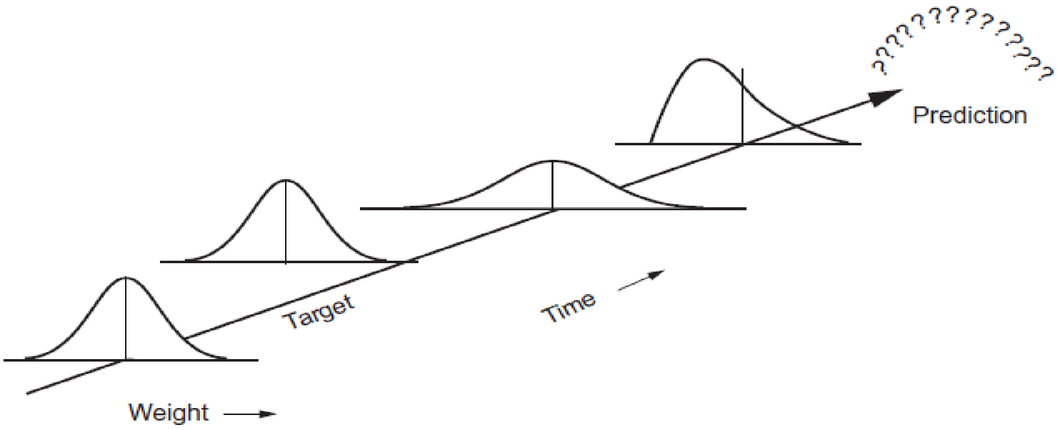

Figure 2-3 Special cause variation.

Statistical Methods for Six Sigma by Anand M. Joglekar
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2-3 Statistical quality control charts:

Quality control charts are graphical tools specifically designed to help in the difficult task of distinguishing between process data that exhibit special cause natural variation and those that exhibit special cause unnatural variation indicating the presence of one or more special assignable cause. the statistical control chart was developed at bell laboratories by Dr. Walter shewhart in 1924 and has become one of the primary tools of modern quality improvement and SPC .while based in abit more statistical theory than meets the eye ,control charts also are intended to be reatively easy for non statisticians and practitioners to use and interpret although the basic format and interpretation of control charts are described in greater detail elsewhere a brief description follows. Aset of observations (called a subgroup in SPC terminology) periodically is sampled from the process,

2-4 Shewhart charts are divided into two categories:

1. Attributes Control Charts used to detect changes in process parameters when the measurements are from a countable set
2. Variables Control Charts used to detect changes in process parameters when the observation come from a continuous distribution.

   For variables control charts, it is assumed that the underying statistical distribution of the continuous data is either from a normal distribution , can be transformed into a normal distribution , or can be grouped into samples that approximate a normal distribution. The foundation of the test for interpretation of the shewhart control charts is the assumption that the distribution of the observations is identical to the underlying statistical distribution used in the construction of the control chart.

2-5 Attributes Control Charts:

Attributes control charts are used when the data is countable. The most common underlying data distributions of attributes control charts is either the binomial distribution or the Poisson distribution. Attributes control charts will not be examined in this analysis.

2-6 Variables Control Charts:

Variables control charts are constructed using observations collected from a process. These observations are either analyzed individually or can be grouped

into samples depending on the availability of the data and the costs associated with data collection . the grouping of observations into samples allows the variables control chart to be constructed and analyzed using structured methodology even though the underlying distribution may not be normal . The statistical basis of grouping the observations into samples is the central limit theorem [Montgomery, 1991]. Thus, if the observations (independent random variables) collected from a given distribution are grouped into a sufficiently large sample .then the sampling distribution of the mean can be approximated by a normal distribution . in practice, the number of observations in samples I s relatively small (usually just 4 or 5), resulting in an approximation to a normal distribution at best. Control limits on a shewhart control chart are developed using sample statistics to estimate the process parameters .Assuming the underlying process parameters remain constant ,the control limits are generally calculated that set the Type 1($\propto$)
Error to be equal to 0.0027 (0.27%) per sample. This means that the chance of obtaining a sample statistic that exceeds the control limits is 1 out of 370 samples when the process parameters do not change . the value of the Type 1 ($\propto$) error can be adjusted to be less susceptible to false alarms; however, reducing the Type 1($\propto$) error will increase the probability of Type Π (β) error (failure to correctly identify a change in process parameters).

The control limits for the sample central tendency and the sample dispersion are calculated using the following equations[2] [Montgomery, 1991]

The most important use of a control chart is to improve the process. We have found that, generally

1. Most processes do not operate in a state of statistical control.
2. Consequently, the routine and attentive use of control charts will identify assignable causes. If these causes can be eliminated from the process, variability will be reduced and the process will be improved.

This process-improvement activity using the control chart is illustrated in Fig.2-4

2-7 Normal distribution

The normal distribution is a continuous distribution that approximately describes many of nature's quantitative phenomena, for example length and weight on humans and other biological creatures. Large areas within statistics inference are based on this distribution. In Figure 2.3 the standardized normal distribution with its mean (μ) and standard deviation (σ) is illustrated. For the standardized normal distribution, $\mu = 0$ and $\sigma = 1$.[3] (Engstrand and Osson, 2003).

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[2] Montgomery, 1991

[3] Engstrand & Olsson, 2003

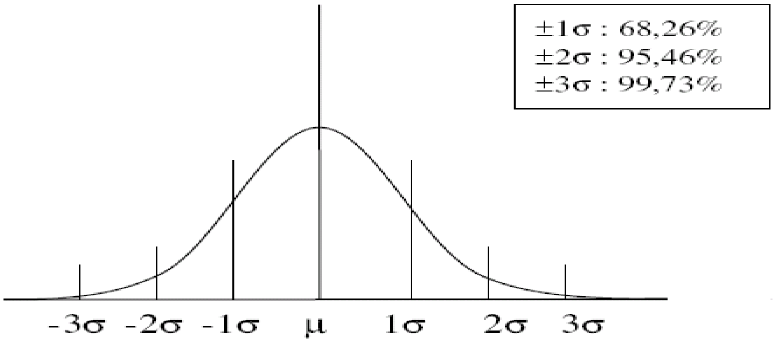

Figure 2-4 A Standardized normal distribution and its variation from the mean. (Engstrand and Osson, 2003)

One standard deviation (σ) away from the mean accounts for 68.26% of the total distribution while two standard deviations away from the mean account for 95.46% and three standard deviations account for 99.73. As seen in Figure 2.3 the normal distribution varies quite much from its mean. This variation is called the natural variability or "background noise". When a process only varies with natural variation it is said to be in statistical control and when it varies more it is said to be out of control. (Engstrand & Olsson, 2003) . Aside from the normal distribution there are other forms of distributions , which can be of good resemblance with the collected data distribution. (Gunnar, 1989) Examples of other continuous distributions are the Lognormal, Exponential, Gamma and Weibull. (Montgomery, 2005) However, when sampling data randomly and displaying the mean value of the samples in a probability distribution, it is according to the central limit theorem expected to be normally distributed.

2-8 The central limits theorem:

This section briefly summarizes the basic result obtained by this famous theorem. Given a population or process, a random variable x, with mean and standard deviation σ, let $\bar{x}$ be the mean of a random N sample made of n elements x_1, x_2, … , $x_n$extracted from this population: when the sample size n is sufficiently large, the sampling distribution of the random variable $\bar{x}$ can be approximated by a normal distribution. The larger the value of n, the better the approximation. This theorem holds irrespective of the shape of the population, i. e., of the density function of the variable x.

The analytic translation of the theorem is given by the following equations:

$$M(\bar{x}) = \bar{\bar{X}} = \hat{\mu} , \qquad (2.1)$$

$$\sigma(\bar{x}) = \frac{\hat{\sigma}}{\sqrt{n}} , \qquad (2.2)$$

Where $\hat{\mu}$ is estimation μ of and $\hat{\sigma}$ is the estimation of σ

2-9 Probabilistic Relationship:

As this relationship depends upon the probabilistic properties of the component and assembly characteristics, it necessary to make certain assumptions regarding these characteristics:

1. Xis are independent of each other.
2. Components are randomly assembled.

3. Xi ~N (μi, σ_i^2); that is, the characteristics, Xi is normally distributed with a mean μi and a variance σ_i (this assumption will be relaxed later on).
4. The process that generates characteristics Xi is adjusted and controlled so that the mean of the distribution of Xi, μi, is equal to the nominal size of Xi, denoted by Bi , which is the mid-point of the tolerance region of Xi. That is,

$$\mu_i = \frac{(U_i + L_i)}{2} \tag{2.3}$$

5. The standard deviation of the distribution of the characteristic Xi, generated by the process, is such 99.73% of the characteristic Xi.

Table (2-1)

Areas for different Ranges under Standard Normal Curve

Parts per million Outside the Range	**% Outside the Range**	**% Covered within the Range**	**Range**
317,400	31.74	68.26	(μ - 1 σ) to (μ + 1 σ)
45,600	4.56	95.44	(μ - 2 σ) to (μ + 2 σ)
2700	0.27	99.73	(μ - 3 σ) to (μ + 3 σ)
63.4	0.00634	99.99366	(μ - 4 σ) to (μ + 4 σ)
0.574	0.0000574	99.9999426	(μ - 5 σ) to (μ + 5 σ)
0.002	0.0000002	99.9999998	(μ - 6 σ) to (μ + 6 σ)

Source: *Statistical Methods for Six Sigma* by Anand M. Joglekar
ISBN 0-471-20342-4 © 2003 John Wiley & Sons, Inc.

2-10 Errors in Control Charts:

Two types of errors are associated with using the control charts. These are type I error and type II error. Type I error is the result of concluding that a process is out of control (based on actual data plotted on the chart) when it is actually in control. For a 3σ control chart this chance (α) is very small (about 0.0027). Type II error is the result of concluding that a process is in control (based on actual data plotted on the chart) when it is actually out of control. This may happen under many situations, such as the process mean changes from its initial setup, but all sample points fall within the control limits. The probability of type II error is generally represented by β and it is evaluated based on the amount of process change and the control limits. A plot of β *versus* the shifting process parameter is known as the operating

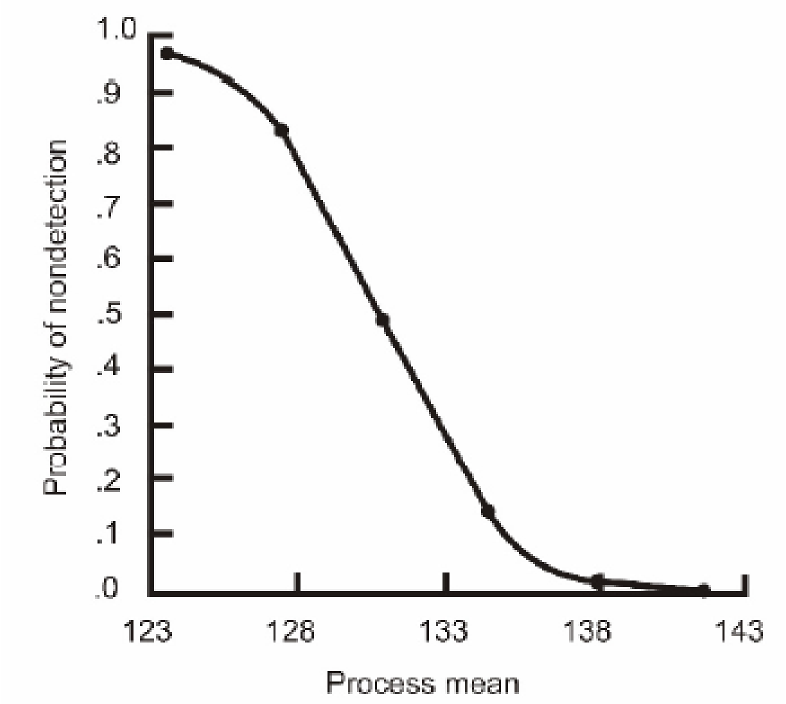

Figure 2 -5 Typical OC curve for control charts

characteristic (OC) curve of a control chart. The OC curve is a measure of the ability of a control chart to detect the changes in process parameters. A good control chart should have an OC curve as shown in Figure 2.6. For small changes in the process parameter, the probability of non detection (β) by the control charts is high. For large changes in the process parameter,β should be small so that it is detected and corrected by the control chart. [4](V .N .A. Naikan)

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[4] V .N .A. Naikan, Statistical Quality Control .Reliability Engineering Center, Indian Institute of Technology , Kharagpur -721302, India

2-11 Average Run Length (ARL)

The performance of control charts can also be characterized by their average run length. Average run length is the average number of points that must be plotted before a point indicates an out-of-control condition (Montgomery, 1985). We can calculate the average run length for any Shewhart control chart according to,α .

$$\text{ARL} = \frac{1}{\alpha} . \qquad (2.4)$$

where p is the probability that an out-of-control event occurs. Therefore, a control chart with 3 sigma control limits, the average run length will be,

$$\text{ARL} = \left(\frac{1}{0.0027}\right) = 370 . \qquad (2.5)$$

This means that if the process remains in-control, in average, there will be one false alarm every 370 samples.

2-12 Other Considerations :

As mentioned earlier, control charts are plotted by taking small samples from the manufacturing process on a regular basis. Therefore, selection of sample size is very important in using the control charts.

2-13 Sample Size:

It can be shown that a larger sample size results in narrow control limits. Decreasing the sample size makes the control limits wider. A larger sample size is needed if the small shift in the process parameter needs to be detected early. Apart from these factors the selection of sample size is influenced by the availability of resources, the types of tests used for sample evaluation, production rate, etc. Theoretically it is most beneficial if we have more frequent large sample sizes. The type of inspection and the resource constraints are the main factors influencing the selection of these. In most practical situations a small sample size at frequent intervals is preferred.

2-14 Rational Subgrouping:

A control chart provides a statistical test to determine if the variation from sample-to-sample is consistent with the average variation within the sample. The key idea in the Shewhart control chart is the division of observations into what are called rational subgroups. The success of charting depends a great deal on the selection of these subgroups. Generally, subgroups are selected in a way that makes each subgroup as homogeneous as possible, and that gives the maximum opportunity for variation from one subgroup to another. However, this selection depends upon a knowledge of the components of the total process variation. In production control charting, it is very important to maintain the order of production. A charted process which shows out of control conditions (and resulting opportunities for correction) may be mixed to create new X-bar – R charts which demonstrate remarkable control. By mixing, chance causes are substituted for the original assignable causes as a basis for the differences among subgroups. Where order of production is used as a basis for subgrouping, two fundamentally different approaches are possible:

- The first subgroup consists of product produced as nearly as possible at one time. This method follows the rule for selection of rational subgroups by permitting a minimum chance for variation within a subgroup and a maximum chance for variation from subgroup-to-subgroup.
- Another subgroup option consists of product intended to be representative of all the production over a given period of time. Product may accumulate at the point of production, with a random sample chosen from all the product made since the last sample.

lf subgrouping is by the first method, and a change in the process average takes place after one subgroup is taken and is corrected before the next subgroup, the change will not be reflected in the control chart. For this reason, the second method is sometimes preferred when one of the purposes of the control chart is to influence decisions on acceptance of product. The choice of subgroup size should be influenced, in part, by the desirability of permitting a minimum chance for variation within a subgroup. In most cases, more useful information will be obtained from, say, five subgroups of 5 rather than from one subgroup of 25. In large subgroups, such as 25, there is likely to be too much opportunity for a process change within the subgroup.

