Chapter 8

Conclusions and Future work

8.1 Conclusions

With regard to uPVC manufacturing and SPC implementation following important conclusions may be summarized as follows.

Flow chart was useful in zooming into important parts of pipe extrusion line, defining process steps and understanding the material flow and the practical aspects about the whole process. One of the advantages of the flowchart was that, communication became very efficient since the involvement, responsibility and authority of the various departments got well defined and delegated. The Flow chart was used to define variable and attribute data under each process. This definition was led to identify most critical parameters, which effect to the final quality of the uPVC pipe. Process conditions were fine tuned according to the variable and attribute data. Work procedures and instructions preparation was done according to the process flow. SPC control locations were defined base on the process flow chart. By analyzing work-in-process rejects under each process most critical SPC control locations were identified. After demarking the boundaries these locations were assigned to the PATs. Internal customer satisfaction was achieved due to through monitoring of variable and attribute data from the incoming raw materials to finished pipe storage. Flow chart was helped to control and minimize external causes to a great extent. Accuracy of the testing methods and calibration of measuring equipments were got more attention at each process step.

The detail cause and effect analysis to the extrusion line was reveled the exact situation of the pipe manufacturing. Since analysis describes main causes for problems and there effects in each step, staff managed to eliminate the effects by treating to the causes. Since it was served as an effective troubleshooting aid. The process knowledge was spread among the PATs when they collect and exchange the causes and effects. If the causes of a major problem were not known, it received higher priority. This led to improve the knowledge in uPVC pipe manufacturing among the workers autonomously. This knowledge was helped to ingredient selection for uPVC formulations and matching them to the process equipment and blending techniques. Finally all production staff managed to obtain the knowledge of unique properties and problems of uPVC from this analysis. Since the thermal sensitivity of uPVC most of the time created the problems, stabilization and overall additives modification were got more attention. Knowledge of the rheology of uPVC was identified as the key to understand the flow behavior in screw extruders and dies. More attention was paid to melt temperature; radial temperature gradient and their effect on melt quality, and temperature measurements techniques. Since cause and effect analysis detail out the fundamental problems of uPVC processing and of conversion operations used to manufacture pipes this prove of great value to all the staff at the production floor in their daily polymer and process work.

Priority analysis was done using Pareto principal. More attention was paid identified causes of pipe rejects. PATs were assigned more realistic goals based on the priority analysis information. A PAT concentrated one process at a time. This approach was achieved maximum process improvements from the collective attempt. Expected reduction of pipe rejects was achieved by adjusting machine setup and work procedures according to the PAT observations.

Process out of control situations identified by using control charts. Control limits were calculated based on measurements from the process itself. Out of control situations were identified on line basis by analyzing control chart patterns. By initiating prompt actions then and there processes were controlled. From planed control charts PATs managed to obtain well-described measurements, knowledge on process control and detection of process disturbances, product assurance, knowledge on the level of control of the process, control limits for process inherent variation. After the process has been brought in control, control chart data is suitable for product assurance. The type of control chart is varying depending on characteristics of the process and the product to be controlled.

The control chart only became effective as a control tool when there is knowledge on which action has to be taken when an out of control situation occurs. Process knowledge was well documented in the out of control action plan. Due to this standard action plan approach among operators and shifts were unique. The relevant officers with out any conflict took documented prompt actions.

A fair knowledge in uPVC and SPC techniques was required to have a proper implementation of SPC in the company. Using SPC techniques out of control situations of processes were identified. uPVC knowledge was used to analyze the out of control situations and to do the fine tuning of work procedures and extrusion machine adjustments.

8.1.1 Need of a pilot project

SPC is a powerful technique that allows, physical and chemical parameters of uPVC pipes to be measured dynamically. As it has real time data feed back as a goal, it predicts the probable outcome of work in processes, and corrective actions can take early as possible to prevent the possible out of control situations. By using SPC, causes for material contamination and reasons for pipe wall thickness variation were discovered. This led to identify the exact causes then and there and managed to take prompt actions. By doing so productive labour and time were saved.

