

EVALUATING THE APPLICABILITY OF SPC TOOLS- CONTROL CHARTS: THE CASE OF ETHIOPIA PLASTIC S.C.

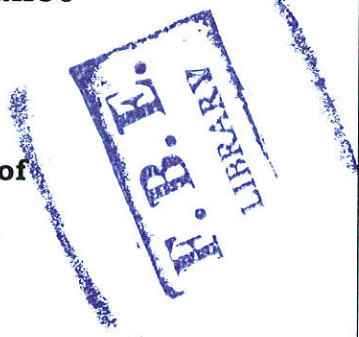
A project report submitted to the School of Graduate
Studies of Addis Ababa University in partial fulfill-
ment of the requirements of the Degree of Masters in
Business Administration

By: Mesfin Teklehaimanot

Under the Supervision of
Dr. Tilahun Teklu

Faculty of Business and Economics
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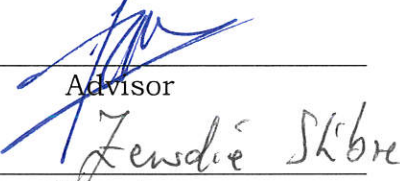
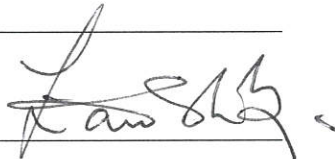
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Statement of Approval

This is to certify that Ato Mesfin Teklehaimanot has completed a research paper entitled “Evaluating the applicability of SPC Tools- Control Charts: The case of Ethiopia Plastic S.C.” under my guidance.

I also approve that this work is appropriate enough to be submitted in partial fulfillment for the requirement of the degree of Masters in Business Administration.

Tilahun Teklu (PhD) _____

Date 01 Aug 2007

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Acronyms

EPSC	Ethiopia Plastic Share Company
ES	Ethiopian Standard
ISO	International Organization for Standardization
LCL	Lower Control Limit
LSL	Lower Specification Limit
PE	Polyethylene
PVC	Polyvinyl Chloride
QMS	Quality Management Systems
QSAE	Quality and Standards Authority of Ethiopia
SPC	Statistical Process Control
SQC	Statistical Quality Control
UCL	Upper Control Limit
USL	Upper Specification Limit

Abstract

Managing quality has become the overall management function to assure that customer requirements are identified and met with satisfaction conforming to the requirements. Managers need to be aware that quality is the responsibility of everyone in the company. The quality inspector, unlike the traditional approach, is no longer a policeman who is there to detect nonconformities or prevent defects. Operators of the production floor are encouraged to monitor and take corrective action whenever necessary on their own operation by making use of statistical process control tools.

Effective implementation of a quality assurance system in a firm requires use of appropriate statistical methods for monitoring conformance to specification starting from the raw materials to the final products. Traditional methods of analysis often provide delayed identification of nonconformance occurrence, placing quality of products at risk. The application of SPC techniques such as Shewhart control charts allows continuous real-time assessment to detect variations so that the process is maintained under a state of statistical control, and improvement action taken to further reduce variation.

Chapter One

1 Introduction

1.1 Background

The marketability of a product or service is generally determined by three fundamental parameters (Hoyle, 2001): price, quality and delivery. Customers require products and services of a given quality to be delivered by or be available by a given time and to be of a price that reflects value for money. Quality is determined by the extent to which a product or service successfully serves the purpose of the user.

Although there are various meanings given by different authors, ISO in the context of its Quality Management System Standard (ISO 9000, 2000), defined quality as the degree to which a set of inherent characteristics fulfils requirements.

Managing quality has become the overall management function to assure that customer requirements are identified and met with satisfaction conforming to the requirements. The needs of the customer may change with time and implies a periodic review of the requirements for quality. As all business start with customers, enterprises small, medium and large are generally conscious of the competitive potential of quality.

Improved quality at the enterprise level lowers its cost of operations and increases its productivity. The firm's ability to produce better products at a reduced (or even the same) price boosts its market share. More productive firms would be able to produce goods or provide services at lower cost thereby attracting more customers and increasing their market share. The adoption of a management strategy that emphasizes quality and excellence would help improve performance at the enterprise level.

Managers need to be aware that quality is the responsibility of everyone in the company. The quality inspector, unlike the traditional approach, is no longer a policeman who is there to detect nonconformities or prevent defects. Operators on the production floor are encouraged to monitor and take corrective action whenever necessary on their own operation by making use of statistical process control tools.

In this regard, this study on the applicability of statistical process control in the Ethiopia Plastic S.C. will offer insight on the nature, extent and causes of variability of the quality of products. Use of statistical process control is expected to serve the company in its effort of implementing ISO 9001:2000 Quality Management Systems (QMS) addressing the requirements of clauses related to product realization, and measurement, analysis and improvement.

1.2 Statement of the problem

Statistical process control (SPC) is regarded in many organizations as an important element of quality management system. It is realized that application of SPC tools such as Shewhart Control Chart is essential for a never ending improvement of quality, with out which it is literally impossible to be competitive in the market. To this effect, a control chart when used appropriately is a proven technique for reducing defects and preventing unnecessary process adjustments.