2-15 Rules for determining statistical control:

2-15-1 Run tests :

If the process is stable, then the distribution of subgroup averages will be approximately normal. With this in mind, we can also analyze the patterns on the control charts to see if they might be attributed to a special cause of variation. To do this, we divide a normal distribution into zones, with each zone one standard deviation wide. Figure 2.7 shows the approximate percentage we expect to find in each zone from a stable process.

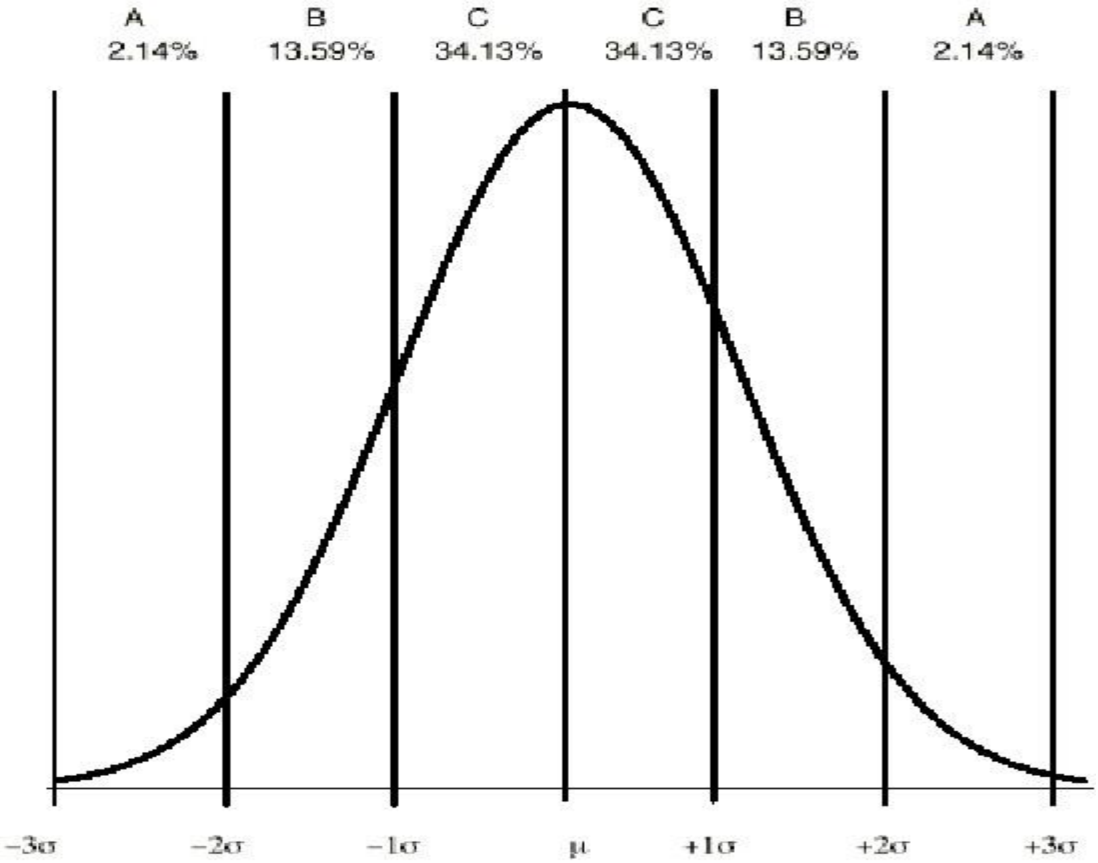


Figure 2-6: Percentiles for a normal distribution.

Zone C is the area from the mean to the mean plus or minus one sigma, zone B is from plus or minus one to plus or minus two sigma, and zone A is from plus or minus two to plus or minus three sigma. Of course, any point beyond three sigma (i.e., outside of the control limit) is an indication of an out-of-control process.

Since the control limits are at plus and minus three standard deviations, finding the one and two sigma lines on a control chart is as simple as dividing the distance between the grand average and either control limit into thirds, which can be done using a ruler. This divides each half of the control chart into three zones. The three zones are labeled A, B, and C as shown on Figure 2.6.

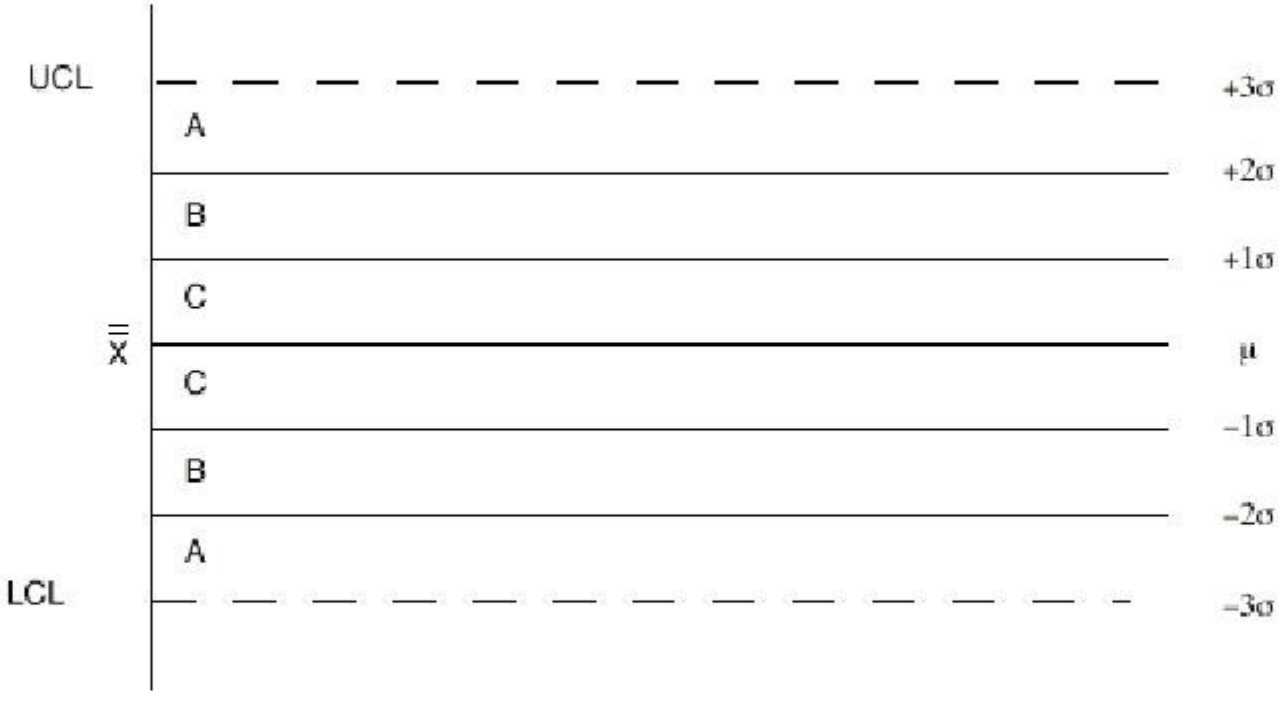


Figure 2-7: Zones on a control chart.

Based on the expected percentages in each zone, sensitive run tests can be developed for analyzing the patterns of variation in the various zones. Remember, the existence of a non-random pattern means that a special cause of variation was (or is) probably present. The averages, np and c control chart run tests are shown in Figure 2.9.

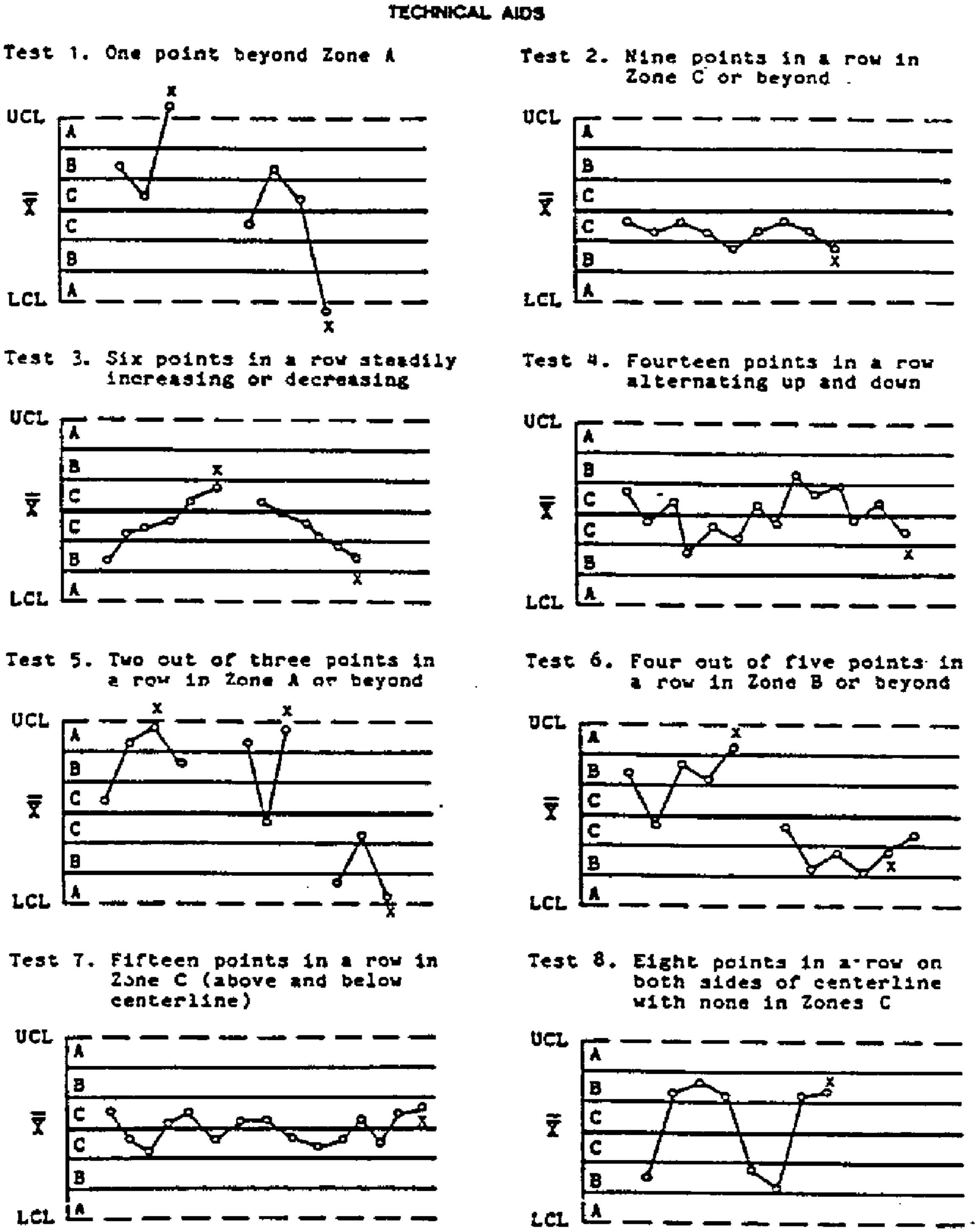


Figure 2-8:

From Nelson, L. S. (1984), "The Shewhart Control Chart--Tests for Special Causes," *Journal of Quality Technology*, Vol. 16, No. 4, 237-239.

2-16 Applications of Control :

Charts Control charts have several applications. This helps us in the following decision making:

1. To decide when to take corrective actions and when to leave the process as it is.
2. They give indications of type of remedial actions necessary to bring the process to control.
3. They help us to estimate the capability of our process to meet certain customer demands or orders.
4. They help us to improve quality.
5. They help us to take decisions such as the need for machine or technology replacement to meet quality standards.

Quality control and improvement are ongoing activities and, therefore, control charts must be maintained or revised as and when changes occur in the process. Installation of a new machine or application of a new technology necessitates the development of new control charts. As mentioned earlier, the quality characteristics are broadly of two types. These are variables and attributes. Variable characteristics are continuous in their range where as attributes are discrete. Therefore, control charts are broadly classified into two categories, viz., control charts for variables and for attributes.

2-17 Control Charts for Variables:

Quality characteristics that can be measured on a numerical scale such as diameter of a shaft, length of a component, strength of a material and weight of a part are known as variables. Process control means controlling the mean as well as the variability of the characteristic. The mean of the variable indicates the central tendency and variability indicates the dispersion of the process. Variability is measured in terms of the range or standard deviation. Various types of control charts are discussed in the following sections.

2-17-1 Mean (x-Bar) Charts:

A mean control chart is often referred to as an x-bar chart. It is used to monitor changes in the mean of a process. To construct a mean chart we first need to construct the center line of the chart. To do this we take multiple samples and compute their means. Usually these samples are small, with about four or five observations. Each sample has its own mean, $\bar{X}$. The center line of the chart is then computed as the mean of all K sample means, where K is the number of samples:

$$\bar{\bar{X}} = \frac{\bar{X}_1+\bar{X}_2+\cdots..+\bar{X}_K}{K} \qquad (2.6)$$

To construct the upper and lower control limits of the chart, we use the following formulas:

Upper control limit (UCL) = $\bar{\bar{X}} + Z\sigma_{\bar{X}}$ (2.7)

Lower control limit (LCL) = $\bar{\bar{X}} - Z\sigma_{\bar{X}}$ (2.8) where $\bar{\bar{X}}$ = the average of the sample means

Z= standard normal variable (2 for 95.44% confidence, 3 for 99.74% confidence)

$\sigma_{\bar{X}} =$ standard deviation of the distribution of sample means, computed as

σ = population (process) standard deviation

n= sample size (number of observations per sample).

Another way to construct the control limits is to use the sample range as an estimate of the variability of the process. Remember that the range is simply the difference between the largest and smallest values in the sample. The spread of the on the sample size being considered. range can tell us about the variability of the data. In this case control limits would be constructed as follows:

Lower control limit (LCL) =$\bar{\bar{X}} + A_2\bar{R}$ (2.9)

Upper control limit (UCL)= $\bar{\bar{X}} - A_2\bar{R}$ (2.10)

where $\bar{\bar{X}} =$ average of the sample means

$\bar{R}$ average range of the samples

$A_2 =$ factor obtained from Table 2.2

Notice that A_2 is a factor that includes three standard deviations of ranges and is dependent.

2-17-2 Range (R) Charts

Range (R) charts are another type of control chart for variables. Whereas x-bar charts measure shift in the central tendency of the process, range charts monitor the dispersion or variability of the process. The method for developing and using R-charts is the same as that for x-bar charts. The center line of the control chart is the average range, and the upper and lower control limits are computed as follows:

where values for D4 and D3 are obtained from Table 2.2

$$CL = \bar{R} \quad (2.11)$$

$$UCL = D3\ \bar{R} \quad (2.12)$$

$$LCL = D4\ \bar{R} \quad (2.13)$$

2-17-3 Using Mean and Range Charts Together:

You can see that mean and range charts are used to monitor different variables. The mean or x-bar chart measures the central tendency of the process, whereas the range chart measures the dispersion or variance of the process. Since both variables are important, it makes sense to monitor a process using both mean and range charts. It is possible to have a shift in the mean of the product but not a change in the dispersion.