The company should not fall into the trap of trying to apply SPC in all process or departments at the same time. Before any SPC implementation takes place, it is a good idea to carry out a pilot implementation. This gives an appreciation of the power of SPC to everyone in the company, and helps the refinement of tools, techniques, training and the overall approach. SPC should therefore be applied in a prioritized manner, often starting with a single process. Once SPC has been used successfully in one process, it is then easier to extend its use to other processes and areas. Before spreading the SPC application company wide, a cost-benefit analysis have to be carried out to determine whether it is actually, financially viable to implement.

8.1.2 Practical difficulties faced during the pilot study

Although SPC is, on the surface, an easy and simple technique, its implementation in a company is a far more complex issue. The practical difficulties were faced when the implementation was concentrated on the methodical aspects of SPC. They were avoided by carefully planning the implementation phase and by forming an organizational structure.

a. *Lack of management and operator commitment and Team work*

Management needs to commit them to SPC, and provide necessary human and economic resources of SPC for the resolution of common and special causes of variation. Management should fully delegate the authority to the process action teams (PATs) to take necessary remedial actions when the process is going out of control. Management support is essential for establishing a responsive environment. Until it becomes apparent to all employees that the SPC project is important it is very difficult to achieve coordinated efforts. Management should provide adequate budget and resources for improvement actions, which lead to continuous improvement of product and process quality.

Teamwork plays a vital role in SPC implementation and can be fostered through better communication across various departments. This is because inputs from all relevant parts of the process are necessary in order to implement changes on complex systems. Moreover, teams contain diverse talents, experience, skills and knowledge from various participants, which is an added advantage in any problem solving activity.

b. *Lack of understanding and lack of training of SPC techniques*

Company wide problems were created due to the lack of understanding and training of SPC techniques within the operators and the senior management. Sufficient time and resources have to be spent on training and education about SPC. Then only it justify the reason of why SPC is being implemented. The facilitator should give a chance to play a vital role in the pilot project with proper authority. The staff must get training through him as and when needed. Training should start with the senior management team and it should then be cascaded down through the organizational hierarchy. Training should include

- Exposure to relevant statistics
- Creation of control charts
- Interpretation of control charts
- Appreciation of the reasons and benefits of SPC

It is important to note that training should not just be short term but on a long-term basis, with regular training follow-ups and briefings.

c. *Lack of knowledge of which product or process characteristics to monitor and measure*

The selection of product characteristics or process parameters is absolutely vital for the success of any SPC initiatives. It is important to priorities all processes according to their importance with respect to the quality of the finished pipe. Prior to implement SPC, it is recommended; a very powerful approach must be taken place to prioritize processes in complicated production systems. PATs have to do a preliminary selection of key processes from a larger number of processes based on statistical and technical criticality. Process prioritization will assist management to identify processes with higher priority and provide guidance on where to allocate the limited economic resources and manpower for continuous improvement of process and product quality.

It is important to select the most critical characteristics of the process, which are most promising for process improvement. It is good practice to select quality characteristics that can be measured precisely, accurately and with stability. Quality characteristics can be any of the following types

- Smaller the better - Tool wear, Surface roughness
- Larger the better - Life of the pipe, Extruder efficiency
- Target the best - Diameter, Thickness, Weight
- Attribute – Good or Bad, Pass or Fail

d. *Inadequate measuring system in place*

There is a great deal of variation in any measurement method and therefore it is essential to ensure that the gauges are capable of doing their intended function. Even simple, measurement process, there can be a great deal of variation. This may be due to the effect of the operator and his skills and experience, the part being measured, the measuring instrument and also the interactions among them. It is essential to ensure the accuracy of measurement to minimize the potential errors in the data. Gauge repeatability and reproducibility studies are a recognized means of measuring the variation gauge. If measurement is not found to be within acceptable limits, SPC should then be deferred.

e. *Lack of communication between engineers, managers, and operators*

Effective communication and teamwork are vital for any quality improvement initiatives. Shop floor operators should be empowered to make real time decisions in terms of the corrective actions affecting their processes.