The Ethiopia Plastic S.C. is implementing initiatives that enable it to maintain and upgrade the quality of its products in a continuous fashion. To this effect a quality management system project is launched, and quality circles are formed to study operational and quality related problems and propose improvement ideas.

Along this line, the research is expected to answer the following questions:

1. Can SPC method be applied to production process of a plastic product?
2. What quality control practice is prevalent in the company to reduce variation in the process and ensure the product conform to specifications?
3. What benefit can be obtained by using a control chart to monitor the production process?

4. What potential constraints may be faced to effectively implement the model, and actions are required to overcome them?
5. How the tool can further be used by the managers to determine the capability of the production process in meeting specific customer requirements?

1.3 Significance of the study

This research is important and has significance in contributing to the effort of improving the quality of plastic products in Ethiopia Plastic S.C.

As it examines the applicability of control charts in monitoring variations in one of the plastic products manufacturing processes, the student researcher believes that this work can be taken by the company management and quality assurance personnel as a spring board to apply statistical process control tools in the production processes.

1.4 Objective of the study

The general objective is focused on analysis and selection of appropriate models of control charts that is applicable to monitor critical quality parameters of the PVC pipe production process.

The specific objectives are to:

- Explore the current quality control practice in controlling variations and reducing nonconformities (defects) in the production process;
- Introduce generic procedure for effective application of control charts;
- Highlight the benefits to be obtained from use of the tool;
- Assess potential constraints that may be faced in introducing control charts in the PVC pipe production process and means of overcoming them; and
- Point out how the tool can further be utilized in determining the capability the process in meeting specifications.

1.5 Scope and limitation of the study

This research study focuses on product quality and production processes of Ethiopian Plastic S.C. Although, the company is engaged in producing nearly thirty types of products, due to time constraint the quantitative data analysis of product parameters is limited to PVC pipes of outer diameter 110mm.



1.6 Research methodology

For the successful accomplishment of the research, the following methods are used.

- Direct observation of quality control personnel and operators during production.
- Interviewing quality control manager and personnel, production manager and operators.
- Reviewing secondary data from the company archives such as quality records, production plan and reports.
- Reviewing books, journal articles and other publications on the World Wide Web.

1.7 Organization of the chapter

This thesis is organized into five chapters. The first chapter deals with the introductory part in which background, objective of the study, significance of the study and methodology are incorporated. The second chapter deals with literature review where basic concepts, terms and studies of other researchers on the subject matter are reviewed. The third chapter is concerned with conceptual framework where various models and standard control chart methods are introduced. Research findings, analysis and interpretation of data are presented in chapter four, while conclusion and recommendation are treated in the fifth chapter.

Chapter Two

2 LITERATURE REVIEW

2.1 *Process defined*

Any activity or set of activities that uses resources to transform inputs to outputs can be considered as a process. For organizations to function effectively, they have to identify and manage numerous interrelated and interacting processes. Often, the output from one process will directly form the input to the next process.

A process is a systematic series of actions (Juran, 1992), or any repeatable sequence of events or operations (Benbow et al., 1992) leading to either a tangible or intangible outcome, or the achievement of a goal.

According to Davenport (1994), a process is simply a structured set of activities designed to produce a specified output for a particular customer or market. It has a beginning and end, and clearly identified inputs and outputs. Processes also have performance dimensions- cost, time, output quality, and customer satisfaction. Here it has to be noted that the definition of process can be applied to both large and small processes- to the entire set of activities to fill the customer order, or to those required just to enter order data into a computer. It is further pointed out that a manager who want to

achieve radical change take an expansive view of processes; those desiring incremental improvement focus on more narrowly defined processes.

In order to ensure products realized by a process fulfill quality requirement, a sound knowledge of the process, i.e. knowledge necessary for controlling the process efficiently and effectively is necessary, and this can be done by employing process analysis (ISO 21747, 2006).

Process analysis can reveal sources of unnecessary complexity in the process. Indicators of process complexity may be an excessive number of work standards, paperwork trails, approval cycles, component parts, vendor, subcontractor, customer options, or management hours spent to obtain results. Benbow *et al.* (2002) opine that reducing complexity is faster and less costly than increasing process efficiency; i.e. defects can be reduced, 100 percent inspection can be eliminated, and product design can be improved.

The main factors responsible for causing process variation (Fox, 1993) are:

- *people*- in setting up a machine, operating a machine, etc;
- *equipment*- bearing wear, tool wear, etc;

- *materials*- size, composition, properties, etc;
- *methods*- operating procedures, maintenance provided, etc;
- *environment*- temperature, power supply fluctuation, etc.

Similarly, Juran (1992) introduced the concept of 'dominant variable' as a variable which is more important than all the rest combined, and include:

- (1) *Setup dominant*. Some processes exhibit high stability and reproducibility of results over many cycles of operation. The design for control should provide the operating forces with the means for precise setup and validation before operations proceed.
- (2) *Time dominant*. Here the process is known to change progressively with time, e.g., depletion of consumable supplies, heating up, wear of tools. The design for control should provide means for periodic evaluation of the effect of progressive change and for convenient adjustment.
- (3) *Component dominant*. Here the main variable is the quality of the input material and component. For short run it may be necessary to resort to incoming inspection. For the long run, the design for control should be directed at supplier relations, including joint planning with suppliers to upgrade the input.
- (4) *Worker dominant*. In these processes, quality depends mainly on the skill and knowledge possessed by the workers. The design

for control should emphasize aptitude testing of workers, training and certification, quality rating of workers, and error proofing to reduce worker errors.

