UNIVERSITY COLLEGE
OF BORÅS
SCHOOL OF ENGINEERING

Statistical Quality Control in Cable Industry
Case Study:
Copper Consumption Reduction in
Nexans IKO Sweden

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Nexans

Master of Science in Industrial Engineering with a major in Quality & Environmental Management Nr 3/2009

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Master thesis
Subject Category: Industrial Engineering

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“New opinion are always suspected, and usually opposed, without any other reason but because they are not already common”

John Locke 1632-1704
(An Essay concerning Human Undersatanding, 1690)

Acknowledgments

Grateful acknowledgement to my parents, who never give up in giving their support to me in all aspects of life.(Payam)

Dedicated to my wonderful parents, for providing me with the opportunity to be where I am, and my girlfriend Nana, for all her love and support during this work. (Reza)

This essay was improved by conversations with a large number of people who helped debug it. Particular thanks to Fredrik Torstensson our supervisor in Nexans IKO Sweden for his enthusiasm, support and his patience. He always tried to find some time to discuss our issues and guide us through our research.

Abstract

This thesis was carried out at the Special Cables group in the Nexans IKO Sweden AB in Grimsås, The company is a worldwide leader in the cable industry, offers an extensive range of cables and cabling systems.

The aim with this thesis is to increase mean average of the electrical resistance in cables and accordingly saving the copper as the raw material. In order to achieve such significance the project offers an approach to find and eliminate causes of variation in a manufacturing process.

In the beginning, some germane literature for the area was studied to get a deeper understanding of the problem. Some of the literature is summarized in the theory chapter of the thesis. The process was then defined and mapped out. Sources of variation were also chosen, in this case facts inside different machines.

Some statistical analysis was accomplished later in the process by applying the theoretical background in the light of the reality of company. Gage R&R was also performed to examine the measurement system in Nexans IKO Sweden.

The study concludes with recommendations for Nexans on five areas for implementation; Tracking and recording data, Optimization of the bunching process, Reach to the state of statistical control, More focus on suppliers, Prevention of over adjustment and main activities within these areas are defined. Finally management commitment is introduced as the most important factor for future success.

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1 Introduction

This chapter describes the background of the thesis, including the reasons for interest in the case. The chapter also includes the purpose created from that background, the chosen delimitation and the organization of the thesis.

1.1 Background

Over time, customers tend to expect more but are prepared to pay less for their requirements. They want higher quality at a lower cost. Many companies look upon quality management as away by witch to maintain competitive benefit. During the last few decades the interest and industrial use of quality-related system, tools and methodologies has grown significantly. Modern quality management is based on the idea that to remain competitive an organization has to incessantly upgrade the way it fulfills the needs of its customers. It is not enough to focus on the finished products that customers receive. How these products are produced, i.e. the processes, also needs to be addressed. (Garvare, 2002)

Shewhart (1931) was one of the first to argue for process control in favor of product control, and also for the use of statistical methods to enhance learning and understanding of manufacturing processes. Advancements in the field of mathematical statistics resulted in the development of problem solving techniques such as statistical process control, design of experiments and process capability studies. (Montgomery, 2005) During the 1970s, process oriented methodologies were developed under labels such as Just In Time (JIT) and lean production. (Schonberger, 1986) The process view was generally restricted to the areas of production and distribution. Cost reduction, through shorter lead times. So reducing the costs of manufacturing is an aim that every company is trying to achieve. An important way to be assumed is reducing the waste that not only has a great impact on the consumptions but also leads us to consider environmental issues more than before.

In the other hand also variation has been a problem since beginning of industrialization, perhaps even earlier. The introduction of mass production, assembly lines and exchangeable parts required consistency and high precision. This problem was initially handled by setting specification limits for important product characteristics. As time passed, focus moved away from the finished products towards improving the capability of production process. (Garvin, 1988) One of the examples is the Six Sigma methodology, the methodology was originally established by Motorola in the 1980s, and is, according to (Klefsjö, 2001) to a large extent based on systematic use of statistical techniques.

The general trends towards more complex products also call attention to the need for a deeper comprehension of the underlying relationships between process and product variables.Figure1.1 presents a generic production process transforming an input, such as raw material and components, into a finished product that has several quality characteristics. Example of controllable parameters is temperatures, pressures, and process time. Examples of uncontrollable or difficult to control parameters are vibrations due to play in bearing, varying air humidity, and inhomogeneous raw material. (Garvare, 2002)

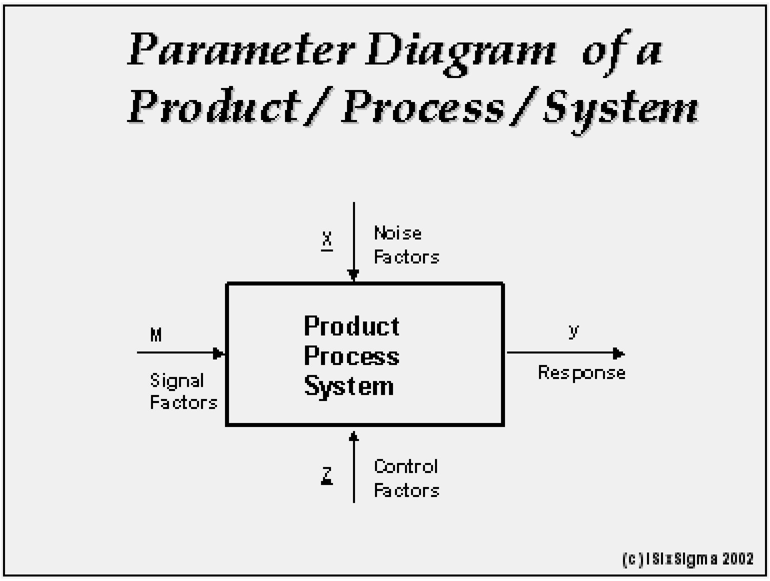


Figure 1.1 Illustration of a generic production process with a set of influencing factors. (Garvare, 2002)

The development of efficient statistical methods for structured inspection and experimentation during the early twentieth century has given rise to many new potential of identifying relations between variables.

1.2 Problem Discussion

There are many ways to deal with quality problems in a manufacturing company. The past 15-20 years many new methods, strategies and tools have emerged in quality area .For example, Total Quality Management, (TQM), has been a popular approach that many companies have adopted. (Pande & S., 2000) In recent years using Statistical process control and Six Sigma has grown in popularity especially in the US and companies like General Electric and Motorola have obtained significant improvement in their performance. (Pande & S., 2000) The pivotal quality principles in production are to prevent, improve and control. (Bergman, 2003) In this study we will look at variation and its causes, and how to improve and control a process using Statistical Process Control (SPC).

This thesis was based on the work accomplished for Nexans IKO Sweden AB. The main products of this company are electrical cables. In cables industry one of the most critical part of the production is the final resistance of a conductor. Nexans goals were to increase the mean average of this resistance and reduce the variation of resistance in the conductors with a corresponding reduction in cost. “Copper Cut” meaning reduction in copper consumption is a term including many benefits such as cost saving and confining environmental aspects in it. Using the theorem of: “The amount of copper used in the unit of length of a specific cable has an indirect relation to the amount of electrical resistance of that part” can lead us to concentrate on the amount of cable electrical resistance in order to achieve the goal, and also fulfill the customer needs, thereby improving of performance of company.

1.3 Purpose & Objectives

At the Special Cables group in the Nexans IKO Sweden AB the research and development in the field of cable production process has been conducted since many years ago. In the beginning of 2008, the Cable Resistance Project was started. The project aims to increase mean average of the electrical resistance in cables about 0.2 ohm, then the benefit of that due to saving the copper as the raw material in one year will be about 130 million SEK for the company. Nexans decided to implement Statistical Process Control (SPC) to reach this target. As a first step towards this, it was decided that a graduate work should be performed within the area.

1.4 Research Area (Company Description)

Nexans the worldwide leader in the cable industry offers an extensive range of cables and cabling systems. The Group is a global player in the infrastructure, industry, building and local area network markets. Nexans addresses a series of market segments from energy, transport and telecom networks to shipbuilding, oil and gas, nuclear power, automotive, electronics, aeronautics, handling and automation. With an industrial presence in 39 countries and commercial activities worldwide, Nexans employs 23,500 people and had sales in 2008 of 6.8 billion Euros. Nexans is listed on NYSE Euronext Paris, compartment A.

- *Nexans IKO Sweden*

Nexans IKO Sweden, with around 500 employees is active in manufacturing of both power and telecom cables. The company is located in Grimsås in Västergötland in the south of Sweden. It is responsible for Nexans operations in Sweden, Denmark, Finland, Estonia, Lativa, and Lithuania. Additional sales offices are located in Gothenburg, Söderköping, Sundsvall, Helsinki and Vilnius. (Nexans in Sweden)

1.5 Delimitation

Due to the lack of time the research area was limited to just one process line in the division of Special cables. However, the results could be extended and applied to the other process lines and other divisions, like Telecommunication and Power. Therefore, the concentration was on one Drawing Machine i.e. No.64 and nine bunching machines.

2 Theoretical Frame of Reference

In this chapter, the theoretical frame of reference is discussed. Areas such as Lean management, Robust Design, Statistical Process Control (SPC), Measurement System Analysis (MSA) are described. Moreover, they are presented in order to form a filter through witch the empirical work and results will be performed and analyzed.

2.1 Lean Management

2.1.1 Lean production definition

Reducing the waste while having the quality is in maximum in order to create value for the customers is the aim of Lean manufacturing while waste is defined as a non-value adding activity consuming the resources. The goal of lean production is described as "to get the right things to the right place at the right time, the first time, while minimizing waste and being open to change".

2.1.2 The Seven Wastes of Lean

The eight wastes focused in lean production on are:

1**. Overproduction**, Producing items earlier or in greater quantities than needed by the customer. Producing earlier or more than is needed generates other wastes, such as overstaffing, storage, and transportation costs because of excess inventory. Inventory can be physical inventory or a queue of information.

2. **Waiting** , Workers merely serving as watch persons for an automated machine, or having to stand around waiting for the next processing step, tool, supply, part, etc., or just plain having no work because of no stock, lot processing delays, equipment downtime, and capacity bottlenecks.

3. **Transportation** , Moving work in process from place to place in a process, even if it is only a short distance ,or having to move materials, parts, or finished goods into or out of storage or between processes.

4. **Over-processing** or incorrect processing, Taking unneeded steps to process the parts, Inefficiently processing due to poor tool and product design, causing unnecessary motion and producing defects. Waste is generated when providing higher quality products than is necessary. At times extra “work” is done to fill excess time rather than spend it waiting.

5. **Excess inventory**. Excess raw material, work in process, or finished goods causing longer lead times, obsolescence, damaged goods, transportation and storage costs, and delay. Also, extra inventory hides problems such as production imbalances, late deliveries from suppliers, defects, equipment downtime, and long setup times.

6. **Unnecessary movement**. Any motion employees have to perform during the course of their work other than adding value to the part, such as reaching for, looking for, or stacking parts, tools, etc. Also, walking is waste.

7**. Defects**, Production of defective parts or correction. Repairing of rework, scrap, replacement production, and inspection means wasteful handling, time, and effort. (Liker, 2005)

2.1.3 The Principles of Lean

- *Specify Value*

The critical starting point for lean thinking is value. Value can only be defined by the ultimate customer. And it's only meaningful when expressed in terms of a specific product (a good or a service, and often both at once), which meets the customer's needs at a specific price at a specific time. Value is created by the producer. From the customer’s standpoint this is why producers exist. Lean thinking therefore must start with a conscious attempt to precisely define value in terms of specific products with specific capabilities offered at specific prices through a dialogue with specific costumer.

- *Identify the Value Stream*

The value stream is the set of all the specific actions required to bring a specific product through the critical management tasks of any business: the problem-solving task running from concept through detailed design and engineering to production launch, the information management task running from order-taking through detailed scheduling to delivery, and the physical transformation task proceeding from raw materials to a finished product in the hands of the customer. Identifying the entire value stream for each product is the next step in lean thinking, a step which firms have rarely attempted but which almost always exposes enormous, indeed staggering, amounts of waste.

- *Flow*

After specifying value and mapping the stream it is the time of the value creating step of flow. Rearranging production activities for a specific product form departments and batches to continuous flow could lead to doubling of productivity and a dramatic reduction in errors and scraps. It can make a positive contribution to value creation and to speak to the real needs of employees at every point along the stream either.

- *Pull*

What customers actually tell they need could be made by the ability to design, schedule, and make exactly what the customer wants just when the customer wants instead of sales forecast. The customer could be allowed to pull the product as needed rather than pushing products, often unwanted, onto the customer.

- *Perfection*

Being perfect is a need arises once the four steps of lean are well implemented. Passing the time the requirements of customer will be changing and the need of seeing the potential needs of customer in advance is felt more. By working with continuous improvement on each process of the manufacturing line the organization is moving towards achieving this goal. (James P. Wamack, 1996)

2.2 Robust Design

Robust Design method, also called the Taguchi Method, pioneered by Dr. Genichi Taguchi, greatly improves engineering productivity. By consciously considering the noise factors (environmental variation during the product's usage, manufacturing variation, and component deterioration) and the cost of failure in the field the Robust Design method helps ensure customer satisfaction. Robust Design focuses on improving the fundamental function of the product or process, thus facilitating flexible designs and concurrent engineering. Indeed, it is the most powerful method available to reduce product cost, improve quality, and simultaneously reduce development interval. (Phadke)

2.2.1 Robustness Strategy

Variation reduction is universally recognized as a key to reliability and productivity improvement. There are many approaches to reducing the variability, each one having its place in the product development cycle. By addressing variation reduction at a particular stage in a product's life cycle, one can prevent failures in the downstream stages. The Six Sigma approach has made tremendous gains in cost reduction by finding problems that occur in manufacturing or white-collar operations and fixing the immediate causes. The robustness strategy is to prevent problems through optimizing product designs and manufacturing process designs. (Phadke M. S.)

2.3 Kano Analysis

Customers’ requirements were divided to three categories by the Japanese Dr Noriaki Kano:

1. **Basic Requirements**. These are basic requirements that, if missing, will make your customers extremely unhappy. When they are there, the customer won’t particularly notice since they are expected.

2. **Variable Requirements**. These are the requirements that will either cause your customers to rate your deliverables high or low.

3. **Latent Requirements**. These are features that go beyond what the customer even imagined. It includes features that the customer may not have been able to express because they are highly innovative or creative. (Przekop, 2005)

Categorizing the customer requirements to meet each of them is the aim of Kano Analysis. The importance of performing each one differs by another one when the basic needs are inevitable to be fulfilled and the latent ones are not requested by the customers yet. The importance is changing the customer requirements over time. It could be understood through different ways like making questioners or making observations. Using customer delighters is the fact acting like an attraction while the basic or variables requirements are met. Passing the time a latent requirement may evolve into a basic customer need. The satisfaction of customers mightn’t be achieved by what delighted them in the past at present. The Kano model offers some insight into the product attributes which are perceived to be important to customers. The purpose of the tool is to support product specification and discussion through better development team understanding. Kano's model focuses on differentiating product features, as opposed to focusing initially on customer needs.

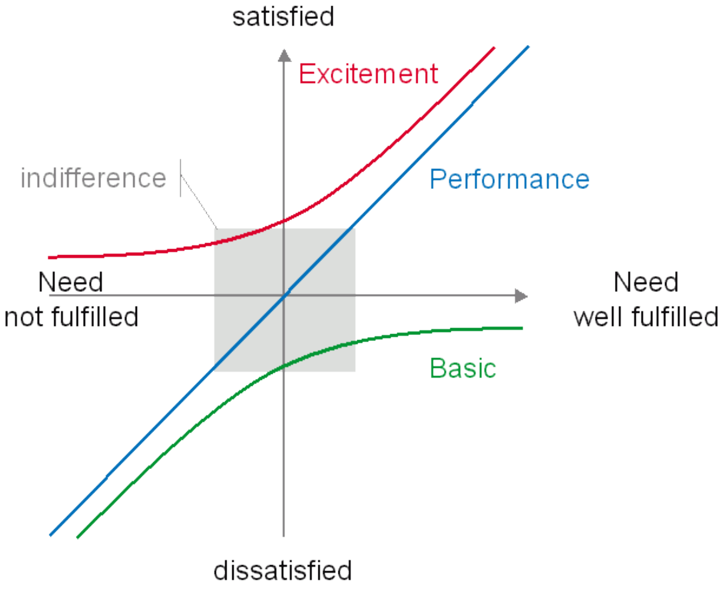


Figure 2.1 Kano Model (Wikipedia-Kano)

2.4 Process Map

Understanding the process could be really difficult since there are many details and inter-relations could be ignored working on it. In order to have a better view on the whole process breaking it down as follow is suggested:

- The inputs to your process
- The tasks within your process
- The flow of work between tasks within your process
- The value that is created within your process
- The outputs of your process
- The measurements of your process

It is a way of understanding better the process by taking the information out of it especially when it is a really complicated case. All the things happening through the process would be written up on the paper to simplify the management of whole. There are several guidelines to follow when creating a process map or list as:

- Follow one item through the entire process. Follow that one item in whatever state it normally goes through the process.
- Identify what really happens to the item, not what is supposed to happen to the item.
- List every single step that happens to the item including errors, inspections, exceptions, wait time, moves and anything else that happens.
- In addition to listing every single step, capture how long each one of those steps takes. (Flanigan, 1995)

2.5 Affinity Diagram

Created in the 1960's by Jiro Kawakita, Affinity diagrams allow large numbers of ideas to be sorted into groups for review and analysis. These, simple to produce, diagrams are particularly useful with large group where ideas which are generated at a fast pace required to be organized. The process for producing the Affinity diagram is:

- Conduct a brainstorming meeting
- Record ideas or issues on post-it notes or cards
- Gather post it notes into a single place
- Sort the ideas into groups based on the team's thoughts. Continue until all notes have been sorted and the team is satisfied with their groupings.
- Name each group with a description of what the group refers to and place the name at the top of each group.
- Capture and discuss the themes or groups and how they may relate. (leanyourcompany.com)

2.6 Statistical Process Control

Definition: Statistical Process Control is the use of valid analytical statistical methods to identify the existence of special causes of variation in a process.

Statistical process control (SPC) involves using statistical techniques to measure and analyze the variation in processes. Most often used for manufacturing processes, the intent of SPC is to monitor product quality and maintain processes to fixed targets. Statistical quality control refers to using statistical techniques for measuring and improving the quality of processes and includes SPC in addition to other techniques, such as sampling plans, experimental design, variation reduction, process capability analysis, and process improvement plans (Montgomery, 2005).A process control system can be described as a feedback system. SPC is one type of feedback system. Such other systems, which are not statistical, also exist. (Figure 2.2)

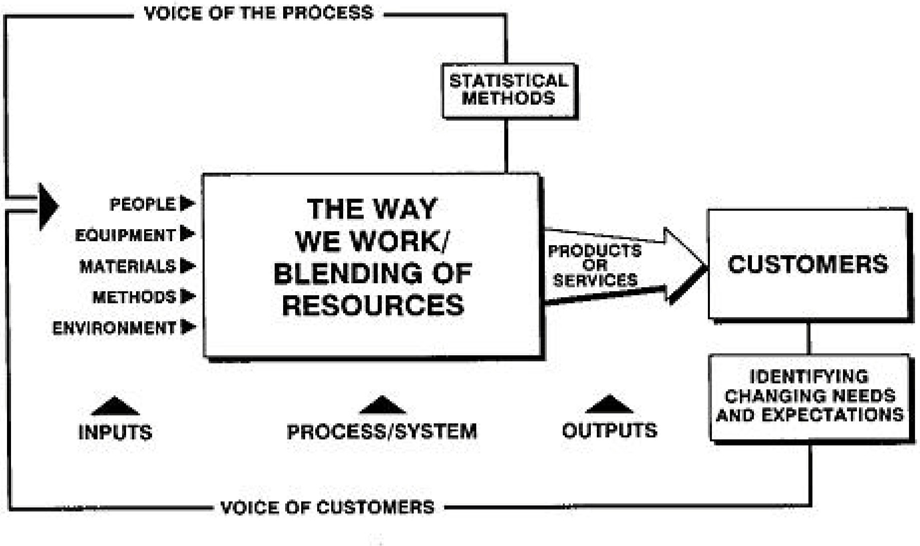


Figure 2.2 Process Control System Model with Feedback (Brown, Lowe, & Benham, 1995)

2.6.1 Distributions

A central concept in statistical process control (SPC) is that every measurable phenomenon is a statistical distribution. There are three basic properties of a distribution:

- location
- spread
- shape

The location refers to the typical value of the distribution, such as the mean. The spread of the distribution is the amount by which smaller values differ from larger ones. The standard deviation and variance are measures of distribution spread. The shape of a distribution is its pattern--peakedness, symmetry and etc. A given phenomenon may have any one of a number of distribution shapes, e. g., the distribution may be bell-shaped, rectangular-shaped, etc. (Pyzdek, 2003)

Probability distributions

A probability distribution is a model for relating how a value of a variable is related to the probability of occurrence of that value in a population25. To set up a model of the distribution, data needs to be collected from the investigated process or phenomena. A very common and useful distribution for describing probability of different phenomenon is the normal distribution. (Montgomery, 2005)

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, μ = 0 and σ = 1.

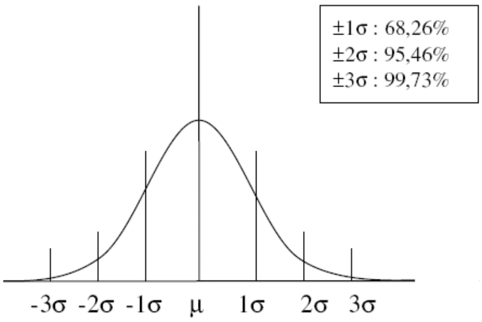


Figure 2.3 a standardized normal distribution and its variation from the mean (μ). (Engstrand & Olsson, 2003)

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.