People who understand the language of control charts were not in a position to fix the processes, and people who can fix the processes did not understand control chart signals.

f. *Not ready to change culture*

Use of SPC involves cultural change in the working environment. Human behavioral issues and resistance to change were crucial in the pilot project. Operators, who know their processes better than anybody, should be empowered to take corrective actions that are within their capability and authority. Empowerment and ownership mean that workers have the opportunity to be recognized for their contribution and feel that they are an important part of the company. If a problem is out of the operator's capability and authority, then the process action team will be responsible for tackling it with the full support of management.

g. *Lack of use of computers and software packages*

The use of computers in the pilot project phase has received less attention. Initially the control charts were plotted manually. This was very tedious and time constrained process. Later the management decided to use Microsoft Excel to construct and analyze control charts. This minimized the time spent to plot the control charts. By using computer generated control charts, PATs managed to identify the assignable causes online basis. The use of familiar and user-friendly computer software packages offer many advantages such as less time spent on mathematical calculations, easier storage and retrieval of data. Computer based training schemes may be a promising and effective way of presenting SPC training material. However, the application of computer software packages should only be allowed after the essential principals of SPC are understood and those involved have acquired control chart interpretation skills.

8.1.3 Critical factors for an effective SPC implementation

After completing the pilot project following critical success factors were identified for an effective SPC implementation.

- Management commitment
- Team work
- Identification of critical quality characteristics
- Control Charts
- Use of a pilot study
- Documentation and update of knowledge of processes
- Measurement system evaluation
- Process prioritization and definition
- Cultural change
- SPC training and education
- Use of SPC soft ware
- Use of SPC facilitators

8.1.4 Requirements for a successful implementation of SPC

- Management and operator commitment
- Understanding and training of SPC techniques
- Investment of time and money
- Constant attention and support of top management
- Delegation of tasks, responsibilities and authority to the lowest possible level
- SPC pilot project, control and guided by an expert with through knowledge of statistics.
- After first introduction of SPC, project reviewing at regular intervals
- The staff have to be familiar with tackling problems through the use of data
- Team work and project management are essential

8.1.5 Benefits gained from the application of the pilot project

- Process improvement led to greater output
- Reduction in wasted efforts and costs
- Better consistency of process output
- Improved operator information: when to and when not to take action
- A predictable process could be achieved
- Created common language on performance of process for different people across departments
- SPC charts helped distinguish special from common causes of variation
- Process and Product Variation reduction
- Created a well reputation for high quality products and there by reduce customer complaints
- Improved efficiency and effectiveness of the extrusion line
- Reduced quality costs
- Reduced need for checking, inspection, and testing efforts
- Better understanding of the process among the workers who involved in the process
- Better communication with customers concerning the pipe's ability to meet their specifications
- Decisions were made on data rather than assumptions

Maximum benefits from SPC cannot obtain from Statistics alone. SPC tools have to apply for elements of a process to control the total variation.

- Man
- Material
- Machine
- Methods
- Measurements

Any variation in the five elements will cause variation in the process output.

8.2 Future Work

The study findings provide groundwork for developing an on-line statistical process control strategy for uPVC pipe extrusion. This research project was conducted with some boundaries such as chosen areas of uPVC pipe production, selected areas of extruder machine, limited number of employees and finally limited time frame. The following are the suggestions for further work.

I. When the number of PATs increases it is impossible to manage and to coordinate them. To fill the gap between top management and the PATs the company can form a SPC steering committee. The manager operations should be the head of the committee and managers of purchasing, quality and maintenance should be members of the committee. The SPC consultant and SPC coordinator should also be part of the committee. The main tasks of the steering committee may be initiation and promotion SPC, providing methods and means, controlling the PATs, and finally reporting to top management.

II. A standard checklist can be used to make sure that the PAT knows what is expected. The PAT will check for completeness and if necessary a brief period of training is organized to ensure that all operators are familiar with the implemented SPC point. A representative of the steering committee can audit the process. The audit includes the activities on the production floor and a check on the following up activities by a PAT. When the performance is approved a meeting is organized in which the PAT members will receive a certificate as an official reward for their results.