- (5) *Information dominant.* Here the processes are of a “job shop” nature, so that there is frequent change in what product is to be produced. As a result, the job information changes frequently. The design for control concentrate on providing an information system that can deliver accurate, up-to-date information on just how this job differs from its predecessors.

2.2 *Process control*

Benbow et al (2002), quoted Deming in emphasizing that the key to quality is in management’s hands- 85% of quality problems are due to the system and only 15% are due to employees. Hence, the heart of his quality strategy is the use of statistical quality control to identify special causes and common causes of variation.

Statistical Process Control (SPC) generally refers to the concept of applying statistical methodology to the problems of process control. The concept includes among other things, collection of the basic data and use of the Shewhart Control Chart to distinguish real changes in the process from apparent changes.

Fox (1993) views SPC as an aspect of Statistical Quality Control (SQC)- quality control methods that rely on the use of statistical disciplines- related to statistical monitoring of a process, whether this is a manufacturing process or a process concerned with the delivery of a service.

SPC is both a diagnostic and prescriptive technique. As a diagnostic technique it assists in locating problem sources, and as a prescriptive technique it helps to solve problems (Benbow et al, 2002). It provides a common internal language for management, supervision, quality assurance/control, and product operations to discuss problems, solutions, decisions and actions.

Calcutt (1995) states SPC, as not simply a collection of techniques but a way of thinking which is essential for a never ending improvement of quality, without which one cannot hope to regain competitiveness in global market, and the reason why SPC is being regarded in many organizations as important element of quality management.

Another explanation is given by Divine and Sherman (1948). Divine and Sherman described SPC as a method for determining the extent to which quality goals are being met without examining every item

produced, and for telling management whether or not variations which occur are exceeding normal expectations.

These writers generally agree that SPC as a statistical technique for the purpose of quality control and improvement of product quality by helping operators and managers locate and remove assignable causes of variation. However, it should be noted that though SPC is a very powerful technique applied in an appropriate context that it gives warning to stop the process and investigate, it does not direct guidance where to look for the source of the problem (Fox, 1993).

A process control usually consists of the following main activities (Juran, 1992):

- (i) Evaluating the actual performance of the process,
- (ii) Comparing actual performance with goals, and
- (iii) Taking action on the difference.

Similarly, Benbow et al (2002) describes process analysis activities in six steps.

- (i) Consult with those persons at all levels and from all functional areas who are knowledgeable about the general steps or operations of a process for a given product or service.

- (ii) With their assistance, list all the steps in the process from beginning to end.
- (iii) Depict these steps as a flow chart. The list may be trimmed down once unnecessary operations have been addressed.
- (iv) Independently list the types of defects, nonconformance, or problems that may occur and code these. Identify where in the process each type of defect is likely to occur, using the code.
- (v) Indicate where in the process the different inspection points occur.
- (vi) Gather data to indicate which defects or problems occur most frequently. Where the most frequent problem occurs, establish Shewhart control chart analysis.

Unlike the traditional tools of problem solving such as hunch, educated guess work, intuition and common sense; SPC takes a systematic approach that requires guided conceptualization first, then data collection, and finally corrective action directly linked to the data (Benbow et al, 2002).

Some of the benefits that can be obtained from using statistical process control techniques are:

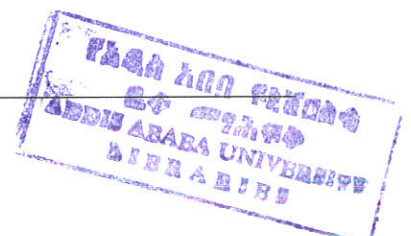
- (i) *Process stability.* All processes are subject to various changes, influences, and constraints, which tend to deviate

from initial setting. Process control aims to regulate the process to counteract these changes, so that the process quality remains within acceptable limits. The capability of a process to meet customer specifications is determined by the stability of the process, the range of variation, and the process aim point.

- (ii) *Powerful problem solving tool.* SPC tools can be used to identify key factors (forces) that promote or hinder the solution of the achievement of a goal. The tools help to define an issue or problem in depth, brainstorm on the root causes and effects, identify potentials for improvement and aid teams in evaluating a situation or available alternatives through analysis of strengths versus weaknesses, opportunities versus threats or costs versus benefits.
- (iii) *Cost saving/ Elimination of waste.* A process going out-of-control may result in large number of defective pieces before it is detected, which may result in considerable loss. Therefore, it is imperative that effective control system be devised, which is able to detect the deviation in the process at the earliest possible moment, so that corrective measures can be applied before an applicable quantity of defective work is produced. Moreover, when processes are controlled, it will not be necessary to operate inspection or intensive

supervision resulting in cost saving and overall improvement in quality.