2.6.2 Central Limit Theorem

The central limit theorem can be stated as follows: Irrespective of the shape of the distribution of the population or universe, the distribution of average values of samples drawn from that universe will tend toward a normal distribution as the sample size grows without bound. It can also be shown that the average of sample averages will equal the average of the universe and that the standard deviation of the averages equals the standard deviation of the universe divided by the square root of the sample size. Shewhart performed experiments showing that small sample sizes were needed to get approximately normal distributions from even wildly non-normal universes. Figure 2.4 was created by Shewhart using samples of four measurements. (Pyzdek, 2003)

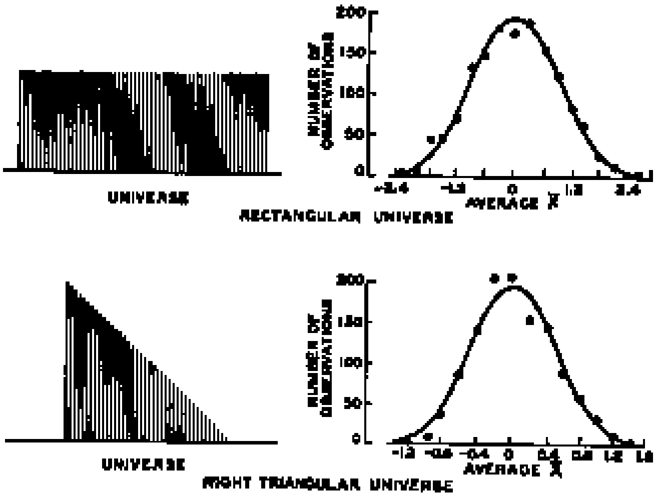


Figure 2.4 Illustration of the central limit theorem. (Pyzdek, 2003)

The practical implications of the central limit theorem are immense. Consider that without the central limit theorem effects we would have to develop a separate statistical model for every non-normal distribution encountered in practice. This would be the only way to determine if the system were exhibiting chance variation. Because of the central limit theorem we can use averages of small samples to evaluate any process using the normal distribution. The central limit theorem is the basis for the most powerful of statistical process control tools, Shewhart control charts.

2.6.3 Prevention versus Detection

A process control system is essentially a feedback system that links process outcomes with process inputs. There are four main elements involved, the process itself, information about the process, action taken on the process, and action taken on the output from the process. By the process, we mean the whole combination of people, equipment, input materials, methods, and environment that work together to produce output. The performance information is obtained from evaluation of the process output. The output of a process includes more than product, it also includes information about the operating state of the process such as temperature, cycle times, etc. Action taken on a process is future-oriented in the sense that it will affect output yet to come. Action on the output is past-oriented because it involves detecting out-of-specification output that has already been produced. There has been a tendency in the past to concentrate attention on the detection-oriented strategy of product inspection. With this approach, we wait until an output has been produced, then the output is inspected and either accepted or rejected. SPC takes you in a completely different direction: improvement in the future. A key concept is the smaller the variation around the target, the better. Thus, under this school of thought, it is not enough to merely meet the requirements; continuous improvement is called for even if the requirements are already being met. The concept of never-ending, continuous improvement is at the heart of SPC.
(Pyzdek, 2003)

Common and special causes of variation

Shewhart (1931, 1980) defined “control” as follows: A phenomenon will be said to be controlled when, through the use of past experience, we can predict, at least within limits, how the phenomenon may be expected to vary in the future. Here it is understood that prediction within limits means that we can state, at least approximately, the probability that the observed phenomenon will fall within the given limits. The critical point in this definition is that control is not defined as the complete absence of variation. Control is simply a state where all variation is predictable variation. A controlled process isn’t necessarily a sign of good management, nor is an out-of-control process necessarily producing non-conforming product. (Pyzdek, 2003)

In any production process a certain amount of inherent or natural variability will always exist. This natural variability or “background noise" is the cumulative effect of many small, essentially unavoidable causes. In the framework of statistical quality control, this natural variability is often called a "stable system of chance causes." (Montgomery, 2005) Where Dr. Shewhart used the term chance cause, Dr. W. Edwards Deming coined the term common cause to describe the same phenomenon. (Pyzdek, 2003)

A process that is operating with only chance causes of variation present is said to be in statistical control. In other words, the chance causes are an inherent part of the process. (Montgomery, 2005) Needless to say, not all phenomena arise from constant systems of common causes. At times, the variation is caused by a source of variation that is not part of the constant system. These sources of variation were called assignable causes by Shewhart, special causes of variation by Deming. (Pyzdek, 2003)

This variability in key quality characteristics usually arises from three sources: improperly adjusted or controlled machines, operator errors, or defective raw material. Such variability is generally large when compared to the background noise, and it usually represents an unacceptable level of process performance. (Montgomery, 2005)

The basic rule of statistical process control is: Variation from common-cause systems should be left to chance, but special causes of variation should be identified and eliminated.

This is Shewhart's original rule. However, the rule should not be misinterpreted as meaning that variation from common causes should be ignored. Rather, common-cause variation is explored "off-line." That is, we look for long-term process improvements to address common-cause variation. The answer to the question "should these variations be left to chance?" can only be obtained through the use of statistical methods. In short, variation between the two "control limits" will be deemed as variation from the common-cause system. Any variability beyond these fixed limits will be assumed to have come from special causes of variation. We will call any system exhibiting only common-cause variation, "statistically controlled." It must be noted that the control limits are not simply pulled out of the air. They are calculated from actual process data using valid statistical methods. Without statistical guidance there could be endless debate over whether special or common causes were to blame for variability.(Pyzdek, 2003)

2.6.4 The Magnificent Seven

The objective with a SPC program is:

- To see if the process is in control or not
- Find as many contribution factors to variability as possible and eliminate them.
- Supervise the process so that the operators quickly notice if a new assignable cause is introduced in the process, in such case eliminate it.

When the SPC program is performed this way the process variation will be reduced, the cost of poor quality will decrease and the product quality will improve. (Bergman, 2003) To achieve the objectives above, a set of useful tools called the Magnificent Seven can be used. The Magnificent Seven or the Seven Quality Control (7QC) tools are graphical statistical tools and methods for continuous improvement (Montgomery, 2005)

A list of the tools is presented here:

- *Check sheet*
- *Histogram or stem-and-leaf plot*
- *Pareto chart*
- *Cause-and-effect diagram*

- *Stratification or defect concentration diagram*
- *Scatter diagram*
- *Control chart*

These tools can be used either alone or together to provide the SPC work. The first step is often to collect data by using a check sheet. Depending on what sort of data needed to be collected the check sheet can be created in many different ways. The process, the product and the influential variables vary a lot between different processes. Therefore, it is important to have a good knowledge of the process so all important factors that effects the process would be included in the check sheet. If an assignable cause is forgotten, it would be hard or even impossible to explain the process variation. The collected data are further analyzed with the other tools. Among these the control chart is known to be the most effective tool for reducing the variability in the process. (Montgomery, 2005) Control charts can be used as an individual methodology for improvement and is then frequently run under the label of Statistical Process Control. (Kjell, 2000) Since, more often the control chart has been applied in this thesis so here it is more explained about this tool.

2.6.5 Control Chart

A control chart is a type of line graph used to assess and maintain the stability of the process. (Ozeki & Asaka, 1996) It is a powerful tool because of:

- Detecting special causes of variation in the process at the time they exist.
- Measuring the natural tolerance of the process that is due to normal variation (or common causes).
- Assisting you in getting the process in control and reaching a capability of meeting drawing tolerance limits consistently.(Griffith, 2000)

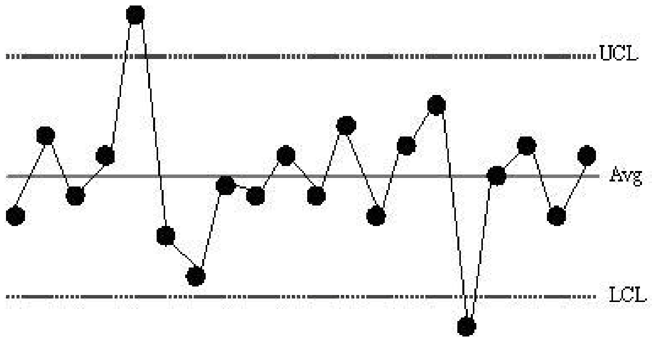


Figure 2.5 A sample Control Chart (Juran, 1998)

In Figure 2.5 the horizontal scale is time, and the vertical scale is quality performance. The plotted points show quality performance as time progresses. The chart also exhibits three horizontal lines. The middle line is the average of past performance and is therefore the expected level of performance. The other two lines are statistical limit lines. They are intended to separate special causes from common causes. (Juran, 1998)

Points within Control Limits

When a point on a chart differs from the average since it is within the limit lines, this difference could be due to common causes. Hence we assume that there is no special cause. In the absence of special causes, the prevailing assumptions include: Only common causes are present, the process is in a state of "statistical control", the process is doing the best it can or the variations must be endured.

The preceding assumptions are being challenged by a broad movement to improve process uniformity. Some processes exhibit no points outside of control chart limits, yet the interplay of minor variables produces some defects. In one example, a process in statistical control was nevertheless improved by an order of magnitude. The improvement was by a multifunctional improvement team which identified and addressed some of the minor variables. This example is a challenge to the traditional assumption that variations due to common causes must be endured. (Pyzdek 1990) In other cases the challenge is more subtle. There are again no points outside the control limits, but in addition, no defects are being produced. Nevertheless the customers demand greater and greater uniformity. Examples are found in business processes (precision of estimating), as well as in manufacture (batch-to-batch uniformity of chemicals, uniformity of components going into random assembly). Such customer demands are on the increase, and they force suppliers to undertake projects to improve the uniformity of even the minor variables in the process. There are many types of control charts. See Section 45, Statistical Process Control, for a more detailed discussion of this important tool. (Juran, 1998)

A fundamental idea in the use of control charts is the collection of sample data according to what Shewhart called the rational subgroup concept. To illustrate this concept, suppose that we are using an X-(xbar) control chart to detect changes in the process mean. Then the rational subgroup concept means that subgroups or samples should be selected so that if assignable causes are present, the chance for differences due to these assignable causes within a subgroup will be minimized. (Montgomery, 2005) two general approaches to constructing rational subgroups are used. In the first approach, each sample consists of units that were produced at the same time(or as closely together as possible).In the second approach, each sample consists of product that are representative of all units that have been produced since the last sample was taken. Essentially, each subgroup is a random sample of all process output over the sampling interval. (Montgomery, 2005)

Indication of Assignable Causes

The most obvious indications of the presence of the assignable causes are the following:

Points outside control limits, Points located outside the control limits indicate a special cause. Whenever possible, the reason and corrective action should be recorded on the chart.

Shift, A shift is a sudden change in level. It indicates that the process has shifted, perhaps caused by a new lot of material, a new operator, or a new machine setting.

Trend, A trend is a gradual rise or fall of plot points (usually six, seven or more consecutive points). It indicates that the process is drifting. Tool wear, wear or loosening of holding devices, operator fatigue, or production schedule changes may be the cause. (Robertson, 1990) Being more accurate several criteria may be applied to a control chart to determine whether the process is out of control. Some of the sensitizing rules we may respond more quickly to the assignable cause including the aforesaid items are shown in here:

1. One or more points outside of the control limits.
2. Two of three consecutive points outside the two-sigma warning limits but still inside the control limits.
3. Four of five consecutive points beyond the one-sigma limits.
4. A run of eight consecutive points on one side of the center line.
5. Six points in a row steadily increasing or decreasing.
6. Fifteen points in a row in zone C (both above and below the center line).
7. Fourteen points in a row alternating up and down.
8. Eight points in a row on both sides of the center line with none in zone C.
9. An unusual or nonrandom pattern in the data.
10. One or more points near a wanting or control limit.(Montgomery, 2005)

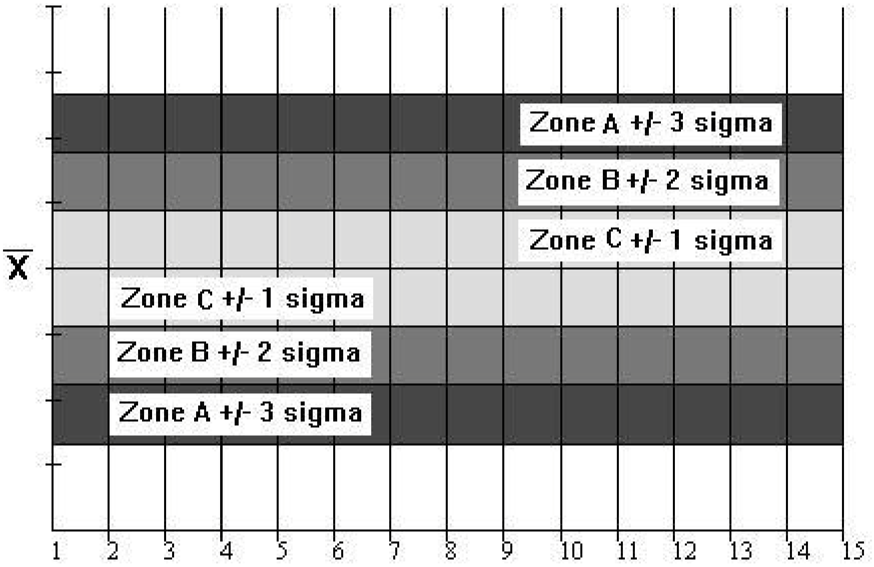


Figure2.6 Different zones of Control Chart (Six Sigma SPC)

Control chart for different uses

When dealing with a quality characteristic that is a variable, it is usually necessary to monitor both the mean value of the quality characteristic and its variability. Control of the process average or mean quality level is usually done with the control chart for means, or the xbar chart. Process variability can be monitored with either a control chart for the standard deviation, called the s chart, or a control chart for the range, called an R chart. (Montgomery, 2005) However although xbar and R are widely used it is sometimes desirable to estimate the process standard deviation directly instead of indirectly through the use of the range of R. This leads to the use of control chart of X- xbar and s where s is the sample standard deviation generally when the sample size is moderately large or variable. (Montgomery,2005)

Control chart for individual measurements

There are many situations in which the sample size used for process monitoring is $n = 1$; that is, the sample consists of an individual unit. Some examples of these situations are as follows:

- Automated inspection and measurement technology is used, and every unit manufactured is analyzed so there is no basis for rational sub grouping.
- The production rate is very slow, and it is inconvenient to allow sample sizes of $n > 1$ to accumulate before analysis. The long interval between observations will cause problems with rational subgrouping.
- Repeat measurements on the process differ only because of laboratory or analysis error, as in many chemical processes.
- Multiple measurements are taken on the same unit of product, such as measuring oxide thickness at several different locations on a wafer in semiconductor manufacturing.
- In process plants, such as papermaking, measurements on some parameter such as coating thickness across the roll will differ very little and produce a standard deviation that is much too small if the objective is to control coating thickness along the roll.

In many applications of the individuals control chart we use the moving range of two successive observations as the basis of estimating the process variability. The moving range is defined as:

$$MR_i = |x_i - x_{i-1}|$$

For the control chart for individual measurements, the parameters are :

$$UCL = \bar{x} + 3\frac{\overline{MR}}{1.128}$$

$$\text{Center Line} = \bar{x}$$

$$LCL = \bar{x} - 3\frac{\overline{MR}}{1.128}$$

(Montgomery, 2005)

There are many important uses for SPC, but not as a problem-solving tool. It mainly functions as a monitoring tool rather than a problem solving tool. Although being so much important as a control tool several arguments could be made on SPC specially when being used alone to improve the process:

- No action is taken on out-of-control charts. Somehow, merely charting them implies compliance.
- Line operators, supervisors, and technicians don’t have a clue on what to do when a point goes outside control limits, so they file away piles of control charts to furnish proof that they exist.
- There is an explosion of control charts dealing with every conceivable parameter as if mere quantity could compensate for meaningful content.
- The walls of a plant are littered with control charts, with plants competing to see who can win the prize of having the most charts.
- In more than 75 percent of control charts, the initial trials to determine control limits are never recalibrated. Once drawn, they are cast in stone.
- There is a mistaken belief that a constant cause system pervades a product or process if the control chart shows that all x and R points are within control limits. In actuality, there is no such thing as a stable process. Designs change, processes change, materials change, environments change, people change, and equipment changes. The only thing constant in industry is change! (Bhote & R., 1999)

2.7 Gauge R&R

2.7.1 Measurement System Facets

Measurement system vital aspects are the two important ones: *accuracy* and *precision*. The accuracy of a measurement system is an expression of the closeness of the average measured values to the true value. In practice, the true value is unknowable, so instead we use an accepted reference value to represent the true value. During a calibration procedure, the measuring device is tested using a reference standard. In turn, the reference standard has been tested using a standard of higher accuracy. This process continues until it reaches a national standard of highest accuracy and authority.

Precision is an expression of the closeness of measurements to each other that is assessed by performing repeated measurements of the same parts under controlled conditions. Precision is composed of discrimination, repeatability, and reproducibility. Discrimination is the smallest difference in values that can be detected by the measurement system. Repeatability is the closeness of measurements of the same part taken by the same appraiser. Reproducibility is the closeness of measurements of the same part, taken by different appraisers. (Sleeper, 2005)

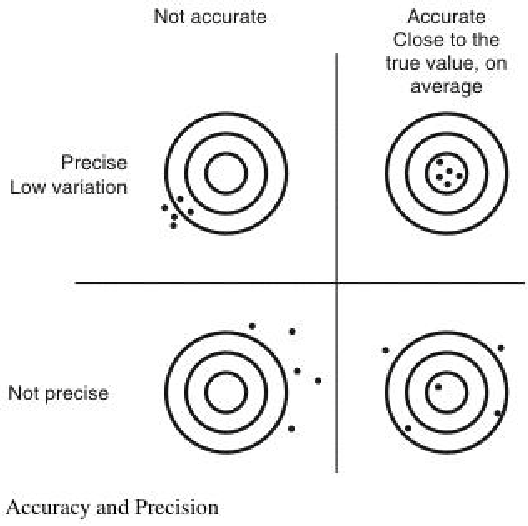


Figure2.7 Accuracy and Precision (Jack B. ReVelle, 2002)

2.7.2 Analysis of variance

In statistics, **analysis of variance** (ANOVA) is a collection of statistical models, and their associated procedures, in which the observed variance is partitioned into components due to different explanatory variables. (Studies in Crop Variation) In the analysis of variance, the variation can be decomposed into four categories: Parts, appraisers, interaction between parts and appraisers, and replication error due to the gage.

The numerical analysis can be done according to the formulas in table 2.1.This is what is called the Analysis of variance (ANOVA) table. The ANOVA table is composed of six columns. The source column is the cause of variation .The DF column is the degree of freedom associated with the source. The SS or sum of square column is the deviation around the mean of the source. The MS or mean square column is the sum of squares divided by degrees of freedom. The F ratio column is calculated only for the interaction; it is determined by the mean square of interaction divided by mean square gage (error). The EMS or expected mean square column determines the linear combination of variance components for each MS. The ANOVA table decomposes the total source of variation into four components: parts, appraisers, interaction of appraisers and parts, a replication error due to the gage. (Ford, GM, Chrysler, 1995)

$$SS_p = \sum_{i=1}^{n} \frac{x^2_{i..}}{kr} - \frac{x^2_{...}}{nkr} \qquad TSS = \sum_{i=1}^{n}\sum_{j=1}^{k}\sum_{m=1}^{r} x^2_{ijm} - \frac{x^2_{...}}{nkr}$$

$$SS_o = \sum_{j=1}^{k} \frac{x^2_{.j.}}{nr} - \frac{x^2_{...}}{nkr} \qquad SS_e = TSS - [\, SS_o + SS_p + SS_{op} \,]$$

$$SS_{op} = \sum_{i=1}^{n}\sum_{j=1}^{k} \frac{x^2_{ij..}}{r} - \sum_{i=1}^{n} \frac{x^2_{i..}}{kr} - \sum_{j=1}^{k} \frac{x_{.j.}^2}{nr} + \frac{x^2_{...}}{nkr} \qquad i = 1, ...n \;\; j = 1, ...k \;\; m = 1,...r$$

ANOVA

Source	DF	SS	MS	EMS	F
Appraiser	k–1	SS_o	$SS_o/k - 1 = MS_o$	$\tau^2 + r\gamma^2 + nr\omega^2$	
Parts	n–1	SS_p	$SS_p/n - 1 = MS_p$	$\tau^2 + r\gamma^2 + kr\sigma^2$	
Appraiser x Part	(n–1)(k–1)	SS_{op}	$SS_{op}/(n-1)(k-1) = MS_{op}$	$\tau^2 + r\gamma^2$	$\frac{MS_{op}}{MS_e}$
Gage (Error)	nk (r–1)	SS_e	$SS_e/nk(r-1) = MS_e$	τ^2	
Total	nkr–1	TSS		Appraiser ~ $N(o,\omega^2)$ Parts ~ $N(0,\sigma^2)$ Appraiser x Part ~ $N(o,\gamma^2)$ Gage(Error) ~ $N(o,\tau^2)$	

Table2.1 ANOVA Table (Ford, GM, Chrysler, 1995)

2.7.3 Repeatability/Reproducibility

These are measurement concepts involving variations in readings. Repeatability is the consistency of measurements obtained when one person measures the same parts or items multiple times using the same instrument and techniques. Reproducibility is the consistency of average measurements obtained when two or more people measure the same parts or items using the same measuring technique. (Brussee, 2004)

- *Repeatability:*

$$EV = r\overline{\overline{R}}$$

EV = Equipment Variation *r = 4.56 for 2 trials, 3.05 for 3 trials*

- *Reproducibility:*

$$\mathrm{AV} = \sqrt{\left(k\overline{\overline{X}}_{\mathrm{Diff}}\right)^2 - \left(\mathrm{EV}^2/n\,r\right)}$$

AV = Appraiser Variation

k = 3.65 for 2 appraisers, 2.7 for 3 appraisers

- *Repeatability and Reproducibility:*

$$\mathrm{R\,\&\,R} = \sqrt{\mathrm{EV}^2 + \mathrm{AV}^2}$$

- *Part Variation:*

$$\mathrm{PV} = jR_{\mathrm{p}}$$

PV = Part Variation

Rp = Range of part averages

j= Depends on number of parts

Part	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
J	**3.65**	**2.7**	**2.3**	**2.08**	**1.93**	**1.82**	**1.74**	**1.67**	**1.62**

Table 2.2 Amount of J according to the number of parts (Brussee, 2004)

- *Total Variation:*

$$\mathrm{TV} = \sqrt{\mathrm{R\,\&\,R}^2 + \mathrm{PV}^2}$$

TV = Total Variation

Percentage of total variation is calculated using the formulas below:

- %EV = 100(EV/TV)
- %AV = 100(AV/TV)
- %R&R = 100(R&R/TV)
- %PV = 100(PV/TV)

Guidelines for acceptable results are:

- **< 10%** *Satisfactory*
- **10%-30%** *May be satisfactory. Depends on the magnitude of the use, cost of new gauges, cost of repairs, etc.*
- **> 30%** *Unsatisfactory. Take corrective action.*

2.8 The Process Improvement Cycle

In applying the concept of continual improvement to process, there is a three-stage cycle that can be useful (Figure 2.8). Every process is in one of the three stages of improvement.