2-17-4 Control Charts for Mean and Standard Deviation (X , S):

Both range and standard deviation is used for measuring the variability. Standard deviation is preferred if the sample size is large (say n > 10). The procedure for construction of X and S charts is similar to that for X and R chart. The following formulas are used:

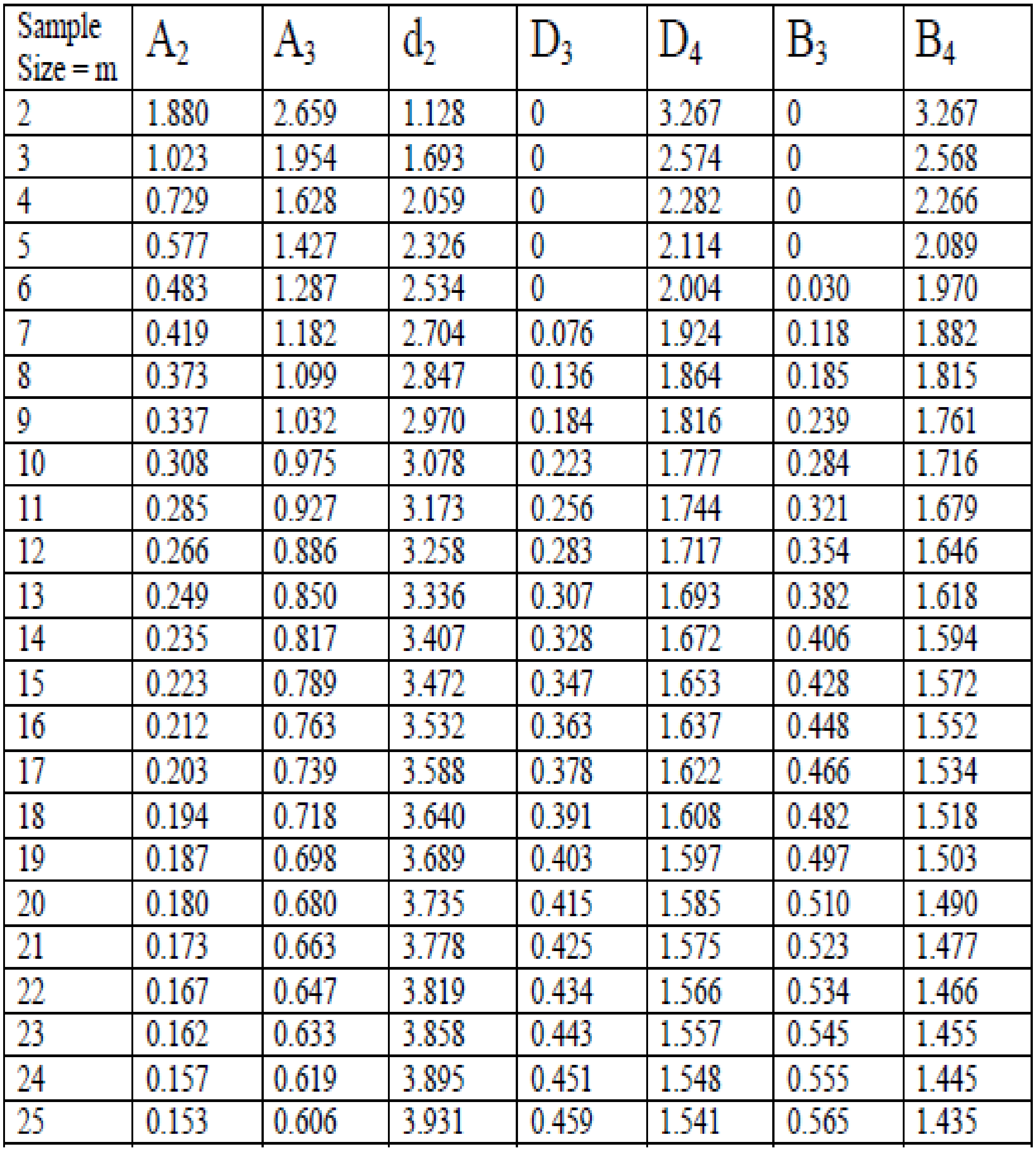
$$CL_s = \bar{S} = \frac{\sum_{j=1}^{g} s_j}{g} \qquad (2.14)$$

$$UCL_s = B_4\bar{S} \qquad (2.15)$$

$$LCL_s = B_3\bar{S} \qquad (2.16)$$

The reader is referred to Appendix A-7 of [1] for the values of B3 and B4 . X and S charts are sometimes also developed for given standard values [1].

Table 2-2: Table of constants for computing limits, and the limit equations



Sample Size = m	A_2	A_3	d_2	D_3	D_4	B_3	B_4
2	1.880	2.659	1.128	0	3.267	0	3.267
3	1.023	1.954	1.693	0	2.574	0	2.568
4	0.729	1.628	2.059	0	2.282	0	2.266
5	0.577	1.427	2.326	0	2.114	0	2.089
6	0.483	1.287	2.534	0	2.004	0.030	1.970
7	0.419	1.182	2.704	0.076	1.924	0.118	1.882
8	0.373	1.099	2.847	0.136	1.864	0.185	1.815
9	0.337	1.032	2.970	0.184	1.816	0.239	1.761
10	0.308	0.975	3.078	0.223	1.777	0.284	1.716
11	0.285	0.927	3.173	0.256	1.744	0.321	1.679
12	0.266	0.886	3.258	0.283	1.717	0.354	1.646
13	0.249	0.850	3.336	0.307	1.693	0.382	1.618
14	0.235	0.817	3.407	0.328	1.672	0.406	1.594
15	0.223	0.789	3.472	0.347	1.653	0.428	1.572
16	0.212	0.763	3.532	0.363	1.637	0.448	1.552
17	0.203	0.739	3.588	0.378	1.622	0.466	1.534
18	0.194	0.718	3.640	0.391	1.608	0.482	1.518
19	0.187	0.698	3.689	0.403	1.597	0.497	1.503
20	0.180	0.680	3.735	0.415	1.585	0.510	1.490
21	0.173	0.663	3.778	0.425	1.575	0.523	1.477
22	0.167	0.647	3.819	0.434	1.566	0.534	1.466
23	0.162	0.633	3.858	0.443	1.557	0.545	1.455
24	0.157	0.619	3.895	0.451	1.548	0.555	1.445
25	0.153	0.606	3.931	0.459	1.541	0.565	1.435

2-17-5 Control Charts for Single Units (X chart):

In many practical situations we are required to limit the sample size to as low as unity. In such cases we use an X chart in association with a moving range (MR) chart. The moving range is the absolute value of the difference between successive observations. The assumption of normal distribution may not hold well in many cases of X and MR charts. The following formulas shown in Table 3.3

are used for developing the charts.

Table 2-3: Control limits for X and MR charts

Chart	CL	UCL	LCL
X	$\bar{X}$	$\bar{X} + 3\overline{MR}/d_2$	$\bar{X} - 3\overline{MR}/d_2$
MR	$\overline{MR}$	$D_4\overline{MR}$	$D_3\overline{MR}$

Source: V.N.A. Naikan

2-18 Cumulative Sum Control Chart (CUSUM):

These control charts are used when information from all previous samples need to be used for controlling the process. CUSUM charts are more effective in detecting small changes in the process mean compared to other charts discussed earlier. The cumulative sum for a sample m is calculated by

$$S_m = \sum_{j=1}^{m} (\bar{X}_i - \mu_0) \quad (2.17)$$

where μ_0 is the target mean of the process. In this case CUSUM is plotted on the y-axis. The details of development and implementation of CUSUM charts are discussed in [10]. A V-mark is designed and developed for taking the decision on the process control while using these charts. A methodology to use CUSUM charts for detecting larger changes in process parameters is also available in this reference. A comparative study of the performance based on the ARL of a moving range chart, a cumulative sum (CUSUM) chart based on moving ranges, aCUSUM chart based on an approximate normalizing transformation, a self-starting CUSUM chart, and an exponentially weighted moving chart based on subgroup variance is discussed in [11, 12]. The CUSUM chart is again compared with several of its alternatives that are based on the likelihood ratio test and on transformations of standardized recursive residual [13]. The authors conclude that the CUSUM chart is not only superior in the detection of linear trend out-of-control conditions, but also in the detection of other out-of-control situations. For an excellent overview of the CUSUM chart techniques the reader is referred to [14]. The adaptive CUSUM (ACUSUM) chart was proposed to detect a broader range of shifts on process mean [15]. A two-dimensional Markov chain model has also been developed to analyze the performance of ACUSUM charts [16]. This improves on the theoretical understanding of the ACUSUM schemes and also allows the analysis without running exclusive simulations. Moreover, a simplified operating function is derived based on an ARL approximation of CUSUM charts [16].

2-19 Moving Average Control Charts:

These charts are also developed to detect small changes in process parameters. The moving average of width w for a sample number r is defined as:

$$M_r = \frac{\bar{X}_r + \bar{X}_{r-1} + \cdots + \bar{X}_{r-w+1}}{w} \qquad (2.18)$$

That means M_r is an average of latest w samples starting from the r-th sample. The control limits for this chart will be wider during the initial period and stabilize to the following limits after the first (w-1) samples:

$$\text{CL} = \bar{\bar{X}} \qquad (2.19)$$

$$(\text{UCL, LCL}) = \bar{\bar{X}} \pm \frac{3\sigma}{\sqrt{nw}} \qquad (2.20)$$

The initial control limits can be calculated by substituting r in place of w in these equations. Larger values of w should be chosen to detect shifts of small magnitudes. These charts can also be used when the sample size is unity.

2-20 Exponentially weighed moving average (EWMA) Charts:

The exponentially weighed moving average (EWMA) control chart was introduced in 1959 [17]. EWMA charts are also used for detecting shifts of small magnitudes in the process characteristics. These are very effective when the sample size is unity. Therefore, these are very useful for controlling chemical and process industries, in discrete part manufacturing with automatic measurement of each part, and in automatic on-line control using micro computers. EWMA is similar to

MA, except that it gives higher weighting to the most recent observations. Therefore, the chances of detecting small shifts in process are better compared to the MA chart. The control limits of the EWMA chart are

$$\mathrm{CL} = \bar{\bar{X}} \tag{2.21}$$

$$(\mathrm{UCL}, \mathrm{LCL}) = \bar{\bar{X}} \pm 3\sigma\sqrt{\frac{p}{n(2-p)}\left[1-(1-p)^{2r}\right]} \tag{2.22}$$

where p is the weighing constant ($0 < p \leq 1$), and r is the sample number. It may be noted that if p = 1, EWMA chart reduces to Shewhart chart and for p = 2/(w +1), it reduces to MA chart. Selecting a small value of p (say 0.05) ensures faster detection of small shifts in process. These charts are also known as geometric moving average control charts. As discussed earlier, violation of the assumption of independent data results in increased number of false alarms and trends on both sides on the centerline. A typical approach followed in the literature to study this phenomenon is to model the autocorrelated structure of the data and use a traditional control chart method to monitor the residuals. See [21–25], for more details. An alternative approach is the exponentially weighted moving average (MCEWMA) chart proposed in [26]. The literature also explores the shift detection capability of the moving centerline exponentially weighted moving average (MCEWMA) chart and recommends enhancements for quicker detection of small process upsets [27].

Table 2- 4 : Limits for Variables Control Charts

Variability Measure	Standards (μ and σ)	Chart	Limits
Range	Known	$\bar{X}$	$\mu \pm A\sigma$
Range	Not Known	$\bar{X}$	$\bar{\bar{X}} \pm A_2\bar{R}$
Standard Deviation	Known	$\bar{X}$	$\mu \pm A\sigma$
Standard Deviation	Not Known	$\bar{X}$	$\bar{\bar{X}} \pm A_3\bar{s}$
Range	Known	R	Centerline = $d_2\sigma$, LCL=$D_1\sigma$ UCL=$D_2\sigma$
Range	Not Known	R	Centerline = $\bar{R}$, LCL=$D_3\bar{R}$ UCL=$D_4\bar{R}$
Standard Deviation	Known	S	Centerline = C_4 , σ LCL=$B_5\sigma$ UCL=$B_6\sigma$
Standard Deviation	Not Known	S	Centerline = $\bar{S}$, LCL= $B_3\bar{S}$ UCL= $B_4\bar{S}$

2.21 Control Charts for Attributes:

Attribute characteristics resemble binary data, which can take only one of two given alternatives. In quality control, the most common attribute characteristics used are “conforming” or “not conforming”, “good” or “bad”. Attribute data need to be transformed into discrete data to be meaningful.

The types of charts used for attribute data are:

1- Control chart for proportion nonconforming items (p chart)

2- Control chart for number of nonconforming items (np chart)

3- Control chart for nonconformities (c chart)

4- Control chart for nonconformities per unit (u chart)

5- Control chart for demerits per unit (U chart)

A comprehensive review of the attribute control charts is presented in [43]. The relative merits of the c chart compared to the X chart for the Katz family covering equi-, under-, and over-dispersed distributions relative to the Poisson distribution are investigated in [44]. The Katz family of distributions is discussed in [45]. The need to use an X chart rather than a c chart depends upon whether or not the ratio of the in control mean is close to unity. The X chart, which incorporates the information on this ratio, can lead to significant improvements under certain circumstances. The c chart has proven to be useful for monitoring count data in a wide range of application. The idea of using the Katz family of distribution in the robustness study of control charts for count data can be extended to the cumulative sum (CUSUM) and exponentially weighted moving average (EWMA) chart.

he p and np charts are developed based on binomial distribution, the c, u, and U charts are based on Poisson distribution. These charts are briefly discussed in this section.

2-21-1 The P Chart:

The p chart is used when dealing with ratios, proportions or percentages of nonconforming parts in a sample. Inspection of products from a production line is a good example for application of this chart. This fulfils all the properties of binomial distribution. The first step for developing a p chart is to calculate the proportion of nonconformity for each sample. If n and m represent the sample size and number of nonconforming items in the sample, then the fraction of nonconforming items p is given by:

$$p = \frac{m}{n} \qquad (2.23)$$

If we take g such samples, then the mean proportion nonconforming p is given by:

$$\bar{p} = \frac{p_1 + p_2 + \cdots p_g}{g} \qquad (2.24)$$

The centerline and the 3σ limits of this chart are as follows:

$$\mathrm{CL} = \overline{p} \qquad (\ 2.25)$$

$$\mathrm{UCL} = \bar{p} + 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}} \qquad (2.26)$$

$$\mathrm{LCL} = \bar{p} - 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}} \qquad (\ 2.27)$$

In many situations we may require to develop p charts with variable sample size. In such situations control charts can be developed either for individual samples or for a few representative sample sizes. A more practical approach is to develop a standardized chart. For this a standardized value z of p for each sample is calculated as follows:

$$z_i = \frac{p_{i-\bar{p}}}{\sqrt{\bar{p}(1-\bar{p})/n_i}} \qquad (2.28)$$

z_i is then plotted on the chart. This chart will have its centerline at zero and the control limits of 3 on either side. A number of rules are developed for decision making on the out-of-control situations. Different types of p-charts and the decision rules are discussed in more detail in [1] and [5]. A p chart has the capability to combine information from many departments, product lines, and work centers and provide an overall rate of product nonconformance.

2-21-2 The np Chart:

The np chart is similar to the p chart. It plots the number of nonconforming items per sample. Therefore it is easier to develop and use compared to the p chart. While the p chart tracks the proportion of nonconformities per sample, the np chart counts the number of defectives in a sample. The binomial distribution can be used to develop this chart. The mean number of nonconformities in a sample is np. The centerline and the control limits for an np chart are as follows:

$$CL = n\bar{p} \tag{2.29}$$

$$UCL = n\bar{p} + 3\sqrt{n\bar{p}(1-\bar{p})}, \tag{2.30}$$

$$LCL = n\bar{p} - 3\sqrt{n\bar{p}(1-\bar{p})} \tag{2.31}$$

np charts are not used when the sample size changes from sample to sample. This is because the centerline as well as the control limits are affected by the sample size. Using and making inferences in such cases are very difficult.