- (iv) *Process selection.* Choosing an over-capable or under-capable process will generally be expensive and will needlessly increase the processing cost. Therefore, from economic consideration, one needs to select a process whose capability matches the requirements of the job.
- (v) *Process improvement.* Often, the target value for the proportion of out-of-specification unit is zero, which is impossible to actually achieve. But it may be observed that setting a target of zero defects is logically the equivalent of adopting a principle of commitment to continually improve a process.
- (vi) *Quality improvement.* The discovery and removal of special cause of variation detected by a point out of control is not by itself improvement but only fire fighting. This only puts the process back to where it should have been in the first place. The transition from keeping the process under control to quality control i.e. keeping the process within the limits of customer specification is an improvement action.
- (vii) *Visual management.* SPC can be used to widely display information to workforce and management. The information can be production targets, quality targets, sales target and achievements in the areas.



- (viii) *Factual decision making.* SPC tools help one make good decisions based on facts instead of giving opinions based on measurements from only a few pieces or cases.

Another important benefit of using SPC is the changes in the mode of thought promoted (Dudding, 1952) that more focus is given to the performance of machines or processes by way of using statistical process control techniques than relying merely on inspection of the final product.

Fox (1993) classified the methodical approach to SPC in to three stages:

- (1) *Collection-* Collect sufficient initial data from the process
- (2) *Control-* Calculate the control limits from the data collected
- (3) *Capability-* Once the process is in statistical control, calculate the capability indexes.

Similarly, Levinson and Tumbelty (1997) identified four requirements for effectively using SPC:

- (1) *Data integrity-* data (measurement) must be accurate;
- (2) *Data traceability-* being able to trace measurements to the process, equipment, and material that produce them;
- (3) *Identification of critical process parameters-* identifying the process steps that have significant effects on product quality;

- (4) *Real-time capability*- feedback must be prompt enough to allow timely process adjustments.

2.3 *Control Charts*

A fundamental tool of SPC is the control chart. ES ISO 7870 (2004) describe control charts as a method for comparing information from samples representing the current state of a process against limits established after consideration of inherent process variability. In other words, the function of the control chart is to help assess the stability of the process, and this is done by examining the plotted data in relation to the control limits.

By analogically Divine and Sherman (1948) elaborate a control chart as that which can be linked to a highway whose control limits are the shoulders on one side and the center line on the other. No car driving along the highway can maintain a perfectly straight path. Unevenness in the road, play in the steering wheel, gusts of wind, and a host of other factors cause slight variation in the path of the car. However, the moment the car swerves outside one of the limits, an assignable cause can be assumed to exist and an investigation should begin. The cause may turn out to be a defect in the steering mechanism, a sleepy driver, or some other correctable factor.

Control charts are fundamental tools of statistical quality control. They are methods for comparing information from samples representing the current state of a process against limits established after consideration of inherent process variability. Their primary use is to provide a means of evaluating whether a manufacturing service or administrative process is or is not in a “state of statistical control”. While originally developed for industrial production and development applications, control chart methods are now widely used in a very broad range of service and support operations as well. In essence, control charts are tools to assist in determining when a process is stable or has changed and they are useful at management levels as well as for the operator to control at the workplace.

Any evaluation of product or process usually differs from the previous evaluation. Such observed differences can result from (Juran, 1992):

- (i) A real change in the product or process.
- (ii) An apparent change arising from chance variation (such apparent changes abound when sample size are small).

An apparent change is a false alarm. It is a waste of time to look for the cause as the cause is not “findable”.

Inherent variability is present in all operations due to numerous, but usually minor, chance causes, so that the observed results from a stable process are not constant, and statistically valid limits are

required to minimize erroneous decisions leading to over- or under-control.

A process is considered to be in a “state of statistical control” if there are no systematic shifts entering the process (ES ISO 7870:2004), or when actions induced cause variation in the results (Hoyle, 2003). In essence, when a process is “in control” it is possible to predict reliably the behavior of that process, whereas when non-chance (or special) causes enter the system, the process is subject to the results of these causes and the outcome cannot be predicted without information about their presence and effect. A process that is found to be not in a “state of statistical control” requires intervention to bring it into such a state. For certain economic or natural phenomena there may be no known way to intervene and the control chart simply serves to identify a lack of control (ES ISO 7870:2004). Therefore, a process that produces unpredictable results is out of control. When variations in the results occur by chance, the process is not under control. The spread of variation in results may exceed the limits or the requirements but, if this is predictable, the process is under control. Process control is, therefore, about understanding variation.

Control charts provide a simple graphical method for evaluating whether or not the process has attained, or continues in, a “state of statistical control”. The determinations are made through comparison of

the values or patterns of some statistical measure(s) for an ordered series of samples, or subgroups, with control limits. There is a variety of specific control charts, each designed for the types of decision to be made, the nature of the data, and the type of statistic used. The word “statistic” emphasizes that measurements are subject to inherent errors from such sources as obtaining the sample, or from the measurement process itself, and therefore represent a sample with inherent sampling variability.

A major virtue of the control chart is its ease of use and construction. It provides an indicator of the “state of statistical control” to the production or service operator, engineer and manager. However, the control chart serves only as part of the complete analysis procedure. It may suggest when an assignable cause has entered the process, but independent study is required to determine the nature of that cause and the corrective action needed (ES ISO 7870:2004).

Any variable (measurement data) or attribute (count data) representing a characteristic of interest of a product or process may be plotted. In the case of attribute data, control charts are commonly maintained of the number or proportion of nonconforming units or of the number of nonconformities found in samples drawn from the process.