III. The selection of product characteristics or process parameters is absolutely vital for the successful SPC implementation. It is important to prioritise all processes according to their importance with respect to the quality of the finished pipe. In complicated production systems Analytic Hierarchy Process (AHP) can be used to select and prioritise the process and parameters.

IV. During the study, two phases out of four were completed. Integral implementation in production and Total quality phases should be completed for the completion of the SPC implementation.

V. Safety, ergonomics, reduction of waste, and logistics also can be included in the assignment of a PIT without limiting to process and product parameters.

VI. The work here has focused on single extrusion line in production department. The extension of these results to other extrusion lines as well as other departments should be investigated.

VII. The results were generated using batch systems. Suitable hardware and software capable of collecting and processing the data in real time will need to be developed. The effect of temperature, and temperature changes, requires further study. A SPC software package and SPC measuring equipments (sensors) will also be required.

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Appendix I

Methods for Total Quality Management (by category)

Management Methods

(1)Acceptable quality level (AQL)
To provide a structure of sampling plans, risks and inspection strategies to ensure that the customer receives the quality that the supplier has contracted to deliver.

(2)Affinity diagram
Organize large amounts of data in groups according to some form of natural affinity.

(3)Arrow diagram
To show the time required for solving a problem and which items can be done in parallel.

(4) Benchmarking
To identify and fill gaps in performance by putting in place best practice, thereby establishing superior performance.

(5)Consensus reaching
To give a team a methodical way of examining alternatives to reach a collective conclusion which all team members can accept.

(6)Contingency planning
To avoid 'firefighting' and waste of resources by planning for contingencies in the completion of a project.

(7)Cost-benefit analysis
To estimate the real cost and benefits of a project under consideration.

(8)Criteria testing
To valuate and compare alternative solutions to a problem by rating them against a list of criteria.

(9)Customer's contingency table
To understand the needs of both internal and external customers for the fulfillment of customer satisfaction.

(10)Deming wheel (PDCA)
A management concept to satisfy the quality requirements of the customer by using the cycle: plan, do, check and action.

(11)Departmental purpose analysis (DPA)
To review the internal customer-supplier relationship.

(12)Error proofing (Pokayoke)
To design an operation in such a way that specific errors are prevented from causing major problems to the customer.

(13)Force analysis
To identify external and internal forces at work when developing a contingency plan.

(14)Gannt charts
For planning the steps necessary to implement quality improvement.

(15)ISO 9000
To demonstrate to yourself, your customers and an independent assessment body that you have an effective quality management system in place.

(16)Just in time (JIT)
To deliver the raw materials or components to the production line to arrive just in time when they are needed.

(17)Kaizen
A Japanese term meaning 'change for the better', the concept implies continues improvement in all company functions at all levels.

(18)Mystery shopping
A technique involving looking at your business from the outside and measuring the efficiency of your own key processes from the customer's viewpoint.

(19)Objective ranking
Helps to place your current activity in perspective and enable you to understand the purpose of your efforts.

(20)Pareto analysis
To separate the most important causes of a problem from the many trivial. Also, to identify the most important problems for a team to work on.

(21)Potential problem analysis (PPA)
To examine plans to identify what can go wrong with them, so that preventive action can be taken.

(22)Problem prevention plan
To anticipate what can go wrong and plan to prevent problems.

(23)Process decision programme chart
To focus on possible sequences to help lead to a desirable result and contingency planning.

(24)Programme evaluation and review (PER) technique
To establish a planning technique for complex and multi-level projects.

(25)Quality circles
A special type of small group activity which forms a vehicle for the development of individuals.

(26)Quality function deployment (QFD)
A technique or discipline for optimizing the process of developing and producing new products on the basis of customer need.

(27) Relation diagram
To illustrate the relationship between problems and ideas in complex situations. Also to identify meaningful categories from a mass of ideas when relationships are difficult to determine.

(28) Teamwork
To organize activity which requires a number of people to collaborate and work together for a common goal.