2-21-3 The c chart

The c chart monitors the total number of nonconformities (or defects) in samples of constant size taken from the process. Here, nonconformance must be distinguished from defective items since there can be several nonconformances on a single defective item. For example a casting may have many defects such as foreign material inclusion, blow holes, hairline cracks, etc. Other examples are the number of defects in a given length of cable, or in a given area of fabric. Poisson distribution is used to develop this chart. If the sample size does not change and the defects on the items are fairly easy to count, the c chart becomes an effective tool to monitor the quality of the production process.

If $\bar{C}$is the average number of nonconformities per sample, then the centerline and the 3σ control limits of the c chart are:

$$CL = \bar{C} \tag{2.32}$$

$$UCL = \bar{C} + 3\sqrt{\bar{C}} \tag{2.33}$$

$$LCL = \bar{C} - 3\sqrt{\bar{C}} \tag{2.34}$$

One of the limitations of the c chart is that it can be used only when the sample size remains constant.

2-21-4 The U Chart:

The u chart can be used in other cases. It can be effectively used for constant as well as for variable sample size. The first step in creating a u chart is to calculate the number of defects per unit for each sample, where u represents the average defect per sample, c is the total number of defects, n is the sample size and i is the index for sample number. Once all the averages are determined, a distribution of the means is created and the next step will be to find the mean of the distribution, in other words, the grand mean.

$$\bar{u} = \frac{\sum_{i=1}^{g} c_i}{\sum_{i=1}^{g} n_i} \tag{2.35}$$

where g is the number of samples. The control limits are determined based on u and the mean of the samples n,

$$\text{UCL} = \text{u} + 3\sqrt{\bar{u}/u} \quad (2.36)$$

$$\text{LCL} = \text{u}-3\sqrt{\bar{u}/u} \quad (2.37)$$

Furthermore, for a p chart or an np chart the number of nonconformances cannot exceed the number of items on a sample, but for a u chart, it is conceivable since what is being addressed is not the number of defective items but the number of defects in the sample.

2-21-5 Control Chart for Demerits per Unit (U chart):

One of the deficiencies of the c and u charts is that all types of nonconformities are treated equally. In actual practice there are different types of nonconformities with varying degrees of severity. ANSI/ASQC Standard A3 classifies the nonconformities into four classes, viz., very serious, serious, major, and minor, and proposes a weighing system of 100, 50, 10, and 1, respectively. The total number of demerits (D) for a sample is therefore calculated as the weighed .[5] V.N.A. Naikan sum of nonconformities of all types as follows:

$$\text{D} = w_1c_1 + w_2c_2 + w_3c_3 + w_4c_4. \quad (2.38)$$

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[5] V.N.A. Naikan 2001, Statistical Process Control ,Reliability Engineering Center, Indian Institute of Technology, Kharagpur – 721302, India

The demerits per sample (U) is defined as U = D/ n where n is the sample size. The center line of the control chart is given by:

$$CL = \bar{U} = w_1\bar{u}_1 + w_2\bar{u}_2 + w_3\bar{u}_3 + w_4\bar{u}_4. \tag{2.39}$$

where $\bar{u}_i$ represent the average number of nonconformities per unit in the i-th class. The control limits of the chart are:

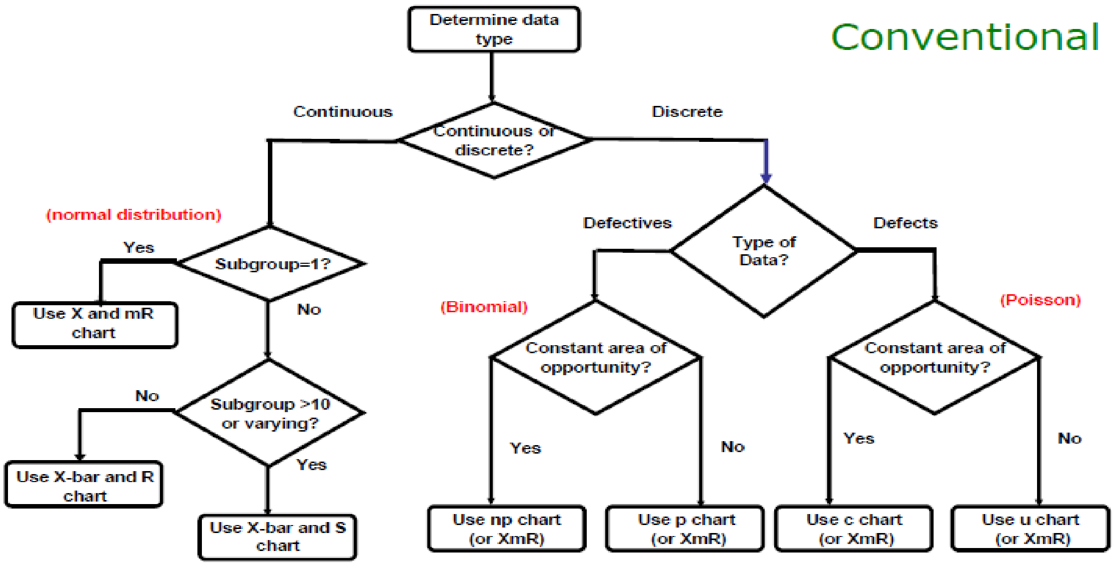
$$UCL = \bar{U} + 3\sigma_u \tag{2.40}$$

$$LCL = \bar{U} - 3\sigma_u \tag{2.41}$$

Where

$$\sigma_u = \sqrt{(w_1^2\bar{u}_1 + w_2^2\bar{u}_2 + w_3^2\bar{u}_3 + w_4^2\bar{u}_4)/n} \tag{2.42}$$

Figure 2-9 Selecting a Process Behavior Chart



From John E. Gibson, (2006) Statistical Process Control and Software System Development

2-22 Multivariate Control Charts :

During the past decades, the technological revolution has dramatically changed the characteristics of modern production. The new manufacturing environments and new market environments require new quality control procedures to more efficiently supply more reliable assurance on product quality. Advanced data-acquisition makes mass high-dimensional data available with low cost. To understand more efficiently the multiple process variables in modern industries, it is necessary to account for the correlation structure of the overall process performance. An objective can be viewed from different viewpoints and described with various perspectives. Any single aspect may not be able to fully reflect the truth of the objective as a whole. Therefore, assessing the performance of the objective in general is sometimes more important.

Business, competition in marketplaces and economic globalization require more efficient allocation of resources. Business factors in different locations, different industries, different functional sectors, from internal and external aspects, need to be integrated into a synthesized consideration. The associations between variables play an important role in optimization of decision making. All of these require systematic analysis tools.

One of the methods of statistical process control that copes this demand is multivariate quality control chart. Multivariate process monitoring has been investigated by Hicks (1955), Jackson (1956) (1959) (1985), Montgomery and Wadsworth (1972), Alt (1985), Hawkins (1991), Tracy, Young and Mason (1992), Lowry et al. (1992), Wierda (1994), Lowry and Montgomery (1995), Sullivan and Woodall (1996), among others.

2-23 Hotelling's T^2Statistic:

Hotelling H. (1931) can be viewed as the originator of multivariate control charts. Hotelling proposed a concept of generalized distance between a new observation to its sample mean. We first illustrate how this method works with a bivariate case. Assuming these X_1 and X_2 are distributed according the bivariate normal distribution. Referring to Figure 2-5, say are the mean, $\sigma_1$and σ_2 are the standard deviation of these two variables respectively. The covariance σ_{12} is used to estimate the dependency between X_1 and X_2. The generalized distance between point A and its mean can be calculated as:

$$X_0^2 = \frac{1}{S_{11}\,S_{22} - S_{12}^2}\left[S_{11}\,(X_2 - \bar{X}_2)^2 - 2(X_2 - \bar{X}_2)(X_1 - \bar{X}_1) + S_{22}\,(X_1 - \bar{X}_1)^2\right] \tag{2.43}$$

This statistic follows the Chi-square distribution with two degrees of freedom. An ellipse can be graphed with the X_1 and X_2 in this equation. Moreover, all the points lying on the ellipse will generate the same Chi-square statistic. As a consequence, every observation can be determined whether its generalized distance exceeds the ellipse by comparing X_0^2 and $\mathrm{X}_{2,\alpha}^2$ where $\mathrm{X}_{2,\alpha}^2$ is the upper α percentage point of the Chi-square distribution with 2 degrees of freedom. The observation will be considered as out-of-control if $X_0^2 > X_{2,\alpha}^2$

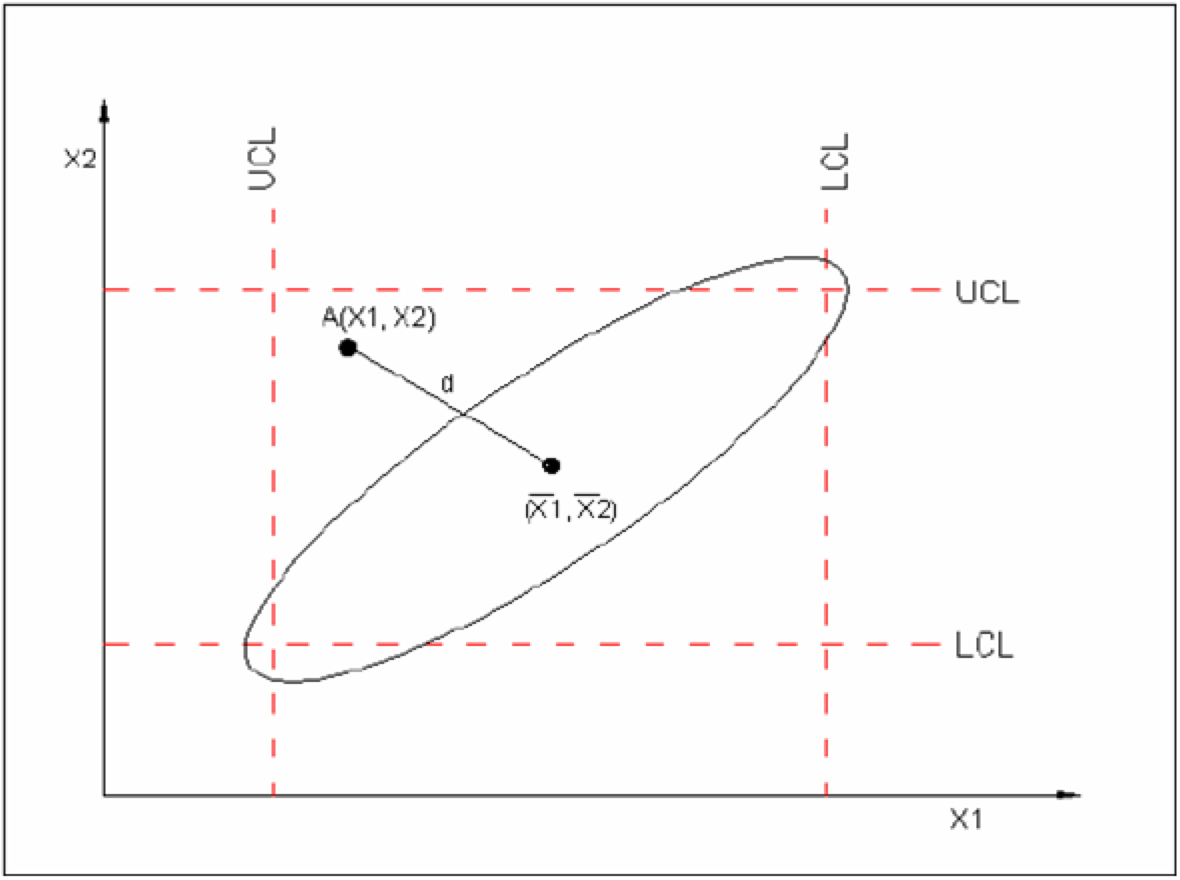


Figure 2-10: A generic bivariate Hotellings T Control region

With the same concept of the generalized distance, it can be extended from bivariate to a multiple p variables. Let $X_{i=}(X_{i1,}X_{i2} \ldots\ldots, X_{ip})$ represent a p dimensional vector of measurements made on a process time period i. The value X_{ij}represents an observation on the j^{th}characteristic. Assuming that when the process is in control, the X_i are independent and follow a multivariate normal distribution with mean vector μ and covariance matrix Σ. Normally μ and Σ are unknown, but we can use $\bar{X}$ and S estimated from a historical data set with n observations.

2-24 Phase I and Phase II:

The application of Hotelling's T^2 statistic shall be categorized into two phases. Phase I tests whether the preliminary process was in control and phase II tests whether the future observation remains in-control (Alt, 1985). Phase I operation refers to the construction of in-control data set. Same idea as Shewhart control chart, control limits are estimated from a period of in-control data. To obtain this in-control data, the raw data set needs to be purged. For instance, the outliers need to be removed and the missing data needs to be substituted with an estimate. During phase I operation, Hotelling's T^2 statistic is calculated for each measurement and compared to the control limit, which will follows Chi-square distribution.[6] (Richard, A.J. & Dean, W.W., 2002).

$$T^2 = (X_i - \bar{X} \dot{)}\, S^{-1}(X_i - \bar{X}) \sim \sim X^2_{\alpha,P} \quad \text{(Chi-square distribution)} \qquad (2.44)$$

Also other research shows that the control limit follows Beta distribution (Mason, Young & Tracy,1992).

$$T^2 = (X_i - \bar{X} \dot{)}\, S^{-1}(X_i - \bar{X}) \sim \frac{(n-1)^2}{n} B_{(\alpha, \frac{p}{2}, \frac{n-p-1}{2})} \qquad (2.45)$$

n: number of preliminary observations

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[6] according to Richard, A.J. & Dean, W.W., 2002.