For variable data, a control chart is usually used for monitoring changes in process center, and a separate chart is used for monitoring changes in process variability. The conventional form of chart for variable data is termed as “Shewhart” chart after the first introducer Walter Shewhart of Bell laboratories in 1920.

A control chart requires data obtained by sampling the process at approximately regular intervals. The intervals may be defined in terms of time (for example hourly) or quantity (for example every lot). Usually such subgroup consists of the same product or service with the same measurable units and the same subgroup size. From each subgroup, one or more subgroup characteristics are derived, such as the subgroup average, \bar{X} , and the subgroup range, R, or the standard deviation, s. A Shewhart control chart is a graph of the values of a given subgroup characteristic versus the subgroup number. It consists of a central line located at a reference value of the plotted characteristic (ES ISO 8258, 2004).

Functions of control charts are (Caulcutt, 1995):

- (i) *process monitoring*, in which measurements are made at regular intervals and the data are plotted as soon as possible, to detect any changes in the process,
- (ii) *problem solving*, in which all the data are available at the outset and are plotted on control charts in the hope that



the charts will help the investigator to discover the cause(s) of the problem, and

- (iii) *assessment of process stability*, in which all the data are available at the outset and are plotted on control charts to determine whether or not the process was stable (in control); this is often followed by an assessment of process capability, in which a histogram of the data is compared with the specification limit(s).

There are two types of error inherent in using control charts, (Deming, 1986, ES ISO 7870, 2004), because of confusion of special causes with common causes of variation:

- (i) *Type I*. Ascribing a variation or mistake to a special cause when in fact the cause belongs to the system (common causes); i.e., when it is concluded that a shift has occurred when in fact none has. These errors lead to expenses related to over-control (superfluous adjustments) or to unnecessary investigations of non-existing problems.
- (ii) *Type II*. Ascribing a variation or mistake to the system (common causes) when in fact the cause was special; i.e., errors in which a shift in level is not detected. These errors lead to waste due to expenditures associated with an unsatisfactory process that was not stopped promptly, and

due to missing opportunities to identify the causes of variations in the process.

The introduction of a control chart is also useful in determining the capabilities of the production process, and action is taken when these estimated capabilities are unsatisfactory in relation to the design specifications.

In non-quantitative terms, process capability is the inherent variability of the products that emerge from a process (Juran, 1992). The term process capability is widely used to designate the inherent reproducibility of a process, the ability to repeat its results during multiple cycles of operation. A high degree of such reproducibility is required by modern industrial societies to meet certain exacting needs: interchangeability on a massive scale, predictable performance, standardization, and so on. Processes that are excessively variable are incapable of meeting the product quality goals, and generate waste in the form of work redone, materials scrapped, etc.

As stated by Juran (1992), the principal method for evaluating process capability is through analysis of data collected under operating conditions, i.e.:

- The process is already in existence.
- Operations are being conducted under “regular” conditions, not “laboratory” conditions.

- The personnel conducting operations are the regular operating forces.

Process capability for such existing process may be evaluated by collecting data on either:

- The quality features of the process itself, or
- The quality features of the product turned out by the process (The product “tells” on the process.)

Fox (1993) recommended that before any process is commissioned it is important to establish its process ‘capability’. Failure to ensure that a process capability is compatible with the specification demanded of its output typically will result in the process operators being blamed for failures which are outside their control. Equally misguided attempts to adjust process equipment to achieve optimum results can result in increased variation.

2.4 *Use of control charts*

Although research papers on applicability of control charts in plastic manufacturing industries were not available at the time of the study, the studies of Harding (1945) “application of statistical control to heavy duty iron production”, Marcuse (1945) “application of control chart to analyze test results in the field of experimental food research using organoleptic testing method”, and Dudding (1952) “The introduction of statistical methods to industry” are reviewed.

Harding (1945), in his article entitled “Statistical Control Applied to High Duty Iron Production”, studied the application of Shewhart control charts in the processes of making a high-duty cast iron amongst a group of fifteen foundries. The study had been carried out by collecting and analyzing past data on chemical and physical test results of the metals for each foundry using Shewhart control chart. The result had shown existence of failures to conform to specification and lack of control in monitoring and controlling variations on principal chemical and physical properties. Moreover, a definite improvement is reported after putting the system into operation attributed to two main factors:

- the psychological effect from using the chart, which by drawing attention to both Average and Range values produced a conscious effort to meet the chart limits; and
- the early warning of an impending change in product properties and breakdown, which also provide information on the probable cause of the change.

Marcuse (1945) studied application of control chart to analyze test results in the field of experimental food research using organoleptic testing method by a panel of experts. She analyzed the test results of a panel of testers examining the palatability of check samples using a scale of 1 to 10 repeating four times a week over a period of seven weeks.

Scores of the testing panel were tabulated preceded by tests of significance to analyze the validity and reproducibility of each tester's scoring. The study revealed that a control chart method can be applied in organoleptic testing, and in grading the quality of food products objectively according to a fixed standard. It also indicated the advantages of using control chart method during an initial training period of judges, as the length of time necessary for a required degree of control in scoring can be determined from its records.