(29) Total productive maintenance
To help a process which aims at making the most effective and efficient use of existing production structures.

(30) Why-how charting
When thinking in both abstract and concrete terms, and needing to move between the two, why-how charting enables a goal to be translated into action.

(31) Zero defects
To allow teams to experience the success involved in meeting ever more demanding targets without demotivating them by not achieving absolute success at once.

Analytical methods

(32) Cause and effect analysis
To examine effects or problems to find out the possible causes and to point out possible areas where data can be collected.

(33) Critical path analysis
A project planning technique, which separates the work, to be done into discrete elements, allowing the key elements that affect the overall project to be identified.

(34) Departmental cost of quality
To provide a financial measure of quality performance of an organization.

(35) Domainal mapping
To assist in the identification of internal customers and their needs.

(36) Evolutionary operation (EVOP)
A sequential experimental procedure for collecting information during on-line production to improve a process without disturbing output.

(37) Failure mode and effect analysis (FMEA)
To assist in the fool proofing of a design or a process.

(38) Fault tree analysis
To perform a quantitative as well as qualitative analysis of a complex system.

(39) Force field analysis
Allow you to identify those forces that both help and hinder you in closing the gap between where you are now and where you want to be.

(40) Minute analysis
To estimate the survival period of a particular product unit under certain conditions, using a simulated experimental environment.

(41) Paired comparison
To help a group to quantify the preferences of its member.

(42) Parameter design
To determine which factors are important in the manufacturing process and to find the optimum set of working condition.

(43) Process cost of quality
To provide a financial measure of the quality performance of an organization

(44) Reliability
To find the cause of failures and try to eliminate them and to reduce the effects or consequences of failure.

(45) Robust design (off – line quality control)
To achieve the proper functioning of a component even when affected by interfering factors, whether external, internal or manufacturing variations.

(46) Solution effect analysis
To examine solutions to problems to find out whether there are any detrimental consequences and to plan the implementation of the solutions.

(47) Stratification
To assist in the definition of a problem by identifying where it does and does not occur.

(48) System design
To apply special scientific and engineering knowledge to produce a basic functional prototype model, having surveyed the relevant technology manufacturing environment and customer need.

(49) Taguchi method
A technique for the optimization of products or process, Taguchi involves a two-stage experimental design that gives the benefits of robustness and efficiency with the minimum number of experiment.

(50) Tolerance design
To find out by experiment where the variability in a process (product) occurs and where adjustments can be made.

<u>Idea Generation</u>

(51) Brainstorming
To generate as many ideas as possible without assessing their value.

(52) Brain writing
To generate as many ideas as possible.

(53) Breaking set
To overcome blocks of thinking by generating new ideas. It is particularly useful in prompting a group to be more receptive to new suggestions.

(54) Buzz groups
A way of getting the immediate reaction of a group to new idea or a problem

(55) Idea writing
To bring all participants into group work.

(56) Imagineering
To assist a company to identify areas of opportunity by concentrating on ideal out comes then working back from it.

(57) Improve internal process (IIP) plan
To provide the structure to develop work plan details for a task using various factors, such as measurable, responsible resources, times and previous task owners.

(58) Lateral thinking
A way of transferring from one frame of reference to another, enabling you to breakdown barriers, which inhibit creative thought.

(59) List reduction
To reduce a list of ideas to one of manageable size.

(60) Mind mapping
A way of generating and recording ideas individually rather than in a group. Mind mapping makes use of word associations, encouraging you to follow your own thought patterns, wherever they lead. It also provides a written record of the ideas generated.

(61) Morphological forced connection
To generate new ideas or ways of approaching problems. It combines lists of attributes and forces new connections between them, to triggering new options.

(62) Multi-voting
To select the most popular or important items from a lists.

(63) Nominal group technique
A way of generating ideas from a group and identifying the level of support within the group for those ideas.

(64) Opportunity analysis
Offers the opportunity to evaluate quickly a long list of options against desired goals and available resources.

(65) Rich pictures
To allow a group of captures all ideas developed, without judgment or analysis, in a pictorial form that allows the strength of the ideas to be recorded.