Both control limits will be approximate when the number of observations is large. The control limit based on Chi-square distribution is established on the assumption that $\bar{X}$ and S are true values μ and Σ, which is just an approximate situation (Mason, Young & Tracy, 1992). Beta distribution is more precise and is a recommendable choice. After purging the raw data with Hotelling's T^2statistic, the in-control data set is ready for monitoring future observations which is termed as phase II operation. The control limit for determining future observation is different from the one in phase I. It follows an F distribution with p and (n-p) degrees of freedom.

$$T^2 = (X_i - \bar{X} \dot{)} S^{-1}(X_i - \bar{X}) \sim \frac{p(n+1)(n-1)}{n(n-p)} F_{(p, n-p-\alpha)} \qquad (2.46)$$

n: number of preliminary observations

Where sample mean$\bar{X} = (\bar{X}_{1,} \bar{X}_{2,} \ldots\ldots, \bar{X}_P)$ is and the covariance of sample

$$S = \begin{bmatrix} S_{11} & S_{12} & S_{13} \ldots. & S_{1p} \\ & S_{22} & S_{23} \ldots. & S_{2P} \\ & & & \\ & & & s_{pp} \end{bmatrix} \qquad (2.47)$$

The idea of using Hotelling's T^2 statistic in phase I and phase II is the same. Each measurement is examined whether it is out-of-control by checking if it deviates extraordinarily from its sample mean. It should be reminded to choose the correct upper control limit on different purposes. The Hotelling's T^2 statistic can be extended for more than two variables. Instead of a 2-dimensional ellipse control region, the result will be presented in a similar way as Shewhart control chart. The T^2 statistics calculated from all the observation will be plotted in a chart againstctime or observation serious and compared to the upper control limit. Figure 2-6 is a generic T^2 control chart. It should be noticed that there is no center line and the lower control limit is set to zero, because the meaning of T^2 statistic is a generalized distance between the observation and its sample mean. [7](Wenchang Chen (Vincent))

2-25 Interpreting Control Charts:

Control charts provide more information regarding process instability than a thermometer does regarding fever. Control charts not only identify the presence of special causes but also provide information regarding the nature of special causes. If the process is stable, then the successive points on the control chart would be like random drawings from the expected distribution of what is being plotted. Significant deviations from this expected random behavior signal special causes, and the nature of these deviations provide clues regarding the nature of special causes. As an example, for a stable process, the plotted values of x_ will be like random drawings from a normal distribution with x= and R_/d2_n_ as the

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[7] Wenchang Chen (Vincent)) 2005, Multivariate Statistical Process Control in Industrial Plants,TUDelft

estimated mean and standard deviation. For a normal distribution, the expectation is that the plotted points will be randomly distributed around the mean, that approximately 68% of the plotted points will be within one standard deviation from the mean, 0.3% of points will be greater than three standard deviations away from the mean, and so on. If, out of 30 plotted points, one is greater than three standard deviations away from the mean, or none are within one standard deviation from the mean, or there is a definite time trend, then these results would be unexpected and would signal the presence of special causes. Tests for the Chart of Averages The basic approach is that if a pattern of points has a very low probability of occurrence under the assumption of statistical control and can be meaningfully interpreted as a special cause, then that pattern constitutes a test for special cause. Eight commonly used tests for detecting special causes of variation for normally distributed averages or individual values are described below and graphically shown in Figure 4.15. Tests 1, 2, 3, and 4 are applied to the upper and lower halves of the chart separately. Tests 5, 6, 7, and 8 are applied to the whole chart. For the purposes of these tests, the ± 3 sigma control limits are divided into six zones, each one sigma wide, and are labeled A, B, and C, as shown in Figure 4.15. Test 1. Special cause is indicated when a single point falls outside 3 sigma control limits (beyond zone A). This suggests a sporadic shift or the beginning of a sustained shift.

2-26 Process or Product Monitoring and Control :

Statistical process control helps mangers achieve and maintain a process distribution that does not change in terms of its mean and variance. The control limits on the control charts signal when the mean or variability of the process changes. A process that is in statistical control, however, may not be producing services or products according to their design specifications because the control limits are based on the mean and variability of the *sampling distribution*, not the design specifications.

Process Capability refers to the ability of the process to meet the design specifications for a service or product. Design specifications often are expressed as a target and a tolerance.

2-27 What is process Capability?

Process capability compares the output of an in-control process to the specification limits by using capability indices. The comparison is made by forming the ratio of the spread between the process specifications (the specification "width") to the spread of the process values, as measured by 6 process standard deviation units (the process "width").

2-28 Process Capability Indices:

We are often required to compare the output of a stable process with the process specifications and make a statement about how well the process meets specification. To do this we compare the natural variability of a stable process with the process specification limits. A capable process is one where almost all the measurements fall inside the specification limits. This can be represented pictorially by the plot below:

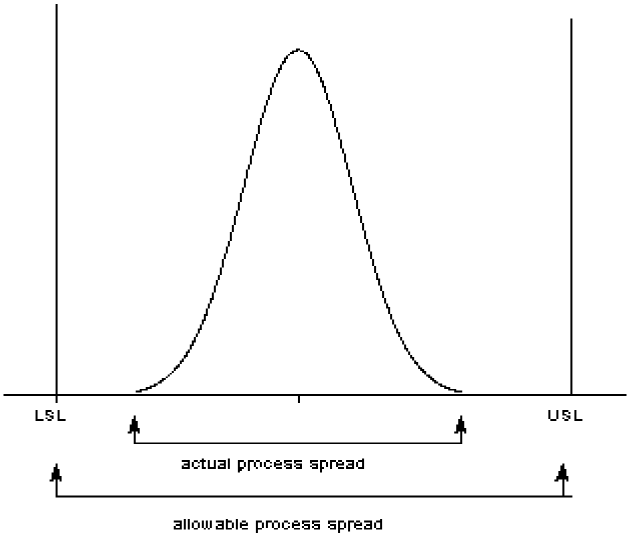

Figure 2-11 Specification Limit

There are several statistics that can be used to measure the capability of a process: C_p , C_{pk} , C_{pm} . Most capability indices estimates are valid only if the sample size used is 'large enough'. Large enough is generally thought to be about 50 independent data values. The C_p , C_{pk} , *and* C_{pm} statistics assume that the population of data values is normally distributed. Assuming a two-sided specification, if μ and σ are the mean and standard deviation, respectively, of the normal data and USL, LSL, and T are the upper and lower specification limits and the target value, respectively, then the population capability indices are defined as follows:

$$C_p = \frac{USL-LSL}{6\sigma} \qquad (2.48)$$

$$C_{pk} = \min[\frac{USL-\mu}{3\sigma},\ \frac{\mu-LSL}{3\sigma}] \qquad (2.49)$$

$$C_{pm} = \frac{USL-LSL}{6\sqrt{\sigma^2+(\mu-T)^2}} \qquad (2.49)$$

<u>Sample estimators</u> for these indices are given below. (Estimators are indicated with a "hat" over them).

$$\hat{C}_p = \frac{USL-LSL}{6s} \qquad (2.50)$$

$$\hat{C}_{pk} = \min[\frac{USL-\bar{X}}{3s}, \frac{\bar{X}-LSL}{3s}] \qquad (2.51)$$

$$\hat{C}_{pm} = \frac{USL-LSL}{6\sqrt{s^2+(\bar{X}-T)^2}} \qquad (2.52)$$

The estimator for C_{pk} can also be expressed as $C_{pk} = C_p(1\text{-}k)$, where k is a scaled distance between the midpoint of the specification range, m, and the process mean, μ ,Denote the midpoint of the specification range by m = (USL+LSL)/2. The distance between the process mean, μ, and the optimum, which is m, is $\mu - m$, where $m \leq \mu \leq USL$. The scaled distance is

$$k = \frac{|m-\mu|}{(USL-LSL)/2}, \qquad 0 \le\ k\ \le 1 \qquad (2.53)$$

(the absolute sign takes care of the case when $LSL \le \mu \le m$ To determine the estimated value, $\hat{k}$, we estimate μ by $\bar{x}$. Note that $\bar{x} \le USL$. The estimator for the C_p index, adjusted by the k factor, is

$$\hat{C}_{pk} = \hat{C}_p\left(1-\hat{k}\right) \text{ since } \ 0 \le k \le 1, \text{ it follows that } \hat{C}_{pk} \le\ \hat{C}_p. \qquad (2.54)$$

To get an idea of the value of the C_p statistic for varying process widths, consider the following plot

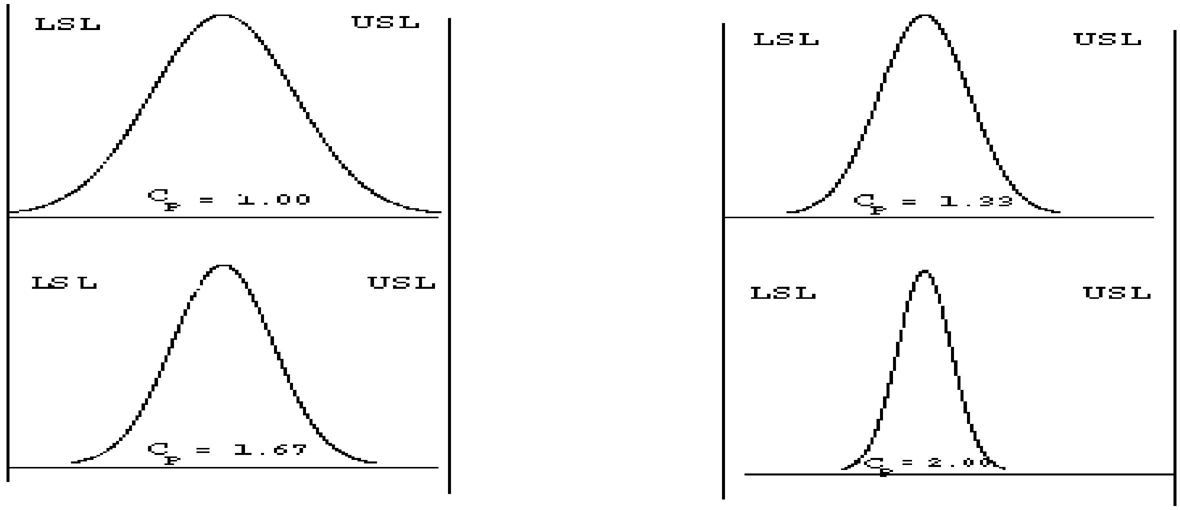

Figure 2.12 Capability Indices

This can be expressed numerically by the table below:

$USL - LSL$	6σ	$8\ \sigma$	$10\ \sigma$	$12\ \sigma$
C_p	1.00	1.33	1.66	2.00
Rejects	.27%	64 ppm	.6 ppm	2 ppb
% of spec used	100	75	60	50

where ppm = parts per million and ppb = parts per billion. Note that the reject figures are based on the assumption that the distribution is centered at μ We have discussed the situation with two spec. limits, the USL and LSL. This is known as the *bilateral* or two-sided case. There are many cases where only the lower or upper specifications are used. Using one spec limit is called *unilateral* or one-sided. The corresponding capability indices are

$$C_{pu} = \frac{allowable\ upper\ spread}{actual\ upper\ spread} = \frac{USL-\mu}{3\sigma} \qquad (2.55)$$

and

$$C_{pl} = \frac{allowable\ lower\ spread}{actual\ lower\ spread} = \frac{\mu-LSL}{3\sigma} \qquad (2.56)$$

Where $\mu$and $\sigma$are the process mean and standard deviation, respectively.

Estimators of C_{pu} and C_{pl} are obtained by replacing $\mu$and $\sigma$by $\overline{x}$ and s, respectively. The following relationship holds

$$C_p = (C_{pu} + C_{pl}) /2. \tag{2.57}$$

This can be represented pictorially by Note that we also can write

$$C_{pk} = \min \{C_{pl,}, C_{pu}\}. \tag{2.58}$$

2-29 Confidence Limits For Capability Indices:

Assuming normally distributed process data, the distribution of the sample $\hat{C}_p$follows from a Chi-square distribution and $\hat{C}_{pu}$and $\hat{C}_{pL}$have distributions related to the non-central *t* distribution. Fortunately, approximate confidence limits related to the normal distribution have been derived. Various approximations to the distribution of $\hat{C}_{pk}$have been proposed, including those given by Bissell (1990), and we will use a normal approximation.

The resulting formulas for confidence limits are given below:

$100(1-\alpha)$% Confidence Limits for C_p

$$\mathrm{pr}\{\hat{C}_p\big(L_1 \le C_p \le \hat{C}_p(L_2)\big\} = 1 - \alpha \tag{2.59}$$

where

$$L_1 = \sqrt{\frac{x^2_{(v,\alpha/2)}}{v}} \qquad L_2 = \sqrt{\frac{x^2_{(v,1-\ \alpha/2)}}{v}} \tag{2.60}$$

v= degrees of freedom

Approximate $100(1-\alpha)\%$ confidence limits for C_{pu} with sample size n are:

$$C_{pu}(lower) = \hat{C}_{pu} - z_{1-\beta}\sqrt{\frac{1}{9n} + \frac{\hat{C}_{pu}^2}{2(n-1)}} \qquad (2.61)$$

$$C_{pu}(upper) = \hat{C}_{pu} - z_{1-\alpha}\sqrt{\frac{1}{9n} + \frac{\hat{C}_{pu}^2}{2(n-1)}} \qquad (2.62)$$

with z denoting the percent point function of the standard normal distribution. If $\beta$is not known, set it to α. Limits for C_{pl} are obtained by replacing $\hat{C}_{pu}$by $\hat{C}_{pl}$.

2-30 What happens if the process is not approximately normally distributed?

The indices that we considered thus far are based on normality of the process distribution. This poses a problem when the process distribution is not normal. Without going into the specifics, we can list some remedies.

1. Transform the data so that they become approximately normal. A popular transformation is the Box-Cox transformation Use or develop another set of indices, that apply to nonnormal distributions. One statistic is called C_{npk} (for non-parametric C_{pk}). Its estimator is calculated by

$$\hat{C}_{mpk} = \min\left[\frac{USL - meadian}{p(.995) - meadian}, \frac{meadian - LSL}{meadian - p(.005)}\right] \qquad (3.63)$$

2. Transform Where p (0.995) is the 99.5th percentile of the data and p (.005) is the 0.5th percentile of the data.(5). [8]

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[8] http://www.itl.nist.gov/div898/handbook/pmc/section1/pmc16.htm

Table 2-5: Capability Indices

Index	Description
$\hat{C}_p = \frac{USL - LSL}{6s}$	Estimates what the process is capable of producing if the process mean were to be centered between the specification limits. Assumes process output is approximately normally distributed.
$C_{pl} = \frac{\mu - LSL}{3\sigma}$	Estimates process capability for specifications that consist of a lower limit only (for example, strength). Assumes process output is approximately normally distributed.
$C_{pu} = \frac{USL - \mu}{3\sigma}$	Estimates process capability for specifications that consist of an upper limit only (for example, concentration). Assumes process output is approximately normally distributed.
$\hat{C}_{pk} = \min[\frac{USL-\bar{X}}{3s}, \frac{\bar{X}-LSL}{3s}]$	Estimates what the process is capable of producing, considering that the process mean may not be centered between the specification limits. (If the process mean is not centered, $\hat{C}_p$overestimates process capability.) $\hat{C}_{pk} < 0$ if the process mean falls outside of the specification limits. Assumes process output is approximately normally distributed.
$\hat{C}_{pm} = \frac{USL - LSL}{6\sqrt{s^2 + (\bar{X} - T)^2}}$	Estimates process capability around a target, T. $\hat{C}_{pm}$is always greater than zero. Assumes process output is approximately normally distributed. $\hat{C}_{pm}$is also known as the Taguchi capability index.[2]
$\hat{C}_{mpk}$	Estimates process capability around a target, T and accounts for an off-center process mean. Assumes process output is approximately normally distributed.

Chapter Three

Khartoum Refinery Company Limited

3 - 20 Flash point

3- 21 Control sulfur compound in diesel

3 -22 Control Gas oil quality

3-1 Introduction :

The great Nile flows through the Sudan hinterland and irrigates this fertile land and the Sudanese enduring civilization. Khartoum Refinery Company Limited is situated in the east bank of the Nile, 70km north of Khartoum, capital of Sudan, and close to the Nile Blend Crude pipeline and the oil product pipeline, the railway linking Port Sudan and Khartoum and El Tahadi highway linking Atbara and Khartoum. All of this is advantageous to the establishment and development of the Refinery. Khartoum Refinery Company Limited (KRC) is the first modern joint venture refinery between Ministry of Energy & Mining of Sudan (MEM) and China National Petroleum Corporation (CNPC). The general agreement for the establishment of the Joint Venture Refinery was signed by the Minister of Energy and at that time Dr Awad Ahmed El Jazz and the former Vice President of CNPC Mr Wu Yaowen in March of 1997. In July 1997, Khartoum Refinery Company Limited was officially registered in Sudan. Construction started in May 1998 and the refinery was commissioned on May 16, 2000.. In early days, the site of the Refinery was a vast expanse of desert, there was no any inhabitants several kilometers around the area. However, the Refinery pioneers and builders built up a modern environment-friendly enterprise adhering to the spirit of "unity and cooperation, hard work, and pioneering innovation". On February 2, 2007 Chinese President Hu Jintao together with Sudanese President Al-Bashir came to the

Refinery for inspection. In his speech, President Hu praised the oil cooperation between Chinese and Sudanese as "a model of South-South cooperation". The two Presidents praised the Refinery as "a model of Chinese-Sudanese cooperation" in their inscription.