In relation to organoleptic testing, specifically, the control chart method was found useful in the following ways:

- It can assist in the selection of a good tasting panel, i.e., persons whose tasting scores are valid and meet the requirements of statistical control;
- It will determine what specific tasting scores must be examined to find out whether assignable extraneous causes are present;
- It will provides a means of minimizing the losses arising from two sources of error i.e. failure to pool the results of those tasters who may be pooled as checks against each other, and pooling results that should not be pooled.

Dudding (1952) in his empirical study indicated that the construction of control charts in practice calls for nothing but the simplest arithmetic, and reference to tables less voluminous than many which are in

common and this can be carried out satisfactorily by persons of average intelligence who have preferably completed high school education.

In response to the question of how and where, the introduction of a novel control chart technique would best be done at those levels of personnel directly interested and on small scale (Dudding, 1952) choosing some item or part of the manufacturing process that has given existence evidence of need for better control.

Control chart as medium of presenting inspection/measurement results at key stages of production, has three main benefits (Dudding, 1952):

- (1) *They assist the planning and supervision of production.* By way of presenting, in a concise form a long-term yet up-to-date picture of events, they can be used to assist day-to-day technical supervision of production, and provide a measure of what can be expected from operators, machines, and processes, which is useful when planning production programs.
- (2) *They improve personal relationships.* They foster interest in tasks which often contain little to interest the person carrying them out; they improve personal relationships between the relatively junior staff in charge of different sections of a manufacturing organization and in particular between inspectors and technical supervisors; they provide a common method for presenting and studying data on a long-term basis

which can be readily understood by all concerned whatever their function or rank; and discussion is guided by reason supported by fact rather than by traditions and hunches.

- (3) *They guide development and research.* The data recorded on control charts can be used for formal statistical investigations when considering long-term projects aimed at improving the quality and reducing the cost of the product.

Although introducing control chart technique in a process where significant variation followed with frequent machine attendant is present will improve uniformity of the products (Dudding, 1952) and Culcutt (1995) argue using the Shewhart standard procedure may not fulfill the required purpose in some processes which may ultimately create the notion that 'control charts don't work with this process'. Use of International Standards such as ISO (or equivalent BSI) standards to create and interpret control chart are recommended (Culcutt, 1995) to avoid such pitfall.



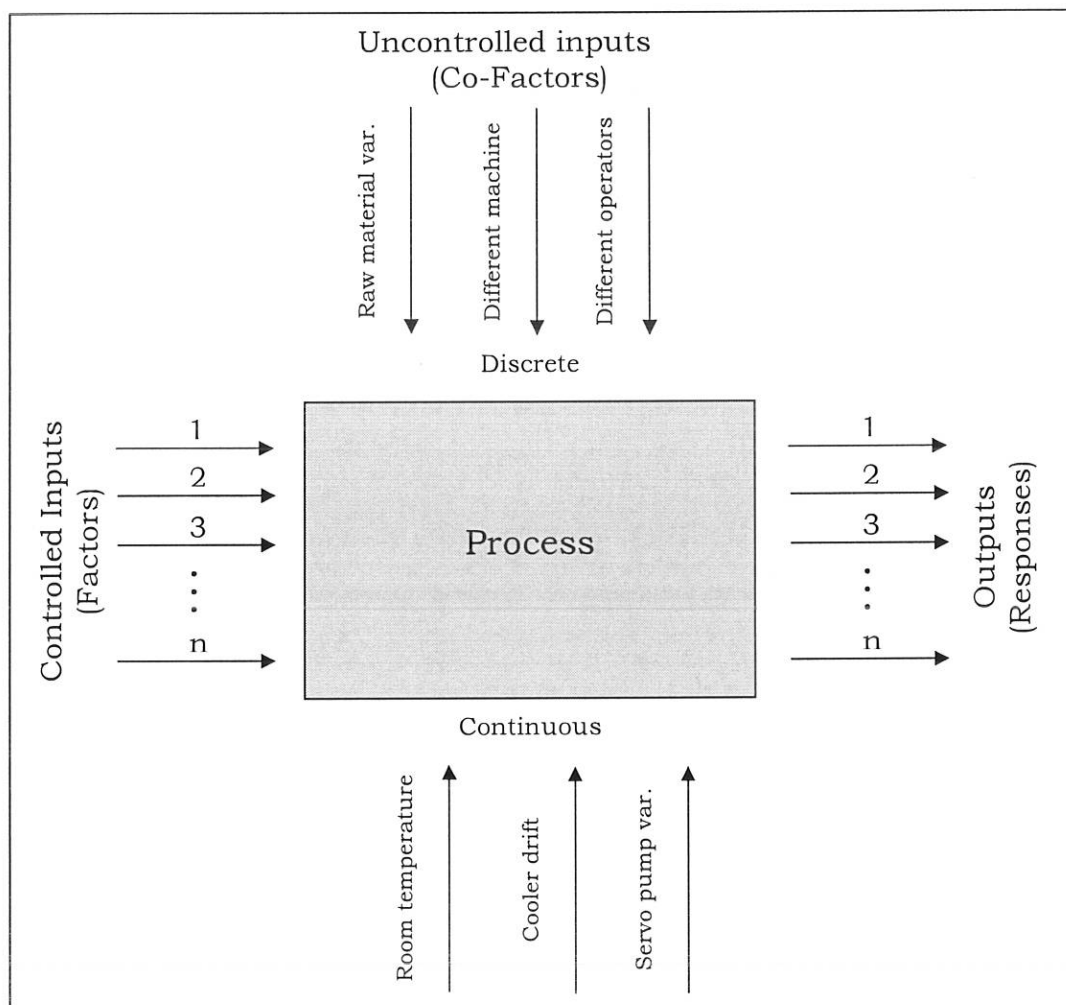
Chapter Three

3 Conceptual Framework

3.1 Process measurement, monitoring and control

A process can be described in the form of a black-box model as seen in the Figure 1. In this figure all of the outputs are shown on the right and all of the controllable inputs are shown on the left. Any inputs or factors that may be observable but not controllable are shown on the top or bottom.