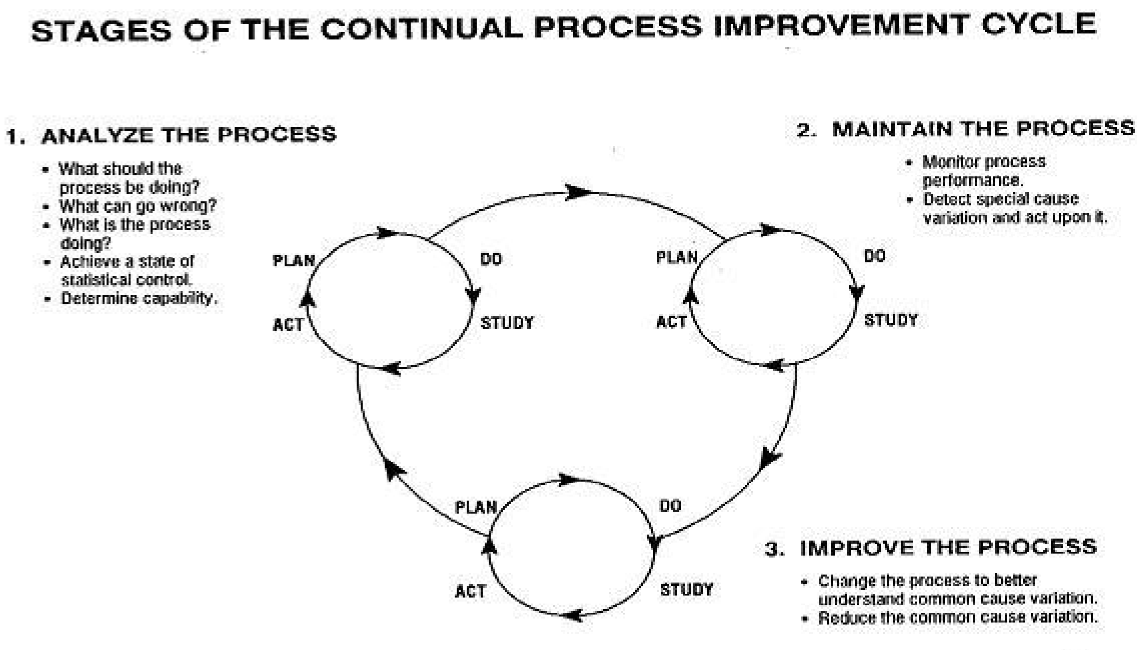


Figure 2.8 The Process Improvement Cycle (Brown, Lowe, & Benham, 1995)

2.9 Design of Experiments

A designed experiment is an approach to systematically varying the controllable input factors in the process and determining the effect these factors have on the output product parameters. Statistically designed experiments are invaluable in reducing the variability in the quality characteristics and in determining the levels of the controllable variables that optimize process performance. Often significant breakthroughs in process performance and product quality also result from using designed experiments. The objective of a designed experiment is to generate information that will allow us to understand and model the relationship between these process variables and measures of the process performance. It is a major off-line quality-control tool because of being used usually during development activities and the early stages of manufacturing, rather than as a routine on-line or in-process procedure. It plays a crucial role in reducing variability. (Montgomery, 2005)

There are three different approaches to be performed:

Classical DOE

This approach is based on the pioneering work of Sir Ronald Fisher, who applied DOE to the field of agriculture as early as the 1920s. Yet Fisher, using only the full factorial method, improved the productivity of the British farm. In fact, Fisher, who used DOE to reduce variation, was the real father of modern day quality control. Walter Shewhart, who is credited with the title, was his student..

Taguchi DOE

Genichi Taguchi of Japan adapted the classical approach, simplifying it with his orthogonal arrays. However, he has not had much success in his own country. He offered his services to the Bell Laboratories of AT&T in USA. Thus was born the Taguchi cult in the 1980s, with companies like AT&T, Ford, Xerox, and ITT becoming the missionaries.

Shainin DOE

The third approach is a collection of simple, but powerful techniques invented or perfected by Dorian Shainin of the United States, a consultant to more than 800 leading companies. Shainin is easily the world’s foremost quality problem solver. Unfortunately, the Shainin techniques have not received the wide publicity and use they deserve because the companies that used these techniques and experienced excellent results were unwilling to share them with others. (Bhote & R., 1999)

Steps to be taken to run a DOE are:

1. ***Recognition of and statement of the problem***

In practice, it is often difficult to realize that a problem requiring formal designed experiments exists, so it may not be easy to develop a clear and generally accepted statement of the problem. However, it is absolutely essential to fully develop all ideas about the problem and about the specific objectives of the experiment. Usually, it is important to ask for input from all concerned parties-engineering, quality, marketing, the customer, management, and the operators (who usually have much insight that is all too often ignored). A clear statement of the problem and the objectives of the experiment often contribute substantially to better process understanding and eventual solution of the problem.

2. ***Choice of factors and levels***

The experimenter must choose the factors to be varied in the experiment, the ranges over which these factors will be varied, and the specific levels at which runs will be made. Process knowledge is required to do this. This process knowledge is usually a combination of practical experience and theoretical understanding. When the objective is factor screening or process characterization, it is usually best to keep the number of factor levels low. (Most often two levels are used.).

3. ***Selection of the response variable***

In selecting the response variable, the experimenter should be certain that the variable really provides useful information about the process under study. Most often the average or standard deviation (or both) of the measured characteristic will be the response variable. Multiple responses are not unusual. Gauge capability is also an important factor. If gauge capability is poor, then only relatively large factor effects will be detected by the experiment, or additional replication will be required.

4. ***Choice of experimental design***

If the first three steps are done correctly, this step is relatively easy. Choice of design involves consideration of sample size (number of replicates), selection of a suitable run order for the experimental trials, and whether or not blocking or other randomization restrictions are involved.

5. ***Performing the experiment***

When running the experiment, it is vital to carefully monitor the process to ensure that everything is being done according to plan. Errors in experimental procedure at this stage will usually destroy experimental validity. Up-front planning is crucial to success.

6. ***Data analysis***

Statistical methods should be used to analyze the data so that results and conclusions are objective rather than judgmental. If the experiment has been designed correctly and if it has been performed according to the design, then the type of statistical method required should not be so complex. Many excellent software packages are available to assist in the data analysis, and simple graphical methods play an important role in data interpretation. Residual analysis and model validity checking are also important.

7. ***Conclusions and recommendations***

Once the data have been analyzed, the experiment must draw practical conclusions about the results and recommend a course of action. Graphical methods are often useful in this stage, particularly in presenting the results to others. Follow-up runs and confirmation testing should also be performed to validate the conclusions from the experiment.

3 Methodology

In this chapter the chosen methodology is presented. The chapter includes a description and discussion of aspects related to the chosen approach and strategy. Other relevant choices that influence the studies, and the validity and reliability of the thesis are discussed.

3.1 Research Approach

Denzin & Lincoln (2000) State that different paradigms of research and theoretical perspectives on research that the researcher believes in influence how the researcher looks at the world and acts in it; Moreover, all research is conducted on the basis of a determined pre understanding of paradigms and theoretical conceptions, whether it is conscious or unconscious, concerning what is important, interesting and relevant. (Bjereld, 1999) The term "methodology" focuses on the best means for gaining knowledge about the world. (Denzin & Lincoln, 2000) Methodology refers to the way in which we approach problems and seek answers. (J.Taylor & Bogdan, 1984)

3.1.1 Case Study

Rather than using samples and following a rigid protocol to examine limited number of variables, case study methods involve an in-depth, longitudinal examination of a single instance or event: a case. They provide a systematic way of looking at events, collecting data, analyzing information, and reporting the results. Case studies lend themselves to both generating and testing hypotheses. (Wikipedia-Case Study) The different ways employed to run the case study in this project are coming here:

Interviews

Most information was gathered by interviewing different employees. Quality manager, operators, machine manufacturer companies and responsible persons for repairing the apparatus were our sources to be acquainted with the whole processes through the related details. Having a holistic view of the whole project was obtained by the guidance of quality manager while his consultations were leading us through every vague situation. Questioning from the appropriate operators was really helpful since they were pretty familiar with the machine's details, parameters and problems. Contacting with the manufacturer of production line machines helped us to know more about the structure of the studied machine showing us the effective controllable factors on the products.

Observations

Observations are based on visits to the field of the case study. (Yin, 1994) notes that there are two types of observations; “direct” and “participant” ones. The difference between the two is that in a participant observation, the researcher is not only a passive observer. (Creswell, 1994) A “complete participant” is a participating researcher, who completely conceals her/his role as an observer, while with an “observer as participant” the observing role of the researcher is known to those observed. When the researcher is a participant as observer” the participation is primary while observation is secondary. Finally, a “complete observer” means that the researcher observes openly, but without participating. In this study our role can judge as a “complete observer”.

3.1.2 Data Analysis

A data bank gathering within the years in the company is a document having the company specifications e.g. company strategy, company manner and company products inherently. Extracting the needed information from such a great source is a way should be taken by different analysis devices. Applying the tools such as SPC can facilitate showing the way of act of company concluding great achievements as the result of true analysis.

3.1.3 Literature Studies

There is a need for a literature study since it is a necessity as a starting point of every research as a deductive approach. Reference books, E-Books, E-journals and Articles were our guidance to walk through this way.

3.1.4 Making Experiments

In order to make reasoning, running experiments is an inevitable affair leading to prove the achievement of literature studies. Some of them are routine as the ordinary processes in the manufacturing line need just supervision, observation and recording the results. Some other ones are needed to be run as some innovative and individual experiments. The result could be the conclusive proof of our theoretical knowledge or provide evidence on a new belief or an unforeseen fact.

3.2 Research Design

A researcher can approach a study item in different ways, in the form of induction or deduction.

3.2.1 Inductive

Inductive reasoning, is the process of reasoning in which the premises of an argument are believed to support the conclusion but do not entail it; i.e. they do not ensure its truth. Induction is a form of reasoning that makes generalizations based on individual instances. (Wikipedia-Inductive Reasoning) A process of thought could be happened using known facts in order to achieve the rules or ideas in general.

3.2.2 Deductive

Inference in which the conclusion about particulars follows necessarily from general or universal premises is called deductive. (Merriam Webster) Using the knowledge or information you have an opinion could be formed or an event could be understood. This work is built to a large extent on a deductive reasoning since it aims to analyze quality aspects within the production line and comparing the analysis with the theory then trying to make conformity with the help of running experiments.

3.3 Validity, reliability and generalization in the thesis

Reliability means to what extent a methodology of investigation or fact collection method gives the same results under the same conditions at different occasions.(Bell, 1993) Validity can be divided in to three different meanings: *External validity* means to what extent the results from the current study can be suitable even for occasions other than those studied *Internal validity* means to what extent the achieved results correspond with “reality”. *Construct validity* means whether one actually studies the context or issue one wants to study for *validity* and for *external, internal* and *construct validity.* (Yin, 1994)

Efforts have been made to increase the validity and reliability of the results in the thesis. It is however, inappropriate to make statistical generalizations, since it is important to understand, gain knowledge and interpret the opinions and experiences of a limited number of persons.

4 Empirical Work

This chapter presents the empirical study that the authors have conducted. The chapter presents the SPC project containing some sections for each phase in the SPC implementation. The chapter also includes summaries of interviews and a focus group discussion.

4.1 Understanding cable process

Empirical work began with understanding the process of production. Facing lack of time it was decided to just focus on one process line in special division of Company. However, the results could be applied for the other lines and divisions. Therefore, the concentration was on one of Drawing Machines i.e. No.64 and nine bunching machines.

Because of not having any information about the production line and not knowing anything about the producing of the cable so in the start the effort was just to understand more and more about the process and machines. It was necessary to know how the machines work, what the relation of every machine to the whole process is and totally what the mechanism of the drawing and bunching machine is. To understand the process the authors decided to go through the details of every part directly. In the mean time the try was asking some questions about every part of the machines from the technicians and some engineers and experts in every part of the process.

A **cable** is one or more wires or bound together, typically in a common protective jacket or sheath. Electrical wire is usually copper because of its excellent conductivity the cable production process consists of five machines:

1. ***Continuous barrel pay-off :***

This machine pulls the wire by motor while the barrel goes from full position to empty by this machine.

2. ***Multi wire horizontal drawing machine :***

“Wire is often reduced to the desired diameter and properties by repeated drawing through progressively smaller dies, or traditionally holes in draw plates.“ (A.Thue, W. 2003) The wire may be heated to red heat in an inert atmosphere to soften it, and then cooled, in a process called annealing. An inert atmosphere is used to prevent oxidation, although some scaling always occurs and must be removed by 'pickling' before the wire is redrawn. An important point in wire-drawing is that of lubrication to facilitate the operation and to lessen the wear on the dies. Various lubricants, such as oil, are employed. Continuous wire-drawing machines differ from the single-block machines in having a series of dies through which the wire passes in a continuous manner. The difficulty of feeding between each die is solved by introducing a block between each, so that as the wire issues it coils around the block and is so helped on to the next die. The speeds of the blocks are increased successively, so that the elongation due to drawing is taken up and slip compensated for. (Wikipedia-Wire Drawing)

3. ***Dancer Machine :***

Dancer role is continuous operation of the drawing line in conjunction with a wire accumulator and also automatic traverse speed correction.

4. ***Spool taking up machine :***

This part of cable production process is to accumulate the wire in the spool. The important point is that the speed of Spool taking up machine is controlled by adjustable wire tension of Dancer Machine.

5. ***Bunching Machine :***

Stranded wire is composed of a bundle of small-gauge making a larger conductor by being twisted around. Bunching Machine is the one twisting the bundles together .Moreover, the lay length of the cables could be adjusted here. The strands would be pulled by the spool in this machine.

This information will be used later in the analysis section where the combination of theories and observation leads to some recommendations for reducing the variation in diameter.

Process mapping:

To formalize the project the authors decided to use the Process map tool. In this part we used the documentations relating to the description of the process and the results from the investigation. This tool is useful to create a shared understanding about the process. As a graphical representation of a process that shows in a 'flow' type style. This way has been used to display the cable process that illustrates how a conductor is being manufactured. Also it is totally helpful to establish boundaries, inputs and outputs in each machine. Microsoft Visio was the program employed to draw the process map. The appropriate information of every part of the process is mentioned here while further details could be found in (Appendix A).

4.1.1 Barrel pay-off Machine

The Barrel Pay-off machine consists of:

- *Pulleys*
- *Barrels*
- *Motor*
- *Cold welder*

The input of this machine is copper with 2.8 mm and the output also is the same .It works with 16 separate barrels while the main task of this machine is continuous pay-off. The critical part of this machine is related to instruction of how to connect the wires by cold welder together and it depends on the quality of wire .The speed of pay-off is between 20-30 cm/sec.

4.1.2 Drawing Machine

The most important parts of this machine are:

- *Dies in different size (Appendix A)*
- *Drawing emulsion*
- *Rotating ceramic roller*
- *Drag bath*
- *Motor*
- *Gear*
- *Emulsion tank*

The input is wire in 1.8 mm but the output can vary in different sizes (Appendix A). Some of the important points of this machine are:

- *Instruction of controlling the dies and also maintenance of them*
- *Controlling the roller speed by adjusting the appropriate motor and gear*
- *Maintenance of the rollers*
- *Decreasing the temperature of strands and dies by spraying the emulsion of oil and water*
- *Controlling the emulsion*
- *The method and amount of mixing oil, foam reducer and calk*

The critical points like strand speed; maintenance duration of dies and drag bath could be directly related to the diameter of output wire and consequently the wire resistance.

4.1.3 Annealing Machine

Annealing machine is directly connected to the drawing machine. It increases wire flexibility by lubricating heating and leading up the wire to subsequent dancer. Passing through annealing machine the strands would be dried by the heat of special pulleys. The most important parts of this machine are:

- *Heater*
- *Glogbad*
- *Rollers*

- *Comb*
- *Dryer*
- *Emulsion control taps*
- *Steam control tap*

The input and output wire diameters of this machine are totally the same and equal to what comes out of drawing machine. Some issues should be considered running annealing machine are:

- *Adjusting the electricity and amount of steam*
- *Adjusting the amount of incoming emulsion in Glogbad*
- *Changing the ingredients and the combination of emulsion*
- *Mixing oil, foam reducer and calk with water*

The critical key points should be considered studying the problem are:

- *The effect of strand speed on the wire diameter*
- *The effect of temperature of outgoing steam on diameter*
- *Amount of steam and electricity*
- *Amount or the height of emulsion*
- *Emulsion specification*

4.1.4 Dancer

The dancer consists of:

- *Pulleys (here:5unites)*
- *Drive shaft*
- *Pneumatic Pump*

The inputs and outputs of the dancer also are the same in diameter. The dancer automatically can control the traverse speed and it makes the drawing line and the spool take up machine connected to each other, the most significant point in dancer is adjusting the pressure of pneumatic pomp according to the weight of the wires. Therefore, some holes are considered to adjust the pressure via a playing shaft.

4.1.5 Spool Taking up Machine

Spool loading and unloading with hydraulic lifting table is doing by this machine. Different parts of this machine are:

- *Conveyors*
- *Ac servo motor of conveyors*
- *Vertical drive shaft*
- *Bell*
- *Genomgong*
- *Bell motor*
- *Oil-tank*
- *Balance weights*

Like dancer machine and annealing machine there is no difference between the inputs and output the critical points having impact on the resistance are the oil material and, speed of bell and the shaft.

4.1.6 Bunching machine

The last part of the cable production process is bunching procedure. Bunching machine consists of two main portions:

1. ***Back Twist Pay-Off Machine***
2. ***Twist Bunching Machine***

Back Twist Pay-Off machine
Different parts of Back Twist Pay-Off are:

- *4 pay-off positions*
- *Magnetic brake*
- *Wire guide pulleys*
- *Wire break sensors*

As bunching machine twists the strands together the input of Back twist pay-off part are the non-wound wires while the output are separate but a little twisted wires. The tension on the wires could be adjusted manually via the magnetic brake by operators. The critical points here are: tension adjustment by magnetic brake, pay-off speed, lay-length adjustment and as the most important one: the resistance of each bundle before mounting on Back twists pay-off.

Twist Bunching Machine

This part is connected to back twist pay-off composing the bunching machine together. Different parts of Twist Bunching Machine are:

- *Rotor bow*
- *Winding spool*
- *Brake to control the spool speed*
- *Rollers*
- *Trot forare*
- *Sprockets*

The input of this part is separate wires while the output is multi wire bundle. Adjusting the lay length is feasible by changing the available sprockets that results in changing the bow speed and consequently changing the winding force that is a crucial factor in establishing the desired lay length. The most critical point in this part is how to control tension on the wire.

4.2 Finding sources of variation

After making the process map and going through the details, it was supposed to find the sources of variation of cable resistance in every part of the process to approach one step closer to the determined goal. Finding sources of variation could help us to focus on specific parts in the process due to decrease the variation and totally increasing the mean average of resistance. Using process map the key factors in each process were defined. Brain storming was here fairly needed since there was not any specific scale to assign the sources of variation among specified key factors. Affinity diagram was the tool employed to do so. Operators of machines, the process line quality manager and the authors were the ones participated in this practice. The results are coming here out of every part of whole process:

Figure 4.1 Affinity Diagram

Barrel Pay-off

It was found that there is no critical point in the Barrel Pay-off machine that can affect the final variation.

Drawing Machine

The important facts related to drawing machine coming out in results are:

- *The dies (maintenance duration of dies)*
- *Drawing emulsion (maintenance duration of Drag-Bath and the mixture of the materials in the emulsion)*
- *Speed of the drawing machine*

Annealing Machine

Referring to one project being done before with the aim of finding the effect of annealing machine on cable resistance no effective factor could be found here. Therefore, the items like electricity and amount of steam (Appendix A) could be ignored looking for the sources of variation.

Dancer

The important factors could be assumed here as the sources of variation are:

- *The tension imposing on wires by dancer*
- *Speed of traversing the wires (speed of spool take up machine)*

Spool Taking up Machine

No important effective factor on the cable resistance could be found here assuming the importance of the other parts.

Bunching Machine

We divided the factors having any effect on the final resistance to into two groups:

- *The factors can impose tension on the wire before the capstan*
- *The factors can impose tension on the wire after capstan*

4.3 Focusing on the sources of variation

Finding the most important sources of variation it was the time of collecting data and studying the variations. Getting access to an available data bank in Nexans Company and not having enough time were the reasons to not gather new data and to rely on the old ones. It was desirable to use the sources to implement DOE method in order to find the optimum situation, but it was not feasible since in practical way changing such factors every time was really difficult and somehow impossible in order to reach the final result .Not having equipped and accurate measurement system to measure these factor was another reason to not be successful in implementing of DOE. As an illustration there was not any specific data right after dancer machine to find the effect of dancer on the final resistance. The last reason was that a lot of factors contributed to make the variation in the resistance but lack of information about these factors was another problem.

As a result of brainstorming it was decided to focus on two major parts of the process i.e. Drawing Machine and Bunching Machine as the first step. It was decided to work on some specific wire types with the hope of extending the results to the other types.

4.3.1 Bunching Machine

At the beginning of this part we faced with such questions like:

- To what extent does bunching phase affect the total variation?
- Do different machines produce considerable different variation? If yes which machine does make more variation than the others?
- In bunching stage, can we make any special ploy to decrease the total variation or increase the mean average of the final yield?

In order to answer these questions the control charts and the other statistical tools to find out more about the twisting process were employed.

A big amount of data including the final resistance of different types of cable coming out of twisting machine was available. Therefore, it was decided to just focus on one specific diameter having more data about it i.e. 0.193 mm. Another criterion leading to come up with this selection was coming back to this question: “Do we have enough data on every bunching machine about it?” The control charts were used then to plot the data regarding every bunching machine in this specific diameter.

“The tool that best address variation between batches or subgroups is **individual control chart since** the control limits are determined by individual readings over a long period of time (between reels) as opposed to sub grouped readings taken during a short period of time (within reels).” (Relyea, 1990) It is likely that the measured resistance on a specific spool will be very similar, and it is reasonable to believe that there will be more variation in average resistance between the spools. However, this notion would be true when the measuring procedure is applied just on the beginning of each spool. Being closer to the end, the measured resistance would differ precisely. Nevertheless it is not worth it to run such an experience on each spool. This situation was handled by using the s chart in the ordinary way to measure variation in spool resistance. However, as this standard deviation is clearly too small to provide a valid basis for control of the process, we decided to treat the average resistance on each spool as an individual measurement and to control the average spool resistance by using a control chart for individuals with a moving-range chart.

Figure 4.2 represent total variation after Bunching process i.e. includes all of the bunching machines.