The Company is operated with cooperative shareholding system and responsibility system of General Manager under the guidance of Board of the Directors. The Board of Directors comprises 4 members from the Sudanese side and 4 from the Chinese side.

- Dr Awad Ahmed El Jazz, the Minister of Energy and Mining serves as Chairman of the Board.
- Mr Zhou Jiping, Vice President of CNPC serves as Vice Chairman of the Board.
- Dr Lual Achek Deng, State Minister of Finance & Economy of Sudan, Dr Omer Mohamed Kheir, Secretary General of MEM,
- Mr Hamad El Neel A Gadir, Deputy Secretary General of MEM,
- Mrs Wang Shali, Senior Vice President of CNODC .
- Mr Wu Dongshan, Vice President of CNODC are directors of the Board.
- Mr Huang Yongzhang from CNODC acts as Executive Director of the Board and the General Manager of the Refinery.

The Company sets up a Deputy General Manager with 4 Division Managers, i.e. Technical Division Manager, Administration Division Manager, Finance Division Manager and Maintenance Division Manager as well as 11 line departments, The line departments perform professional management and production units conduct systematic operation.

- The Refinery was originally designed to process 2.5 million tons of crude oil per year. However, due to the increasing demand of products especially diesel, both shareholders decided to increase the processing capacity in two phases - Phase I was put into operation on Sept 14, 2004 adding 1 million tons per year to the original capacity while Phase II was put into operation on June 30, 2006, bringing the actual processing capacity of the whole refinery up to 5 million tons per year. The occupied area is 1.2 million square meters, there are fifty-five (55) units in the refinery.

The Refinery was designed and constructed by Chinese in accordance with Chinese codes and standards, five (5) Chinese design institutes comprising Beijing Design Institute, Luoyang Design Institute and Huadong Design Institute etc undertook the design of the Refinery. China Petroleum Engineering & Construction Corporation (CPECC) is the general contractor under the supervision of Consultancy Company.

3-2 The main production units of the Refinery :

- Crude Distillation Unit (CDU).
- Delayed Coking Unit (DCU).
- Residue Fluid Catalytic Cracking Unit (RFCC).
- Semi-regenerative Catalytic Reforming Unit (SCR).
- Diesel Hydrotreating Unit (DHT).
- Jet Fuel Unit.
- Coker Gasoline & Diesel Hydrotreating Unit (GDHT).
- Continuous Catalytic Reforming Unit (CCR).

3-3 KRC is self dependant on utilities,

- besides the above process units, it has Power Station,
- Water Purification Station (on the bank of the Nile),
- Air Separation & Air Compression Unit,
- Cooling Water Treatment System.
- Boiler Feed Water Treatment System.
- Sour Water Stripping Unit.
- Waste Water Treatment System.
- Oil Movement & Storage System.
- Central Laboratory.

3-4 The annual output of

- gasoline is 1.45 million tons.
- jet-A1 330 thousand tons.
- diesel 2 million tons.
- LPG 400 thousand tons.
- fuel oils 300 thousand tons.
- petroleum coke 300 thousand tons.

3-5 Atmospheric Crude Distillation Unit (CDU)

is designed to process 2.5 million tons of crude oil per year, the produced long residue is used as feed to RFCC unit.

3-6 The processing capacity of Residue Fluid Catalytic Cracking Unit (RFCC)

is 1.8 million tons per year, this unit is designed to use super-stable molecular sieve catalyst, adopt two stages of catalyst regeneration and energy recovery by flue gas cooler, waste heat boiler and flue gas expander.

3-7 The processing capacity of Semi-regenerative Catalytic Reforming Unit (SCR)

is 150 thousand tons per year. The unit is characterized by high efficiency four-in-one heater, hydrogen production with naphtha and reforming catalyst regeneration at high pressure.

3-8 The processing capacity of Diesel Hydrotreating Unit (DHT)

is 500 thousand tons per year, taking RFCC diesel as feedstock

3-9 The original processing capacity of Jet Fuel Unit

is 180 thousand tons per year, after expansion in the year of 2007, it reaches 330 thousand tons per year.

3-10 The processing capacity of Delayed Coking Unit (DCU)

is 2 million tons per year, crude oil is directly sent to this unit for processing

3-11 Coker Gasoline & Diesel Hydrotreating Unit (GDHT)

with processing capacity of 1.2 million tons per year uses coker gasoline and coker diesel as feedstock This unit produces high quality diesel, and at same time it provides feedstock to.

3-12 Continuous Catalytic Reforming Unit (CCR):

The processing capacity of Continuous Catalytic Reforming Unit (CCR)

is 400 thousand tons per year. This unit can continuously regenerate the deactiviated reforming catalyst, and produce high octane number gasoline with high yield.

3-13 Power station :

Power station consists of four boilers, three steam turbine generators and two gas turbine generators as well as its auxiliary facilities. The total installed capacity is 70 thousand kilowatt, steam generating capacity is 356 tons per hour in total.

3-14 Power Station supplies power:

Power Station supplies power, steam and demineralized water to the whole refinery. Air Separation & Air Compression unit (AS/AC) produces 2,300 cubic meters per hour of nitrogen, it is equipped with six centrifugal air compressors and one screw compressor, and supplies nitrogen and air to the whole refinery.

3-15 Water Supply and Drainage System:

Water Supply and Drainage System includes water purification station of 1,600 cubic meters per hour, fire water booster station of 1,250 cubic meters per hour, circulating cooling water systems of 20,000 cubic meters per hour and waste water treatment plant of 300 cubic meters per hour.

3-16 Oil Movement & Storage System :

Oil Movement & Storage System consists of eight (8) floating roof crude tanks of 30,000 cubic meters each, twenty-three (23) intermediate product tanks of 61,000m^3 in total, forty-one (41) finished product tanks of 153,000 cubic meters in total, the designed oil product throughput is 3.95 million tons per year.

3-17 Central Laboratory

is capable to analyze crude oil, intermediate products, finished products,

FCC catalyst and water. The number of test methods is over 200. ASTM standards are adopted for all petroleum products analysis. There are over 300 sets of analysis apparatus and various auxiliary facilities. On December 16, 2002 the Central Laboratory obtained ISO9001 and ISO17025 certificates.

After expansion, the Refinery owns two independent process flows which can process light crude and heavy crude respectively. The original process flow consists of atmospheric crude distillation unit----residue fluid catalytic cracking unit–--semi-regeneration reforming unit---diesel hydrotreating unit. The expansion process flow consists of delayed coking unit, coker gasoline & coker diesel hydrotreating unit, continuous catalytic reforming unit, consequently variety of KRC products becomes richer with high quality. Ultimately, the Refinery became adaptable to different crude and flexible to process operation.

Automation level in the Refinery is high with DCS system, and the overall processing technology reached advanced international level.

The Refinery’s products are of high quality. The gasoline produced by the Refinery is all unleaded. Being environmentally friendly product, the diesel is low in sulfur and aromatics content and light in color and meets Euro IV standard. Gasoline, diesel, jet fuel and LPG satisfy the demands of Sudan local market, surplus gasoline is exported to the neighboring countries of Sudan and international markets. Khartoum Refinery always gives top priority to HSE aspects. The Refinery has been running stable without any serious accidents since it was put into production on May 16, 2000. In year 2006, the Refinery passed the international HSE certification and was awarded qualification certificates of ISO 9001:2000, ISO14001:1996 and OHSAS 18001:1999 by British Standard Institute (BSI).

Environmental protection is the basis for the sustainable development of the Refinery. HSE–IMS system was applied in the Refinery. HSE-IMS system covers the management of health, safety and environment protection. “Three Wastes” discharge are strictly controlled according to the standard, the industrial wastes are treated strictly according to the local law, and air quality and noise level all reach environmental standards. In addition, the production waste water and domestic waste water are fully utilized for the afforestation around the refinery, which effectively decreases the sandstorm’s influence on the Refinery, and improves the working and living surrounding of the staff and the local people.

Khartoum Refinery always pays high attention to production management and conducted various kinds of technical activities to ensure safe, stable and long-term running of the Refinery. The Refinery conducts overhaul every 2.5 years, the economic and technical indices of the Refinery are up to the advanced level, light oil yield is more than 75%, comprehensive production rate is over 92%, and processing loss is less than 0.7%. Since it was put into production, the Refinery played big role in Sudan economy. The training of Sudanese staff is enhanced to improve theoretical and practical operation skills. The nationalization plan is being implemented successfully.

From construction to production, the Refinery got great supports from Chinese and Sudanese governments and both shareholders. Mr Bashir President of Sudan and Chinese President Hu Jintao all visited the Refinery, inspecting and directing the work of the Refinery.

The establishment and successful operation of the Refinery is of great significance in terms of setting up and forming a system incorporating upstream and downstream and enabling the self-supply of petroleum products for Sudan. On June 30, 2000 Sudanese government held a grand ceremony in the Refinery to celebrate the 11th anniversary of National Salvation Day.

Both shareholders pay high attention to the expansion project of the Refinery.

Khartoum Refinery is widely regarded as a model of China and Sudan cooperation. As a pride of the nation, Khartoum Refinery received lots of important visitors from other countries, and many government officials speak highly of the successful cooperation between the two parties and excellent performance of the Refinery.

The development of Khartoum Refinery also benefits the local people. Presently the Refinery supplies water and power to the local residents without any charge, and devotes to some public welfare establishments such as schools and “KRC Friendship Hospital” for the convenience of education and medical treatment of the local people. In addition, Khartoum Refinery actively devotes to fighting flood, providing disaster relief and helping the poor etc, all these benefactions are highly appreciated by the local people, hence gain respect and support of the local people.

One of the indirect contributions of KRC to the economy of the Sudan is the erection of Garri Power Station (400 megawatt) and Khartoum Petrochemical Plant for the production of polypropylene next door to KRC which provides them with all necessary petroleum products.

Now the Refinery is like a brilliant pearl shining over the Nile River. Wild desert is covered by standing refinery columns. With great care of both Chinese and Sudanese, Khartoum Refinery is destined for a magnificent industrial enterprise.

The control on specific product means control on group of product physical properties . this leads to the control on product quality. to control diesel , most important properties that controls diesel quality must be done. There for many tests on diesel quality must be done as follows :

3-18 Control density of diesel

Density test is the most important test in the liquids . The density of diesel fuel varies from (0.82-0.86) . if the density is over this range its became a mazoat. If it’s low it returns to kerosene.

3-19 control (cetena number):

Diesel burn in diesel machine by pressure not by electrical spark . Diesel cetena number proov diesel ability to burn without pressure. cetena number is known as a percentage for cetin, methyl and naphthalene volume which is the same with selected oil

3-20 Flash point :

Flash point means the temperature in which heated diesel steam is flashed in specific conditions when its near a flame .this helps in saving diesel from flash in specific temperature.

3-21 Control sulfur compound in diesel :

Sulfur is the most common substance in oil products . Sulfur has bad effect in machines. This means sulfur is an important factor in oil product quality include diesel. therefor it's important to get rid of or reduce it .it must be not more than 1% in diesel .

3-22 Control Gas oil quality :

Density determine gas oil quantity in shipping .liquids density determine its type. Therefore gas oil has specific density point .if it increase its return to kerosene , if its decrease its return to gas . To know if the gas oil is under control , 25 samples has been taken. Each sample contains 4 items.it taken in equal terms every day . the result was as follows in table(13)

Appendix No (1): Data of density desial

	Observations			
Sample	**4X**	**3X**	**2X**	**1X**
1	840.1	840.9	839.7	839.9
2	839.8	840.5	839.6	838.2
3	840.6	839.7	840.5	839.8
4	840.1	840.2	839.3	839
5	839.6	838.6	838.3	838.9
6	837.9	838	839.1	839
7	838.6	839.4	838.8	838.5
8	838.3	838.6	838.6	837.6
9	837.7	839.5	839.3	838.9
10	838.9	841.1	840.7	840.1
11	839.6	840	839.1	839.4
12	837.9	837.9	837.3	837.6
13	838.8	839.4	838.2	839.4
14	839.6	838.6	838.4	838.1
15	837.6	839	839	839.5
16	840.6	840.8	841.3	840.5
17	840.4	839.2	840.6	841.2
18	839.7	839.5	840	840.8
19	839.4	836.8	840.4	839.2
20	838.8	839.3	839.2	839.4
21	839.2	840.2	840.5	840.2
22	840.1	839.3	840	840.3
23	839	840	840.3	839.6
24	840.9	840.9	839.8	839
25	840	839.1	839	840.8

X_1 =TANK1

X_2 =TANK2

X_3 =TANK3

X_4 =TANK4

Source : Khartoum Refinery Company Limited

Appendix No (2): Data of density gas oil (3/6/2014-28/6/2014)

	Observations			
Sample	**x1**	**x2**	**x3**	**x4**
1	**739.5**	**739.7**	**739.7**	**741.2**
2	**739.6**	**739.4**	**740.1**	**740.1**
3	**739.4**	**739.1**	**739.9**	**739.8**
4	**739.3**	**739.5**	**739.3**	**739**
5	**739.5**	**739.4**	**739.5**	**739.4**
6	**740.2**	**739.5**	**740.7**	**740.7**
7	**739.8**	**739.6**	**740.8**	**739.4**
8	**740.4**	**740.3**	**740.5**	**739.5**
9	**739.7**	**741.1**	**740.3**	**740**
10	**739**	**739.8**	**740.8**	**739**
11	**739.3**	**739.4**	**740.3**	**739.9**
12	**739**	**740.6**	**740**	**739.7**
13	**736.7**	**739.3**	**739.4**	**739.1**
14	**737.8**	**739.9**	**739.7**	**739.1**
15	**738**	**738.7**	**739.8**	**740.3**
16	**732.7**	**739**	**739**	**740**
17	**738.9**	**739.3**	**740.2**	**739.9**
18	**736.4**	**739.5**	**740.2**	**739.6**
19	**739.3**	**740.1**	**739.7**	**739.5**
20	**739.6**	**739.9**	**741.3**	**738.4**
21	**739.4**	**739**	**739.6**	**738.3**
22	**739.7**	**739.6**	**739.2**	**739.2**
23	**738.9**	**739.3**	**739**	**740.1**
24	**739.1**	**738.8**	**738.9**	**739.5**
25	**736.4**	**739.2**	**739.1**	**739.6**

X_1 =TANK1
X_2 =TANK2

X_3 =TANK3

X_4 =TANK4

Source : Khartoum Refinery Company Limited

Appendix (3): Data of cetane index diesel (3/6/2014-28/6/2014)