(66) Snowballing
Sometimes call "pyramiding"; snowballing is a technique for gathering information for ideas.

Data collection, analysis and display

(67) Suggestions scheme
To generate ideas for improvement.

(68) Bar charts
To display discrete data collected by check sheets so that patterns can be discovered.

(69) Basic statistics
The mean, medium, mode, range and standard deviation are ways of summarizing and describing large volumes of data. The first three are measures of location; the last two are measures of spread. .

(70) Box and whisker plots
To provide a simple way of drawing the basic shape of the distribution of a set of data.

(71) c chart
To identify when the number of defects in a sample of constant size is changing over time.

(72) Check sheets
To collect data when the number of times a defect or value occurs is important.

(73) Concentration diagrams
To collect data when the location of a defect or problem is important.

(74) Cusum charts
To identify when the mean value is changing over time.

(75) Dot plots
A simple graphic device, which presents observations as dots on a horizontal state.

(76) Flow charts
To generate a picture of how work gets done by linking together all the steps taken in a process.

(77) Geometric moving average
To identify trends in small changes in the process mean. The geometric moving averages is sometimes called the exponentially weight moving average. (EWMA).

(78) Histograms
To display continuous data collected by check sheets so that any patterns can be discovered.

(79) Hoshin kanri (quality policy development)
To delight the customer through the manufacturing and servicing process by implementing the quality goals of the organization.

(80) Is/is not matrix
To identify patterns in observed characteristics by a structured form of stratification.

(81) Matrix data analysis
To provide a picture of numerical data from a matrix diagram in an efficient way.

(82) Matrix diagram
To provide information about the relationship and importance of task and method elements of the subject.

(83) Moving average
To identify trends in data when short-term variation or cyclical patterns are confusing the long-term picture.

(84) Multi-vari charts
To show the dispersion in a process over short and long term, using a graphic control chart.

(85) np chart
To identify when the number of defective items in a sample of constant size is changing over time.

(86) Paynter charts
To display information over time in way that allows changers in patterns of failure to be discovered. Paynter charts will show when one failure mode takes over from another in terms of importance or when the overall failure rate is changing over time.

(87) p chart
To identify when the percentage of defective items in a sample of variable size is changing over time.

(88) Pie charts
A way of pictorially representing data, pie charts are an effective mean of showing the relative size of the individual parts to the total.

(89) Process analysis
Enables a group two look for opportunity to improve process. It can also be used to identify standards and measures for critical parts of process.

(90) Process capability
To demonstrate whether a process is capable of meeting a specification and to calculate an index to show this capability.

(91) Sampling
A method by which a small number of items (the sample) is drawn from a larger number of items (the population) in order to draw a conclusion about the population based upon information from the sample.

(92) Scatter diagrams
To allow the relationship between cause and effect to be established.

(93) Spider web diagrams
To show performance against a target when survival criteria are being set.

(94) Statistical process control (SPC)
To identify when process are changing over time.

(95) Stem and leaf diagram
To present raw data and to show their distribution visual.

(96) Tally charts
To collect data when the value of a defect or problem is important.

(97) Tree diagrams
To identify the tasks and methods needed to solve a problem and reach a goal.

(98) u chart
To identify when the number of defect in a sample of variable size is changing over time.

(99) X moving range (X-MR) chart
To identify when a value is changing over time.

(100) X-R chart
To identify when the mean value or range in sample of constant size is changing over time.

Appendix 2

SLS 147: 1993 Scale of sampling

No. of PVC pipes in the lot	**Out side Diameter up to and including 110mm**		**Out side Diameter above 110mm**		**Size of Sub Sample**
	Sample Size	Acceptance No.	Sample Size	Acceptance No.	
A	**B**	**C**	**D**	**E**	**F**
Up to 1,000	20	1	8	0	3
1,001-3,000	32	1	13	0	3
3,001-10,000	50	2	20	1	5
10,001 and above	80	3	32	1	5

Table A.2.1 The scale of sampling

All uPVC pipes in a single consignment of the same type and size manufactured under essentially similar conditions shall constitute a lot.