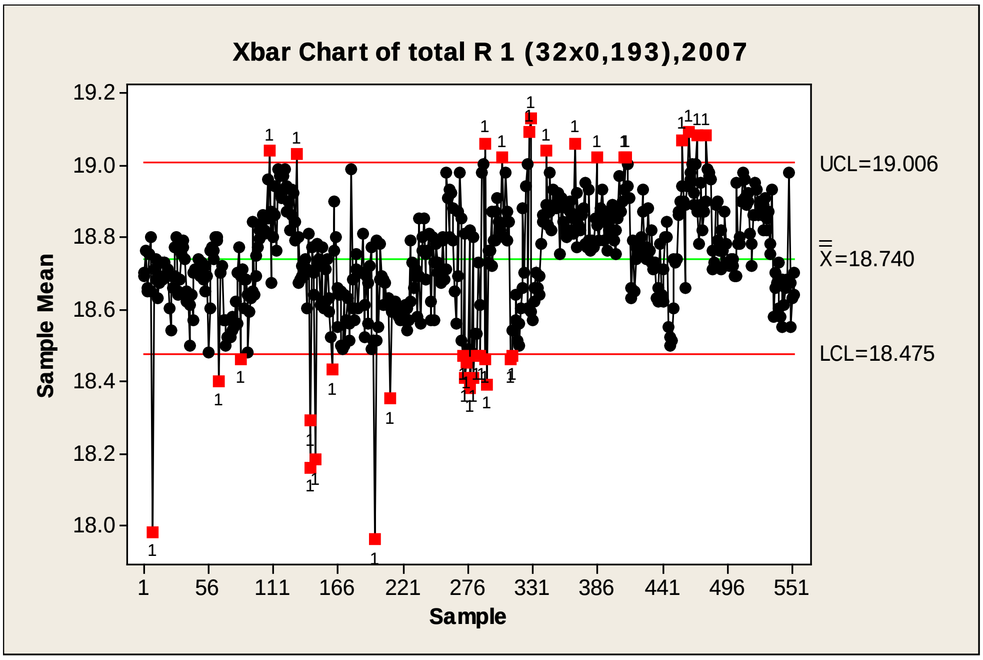
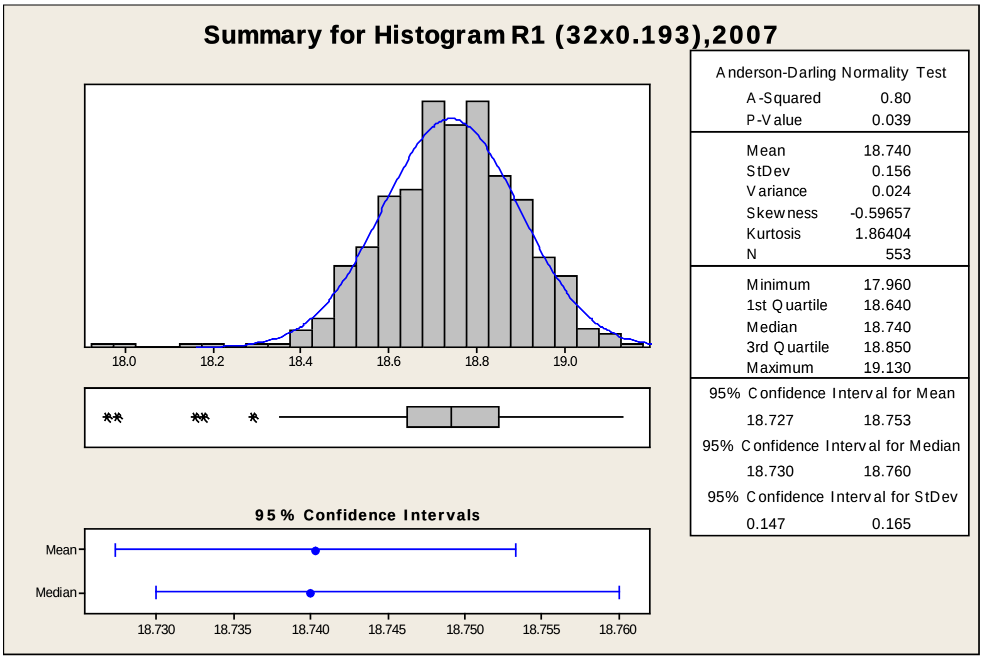


Figure 4.2 All Bunching Machines Control Chart (2007)



Anderson-Darling Normality Test	
A-Squared	0.80
P-Value	0.039
Mean	18.740
StDev	0.156
Variance	0.024
Skewness	-0.59657
Kurtosis	1.86404
N	553
Minimum	17.960
1st Quartile	18.640
Median	18.740
3rd Quartile	18.850
Maximum	19.130
95% Confidence Interval for Mean	
18.727	18.753
95% Confidence Interval for Median	
18.730	18.760
95% Confidence Interval for StDev	
0.147	0.165

Figure 4.3 All Bunching Machine Histogram (2007)

Rest of the figures represents the variation coming from every machine. Some other statistical details could be observed that will be used in analysis chapter.

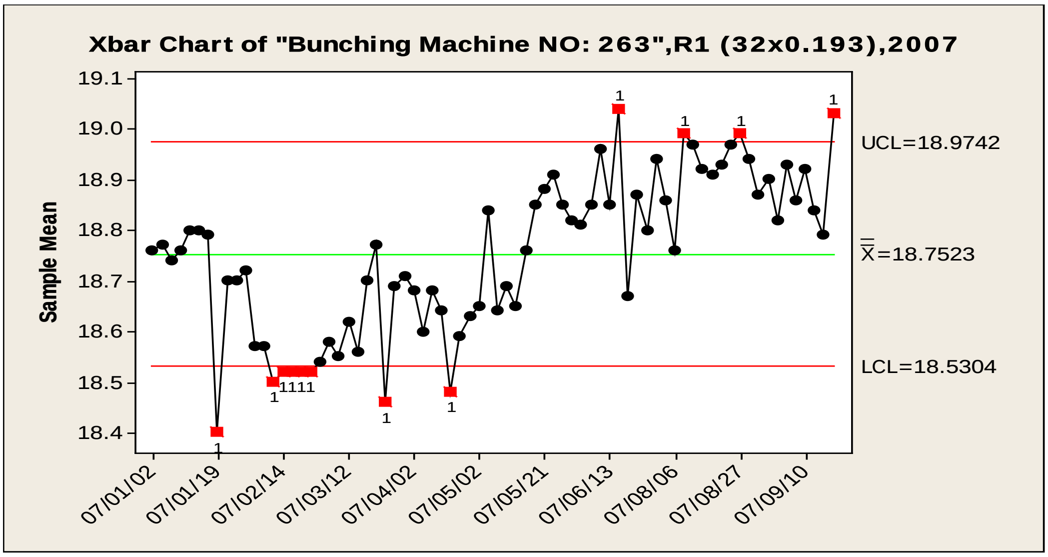
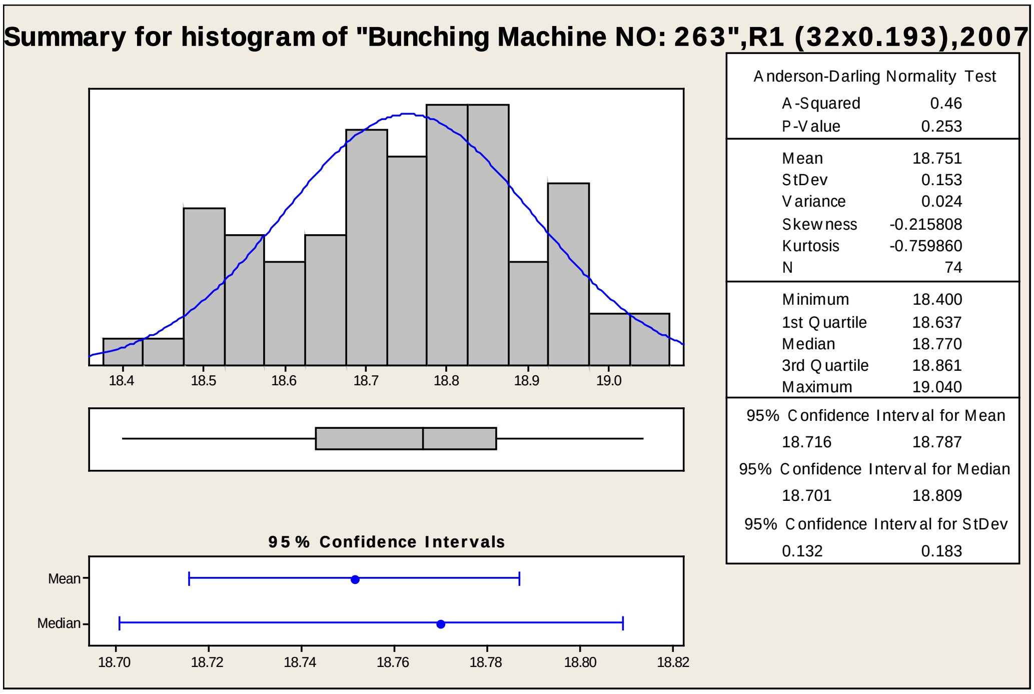


Figure 4.4 Bunching Machine No.263 Control Chart (2007)



Anderson-Darling Normality Test
A-Squared 0.46
P-Value 0.253

Mean	18.751
StDev	0.153
Variance	0.024
Skewness	-0.215808
Kurtosis	-0.759860
N	74
Minimum	18.400
1st Quartile	18.637
Median	18.770
3rd Quartile	18.861
Maximum	19.040

95% Confidence Interval for Mean
18.716 18.787

95% Confidence Interval for Median
18.701 18.809

95% Confidence Interval for StDev
0.132 0.183

Figure 4.5 Bunching Machine No.263 Histogram (2007)

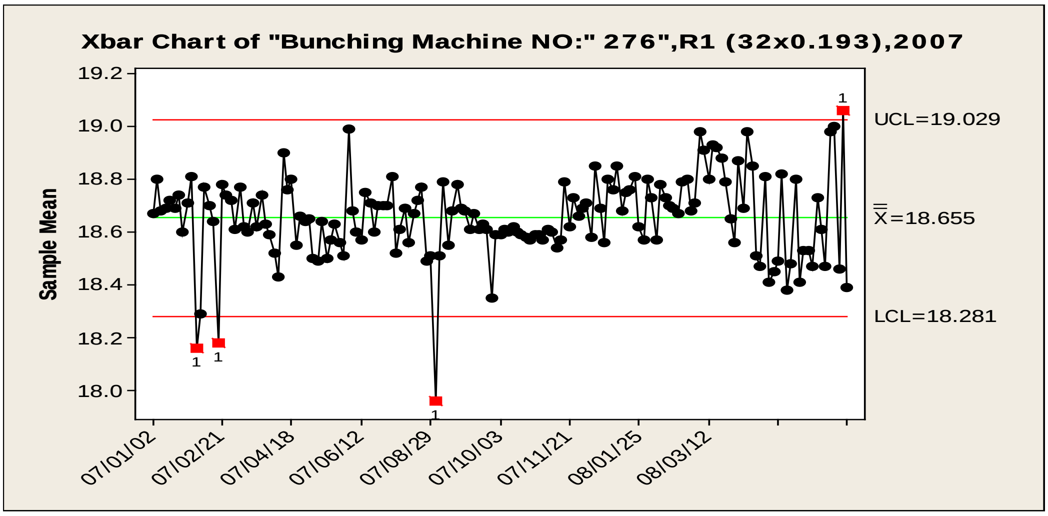
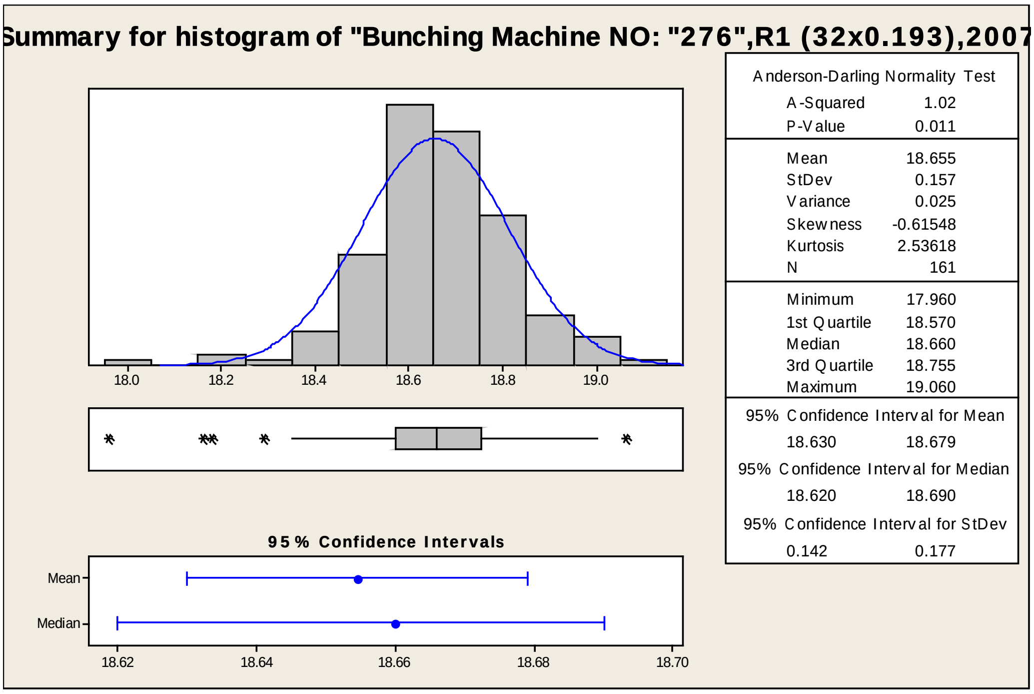


Figure 4.6 Bunching Machine No.276 Control Chart (2007)



Anderson-Darling Normality Test	
A-Squared	1.02
P-Value	0.011
Mean	18.655
StDev	0.157
Variance	0.025
Skewness	-0.61548
Kurtosis	2.53618
N	161
Minimum	17.960
1st Quartile	18.570
Median	18.660
3rd Quartile	18.755
Maximum	19.060
95% Confidence Interval for Mean	
18.630	18.679
95% Confidence Interval for Median	
18.620	18.690
95% Confidence Interval for StDev	
0.142	0.177

Figure 4.7 Bunching Machine No.276 Histogram (2007)

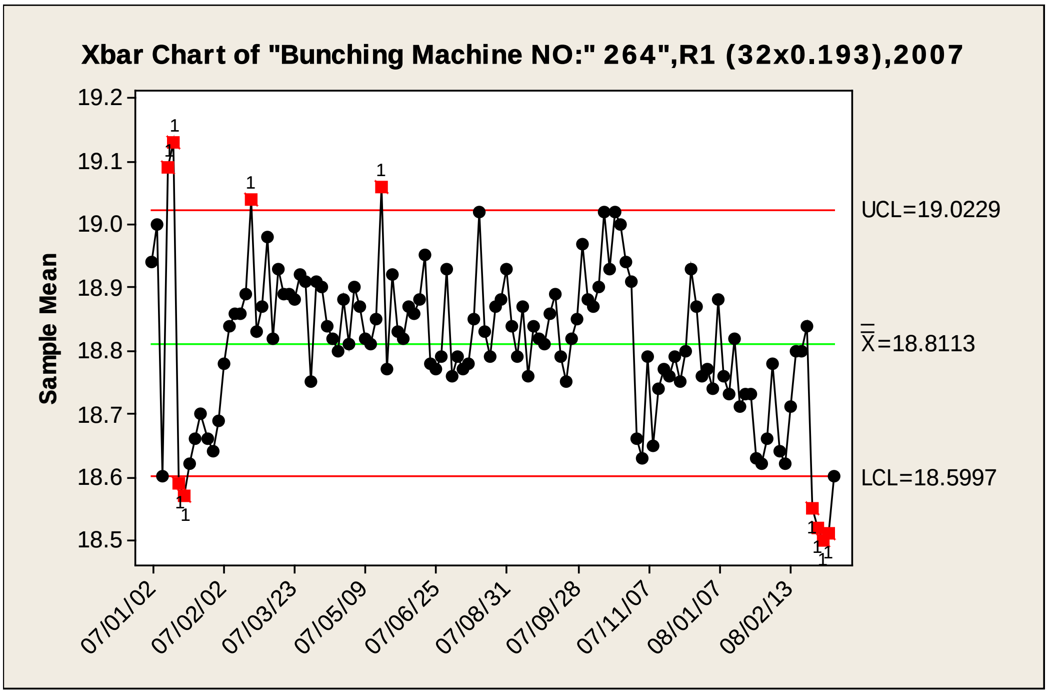
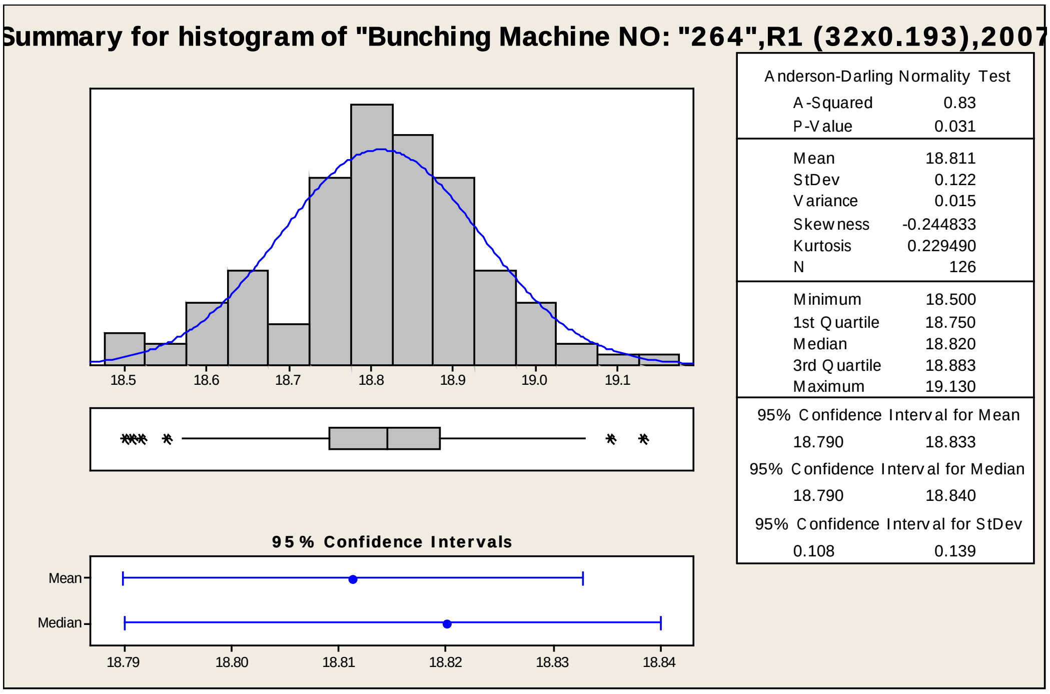


Figure 4.8 Bunching Machine No.264 Control Chart (2007)



Anderson-Darling Normality Test	
A-Squared	0.83
P-Value	0.031
Mean	18.811
StDev	0.122
Variance	0.015
Skewness	-0.244833
Kurtosis	0.229490
N	126
Minimum	18.500
1st Quartile	18.750
Median	18.820
3rd Quartile	18.883
Maximum	19.130
95% Confidence Interval for Mean	
18.790	18.833
95% Confidence Interval for Median	
18.790	18.840
95% Confidence Interval for StDev	
0.108	0.139

Figure 4.9 Bunching Machine No.264 Histogram (2007)

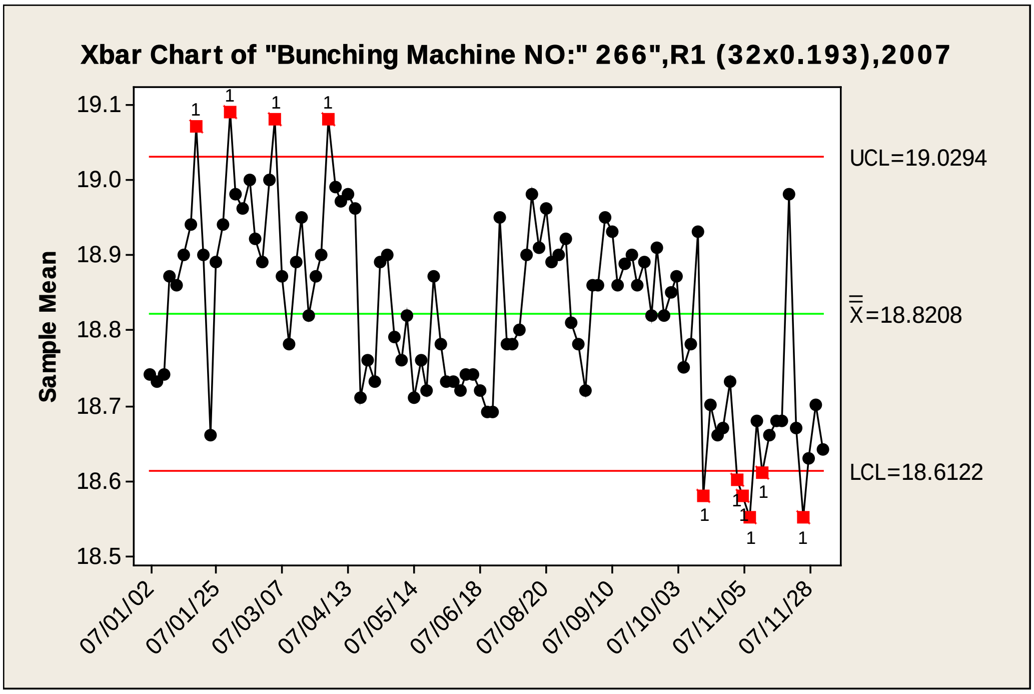


Figure 4.10 Bunching Machine No.266 Control Chart (2007)

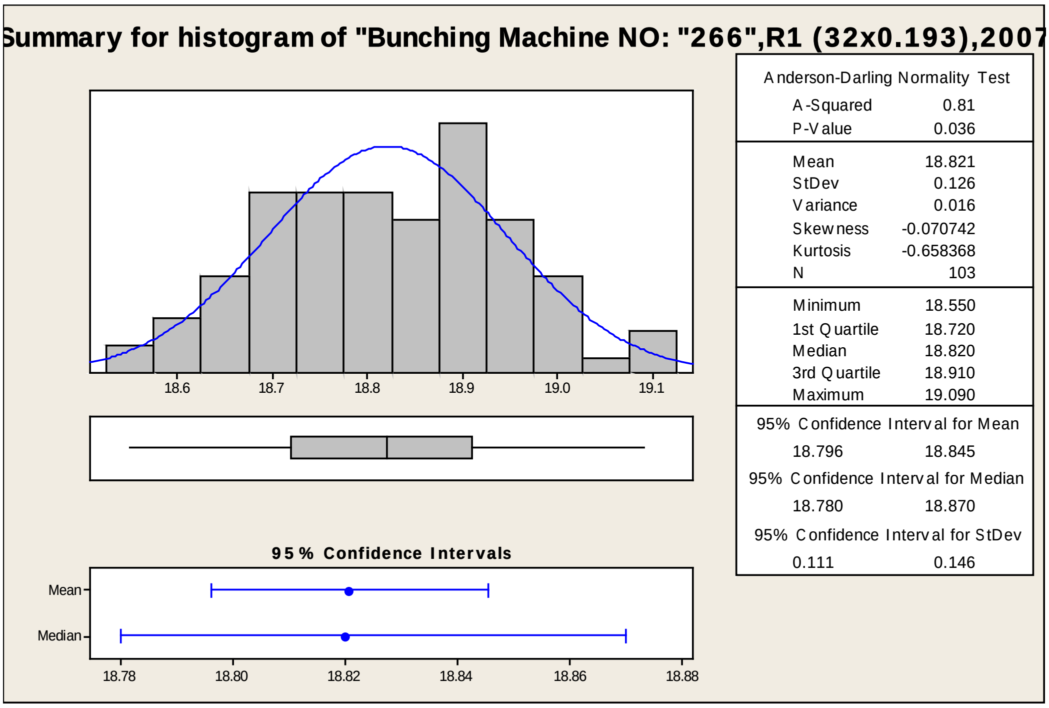


Figure 4.11 Bunching Machine No.266 Histogram (2007)