	Observations			
Sample	**x1**	**x2**	**x3**	**x4**
1	**53.3**	**53.6**	**53.5**	**53.5**
2	**53.3**	**53.8**	**53.4**	**53.5**
3	**52.8**	**53.4**	**53.6**	**53.4**
4	**52.1**	**52.3**	**53.0**	**53.2**
5	**52.8**	**52.8**	**52.6**	**53.3**
6	**52.5**	**52.7**	**52.6**	**52.5**
7	**52.6**	**52.7**	**52.8**	**52.6**
8	**52.6**	**52.4**	**52.6**	**52.9**
9	**53.3**	**53.8**	**53.5**	**52.2**
10	**53.2**	**53.3**	**53.1**	**52.6**
11	**52.8**	**53.1**	**52.8**	**53.1**
12	**52.8**	**52.5**	**52.9**	**52.7**
13	**53.1**	**53.0**	**52.7**	**52.7**
14	**53.5**	**53.5**	**53.3**	**52.8**
15	**53.5**	**53.3**	**53.7**	**53.4**
16	**53.5**	**53.3**	**54**	**52.9**
17	**53.4**	**53.6**	**53.8**	**53.6**
18	**53.9**	**53.4**	**53.2**	**52.5**
19	**53.5**	**53.6**	**53.8**	**53.5**
20	**53.3**	**53.4**	**53.2**	**53.3**
21	**53.4**	**53.4**	**53.6**	**53.3**
22	**53.2**	**53**	**52.9**	**53.2**
23	**53**	**52.7**	**53**	**52.6**
24	**52.9**	**52.6**	**52.3**	**53.5**
25	**52.4**	**52.8**	**52.6**	**53.4**

X_1 =TANK1

X_2 =TANK2
X_3 = TANK3
X_4 =TANK4

Source : Khartoum Refinery Company Limited

Appendix No (4): Data of flash point diesel (3/6/2014-28/6/2014)

	Observations			
sample	**X1**	**X2**	**X3**	**X4**
1	**83.0**	**82.5**	**83.0**	**82.5**
2	**82.0**	**83.5**	**82.0**	**82.5**
3	**79.5**	**81.0**	**81.0**	**81.0**
4	**80.0**	**65.5**	**81.5**	**81.0**
5	**76.5**	**76.5**	**77.5**	**71.0**
6	**78.5**	**77.5**	**78.5**	**77.5**
7	**78.0**	**78.0**	**77.5**	**77.0**
8	**77.0**	**78.5**	**78.5**	**78.5**
9	**78.5**	**78.5**	**78.5**	**77.5**
10	**80.5**	**81.5**	**82.0**	**78.5**
11	**79.5**	**78.5**	**79.5**	**79.5**
12	**77.5**	**76.5**	**77.5**	**77.5**
13	**78.5**	**77.0**	**77.0**	**77.5**
14	**77.5**	**71.5**	**76.5**	**76.5**
15	**80.5**	**80.5**	**79.5**	**76.5**
16	**81.0**	**82.0**	**82.5**	**82.0**
17	**80.5**	**81.0**	**80.0**	**81.0**
18	**82.0**	**80.5**	**80.0**	**80.5**
19	**79.5**	**81.5**	**74.5**	**79.5**
20	**80.5**	**79.5**	**80.5**	**80.0**
21	**80.5**	**80.5**	**81.5**	**79.5**
22	**81.0**	**79.5**	**79.5**	**81.0**
23	**78.0**	**79.5**	**79.0**	**80.0**
24	**78.5**	**80.0**	**80.0**	**80.5**
25	**79.5**	**79.5**	**78.0**	**80.0**

X_1 = TANK1

X_2 = TANK2

X_3 =TANK3

X_4 = TANK4

Source : Khartoum Refinery Company Limited

Chapter Four

Application Part

4-1 Check quality of diesel:

4-1-1 Test quality of density using R and X-BAR charts:

Mean and Rang charts are used to monitor different variables. The mean or x-bar chart measures the central tendency of the process, whereas the range chart measures the dispersion or variance of the process. Since both variables are important, it makes sense to monitor a process using both mean and range charts. It is possible to have a shift in the mean of the product but not a change in the dispersion.

From above control limits we can construct control chart for R and X-BAR of density diesel , Figure (4.1) to illustrate control charts of R for density diesel

To prepare the mean chart ; means , range values of subgroup, total mean and range averages are calculated as shown below in the table:

The mean for the first group is calculated as follows :

$$\bar{X}_1 = \tfrac{1}{4}\textstyle\sum_i^4 \frac{839.9 + 839.7 + 840.9 + 840.1}{4} = 841.975$$

$$\bar{X}_{25} = \tfrac{1}{4}\textstyle\sum_i^4 \frac{839.9 + 839.7 + 840.9 + 840.1}{4} = 841.725$$

The range for the first group is calculated as two groups as follows:

$R_1 = x_{(4)} - x_{(1)} = .5$

$R_1 = x_{(4)} - x_{(1)} = 1.1$

The total mean ($\bar{\bar{X}}$) is computed as follows:

$$\bar{\bar{X}} = \frac{1}{25}\sum_{i=1}^{25}\frac{839.9 + 839.7 + 840.9 + 840.1}{4} = 839.460$$

$$\bar{R} = \frac{1}{25}\sum_{i=1}^{25}\frac{839.9 \ + \ 839.7 \ + \ 840.9 \ + \ 840.1}{4} = \ 1.464$$

The two control limits for the mean chart is calculated according to the limit control equations as follows:

Upper Control Limit(UCL):

UCL=$\bar{\bar{X}} + \ A_2\bar{R} = 839.460 + 0.729 * 1.464 = \ 840.456$

Central Line (CL): CL= $\bar{\bar{X}} = 839.460$

Lower Control Limit (LCL):

LCL =$\bar{\bar{X}} - \ A_2\bar{R} = 839.460 - 0.729 * 1.464 = \ 838.376$

Whereas the value for the constant (A_2) for a sub group with volume 4 equal (0.729) as shown in table (2.1)

4-1-2 Test quality of density using R charts:

To prepare range chart ; the calculation for group range values and the range average is done as the table(4.1) blow shows .

Then the control limit for range chart is calculated by using the control limits as follows :

Upper Control Limit (UCL): UCL = D 4 = 2.282 * 1.464 = 3.340848

Central Line = 1.464

Lower Control Limit (LCL): LCL = D3 $\bar{R}$ = 0 * 1.464 = 0

Whereas the value for two constants for sub group with size 4 equal (2.282) and zero respectively .

Table (4.1): Control limits for R and X-BAR of density diesel

Control charts for variables	Constants of limits	Sample size	Subgroups number	centerline	LCL	UCL
R	D3= 0 D4= 2.282	4	25	1.464	0	3.340848
X-BAR	A2= 0.729	4	25	839.416	838.376	840.456

Source : Researcher

Using SPSS program to drawn X-bar and Range chart :

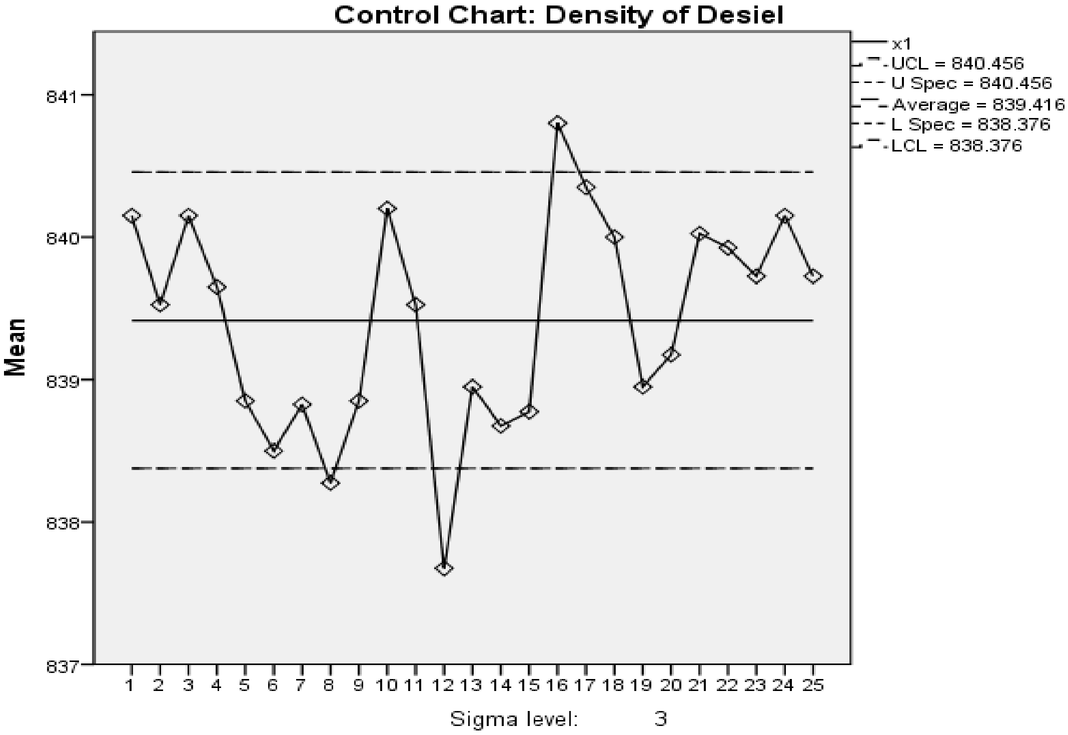

Figure 4.1: X-Bar chart for diesel density

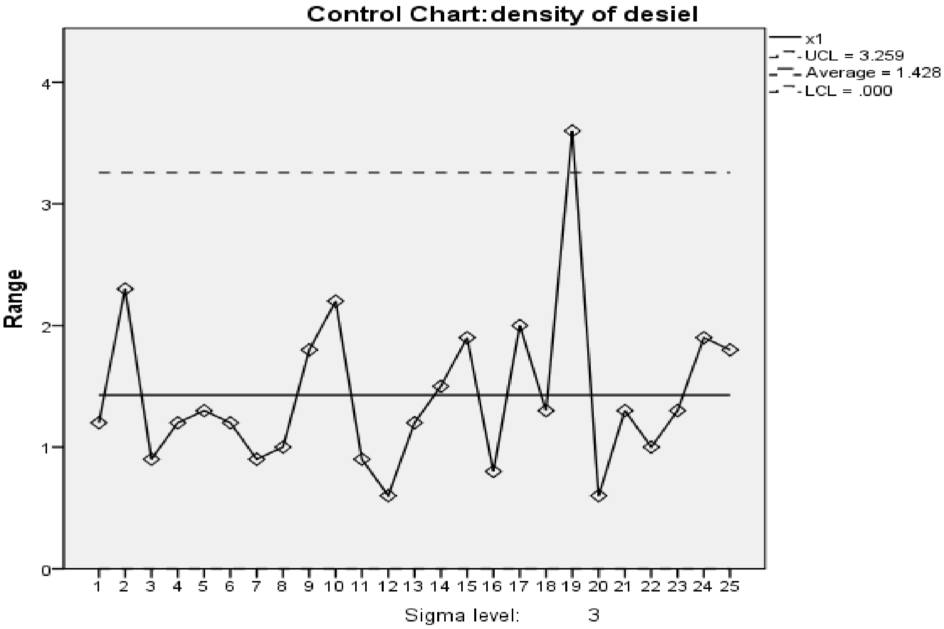

Figure 4.2: Range chart for diesel density

First It is better to interpret the range chart , if the process under statistical control then the mean chart must be interpret to know if the mean process output is under control or not .

From the Figure(4.1)&(4.2) 25 random sample with size 4 from diesel production has been tested . The Range map shows that the process is out of the statistical control for a point out of the upper control limit. That means there is no statistical stability in diesel density. Unlike other groups , the sub group with no. 19 show that the scatter is big in diesel density. Also the range map shows that the process unstability was in sub group 19. For process stability , the special cause must be determine and remove .

The mean chart shows a sub group point no. 12 out of lower control limit , and the sub group point no. 17 out of upper control limit . that indicates the average for the process is out of control limits which means that the diesel product density doesn’t meet the specifications .

4-1-3 Test quality of Flash Point using R and X-BAR charts:

To control flash point for diesel product by using mean chart and range chart , the same last steps must be followed to calculate upper & lower control limits and central line for each chart .

The limits for control chart $(\bar{X})$ and chart (R) to flash point of diesel are

Table (4.2): Control limits for R and X-BAR of flash point diesel

Control charts for variables	Constants of limits	Sample size	Subgroups number	centerline	LCL	UCL
R	D3= 0 D4= 2.282	4	25	2.780	0	3.344
X-BAR	A2= 0.729	4	25	79.225	77.199	81. 251

Source : Researcher

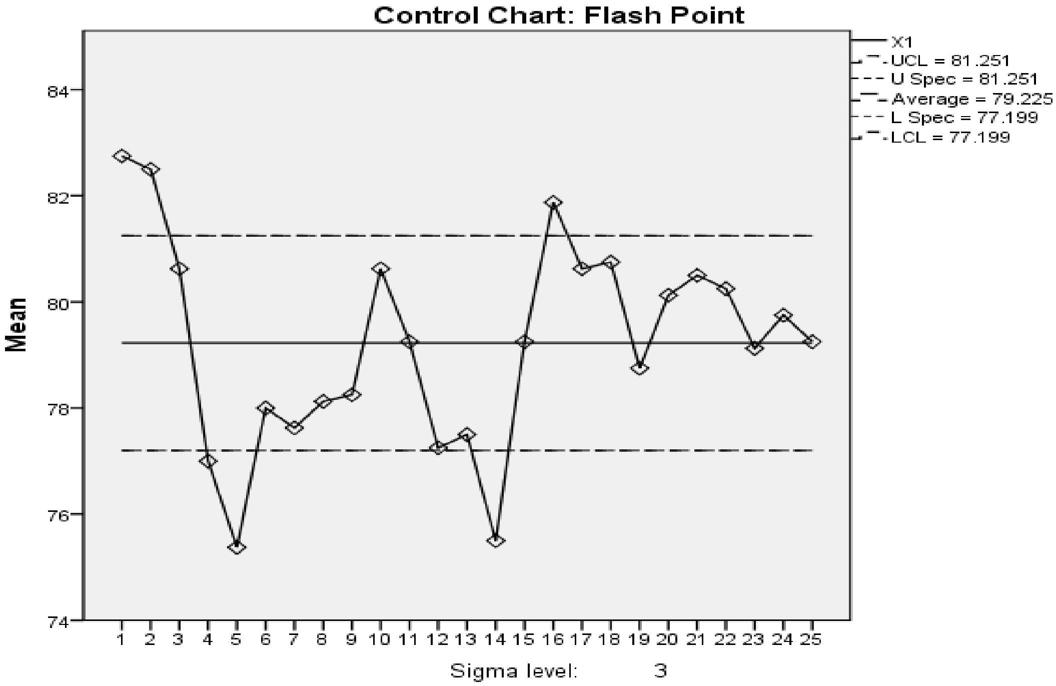

Figure 4. 3 : X-Bar char for flash point of diesel

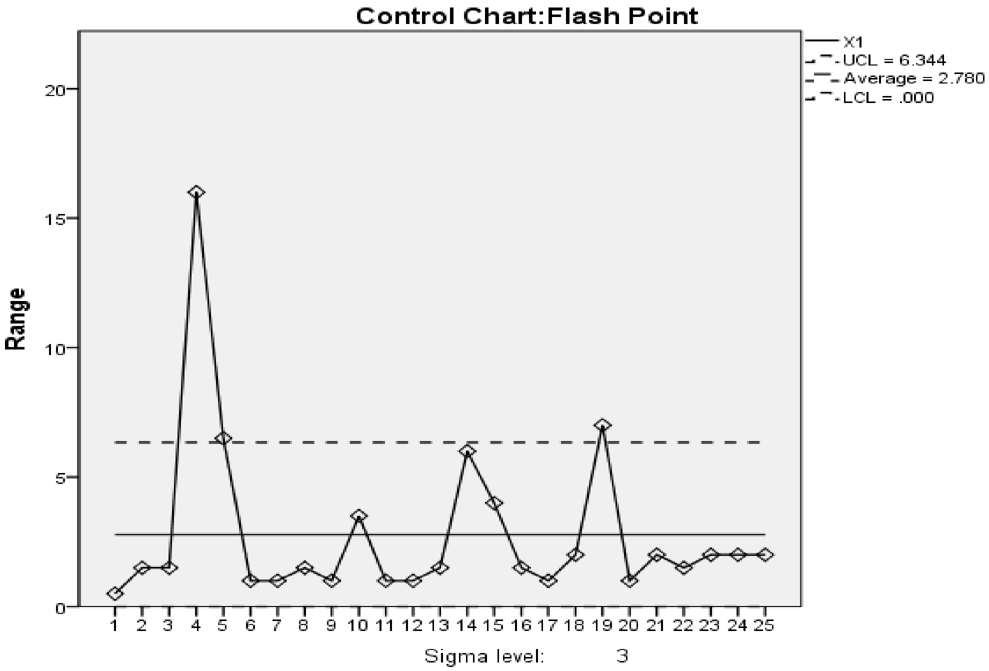

Figure 4.4 : range char for flash point of diesel

As we have mentioned before , it is better to interpret the range chart . If the process is under statistical control , the mean chart must be interpreted to know if the process average output is under control or not .