Figure 1: Model of a process

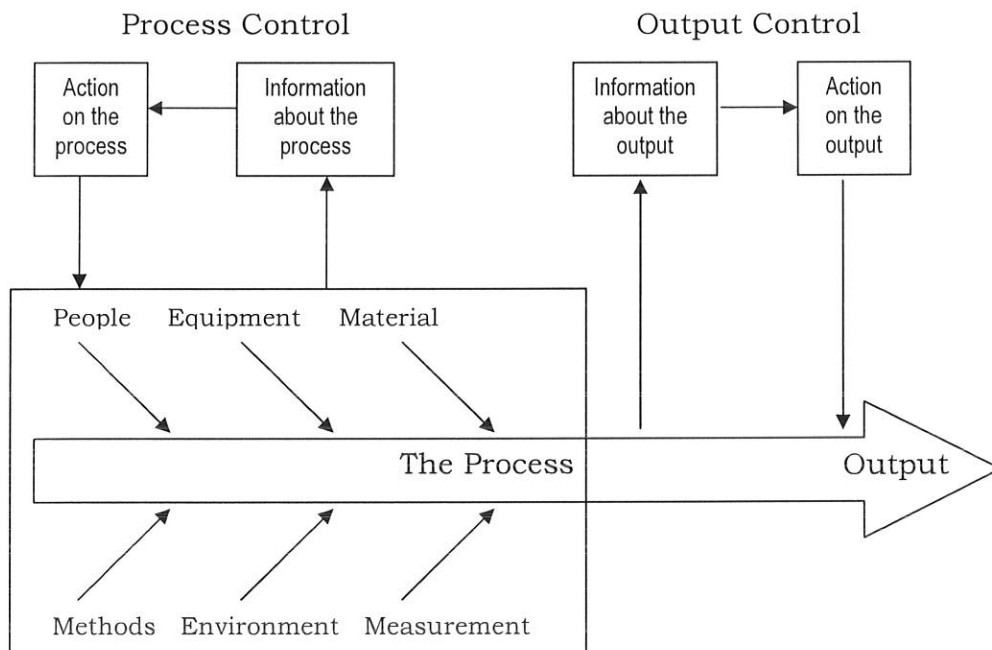


Source: Adapted from NIST, Engineering Statistics Handbook,
www.itl.nist.gov/div898/handbook/ppc/ppc.htm

Implementing a quality management system requires an organization to measure, monitor and analyze the process identified. Measuring process is rather different to measuring the output of processes- this is commonly referred to as inspection or product verification.

Hoyle (2001) stated measuring is concerned with determination of the quantities of an entity such as time, speed, and capability indices whereas monitoring is concerned with continual observation aside from periodic measurement. Furthermore, analyzing process is concerned with understanding the nature and behavior of processes for the purpose of their design, development and improvement. A process control model, as illustrated in Figure 2, highlights a process can be managed only when the personnel responsible for the process is equipped with the facts about its performance. One can not claim success, failure or make improvements unless he/she knows the current performance of the process.

Fig 2: Process control model



Source: Adapted from Hoyle (2001), ISO 9000 Quality System Handbook, 4ed.

Hoyle (2003) listed the eleven steps in order to bring a process under control:

- i. Determine what parameter is to be controlled.
- ii. Establish its criticality and whether you need to control before, during or after results are produced.
- iii. Establish a specification for the parameter to be controlled, which provides limits of acceptability and units of measure.
- iv. Produce plans for controls that specify the means by which the characteristics will be achieved, and variation detected and removed.

- v. Organize resources to implement the plans for quality control.
- vi. Install a sensor at an appropriate point in the process to sense variance from specification.
- vii. Collect and transmit data to a place for analysis.
- viii. Verify the results and establish whether the variance is within the range expected for a stable process, where all variation is due to common causes.
- ix. Diagnose the cause of any variance beyond the expected range – the variation due to special causes.
- x. Propose remedies and decide on the action needed to restore the status quo.
- xi. Take the agreed action and check that process stability has been restored.

3.2 Nature of Shewhart control charts

As described by ISO 8258:1991, a Shewhart control chart requires data obtained by sampling the process at approximately regular intervals. The intervals may be defined in terms of time (for example hourly) or quantity (every lot). Usually, each subgroup consists of the same product or service with the same measurable units and the same subgroup size. From each subgroup, one or more subgroup characteristics are derived, such as the subgroup average, \bar{x} , and the

subgroup range (R), or the standard deviation (s). A Shewhart control chart is a graph of the values of a given subgroup characteristic versus the subgroup number.