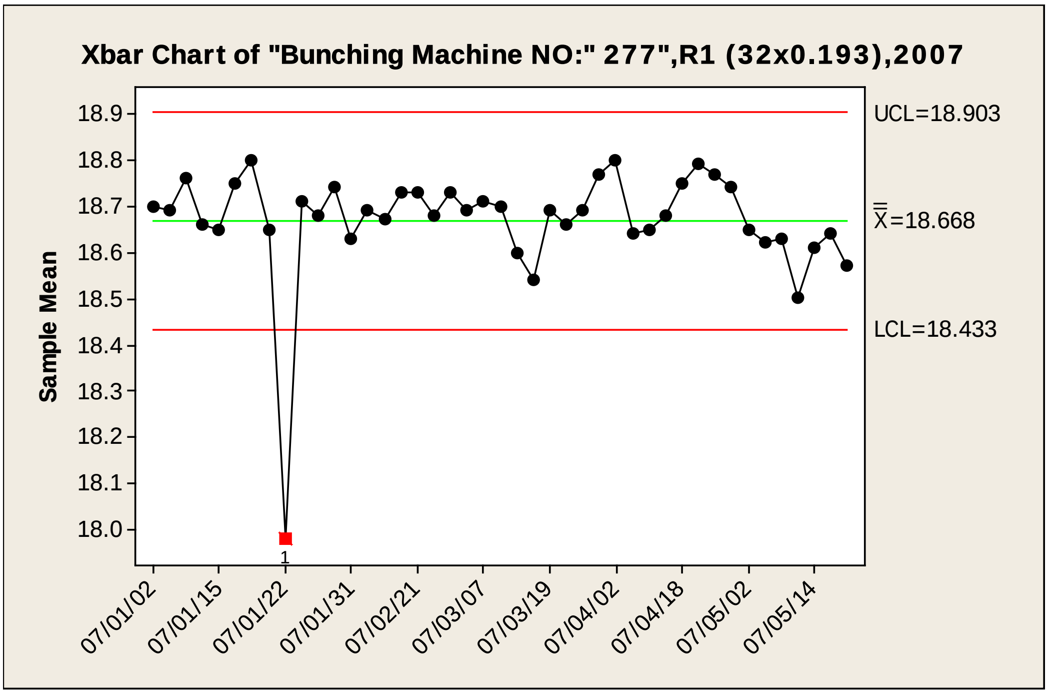
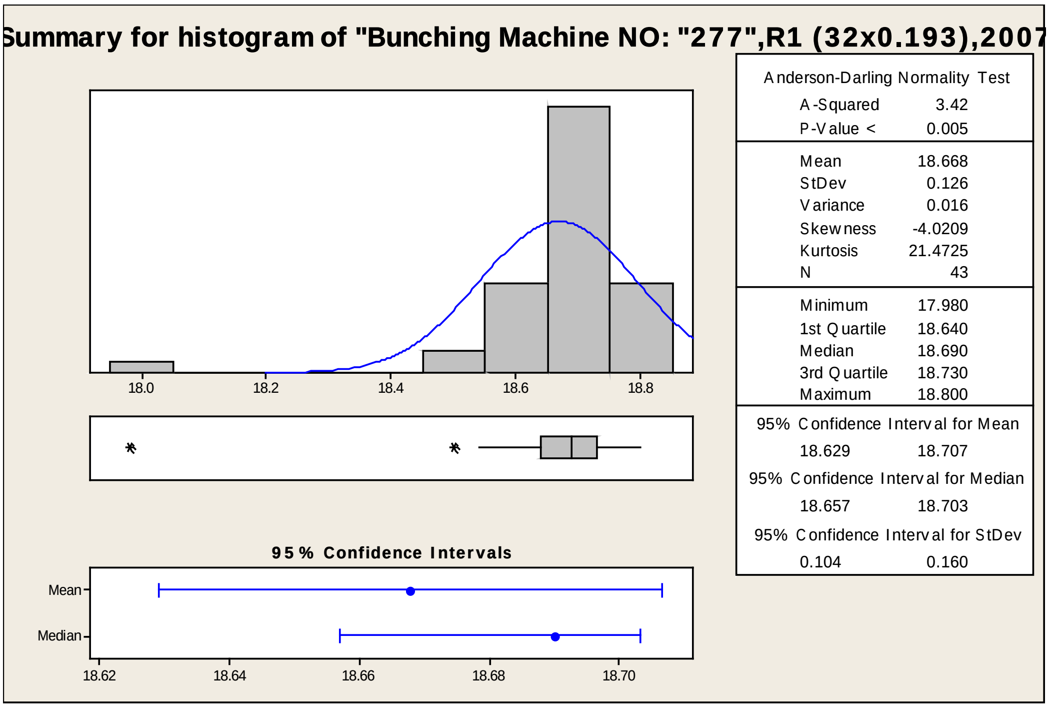


Figure 4.12 Bunching Machine No.277 Control Chart (2007)



Anderson-Darling Normality Test	
A-Squared	3.42
P-Value <	0.005
Mean	18.668
StDev	0.126
Variance	0.016
Skewness	-4.0209
Kurtosis	21.4725
N	43
Minimum	17.980
1st Quartile	18.640
Median	18.690
3rd Quartile	18.730
Maximum	18.800
95% Confidence Interval for Mean	
18.629	18.707
95% Confidence Interval for Median	
18.657	18.703
95% Confidence Interval for StDev	
0.104	0.160

Figure 4.13 Bunching Machine No.277 Histogram (2007)

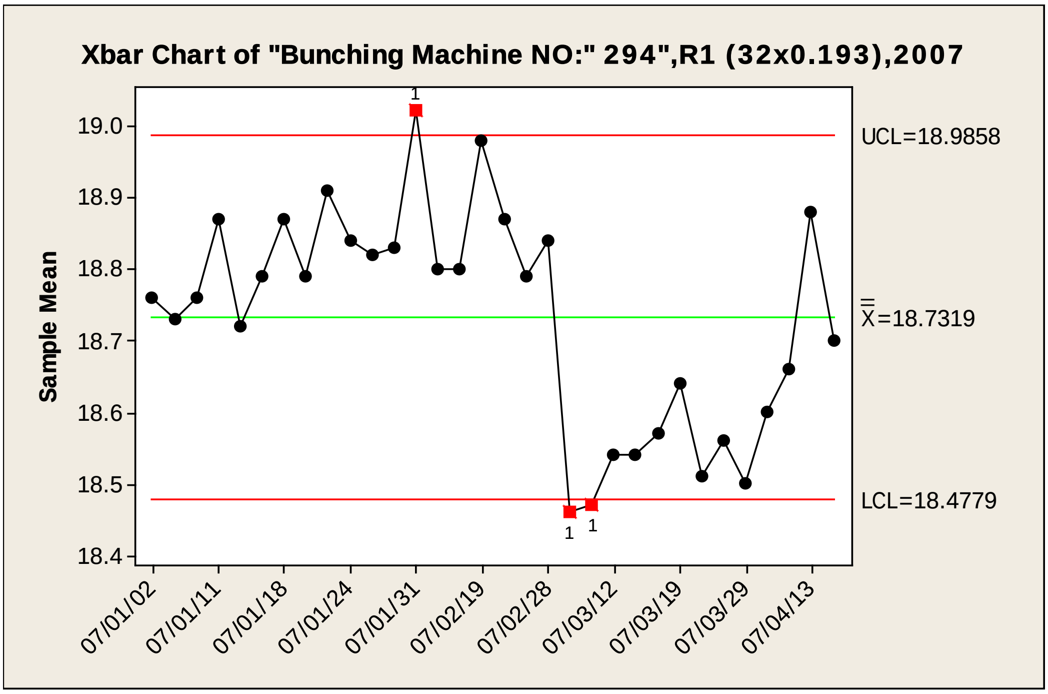
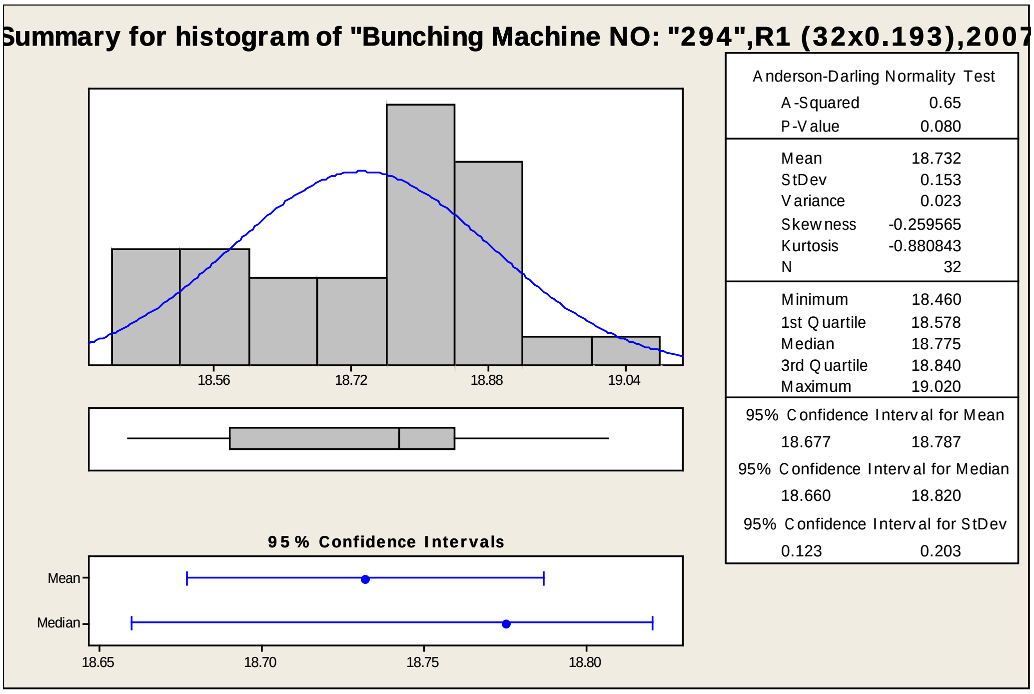


Figure 4.14 Bunching Machine No.294 Control Chart (2007)



Anderson-Darling Normality Test	
A-Squared	0.65
P-Value	0.080
Mean	18.732
StDev	0.153
Variance	0.023
Skewness	-0.259565
Kurtosis	-0.880843
N	32
Minimum	18.460
1st Quartile	18.578
Median	18.775
3rd Quartile	18.840
Maximum	19.020
95% Confidence Interval for Mean	
18.677	18.787
95% Confidence Interval for Median	
18.660	18.820
95% Confidence Interval for StDev	
0.123	0.203

Figure 4.15 Bunching Machine No.277 Histogram (2007)

As here could be seen, the result from the data relating to the year of 2007 are drawn. Comparing Standard Deviations of each bunching machine with the data coming from 2007 any noticeable difference between them could not be recognized (Table 5.1).

Machine No.	**263**	**276**	**264**	**266**	**277**	**294**
SDev	**0,153**	**0,157**	**0,122**	**0,126**	**0,126**	**0,153**

Table 4.1 Standard Deviations of different Bunching Machines (2007)

4.3.1.1 Experiments on Bunching Machine

Assuming a black box with the input of untwisted parallel wires and the output of twisted wire and studying any probable difference between them shows if there is any effect from bunching machine on the cable electrical resistance. The result coming out of experiments drawn in (Appendix B) shows the existent of such a difference between incoming and outgoing electrical resistance of wires resulting in the effectiveness of Bunching Machine on cable resistance. An example of such a comparison is brought here:

The wire coming out of bunching machine is an "*R1 (32x0, 193)* "type with the electrical resistance of *18.97* consisting of 4 bundles coming in to the bunching machine parallelly with the electrical resistances of: *73.2, 74.3, 74.6* and *73.2* Ohm. Using the appropriate formula having resistances in parallel we have: $1/\Omega = 1/73.2 + 1/74.3 + 1/74.6 + 1/73.2$ consequently Ω would be *18.4549* Ohm. Comparing incoming total resistance with the one coming out of machine a difference of 0.52 Ohm would be observed.

The result of experiments shows the increasing effect of Bunching Machine on the out-coming wire resistance. The positive effect of Bunching Machine makes the mind looking for the optimum setting to get the out-coming wire resistance closer to the specification limits. Comparing the different Bunching Machines and finding how effective they are on the electrical resistance is another step should be taken to get closer to the project's goal. Studying the mechanism of Bunching Machine two different ways of affecting on wire electrical resistance could be recognized:

1. *Twisting Effect*
2. *Elongation Effect*

The first effect is due to the winding bow twisting while the other one comes from the tension imposed by Bunching Machine on the wire. Rewording in mathematical formula the outcoming wire electrical resistance would be: $X=X1- Y + Z$ While: Having a look on the formula X could be found as a resultant of $X1$, Y and Z. While $X1$ represents the incoming wire to the Bunching Machine Y and Z are the factors caused by the machine, dependent respectively on twisting action and inherent tension of the machine. To optimize X it seems reasonable to increase Z and inversely decrease Y. Therefore, it is needed to focus on twisting and elongation procedures separately, find the reasons and try to calculate each of Y and Z. The big problem here was how to separate the effect of each of these two important factors when the total effect comes out as the sole wire resistance. To differentiate the effects of different factors mathematical way was the path getting through.

In this part our main four goals were to understand:

1. How can we increase the outcome resistance after the bunching?
2. Which bunching machine has the most positive effect on the resistance?
3. What is the optimum setting of bunching machine to get our preferred outcome resistance?
4. How can we set the optimum setting?

To achieve the first one as could be seen in the formula by increasing the Z the X also would be increased. Therefore, it needs to increase the effect of elongation in the bunching machine. This is possible just with the focus on the tension area. Due to reach our second target again it is necessary to find the Z for each machine separately and then to compare it with the other machines. Moreover, for the third and fourth one, optimum setting means finding the optimum situation of machine to have the optimum set of the tension among the several parts. Therefore, it is possible just by having the effect of tension and automatically elongation in every bunching machine. Consequently, before getting advance in this project it is really needed to find the effect of elongation during the twisting.

Calculation of the effect of twisting on the resistance:

Before analyzing it was thought the twisting should have the large impact to reduce the resistance in the conductors so it was needed to measure it if requested to deal with that in order to change its effect.

To calculate Y it is needed to calculate how much the effect of twisting on the length of special type of conductor is and what the total different of the length before and after twisting is. It should be mentioned that every type of conductor has the special lay-length *(t)* that it has the effect on the amount of deference in the length.

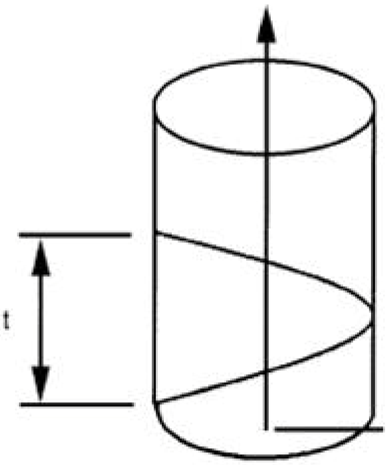


Figure 4.16 Spiral shape of wire (You-hua, 2000)

As shown in Figure 4.16 when the pitch of spiral is t and the pitch diameter is *D*, if spreading out the spiral, the spiral length *L* can be achieved from this equation to calculate the length of the wire :

$$l^2 = (\pi D)^2 + t^2.$$

Since dealing with unconcentrated conductor in this calculation after contraction of the twisted cable a minimal outer diameter of a cable could be achieved. From the hand book, the pitch diameter *D* of individual stage cable is:

$$D_1 = \frac{1.154^2}{2.154}\sqrt{N_1} \cdot d,$$

N1 is the number of twisted thread while *d* is the single thread diameter.

For example having 16 × 0.193 if pitch be *34* mm then *L* = *0.034033* m, it means that spreading out every *34* mm, in this type of the conductor, the total length will be *34.033* mm. So if spreading *1000* mm out then it will *be 1000 / 34 = 29.411,*

29.411 × 0.033 = 0.97056

So $1000 - 0.97056 = 999.029 = L2$

Where:

L1 is the length of the conductor before twisting, measured in meters

A1 is the cross-sectional area before twisting, measured in square meters

L2 is the length of the conductor after twisting, measured in meters

A2 is the cross-sectional area after twisting, measured in square meters

Since:

$$L2 \times A2 = L1 \times A1$$

So $A1 = 0.999\ A2$

Since:

$$\Omega 2 - \Omega 1 = \rho L/A2 - \rho L/A1$$

Then

$$\Omega 2 - \Omega 1 = -\ \rho L\ (0.001)\ /\ 0.999 \times A2 = (-\rho \times 1 \times 1)\ /\ (999 \times A2)$$

Since:

$$A2 = 1.5\ \text{mm}^2 \text{ and } \quad \rho\ (\text{copper}) = 1.72 \times 10^{-8}$$

Then

$$\Omega 2 - \Omega 1 = -\ 0.00001147 \sim 0.000$$

Because of being so small considering the measurement system accuracy the amount of *Y* could be assumed totally negligible and equal to zero in the formula $X=X1-Y+Z$.

As a result as it is evident from the theoretical point of view it is assumed that twisting does not have any impact on the final resistance so the *Y* factor in the formula could be eliminated. The new formula would be: $X=X1 + Z$, to prove this achievement in the practical way some experiments were designed. Due to get reliable results performing the Gauge R&R seems inevitable. (You-hua, 2000)

Experiment of the effect of twisting on the resistance:

To examine the correctness of the result of the theoretical calculation the empirical experiment was implemented. To run such an experiment 10 samples of 1.2 meter twisted wire were collected randomly from different spools of (*32×0.193)*. Every wire was installed on the measuring apparatus to achieve the magnitude of electrical resistance by each operator separately in 3 runs. The measurement results were recorded all together. The results are:

Operator A	18.673	18.677	18.714	18.762	18.682
	18.68	18.681	18.716	18.758	18.684
	18.676	18.68	18.715	18.764	18.688
Operator B	18.67	18.683	18.707	18.774	18.683
	18.672	18.679	18.707	18.767	18.682
	18.67	18.677	18.713	18.77	18.681

Table 4.2 Parallelize Experiment

Untwisting each wire turning to 16 single wires was done afterwards. The appropriate electrical resistance of every bunch of parallel wires was measured by every operator thereafter. The results are:

Operator A	18.706	18.698	18.826	18.791	18.762
	18.685	18.694	18.819	18.784	18.71
	18.712	18.705	18.778	18.782	18.705
Operator B	18.705	18.685	18.733	18.754	18.646
	18.678	18.668	18.705	18.754	18.682
	18.661	18.662	18.703	18.763	18.689

Table 4.3 Untwisting Experiment

Measuring of the elongation in every Bunching machine

The result can show us that which machine can have the most effect on the resistance and which machine has the less effect on it that could be a guide to the machines needed to be focused on. After finding the effect of twisting in the process of bunching is ignorable, it just can be deal with the effect of tension on the elongation in bunching machines.

With regards to find that which machine has the most effect on the elongation and which one has the less, having the output resistance and the input resistance of the wire seems necessary. Therefore, the effect of elongation on the resistance in every machine could be extracted, and by comparing the effects in each machine the point that which machine has the positive effect on total resistance and which one has the negative effect could be perceived. But the most important problem in this phase was the lack of information about the input of each bunching machine, therefore; by comparing the output resistance of every machine, it could not be decided how much the effect of elongation on the resistance inside each machine is. Therefore, as an experiment, it was decided to prepare the input resistance of every machine.

The problem was the need to having enough data due to get the accurate result from the analysis. However, preparing enough data about the input resistance was really time consuming and a few samples just were taken that may conclude an inaccurate result! The data being prepared by the operators in two weeks could be found in Appendix B

- *Analyzing the data :*

Since $X=X1 +Z$ and X is available, and $X1$ could be achieved by calculation finally Z that is the effect of elongation on the output resistance could be found. To calculate $X1$, because of having a parallel wire, it is needed to use this formula: $1/X1 = 1/R1 + 1/R2 + \dots + 1/Rn$ that $R1 \dots Rn$ stands for the resistance of the input spool. The first bunching machine is machine number 277 (Appendix B). For the 8 × 0.193, R= 0.75 conductor, the resistance of the input spool consecutively is : *74.61 , 74,65 , 74,70* so after the calculation $X1$ is *24.90* and the output resistances respectively are : *24.98 ,25.11, 25.04* , so by subtracting these numbers from the $X1$ the result would be:

0.0, 0.21, 0.14

It is then the effect of elongation on the resistance in machine 277 in every output spool that comes out after the bunching 3 spool together!

As a conclusion, the average of each machine could be compared to each other, also the error of measurement system should be considered that it can be found in detail in Gauge R&R part that is 0.027749.

As a result, machine no 277 and 264 elongate the conductor more than machine 273 and it is needed to find one solution to make the balance.

4.3.2 Drawing Machine

Drawing machine is another important part of the whole process. Different plots have been drawn out of the data bank collected during recent years. Here, one sample out of many is shown in order to study nearly the same patterns of all of them. The resistance of every strand coming out of annealing machine with the specification limit of 75 ohm since 01-01-2006 until 01-04-2008 has been collected from the company data bank and plotted in a unique control chart.