Figure 4 shows two points from subgroup out of control limits . That means the process is out of statistical control for two points falls is out of upper control limit . this indicate that there is no statistical stability in flash degree variation . It also shows that the scatter in diesel flash point degree for subgroups no. 4 &5 is big unlike other groups.

Mean chart draw no.3 . show many points of subgroups fall out of lower & upper control limit . Which means the process average is out of control limits . this indicates that quality of diesel flash product doesn't meet the specification .

4-1-4 Test quality of cetane number using R and X-BAR charts :

To control diesel cetane number using mean chart and range chart , the same steps must be followed to calculate the upper lower control limit , lower control limit and central line for each map .

Table (4.3): Control limits for R and X-BAR Cetena index

Control charts for variables	Constants of limits	Sample size	Subgroups number	centerline	LCL	UCL
R	D3= 0 D4= 2.282	4	25	.708	0	1.616
X-BAR	A2= 0.729	4	25	52.911	52.395	53.427

Source : Researcher

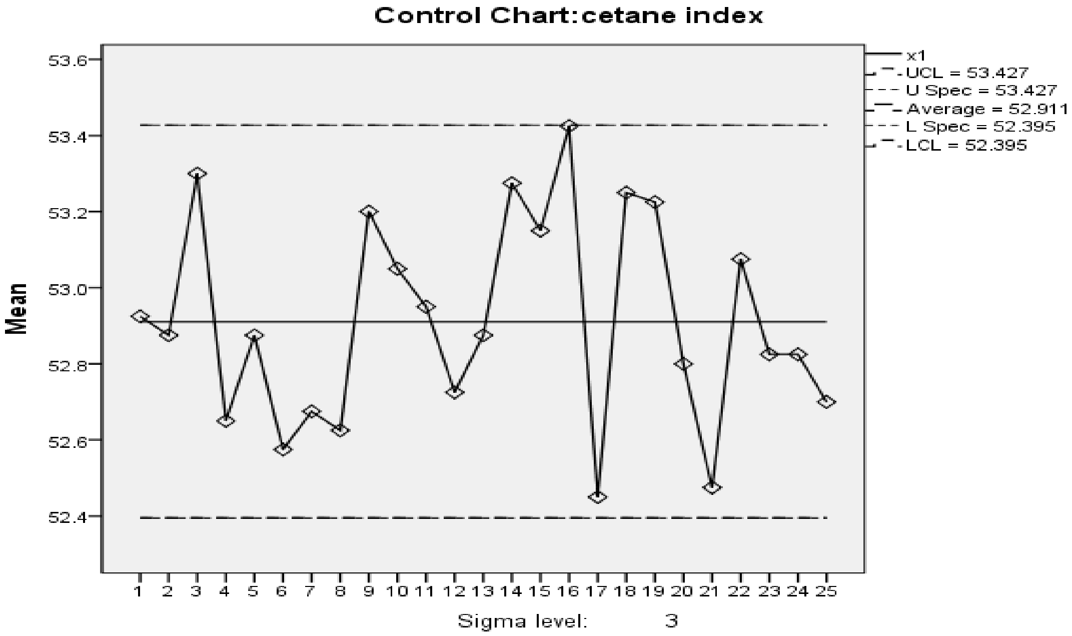

Figure 4.5 the X-Bar chart to diesel production cetane number

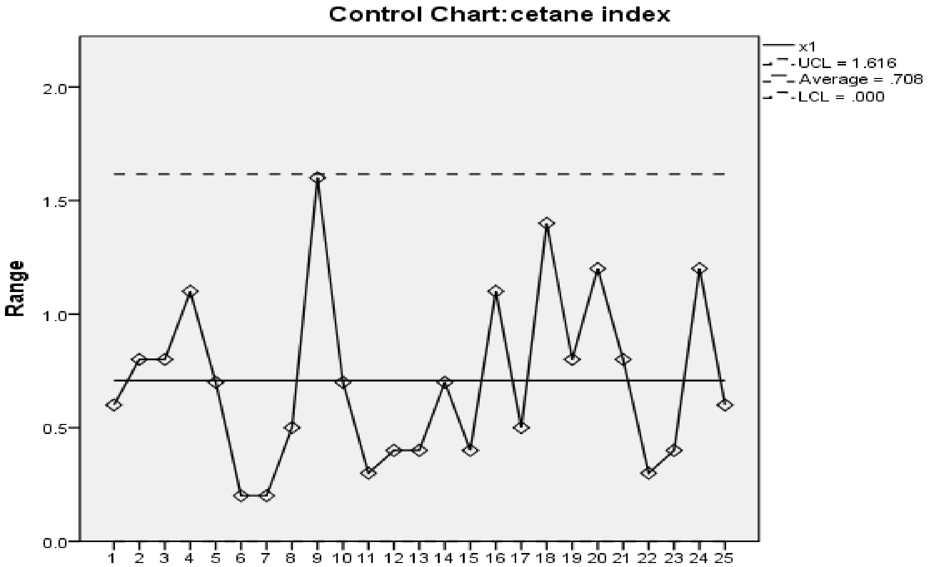

Figure 4.6 the range chart to diesel production cetane number

Figure (5) shows subgroup points out of allowed control limits . That means there is salability in scatter for diesel product cetane number . Therefore in the mean char no. 5 all the subgroup points fall in the allowed limits and there is no random changes . This means stability for diesel cetane number average which means it meet the specification.

4-2 Check quality of Gas Oil :

4-2-1 Test quality of density using X-BAR and S charts:

First : using using X-BAR chart to test quality of density

To prepare mean chart ; calculate means and standard deviation .then calculate the total mean for all the averages and standard deviation, as the table below shows

The calculation for standard deviation for the first and second group as follows :

$$S_1 = \sqrt{\frac{1}{n-1}\sum_{i=1}^{4}(x_{1j} - \bar{x}_1\ )^2}$$

$$= \sqrt{\frac{1}{4-1}[(739.50 - 740.025)^2 + \cdots + (741.20 - 740.025)^2]} = .788987$$

$$S_2 = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_{2i} - \bar{x}_2\ )^2}$$

$$= \sqrt{\frac{1}{4-1}[(739.60 - 739.800)^2 + \cdots + (740.10 - 739.800)^2]} = .355903$$

The calculation of the men for all standard deviation average as follows:

$$\bar{S} = \frac{\sum_{i=1}^{25} S_j}{25} = \frac{= .788987+.355903+\cdots+.309570}{25} = .7850486$$

Calculation of the two limits of the mean chart is as follows

Upper Control Limit (UCL)

UCL = $\bar{\bar{X}} + A_3\bar{S}$ =739.44 +1.628*.7850486 =740.7181

Central Line = $\bar{\bar{X}}$ = 739.44

Lower Control Limit (LCL)

LCL = $\bar{\bar{X}} - A_3\bar{S}$ =739.44 -1.628*.7850486 = 738.1620

The value for the constant (A_3) for subgroup with size 4 equal .(1.628)

Using SPSS program draw mean chart.

Second: standard deviation chart:

To prepare standard deviation chart first calculate the standard division for each subgroup , then calculate the mean for standard deviation, after that calculate control limits for chart using control limit equation as follows:

Upper Control Limit (UCL) =UCL =$B_4\bar{S}$ = 2.266* 0.7850486 = 1.7892

Central Line = $\bar{S}$ = 0.78504860

Lower Control Limit (LCL)= LCL = $B_3\bar{S}$ =0* 0 .7850486= 0

The value for two constant(B_3)and(B_4)for subgroup with size (4) equal (2.266) and zero respectively.

Table 4.4 Control limits for ($\bar{X}$) and (**S**) chart of Gas oil density

Control charts for variables	Constants of limits	Sample size	Subgroups number	centerline	LCL	UCL
S	B_4= 0 B_3= 2.266	4	25	.78504860	0	1.77892
X-BAR	A_3= 1.628	4	25	739.44	738.1620	740.7181

Source : Researcher

25 random samples from gas oil has been tested to control gas oil density . each sample's size equal 4 item . after draw the upper control limit , the lower control limit , the center line for mean & standard deviation char and draw expectation for data using spss we get mean char no.1 and standard division char as shown bellow:

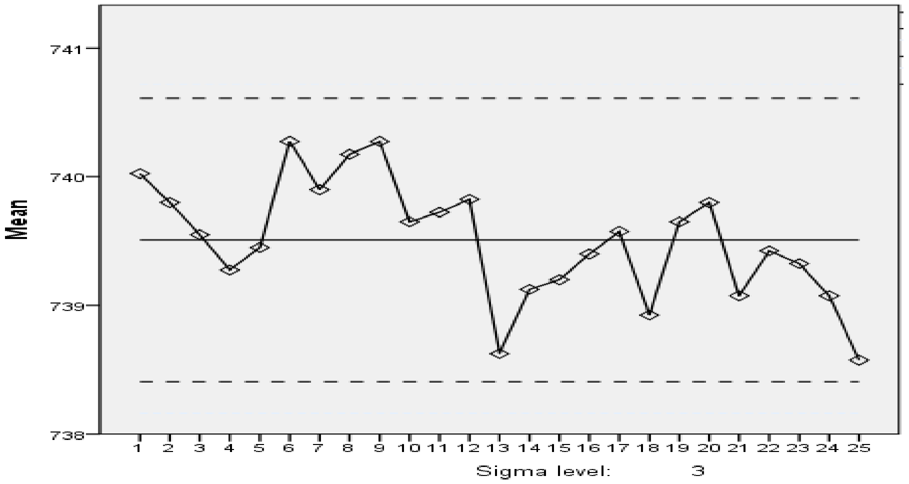

Figure 4.7 : X-Bar char for gas oil density

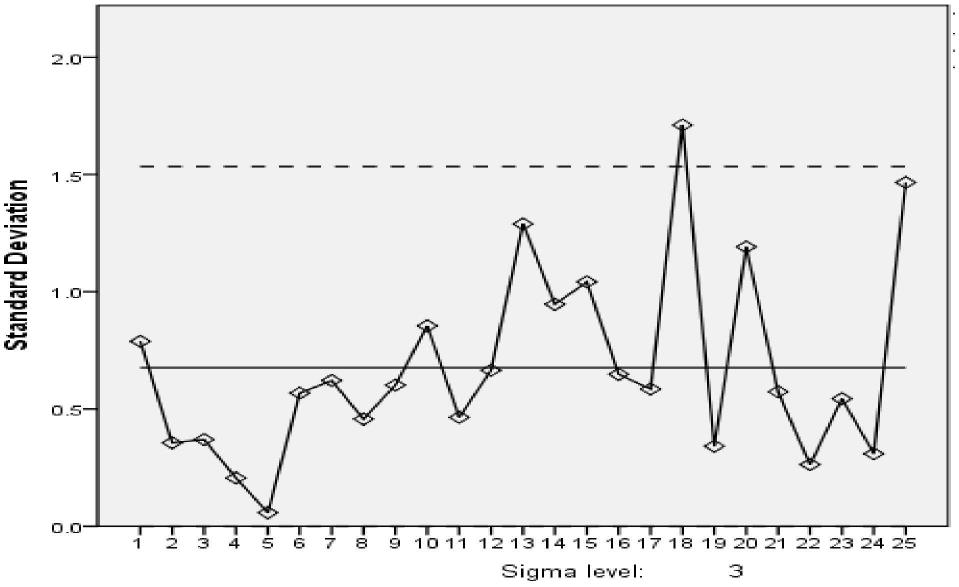

Figure 4.8 standard deviation chart

As the mean chart upper and lower limits depend on standard deviation values , it’s better to interpret standard division control chart. If the standard deviation charts shows that the process is under statistical control then interpret mean chart to know if the process output average is under control or not . if the standard division chart shows that the process is out the control , it is better not to interpret the mean chart. The standard deviation chart figure no.2 shows that the process is out of control . that because the point fall out of the upper control limit . The data table no.2 shows that the standard deviation for subgroup no.18 is big compared to other subgroups . The mean chart figure no.1 shows that all subgroup points fall inside the control limits. But there is no random behavior to distribute the points which means that the process is not stable . That means the gas oil does not meet the specification.

Chapter Five

Conclusion and Recommendations

5-1 Conclusion

5-2 Recommendations

5-1Conclusion:

After testing random samples from diesel production with subgroup size 25 , each subgroup contain 4 items it shows that :

1- The density and the flashpoint for diesel production in Khartoum refinery does not meet the specification.

2- Unlike other subgroups ,the scatter in diesel density for subgroup no.19 is big which means there is a special reason in subgroup no.19.

3- The mean chart for diesel production density shows that the point of subgroup no.12 falls out the lower control limit . It is also shows that the point of subgroup no.17 falls out the upper control limit . that means there is special reason which must be known it and removed to make the process stable.

4- Diesel flash point is out of control . The scatter in diesel flashpoint in subgroup no(4) and subgroup no(5) is big.

5- The X-bar chart for degree of flash point diesel shows that there is many points of subgroups fall out the upper control limit .this indicates that the average process is out of control limit.

6- The study shows that the cetane number meets the diesel specification.

Second : from the test of random sample of gas oil with size 25 subgroups , each subgroup contains 4 items ; it shows the following:

1- The standard deviation for subgroup no 18 is big compared to other subgroups.

2- The mean chart shows the process is not stable and there is nonrandom behavior to distribute the points. That means there is special cause that must be found and removed.

3- The Gas Oil density is not meet specification.

5-2 Recommendations:

1- Monitor stability of cenat number Diesel must be controlled according to the standard specification.

2- Density of Diesel must meet the standard specification.

3- The Flashpoint of Diesel must meet the standard specification to save diesel from burn if it heat.

4- density of Gas oil must meet the standard specification.

5- Must use of statistical methods to control petroleum product , which has an effect in saving specific specification.

6- Give refinery personnel training courses on how to use statistical control quality.

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