The number of uPVC pipes to be taken from the lot shall depend on the size of the lot and outside diameter of uPVC pipes.

uPVC pipes shall be selected at random. In order to ensure randomness of selection, Random number tables as given in SLS 428 shall be used.

If the lot has been found satisfactory in respect of visual and dimensional requirements, a sub sample of size as given in column F shall be drawn at random from the sample obtained.

The required test pieces for each requirement shall be cut (one piece from one uPVC pipe) from the uPVC pipes of the sub sample.

The lot shall be declared as conforming to the requirements of the standard if the number of uPVC pipes, which have defects less than or equal to the corresponding acceptance number given in column C or column E.

Appendix 3

The $\bar{X}$ (Average) and R (Range) chart procedure

Step 1. Select a process measurement

Chose a critical product or process measurement to chart. There may be obvious measurement for which process control is important, but in some cases, process analysis may be necessary to determine the critical measurement. For initial efforts measurements should have good potential for process improvement or should be important in the self-certification plan. Self-certification includes the use of control charts as proof of good quality for the customer. Considerations could include the following:

- There may be a trouble spot in the process that the chart can detect.
- There is a trouble spot determined by evidence from scrap analysis or customer (or downstream) complaints that the chart will help resolve.

Step 2. Decrease Variability

Eliminate any obvious sources of variation before starting the chart. Chart interpretation should concentrate on the less conspicuous problems.

Step 3. Check the Gauges

Be sure the gauges are working properly and that gauges variation is at an acceptable minimum. Variation that shows up on the chart should primarily reflect process variation. Excessive gauge variation makes the interpretation of process variability more difficult and sometimes impossible. The rule of 10 for gauges states that the gauge should be 10 times more accurate than the measurement accuracy. This is absolutely necessary to measure and control variability realistically.

Step 4. Make a sample plan

Devise a sampling plan that consists of two parts. First, choose the sample size. Larger samples of six or seven can lead to more reliable estimates of variation and average value but are more costly. The extra time involved to take the larger sample of measurements could be a factor. The cost of samples of four or five may be more reasonable. Small samples of two or three are appropriate for monitoring a process that is in statistical control, but if the product out put is small, small samples used with an X bar and R chart can give more reliable process information than an individual and moving range chart. Second, determine the sampling frequency. The number of samples per shift depends on the product output, operator time available for measuring and charting, and the time pressure for statistical control.

There are two basic concepts involved in determining sample times. First, the sample must be a random sample. Second, sampling must be done often enough to indicate any changes that may occur in the process. A change will usually show either the presence of special-cause variation or the elimination of special-cause variation. Both of these sampling concepts can be utilized by setting the basic sampling plan using the random sample method illustrated in Srilanka Standards Institute. In addition, the worker in charge is given the leeway of taking additional samples whenever a potential process change is suspected.

Step 5. Set up the charts and process log

Choose the scale for the X bar and R chart. For a continuous charting situation, the chart scales will have been established on the previous chart. For a new chart, use an educated guess to set up the scales. When establishing scales, avoid the two extremes if possible keep scales from being too large or too small.

Keep a process log during the control charting, and in it, be sure to note the time and make a comment about any occurrence that may have some effect on the process (either good or bad). The date and time should accompany each sample. The process log may be kept on the control chart or may be a separate comment sheet attached to the chart. When variation problems occur, the combination of a process log and control chart can be very beneficial to the operator or process control team as they attempt to isolate and eliminate the problems.

Step 6. Take the samples and chart the points

As the samples are taken, write the measurements on the control chart. Calculate the sample average and range, chart their points, and draw the next leg of the broken-line graph. If this is a first chart, any analysis usually must wait until the chart is completed. If this is a continuation chart, the scale, average line, and control limit lines are transferred from the previous chart and chart analysis is an ongoing process as the chart develops.