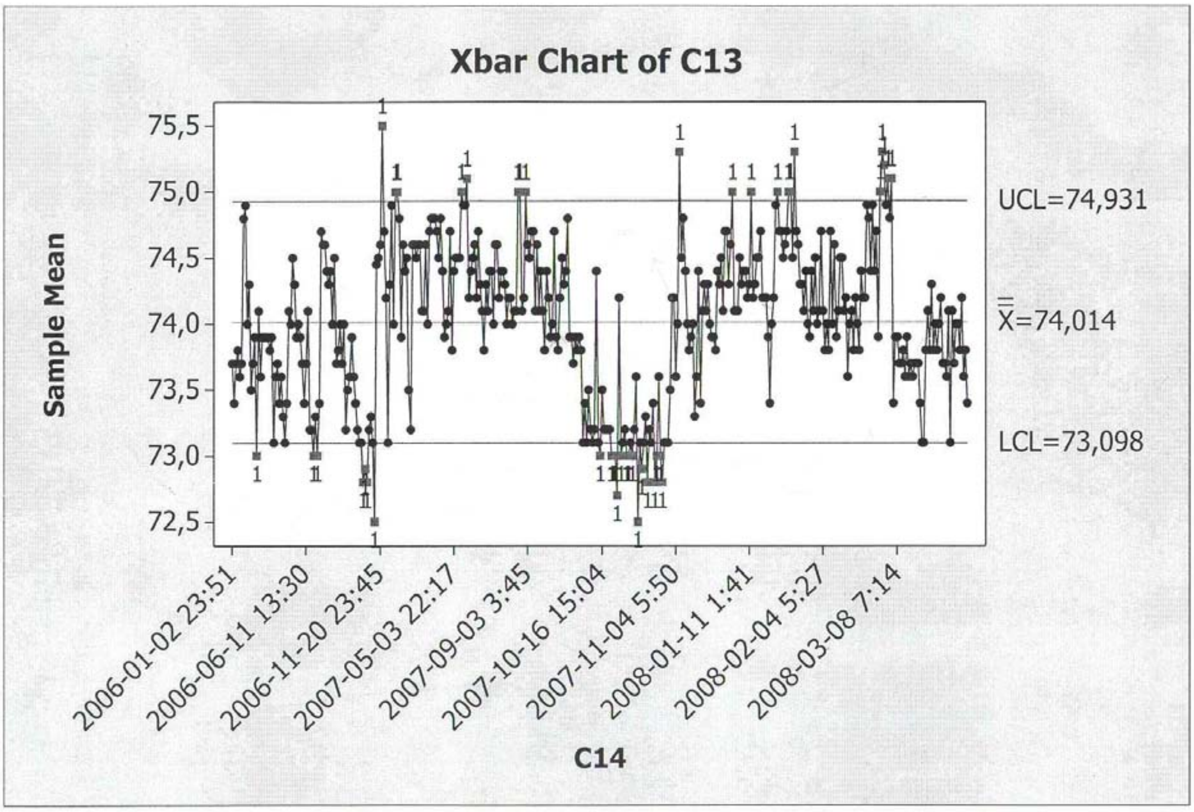


Figure 4.17 Drawing Machine Control Chart (2006-2008)

While UCL is 74.931 that is so close but lower than USL many points could be found out of it. The differences observed in the drawing machine in different intervals being resulted from some sources of variations like dices, raw materials and operators.

Different means in different intervals show the dependability of the products to the main factor of time. In this example the diagram could be divided to 5 distinct diagrams according to different durations that all of them except the last one are discussed in detail in chapter 5. It was decided not to deal with the last part here because of not knowing what has happened then after.

4.4 Gage R&R

As seeing before, while calculating the resistances due to elongation in the bunchers and also calculating the variation between the output resistances and totally in whole process it is really needed to find how much of this variation is due to the measurement system and how much the measurement system is reliable. Therefore, it is necessary to find that if the variability of a measurement system is small comparing with the manufacturing process variability, and also if the measurement system is stable over time. Finally, it is important to know how much the output resistance is accurate and how much the range of its change is meaning in the reliability of analyses and results. Answering these questions it is needed to use Gage R&R.

Data collection

Five spools were randomly sampled across all major sources of process variation (machine, time, and shift, job change) to be representative of those typically produced. The spools were coded to identify to identify measurements from specific spools.

The first operator measured each of the 5 spools in random order. Then, the 5 spools were randomized again and given to the second operator for measurement. This process was repeated three times for each operator, for a total of 30 measurements. (Appendix C)

Interpreting our result

The result coming from analyzing is in below. The analysis of variance (ANOVA) was used to calculate variance components:

GAGE R&R STUDY WORKSHEET

PARTS: 5 OPERATORS: 2
REPLICATES: 3 TOTAL RUNS: 30

GAGE R&R STUDY - ANOVA METHOD

TWO-WAY ANOVA TABLE WITH INTERACTION

SOURCE	DF	SS	MS	F	P
PARTS	4	0,0337525	0,0084381	*	*
OPERATORS	1	0,0000000	0,0000000	*	*
PARTS * OPERATORS	4	0,0000000	0,0000000	0	1,000
REPEATABILITY	20	0,0005133	0,0000257		

Estimate the percent variation due to the measuring system. The percent variation appears in the Gage R&R table. The two-way ANOVA table includes terms for the part operator (Operator), and operator-by-part interaction (Spool*Operator).

SOURCE	VARCOMP	%CONTRIBUTION (OF VARCOMP)
TOTAL GAGE R&R	0,0000214	1,50
REPEATABILITY	0,0000214	1,50
REPRODUCIBILITY	0,0000000	0,00
OPERATORS	0,0000000	0,00
PART-TO-PART	0,0014028	98,50
TOTAL VARIATION	0,0014242	100,00

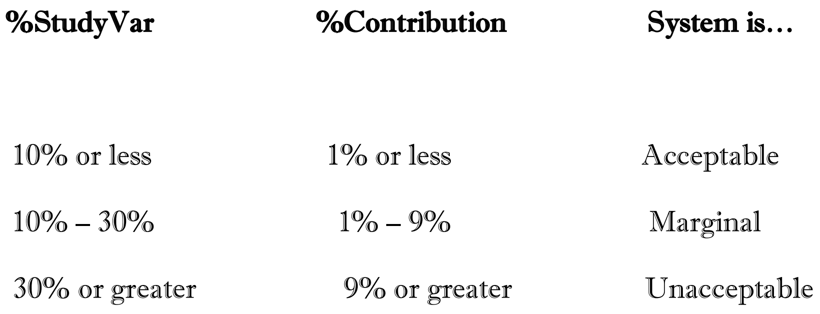
98.5% of the total variation in the measurements is due to the differences between parts. This is considered very well. When %Contribution for Part-to-Part is high, the system is able to distinguish between parts.

Also the Gage R&R could be seen graphically that includes: Components of variation, R chart by operators, X bar chart by operators, in (Appendix D)

- *Percent study variation*

Using %StudyVar when interested in comparing the measurement system variation to the total variation is always recommended. Therefore, according to the AIAG guidelines for the gage R&R here it follows as:

SOURCE	STDDEV (SD)	STUDY VAR (6 * SD)	%STUDY VAR (%SV)
TOTAL GAGE R&R	0,0046248	0,027749	12,25
REPEATABILITY	0,0046248	0,027749	12,25
REPRODUCIBILITY	0,0000000	0,000000	0,00
OPERATORS	0,0000000	0,000000	0,00
PART-TO-PART	0,0374538	0,224723	99,25
TOTAL VARIATION	0,0377383	0,226430	100,00



%StudyVar	**%Contribution**	**System is…**
10% or less	1% or less	Acceptable
10% – 30%	1% – 9%	Marginal
30% or greater	9% or greater	Unacceptable

Source: page 77 of [1].

As %StudyVar for gage R&R is 12.25 and since %contribution is 1.50 then totally it shows that the system is **Marginal.** So dealing with the final resistances the amount of +-**0.0277749** ohm error in calculation should be considered.

5 General Discussion and Conclusions

In this chapter the empirical findings and conclusions concerning the purpose and objectives of the thesis are presented. Lastly, conclusions from the whole thesis are drawn, and suggestions are given for further study.

5.1 Analysis of the bunching machines

Comparing the Standard Deviations

More objective comparison between the bunching machines can be achieved by understanding the amount of standard deviation within each machine. Table 4.1 represents the Standard deviation in each bunching machine during one year (2007).

As much as doing investigation on the data no strong reason that can prove which bunching machine makes more variation than the others could be figure out. By taking into consideration the numbers of data in each table the consistent behavior of standard deviation between each bunching machine could not be obtained.

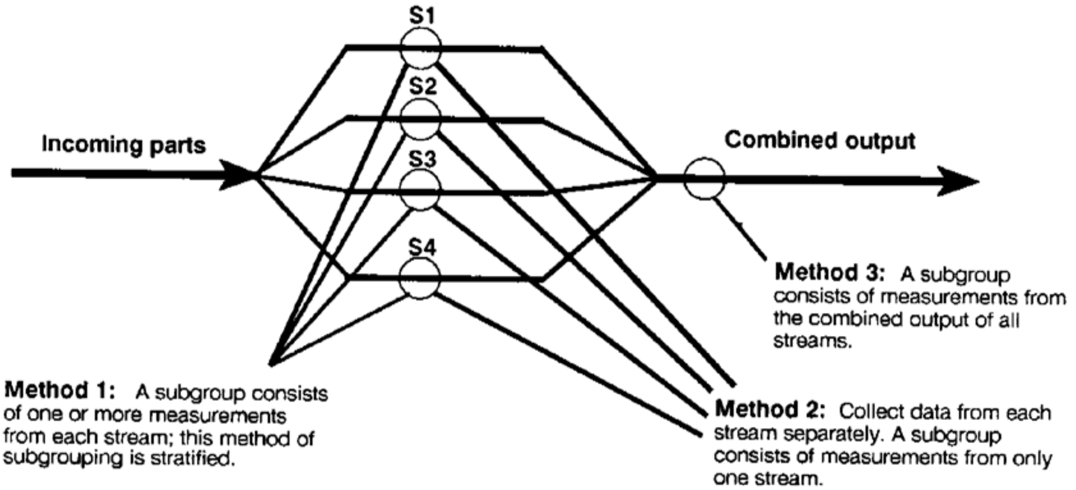


Figure 5.1 Methods to collect data from the output of a multiple stream production process (Brown, Lowe, & Benham, 1995)

According to the production process, the data collection is from the output of a multiple stream production process (Figure 5.1). As an illustration, a production process consists of four parallel operations. It is suggested that variation in process output should be studied with control charts, so a decision needs to be made on how to collect the data for the charts. The data here is coming out by measurement on the outputs of all streams together regardless the appropriate sources.

As a general rule, in this method of collecting data, variation that is represented within subgroups should be the kind of variation believing to be the least significant or the least interesting as a subject of current study. In all cases, a method of subgrouping should be used that will allow questions about the effects of potential sources of variation to be answered. Moreover, as the complementation it was observed that twisting does not have so much effect on the final resistance.

As a result of this method, comparison of the standard deviations will not indicate which bunching machine has more contribution to produce the variation on the last yield than the others.

Process control and process capability

Using the control chart to understand and reduce product variation is one form of process control. Manufacturing can be separated into two really general categories: the manufacturing of individual or discrete items and the manufacturing of continues or homogenous product such as wire and cable. Thus, as it is clear in the charts, the tools addressing best the variations between the resistances of the output spools are referred to as the individual control chart. In fact, control limits are determined by individual readings over a long period of time (between spools) as opposed to sub grouped readings taken during a short period of time (within spools).“The process must first be brought into statistical control by detecting and acting upon special causes of variation. Then its performance is predictable, and its capability to meet customer expectation can be assessed. This is a basis for continual improvement.” (Brown, Lowe, & Benham, 1995) Every process is subject to classification based on capability and control. A process can be classified into 1 of 4 cases, as illustrated by the following chart:

	Control	
Meeting Requirements	In Control	Not In Control
Acceptable	Case 1	Case 3
Not Acceptable	Case 2	Case 4

Table 5.1Classsificatio of the Processes (Brown, Lowe, & Benham, 1995)

It is obvious that the charts shown in figure 4.4 … 4.15 all at least have one value falling outside the upper or lower control limits that are correspond to the ± 3 sigma limits.”Because moving ranges are involved, the points being plotted on the range chart are correlated. Therefore, valid signals occur only in the form of points beyond the control limits.” (Brown, Lowe, & Benham, 1995)Consequently, the bunching process would be a case 3 process. A case 3 process meets tolerance requirements but is not in statistical control. Special causes of variation should be identified and acted upon.

According to the control charts in figure 4.4 … 4.15 there is little value in making predictions based on data collected from a process that is not stable and not repeatable over time. Special causes are responsible for changes in the shape, spread or location of a process distribution and thus can rapidly invalidate prediction about the process.” That is, in order for the various process indices and ratio to be used as predictive tools, the requirement is that the data used to calculate them are gathered from processes that are in a state of statistical control” (Brown, Lowe, & Benham, 1995)

Common and special causes

The occurrence of a pattern or trend can be a proof of the influence of a special cause during the time of that pattern or trend. This could give the first caution of an unfavorable condition during the bunching process which should be corrected. On the other hand, comparison of patterns between the range and average charts can give added insight. This could be more effective if we compare the charts for several different diameters those come from a certain bunching machine. In addition to the presence of points beyond control limits or long runs, other distinct patterns may appear in the data that give clues to special cause. Care should be taken not to over-interpret the data, since even random data i.e. common causes can sometimes give the illusion of nonrandomness i.e. special causes. (Brown, Lowe, & Benham, 1995)

Misunderstanding of variation

Dr. W.E Deming identifies two mistakes frequently made in process control: Mistake1. Ascribe a variation or a mistake to a special cause, when in fact the cause belongs to the system (common causes). Mistake2. Ascribe a variation or a mistake to a system (common causes), when in fact the cause was special. Over adjustment is a common example of mistake NO .1. Never doing anything to try to find a special cause is a common example of mistake NO 2. (Brown, Lowe, & Benham, 1995)

While it is wise to investigate all signals as possible evidence of special causes, it should be recognized that they may have been caused by the system and there may be no underlying local process problem. If no clear evidence of a special cause is found, any “corrective” action will probably serve to increase, rather than decrease, the total variability in the process output. (Brown, Lowe, & Benham, 1995)

5.2 Analysis of the drawing machine

According to Figure 4.17, the aforementioned diagram in chapter 4 could be split into 4 separate single charts.

The first one belongs to the days between 02-02-2006 and 23-10-2006. The mean is equal to 73.695 while UCL is equal to 74.553.Having about 5 points out of upper control limit and the descending pattern of about 29 successive points indicates the existence of assignable causes.

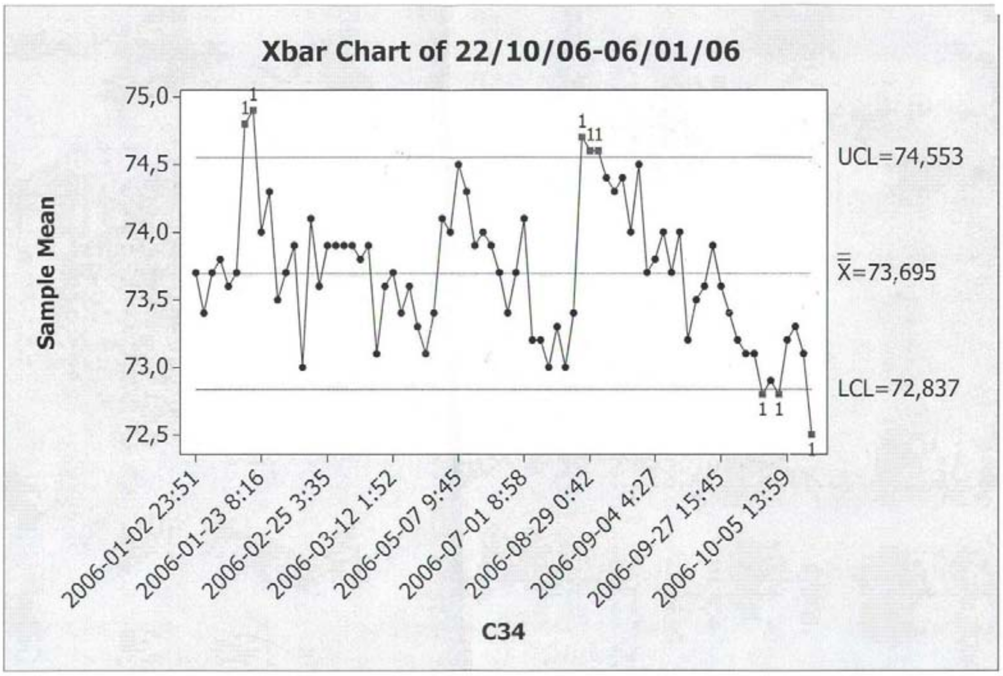


Figure 5.2 The Drawing Machine Control Chart (02/02/06-23/10/06)

The second one consists of samples taken between 23-10-2006 and 08-10-2007. The mean is equal to 74.355 that sounds reasonable while UCL is equal to 75.279. The capability is under question since UCL is above USL equal to 75.

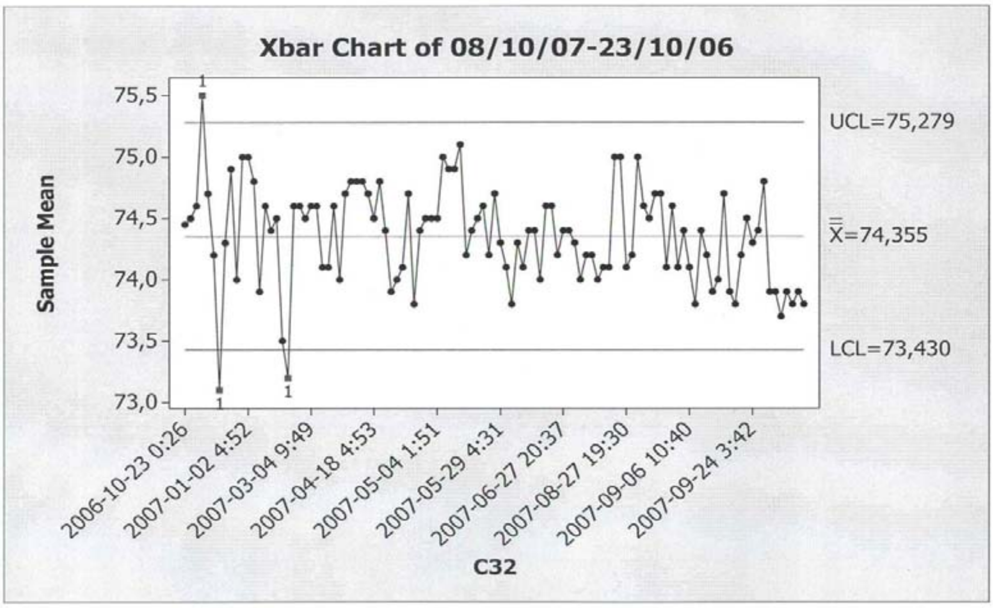


Figure 5.3 The Drawing Machine Control Chart (23/10/06-08/10/07)

The third one belongs to the time between 08-10-2007 and 02-11-2007.The average is about 73.168 and UCL is equal to 74.082 that is far behind of 75 representing USL

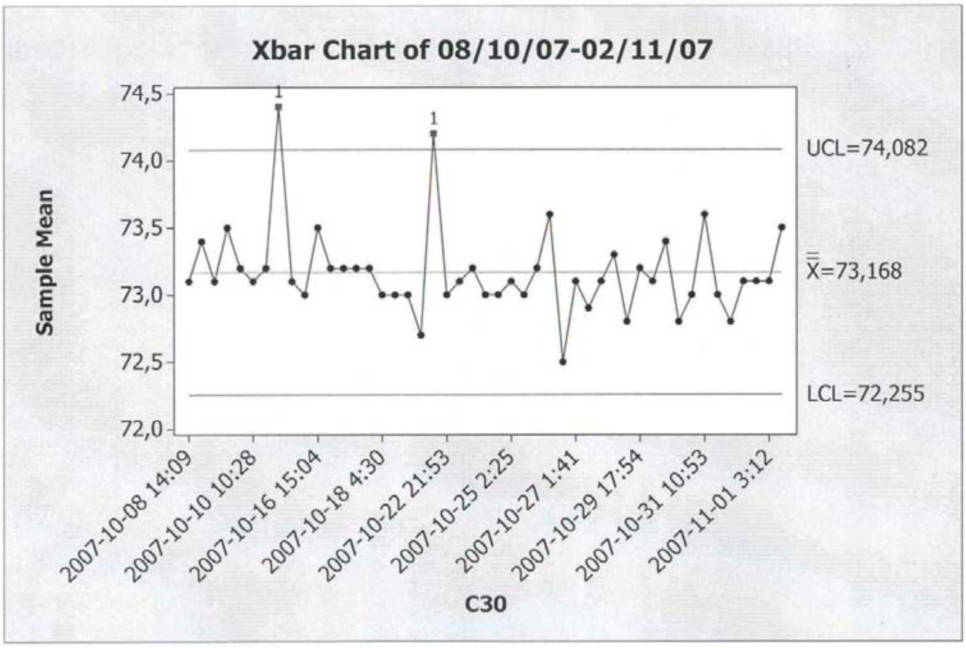


Figure 5.4 The Drawing Machine Control Chart (08/10/07-02/11/07)

The fourth diagram includes the days between 03-11-2007 and 03-03-2008. The average is 74.334 while UCL equal to 75.249 is above the determined USL. Therefore, the capability is questionable. Different descending and ascending pattern of successive points and some points out of limit show the probability of existence of assignable causes

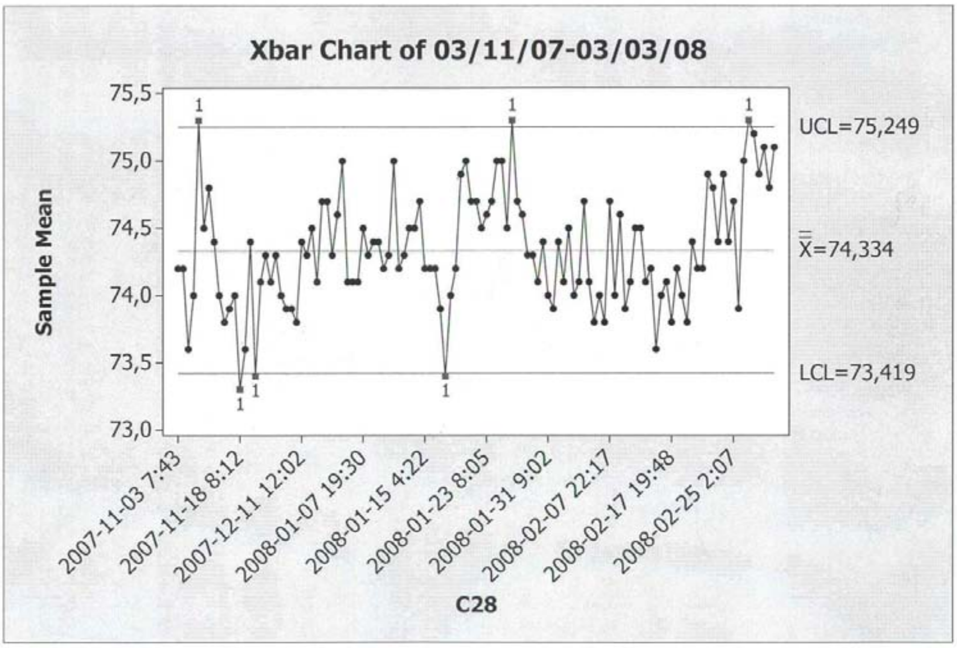


Figure 5.5 The Drawing Machine Control Chart (03/11/07-03/03/08)

These differences in the means and not having capability in all the diagrams show the existence of assignable causes. Through many probable causes, **Suppliers** factor, **Dies** factor and **Measurement** factor were the ones coming out as the most efficient causes after the team consensus. To define the effectiveness of every factor it is needed to control each of them and run DOE experiment. Because of the lack of tracing in order to find the appropriate supplier of each outcome of annealing machine the available data is not enough to run such an experiment.

Based on the discussion and analysis above, final conclusion can be drawn to summarize the critical issues and major keys to improve the cable manufacturing process and increase average of the final resistance in *Nexans IKO Sweden*.

5.3 Conclusion

- In order to increase the average of the final resistance finding which one of the bunching machines makes more variation than the others should be undertaken. Therefore, tracking of output data is suggested that means measuring the resistance of spools coming in to the bunching machine as inputs.

- Unfortunately it is not possible to use exact formulas for the calculation of the tension levels and then of the elongation - reduction of weights and increase of resistance. As a matter of fact the strain/stress ratio for the copper wires is not linear and functions of the annealing degree. Furthermore, too many tests should be carried out to get valid parameters for general formulas. It is then necessary to run some tests on existing machines by testing all the parameters one by one and employ DOE method, in order to the optimization of the bunching process.

- For the purpose of reducing the variation within the bunching process, the special causes of variation must be addressed. When reaching a state of statistical control, the process´ current level of long-term capability can be assessed. The resolution of a special cause of variation usually requires local action, i.e., by the operators. This is especially true during the early process improvement efforts. Desirable change also should be understood and institutionalized during the bunching process. Construction and use of control charts and other tools will allow for efficient monitoring of the process. When the tool signals that the process has changed, quick and efficient measures can be taken to isolate the causes and act upon them. After all special causes have been addressed and the process is running in statistical control. The continuous control chart can employ as a monitoring tool. As one succeeds in taking the proper action on special causes, those that remain will often require management action rather than local action. Once special causes are properly identified, the control chart can be reassigned from the task of monitoring and controlling the product parameter to monitoring and controlling the process parameter.

- Recording the data of each incoming barrel and following it up to having bundles on the spools is a necessity should be considered as a preliminary step. The outcome could be used to run DOE experiment resulting in finding the effectiveness of each factor. An example could be finding the differences between different suppliers. Reducing the sources of variation coming from suppliers could be made by showing them what is expected and what changes are needed. Changing the suppliers and dealing with new ones could be effective at the end.

- Running Gauge of R&R can help us to find the error of every measuring apparatus and every operator. The conclusion may result in changing or calibration of each measuring apparatus or training of operators.

- During the manufacturing process the sampling result might be between the control limits, but as it is just one sample among many probable ones that could have been taken, the probability rules tell not to look at the process with one hundred percent confidence as a stable process. As an example, taking one sample between 1.44 standard deviations, the operator could be 68% confident that the process average is within 1.44 standard deviations but no adjustment is recommended here as the degree of confidence is reliable. On the other hand, when this sample is out of this range the adjustment should be taken. Such a method could be undertaken using the average of sampling depending on the number of samples. (Appendix E)

As a final word a there is a clear path to becoming competitive for any wire and cable company that truly wants to be competitive. Specifically

Management must make a commitment to understanding and reducing all process variation as much as possible.

Management must make a commitment to provide only capable processes to the local work force, and to provide them with the tools and training to recognize when stability does not exist.

Management must allow the local work force the time to understand process variation and make corrections, when necessary, in order to restore stability-not to just make adjustments to compensate for the lack of stability.

The local work force must accept the responsibility for learning to use the tools that are provided by management, and conscientiously apply those tools to maintain stability.

The local work force must be willing to accept full responsibility for the quality of the product; the days of relying upon a roving inspector are over.
(Relyea, 1990)

A concerted effort by management and the local work force to fully understand and reduce variation, and to use statistical process control to learn as much about the process as possible, can make the Swedish wire and cable company as competitive as their counterparts.

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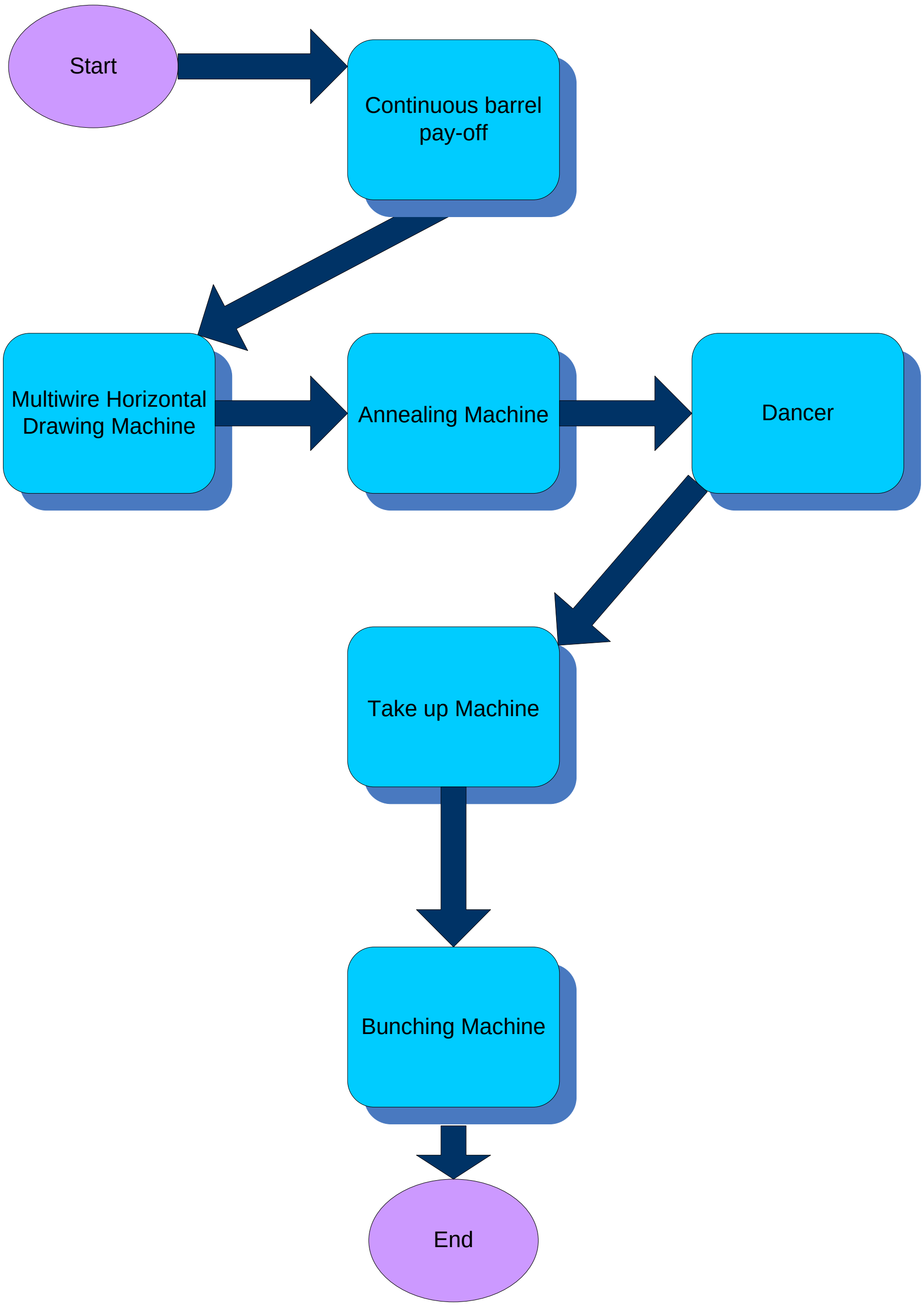
Appendices

Appendix A: Cable Process Map

Cable Process Map



-Continuous barrel Pay-Off

-Continuous operation through welding of wire end to wire start

-Drawing Machine

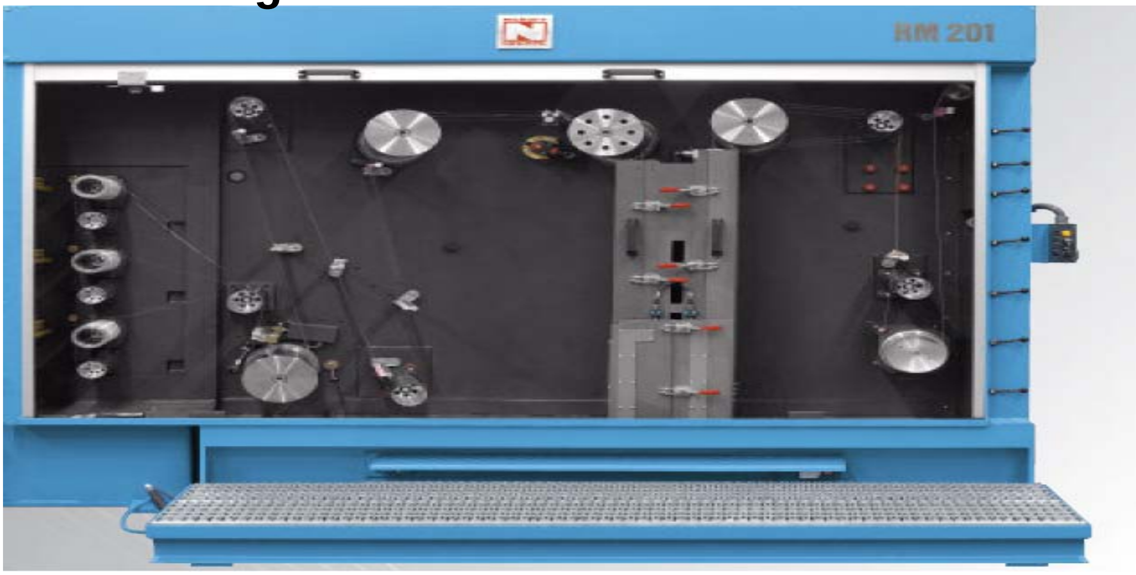
-Decreasing the diameter of strands by passing through different dices successively

-Decreasing the temperature of strands and dices by spraying the emulsion of oil and water via drag bath system

-Having guiding rollers with a higher speed than strand speed.

-Using different gears and motor in order to rotate the rollers

-Annealing Machine

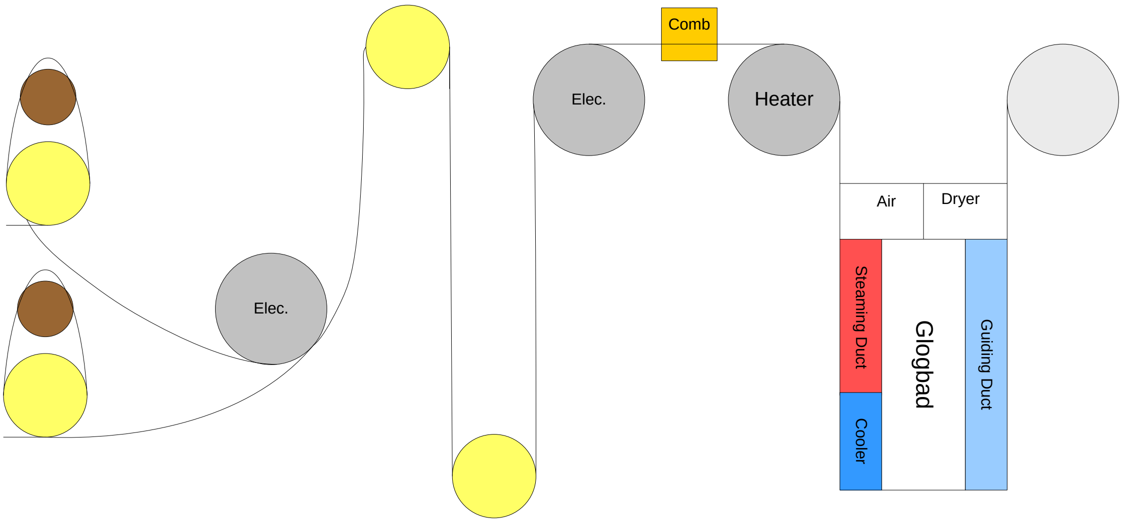


-Increasing wire flexibility by lubricating and heating

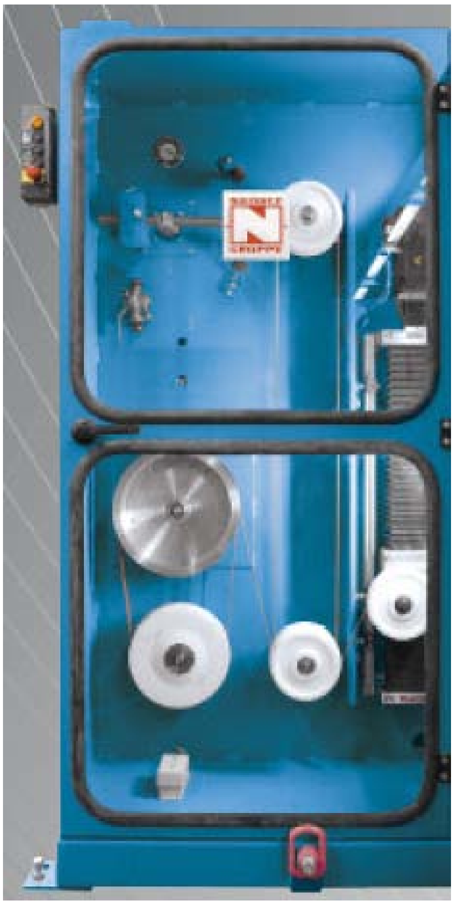
-Leading up to the subsequent dancer

-Manually adjustable heating system by changing the amount of imposed electricity

-Complete drying of strand

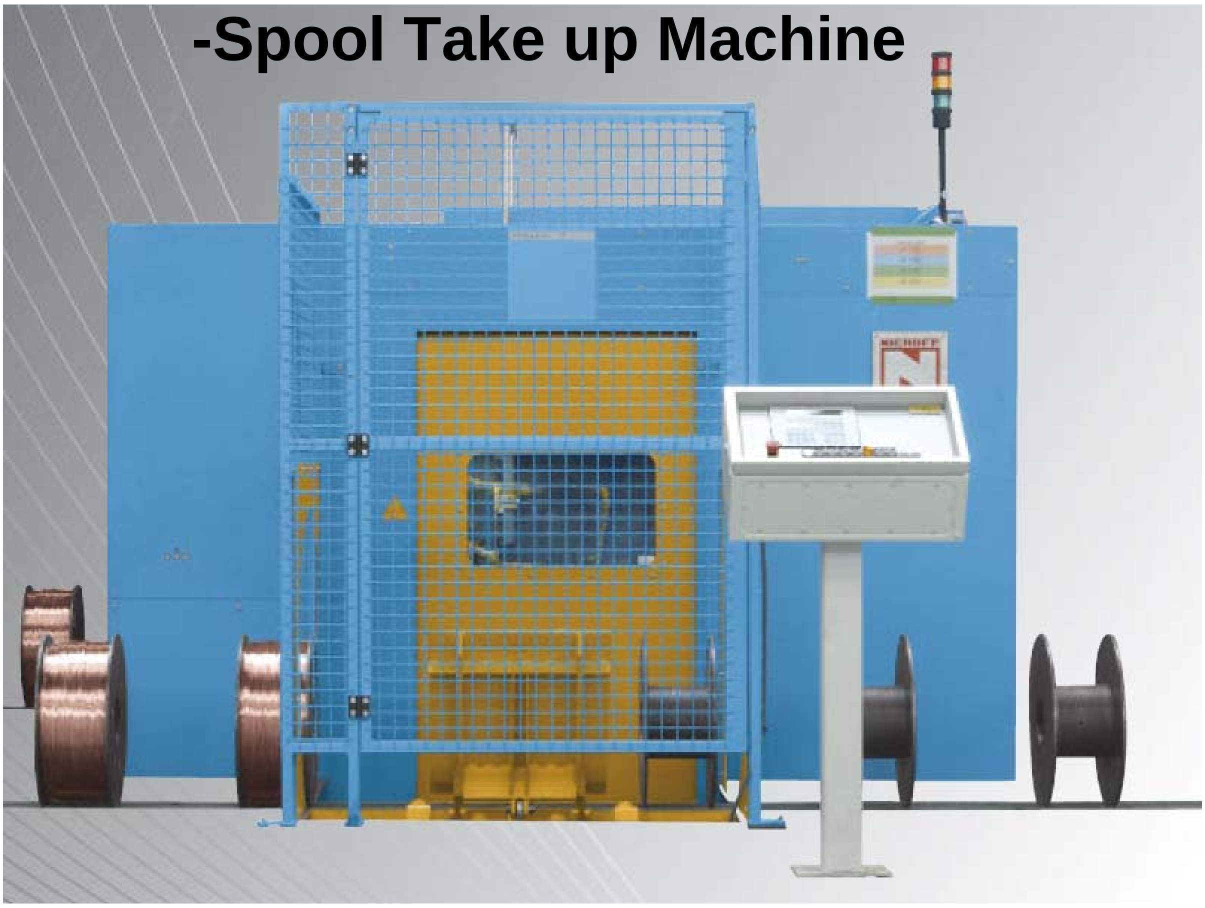


-Dancer



-Continuous operation of the drawing line in conjunction with a wire accumulation

-Spool Take up Machine



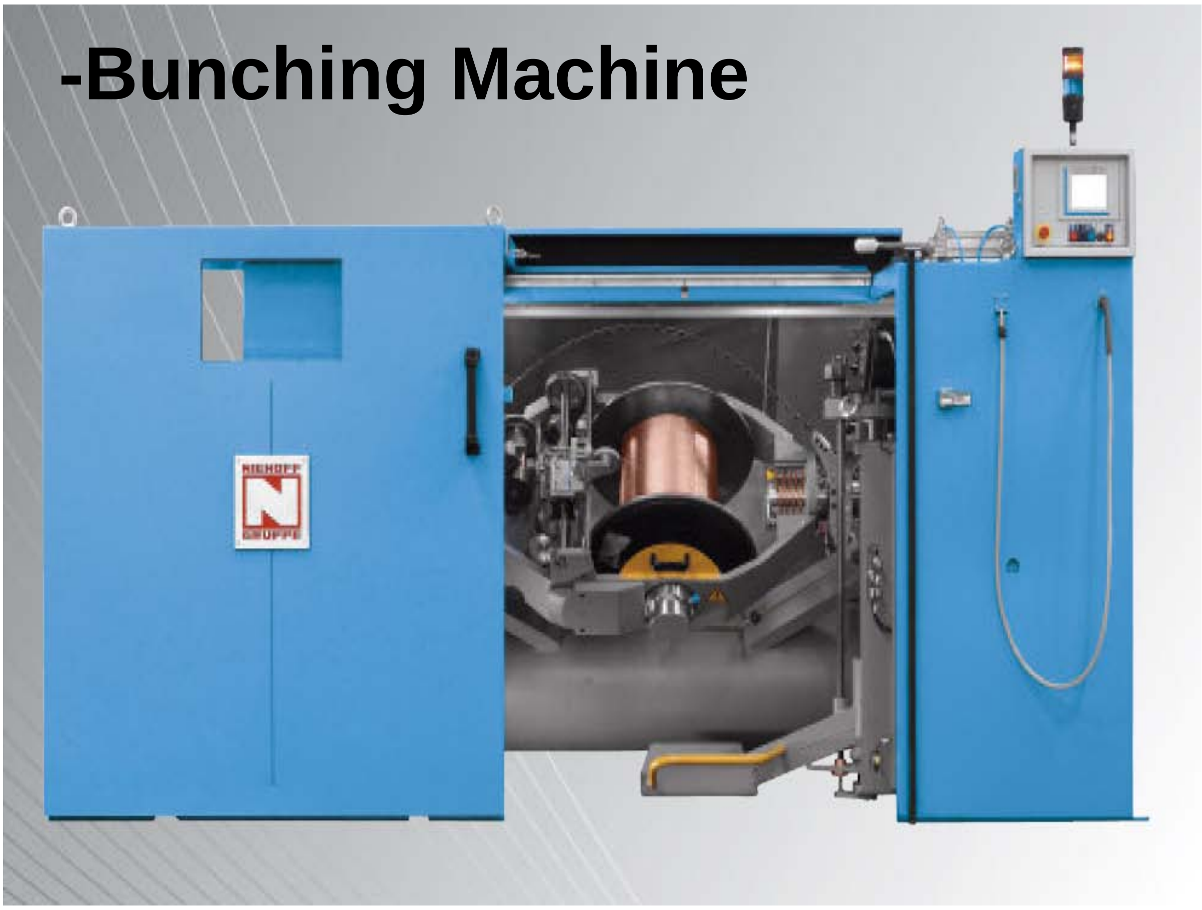
-Wire traversing via Genomgong

-Having vertically cantilever drive shaft

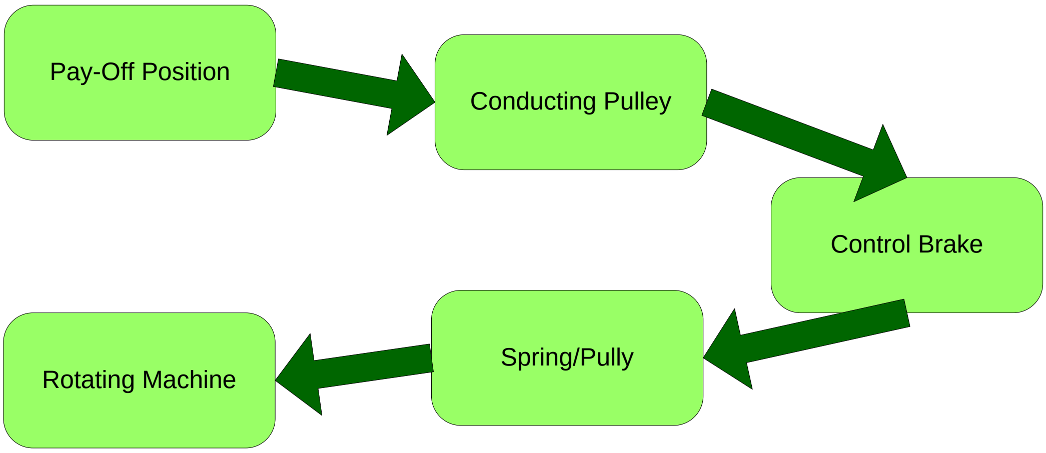
-Spool loading and unloading with hydraulic spool lifting table

-Fully automatic spool change

-Bunching Machine



-Twisting the bundles



Pay-Off Position

Conducting Pulley

Control Brake

Spring/Pully

Rotating Machine

Barrel Pay-Off

With what? (Materials/Equipment)

- Cold Welder
- Pulleys
- Barrels
- Motor

With who? (Competence/Skills/Training)

- 2 operators/shift

Inputs	Process	Outputs
1.8	Annealing Machine	1.8

How? (Methods/Procedures/Techniques)

- 16 separate barrels
- pulling wire by motor
- changing from empty to full barrel
- wire guiding by pulleys
- instruction how to connect the wires by cold welder

With what key criteria? (Measurement/Assessment)

- speed : 20 - 30 cm/sec
- quality of copper

Drawing Machine

With what? (Materials/Equipment)

- Drawing die: 0,193- 0,212- 0,233- 0,256- 0,283-0,311- 0,342- 0,376- 0,415- 0,457- 0,504- 0,555-0,623- 0,699- 0,785- 0,881- 0,989- 1,110- 1,246-1,398- 1,568
- Drawing emulsion
- Roller rotating speed

With who? (Competence/Skills/Training)

- 2 operators/shift

Inputs	Process	Outputs
1,8	Drawing Machine	0.193

How? (Methods/Procedures/Techniques)

- Instruction die control/maintenance
- Instruction how to control the drawing emulsion
- Control of roller speed by adjusting motor and gear, roller condition, roller maintenance

With what key criteria? (Measurement/Assessment)

- Drawing die 0,193 + 0,003
- Emulsion 7 % oil, no bacteria, temp 20 - 35°C, conductivity < X
- Strand speed

Annealing Machine

With what? (Materials/Equipment)

- Heater (electricity)
- Glogbad (dryer,steam,emulsion)
- Rollers(speed,condition)
- Comb
- Dryer

With who? (Competence/Skills/Training)

- 2 operators/shift

Inputs	Process	Outputs
0.193	Annealing Machine	0.193

How? (Methods/Procedures/Techniques)

- Adjusting the electricity of heater
- Adjusting the amount of steam
- Adjusting the amount of emulsion
- Changing the emulsion material and combination

With what key criteria? (Measurement/Assessment)

- Outgoing Diameter
- Strand speed
- Temperature of outgoing strand
- Temperature of steam
- Height of emulsion
- Amount of electricity
- Emulsion spesifications

Dancer Machine

With what? (Materials/Equipment)

- 5 pulleys
- Drive shaft (arm)
- Pneumatic pomp

With who? (Competence/Skills/Training)

- 2 operators/shift

Inputs	Process	Outputs
0.193	DANCER MACHINE	0.193

How? (Methods/Procedures/Techniques)

- Continuous operation of the drawing line in conjuction with a wire accumulator
- Automatic traverse speed correction
- Instruction how to control and adjust the pressure of pneumatic dancer (pomp)
- Dancer control take up machine speed by adjustable wire tension

With what key criteria? (Measurement/Assessment)

- Pressure , Ex: 16 * 0.193 should be 2 bar
- Diameter of wires
- Weight of wires
- Hole number on the shaft !