When continuation charts are used (which is most of the time) the operator or worker in charge must know the various trouble patterns on control charts and to be able to recognize them as soon as they appear so that immediate action can be taken. Furthermore, they should learn to anticipate problems. For example, shifts and runs are slow to develop (they need seven samples in their patterns). When four points show up on the chart could be interpreted as the start of one of these patterns, the worker in charge should start thinking about what possible process change could be occurring. It may be false alarm, but if not, the problem will be identified sooner. Sampling times should be frequent enough to reflect any process changes, so if a change is suspected, additional samples should be taken. Take action when problems show up. It is much easier to diagnose problems when they occur than to analyze the problem when it shows up on a control chart analysis a few days later.

Step 7. Calculate averages and control limits

A population is the collection of all individuals in a lot. Generally, populations are very large, making it impractical to collect data on each individual pipe to calculate population mean and range of thickness. That is why samples are used and calculate the sample mean and range. Sampling involves taking a small representative group from the pipe lot. For a sample to be representative, every item must have an equal chance of being selected for the sample. The results from the samples are then translated back to estimate the thickness of the population.

$m = No.\ of\ samples$

$n = No.\ of\ measurements\ in\ a\ sample$

$$\overline{\overline{X}} = \frac{\overline{X}_1 + \overline{X}_2 + \ldots\ldots + \overline{X}_m}{m}$$

$$R = X_{max} - X_{min}$$

$$\overline{R} = \frac{R_1 + R_2 + \ldots\ldots + R_m}{m}$$

Control limits for the $\overline{X}$ chart

UCL = $\overline{\overline{X}} + A_2\overline{R}$

Center line = $\overline{\overline{X}}$

LCL = $\overline{\overline{X}} - A_2\overline{R}$

Control limits for the R chart

UCL = $D_4\overline{R}$

Center line = $\overline{R}$

LCL = $D_3\overline{R}$

Shewhart constants for $\overline{X}$ and R charts

Sample Size (n)	A_2	D_3	D_4
2	1.880	0	3.267
3	1.023	0	2.574
4	0.729	0	2.282
5	0.577	0	2.115
6	0.483	0	2.004

Sample calculation for first 5 samples of Table 7.3

Sample No.	1	2	3	4	5
	1.41	1.37	1.35	1.32	1.31
Sample	1.31	1.31	1.34	1.27	1.37
Measurements	1.37	1.31	1.29	1.29	1.33
	1.34	1.31	1.27	1.30	1.38
	1.28	1.38	1.32	1.24	1.29
Average	1.34	1.34	1.31	1.28	1.34
Range	0.13	0.07	0.08	0.08	0.09

m = 5 - No of samples

n = 5 - No of measurements in a sample

Therefore A2 =0.577 D3 =0 D4 = 2.114

Refer sample No. 1

$\overline{X}$ = Sample Total / Sample Size (n)

(1.41+1.31+1.37+1.34+1.28) / 5 = 1.34

R = 1.41-1.28 =0.13

Refer all five samples

$$\overline{R} = \frac{\sum R}{n} = \frac{(0.13+0.07+0.08+0.08+0.09)}{5} = 0.09$$

$UCL_R = D_4 \overline{R}$ = 2.114 * 0.09 = 0.19026

$LCL_R = D_3 \overline{R}$ = 0 * 0.09 = 0

$$\overline{\overline{X}} = \frac{\sum \overline{X}}{n} = \frac{(1.34+1.34+1.31+1.28+1.34)}{5} = 1.322$$

$$UCL_{\bar{X}} = \bar{\bar{X}} + A_2\bar{R} = 1.322 + 0.577 * 0.09 = 1.3739$$

$$LCL_{\bar{X}} = \bar{\bar{X}} - A_2\bar{R} = 1.322 - 0.577 * 0.09 = 1.2700$$

Step 8. Monitor the process

When the process is in control and capable, a monitoring process should be used. Continuous control charts with one or two samples per shift work well. Another monitoring method would use the pre control procedure.

Step 9. Continuous improvement

Quality improvement is a continuous process. The operator should stay alert to occurrences that lead to errors or are related to measurement variability. A sequence of small improvements over a period of a year or two can result in a substantial improvement in quality.