Spool taking up Machine

With what? (Materials/Equipment)

- Conveyors
- Ac servo motors of conveyors
- Vertical drive shaft
- Bell
- Genomgong
- Bell Motor
- Oil-Tank
- Balance Weights

With who? (Competence/Skills/Training)

- 2 operators/shift

Inputs	Process	Outputs
0.193	Annealing Machine	0.193

How? (Methods/Procedures/Techniques)

- Maintenance of Genomgong
- Controlling the speed of drive shaft
- Controlling the speed of the bell rotation by motor speed via incoming signal from dancer
- Adjusting the amount of oil
- Adjusting the balance weights???

With what key criteria? (Measurement/Assessment)

- Oil specifications
- Max/Min rate of Bell speed
- Max/Min rate of drive shaft speed
- The dancer pressure
- The Max/Min torque of bell

Back twist
Pay-Off

With what? (Materials/Equipment)

- 4 Pay-Off position
- Magnetic brake
- Wire guide pulleys
- Wire break sensors

With who? (Competence/Skills/Training)

- 2 operators/shift

Inputs

Non-winding wires
Wire diameter = m

Process

Back twist
Pay-Off

Outputs

Wires of each bundle separately a little twisted together

Wire diameter =< m

How? (Methods/Procedures/Techniques)

- Magnetic brake control instruction
- How to control force on the wire
- Manually adjustable tension before twisting

With what key criteria? (Measurement/Assessment)

- Tension adjustment by magnetic brake
- Pay-Off speed
- Preparation of the machine before the start
- The resistance of each bundle before Pay-Off
- Lay length
- Force on the strand
- Guiding holes

Twist Bunching Machine

With what? (Materials/Equipment)

- Rotor bow
- Winding spool
- Brake to control the spool speed
- Rollers (2 important)
- Trötforare

With who? (Competence/Skills/Training)

- 2 operators/shift

Inputs

Separate strands
Strand dia = m

Process

Twist Bunching Machine

Outputs

Multi wire bundle (conductor)

Conductor dia > m

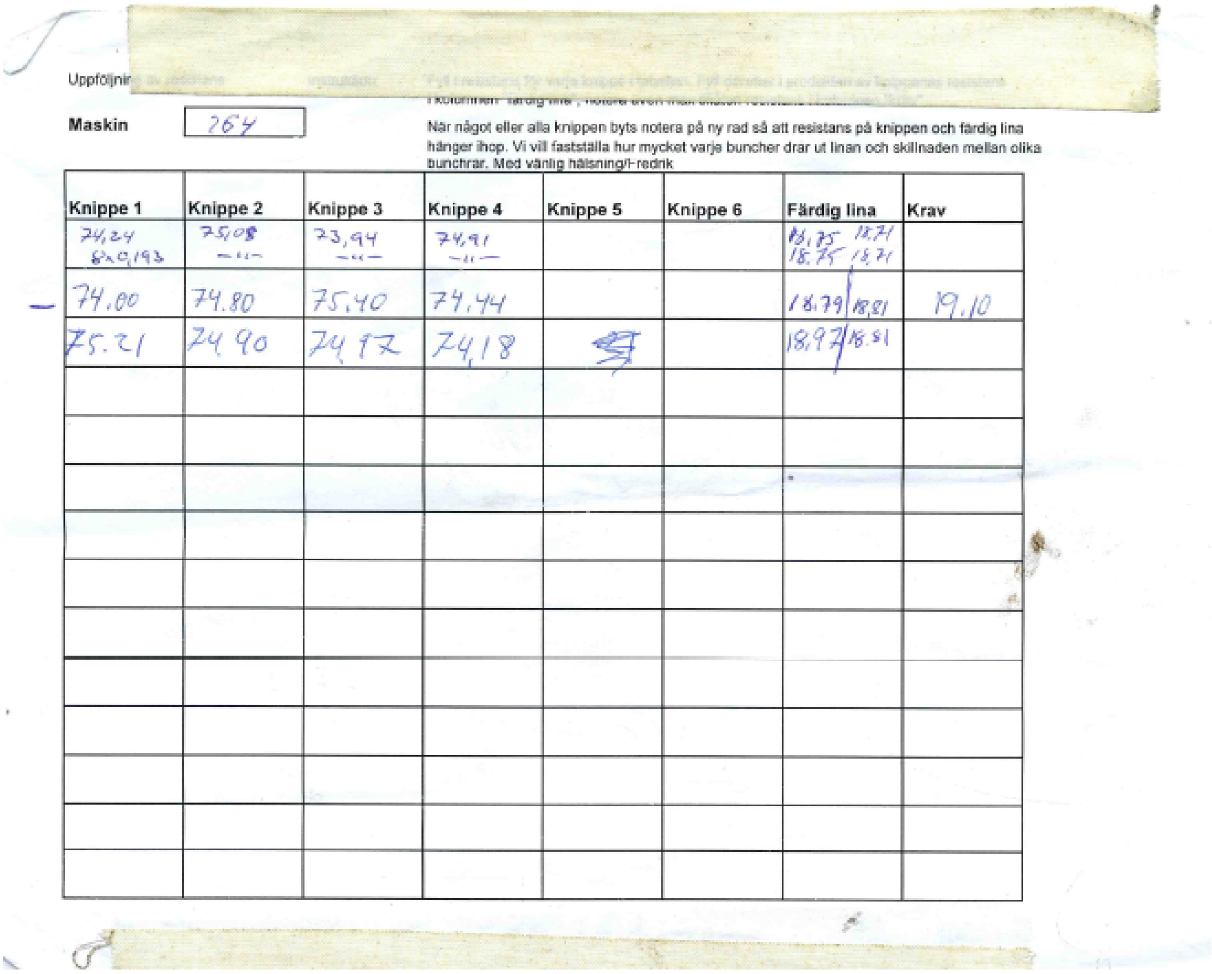
How? (Methods/Procedures/Techniques)

- Adjustment instruction of (bow speed , lay length, winding force)
- Adjust the lay length by adjusting the bow speed
- Adjust the bow speed by changing the sprockets
- The strands can be pulled directly by the spool
- Controlling the tension by adjustment of the bundle around of the roller

With what key criteria? (Measurement/Assessment)

- Brake to control spool speed
- Bow speed
- Winding force
- Tension in the roller
- Lay length
- Genomgong

Appendix B: Difference between incoming and outgoing electrical resistance of wires during bunching process



Uppföljning av resistans

Instruktion: "Fyll i resistans för varje knippe i tabellen. Fyll därefter i produkten av knippornas resistans i kolumnen "färdig lina", notera även max tillåten resistans i kolumnen "Krav"

Maskin 264

När något eller alla knippen byts notera på ny rad så att resistans på knippen och färdig lina hänger ihop. Vi vill fastställa hur mycket varje buncher drar ut linan och skillnaden mellan olika bunchrar. Med vänlig hälsning/Fredrik

Knippe 1	Knippe 2	Knippe 3	Knippe 4	Knippe 5	Knippe 6	Färdig lina	Krav
74,24 8x0,193	75,08 –"–	73,94 –"–	74,91 –"–			18,75 18,71 18,75 18,71	
74.00	74.80	75.40	74.44			18,79 | 18,81	19.10
75.21	74 90	74 92	74,18			18,97 | 18.81	

Uppföljning av resistans

Instruktion: Fyll i resistans för varje knippe i tabellen. Fyll därefter i produkten av knippenas resistans i kolumnen "färdig lina", notera även max tillåten resistans i kolumnen "krav".

När något eller alla knippen byts notera på ny rad så att resistans på knippen och färdig lina hänger ihop. Vi vill fastställa hur mycket varje buncher drar ut linan och skillnaden mellan olika bunchrar. Med vänlig hälsning/Fredrik

Maskin 277

	Knippe 1	Knippe 2	Knippe 3	Knippe 4	Knippe 5	Knippe 6	Färdig lina	Krav	
	36,88 16x0,193						37,11, 37,23	38,20	R 0.5
[illegible]	[illegible]	8x0,193 74,81	8x0,193 74.65	8x0,193 74.70			24,98 25,11 25,04	25.50	R 0.75

Uppföljning av resistans

Maskin 273

Instruktion: Fyll i resistans för varje knippe i tabellen. Fyll därefter i produkten av knippenas resistans i kolumnen "färdig lina", notera även max tillåten resistans i kolumnen "krav".

När något eller alla knippen byts notera på ny rad så att resistans på knippen och färdig lina hänger ihop. Vi vill fastställa hur mycket varje buncher drar ut linan och skillnaden mellan olika bunchrar. Med vänlig hälsning/Fredrik

	Knippe 1	**Knippe 2**	**Knippe 3**	**Knippe 4**	**Knippe 5**	**Knippe 6**	**Färdig lina**	**Krav**
–	73,99	74,24	74,91				24,75 24.90	
*	74,99	74.94	74,24				25,04	25,50

2000

pföljning av resistans

Instruktion: Fyll i resistans för varje knippe i tabellen. Fyll därefter i produkten av knippenas resistans i kolumnen "färdig lina", notera även max tillåten resistans i kolumnen "krav".

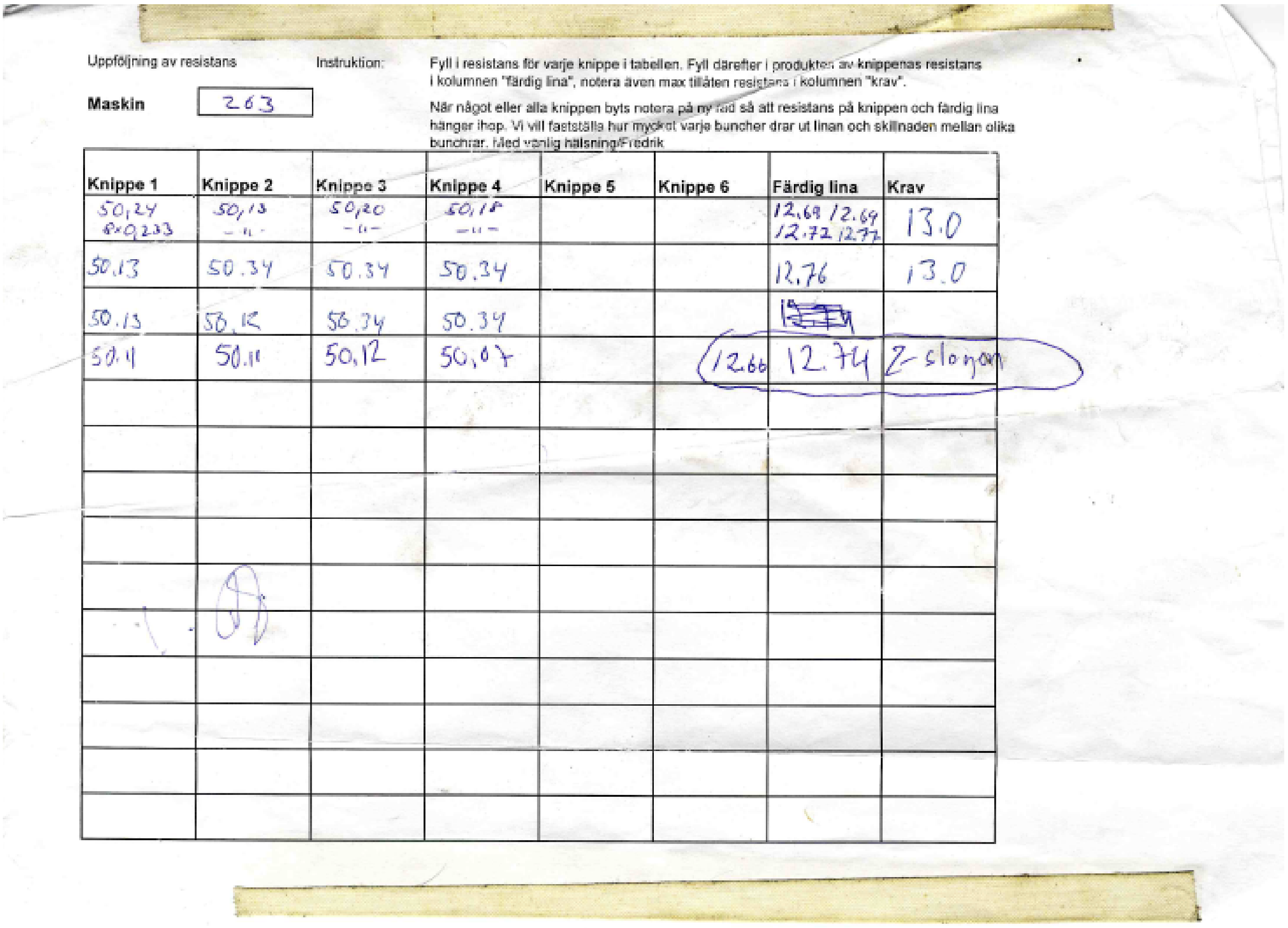
När något eller alla knippen byts notera på ny rad så att resistans på knippen och färdig lina hänger ihop. Vi vill fastställa hur mycket varje buncher drar ut linan och skillnaden mellan olika bunchrar. Med vänlig hälsning/Fredrik

Maskin 265

8 [illegible]

Knippe 1	Knippe 2	Knippe 3	Knippe 4	Knippe 5	Knippe 6	Färdig lina	Krav
~~51,23~~	~~50,74~~	~~50,86~~	~~50,74~~			7,27	7,23
~~25.41~~ 50,16 8×0,233	25.28 16×0,233	25.28 16×0,233	25.34 16×0,233			7,23 ~~7,25~~ 7,24	

?



Uppföljning av resistans

Maskin 263

Instruktion: Fyll i resistans för varje knippe i tabellen. Fyll därefter i produkten av knippenas resistans i kolumnen "färdig lina", notera även max tillåten resistans i kolumnen "krav".

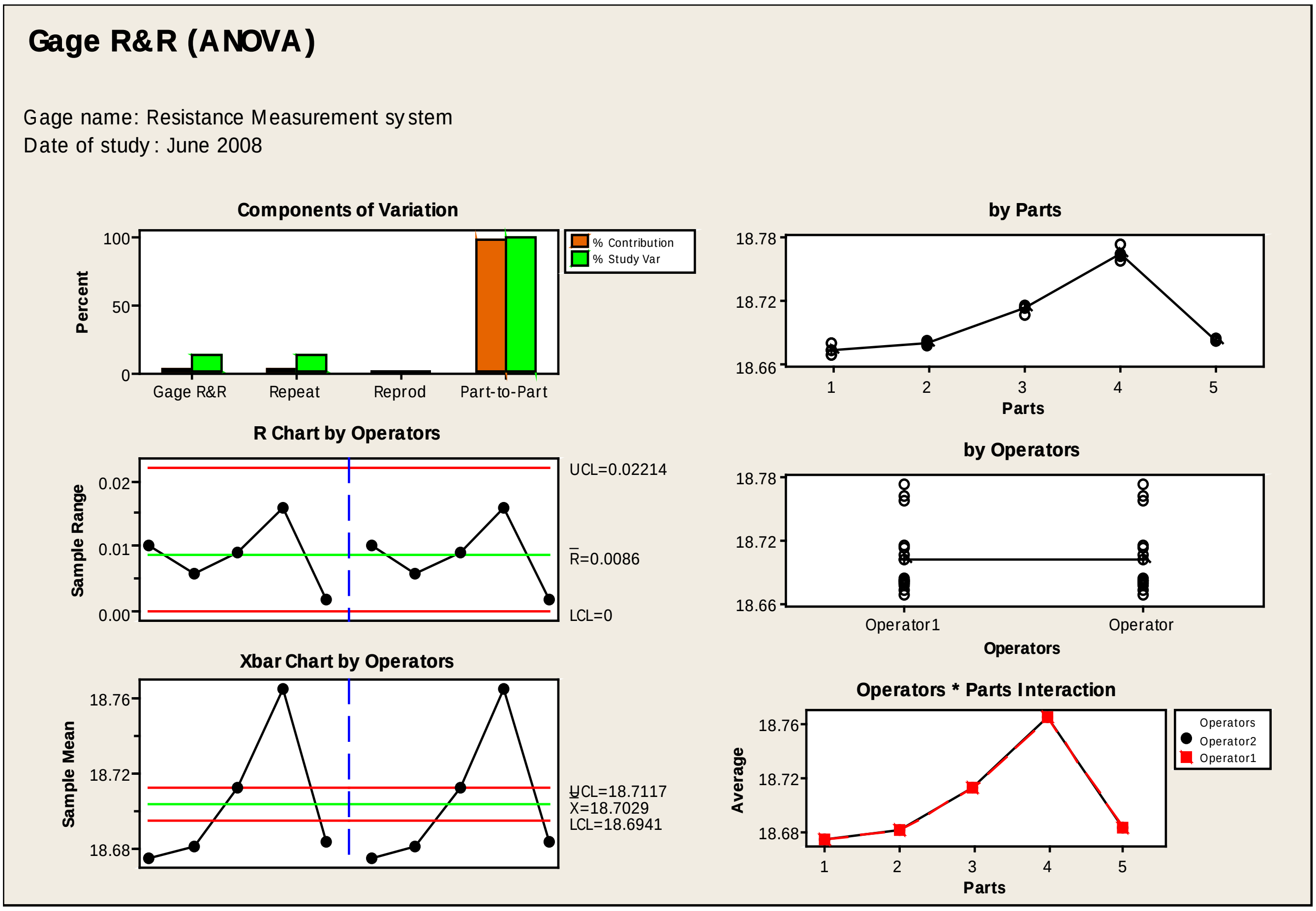
När något eller alla knippen byts notera på ny rad så att resistans på knippen och färdig lina hänger ihop. Vi vill fastställa hur mycket varje buncher drar ut linan och skillnaden mellan olika bunchrar. Med vänlig hälsning/Fredrik

Knippe 1	Knippe 2	Knippe 3	Knippe 4	Knippe 5	Knippe 6	Färdig lina	Krav
50,24 8×0,233	50,13 – " –	50,20 – " –	50,18 – " –			12,69 12.69 12.72 12.72	13.0
50.13	50.34	50.34	50.34			12,76	13.0
50.13	50,12	50.34	50.34			[illegible]	
50.11	50.11	50,12	50,07		12.66	12.74	Z-slangen

Appendix C: Gauge R&R measurements

RunOrder	Parts	Operators	Measure
1	1	Operator1	18.673
2	2	Operator1	18.677
3	3	Operator1	18.714
4	4	Operator1	18.762
5	5	Operator1	18.682
6	1	Operator2	18.67
7	2	Operator2	18.683
8	3	Operator2	18.707
9	4	Operator2	18.774
10	5	Operator2	18.683
11	1	Operator1	18.68
12	2	Operator1	18.681
13	3	Operator1	18.716
14	4	Operator1	18.758
15	5	Operator1	18.684
16	1	Operator2	18.673
17	2	Operator2	18.677
18	3	Operator2	18.714
19	4	Operator2	18.762
20	5	Operator2	18.682
21	1	Operator1	18.67
22	2	Operator1	18.683
23	3	Operator1	18.707
24	4	Operator1	18.774
25	5	Operator1	18.683
26	1	Operator2	18.68
27	2	Operator2	18.681
28	3	Operator2	18.716
29	4	Operator2	18.758
30	5	Operator2	18.684

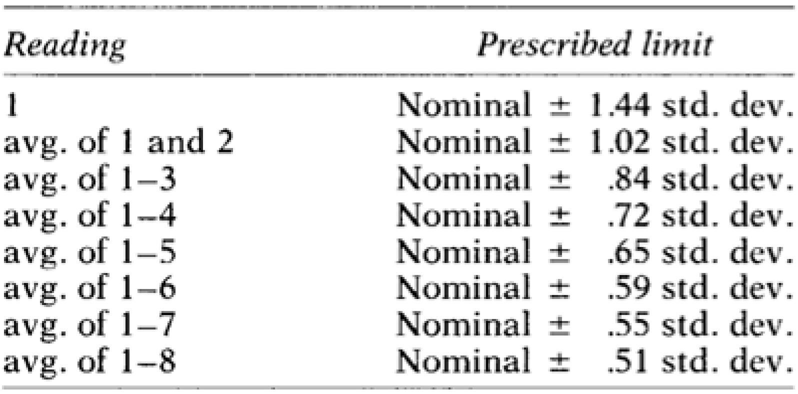
Appendix D: Graphical Gauge R&R



Gage R&R (ANOVA)

Gage name: Resistance Measurement system
Date of study: June 2008

Appendix E: Criteria for operator reading at setup



Reading	*Prescribed limit*
1	Nominal ± 1.44 std. dev.
avg. of 1 and 2	Nominal ± 1.02 std. dev.
avg. of 1–3	Nominal ± .84 std. dev.
avg. of 1–4	Nominal ± .72 std. dev.
avg. of 1–5	Nominal ± .65 std. dev.
avg. of 1–6	Nominal ± .59 std. dev.
avg. of 1–7	Nominal ± .55 std. dev.
avg. of 1–8	Nominal ± .51 std. dev.