It consists of a central line (CL) located at a reference value of the plotted characteristic. In evaluating whether or not a state of statistical control exists, the reference value is usually the average of the data being considered. For process control, the reference value is usually the long-term value of the characteristic as stated in the product specifications or a nominal value of the characteristic being plotted based on past experience with the process or from implied product or service target values. The control chart has two statistically determined control limits, one on either side of the central line, which are called the upper control limit (UCL) and the lower control limit (LCL).

The control limits on the Shewhart charts are at a distance of 3σ on each side of the central line, where σ is the population within-subgroup standard deviation of the statistic being plotted. The within subgroup variability is used as a measure of the random variation. Sample standard deviations or appropriate multiples of sample ranges are computed to give an estimate of σ . This measure of σ does not include subgroup-to-subgroup variation but only the within-subgroup components. The 3σ limits indicate that approximately 99,7 % of the subgroup values will be included within the control limits, provided the process is in statistical control. Interpreted another way, there is

approximately a 0,3 % risk, or an average of three times in a thousand, of a plotted point being outside of either the upper or lower control limit when the process is in control.

When a process is in statistical control, the control chart provides a method for continuously testing a statistical null hypothesis that the process has not changed and remains in statistical control.

When a plotted value falls outside of either control limit or a series of values reflect unusual patterns the state of statistical control can no longer be accepted. When this occurs, an investigation is initiated to locate the assignable cause and the process may be stopped or adjusted.

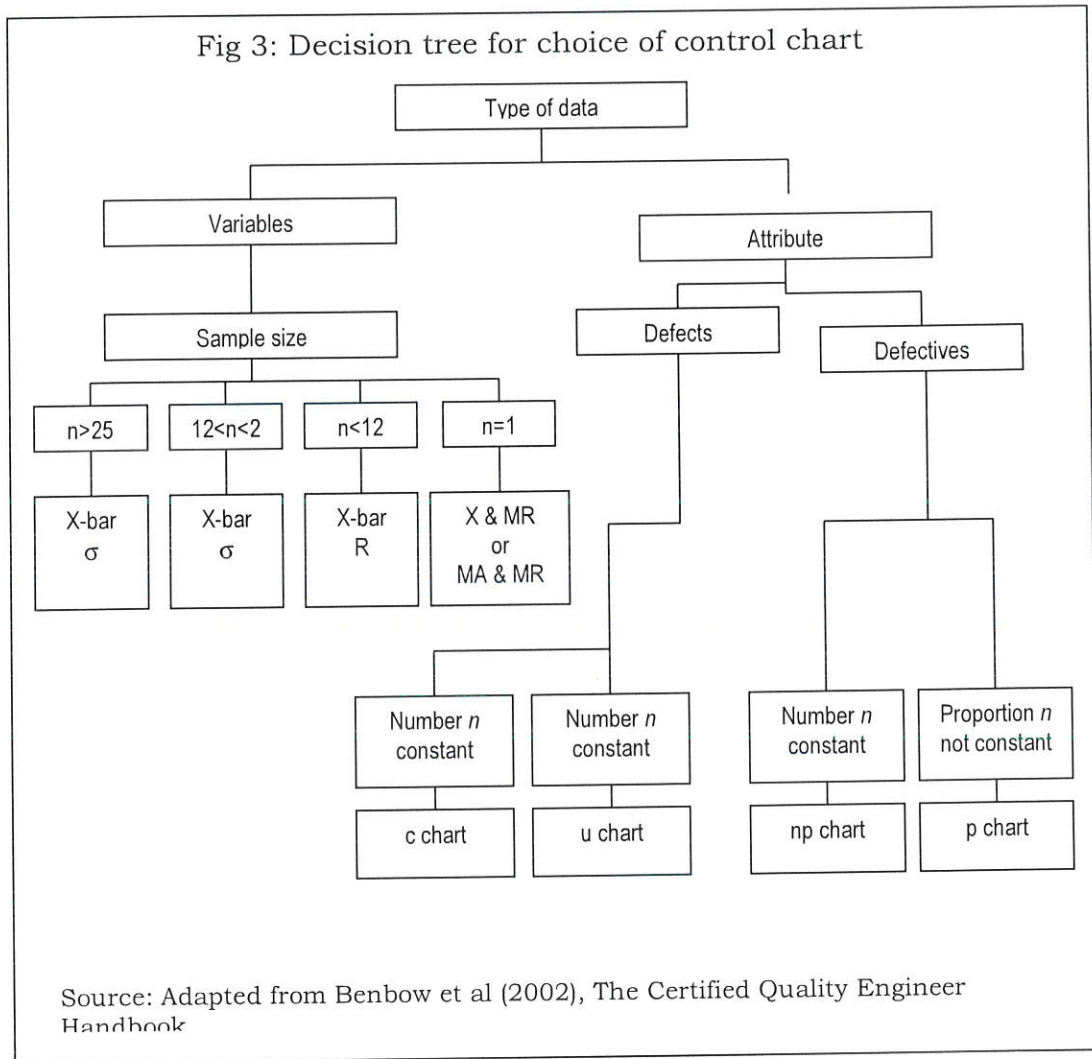
When control charts are first set up for a process, it frequently occurs that the process will be found to be out of control. Control limits calculated from data from an out-of-control process would lead to erroneous conclusions because they would be too far apart. Consequently, it is always necessary to bring an out-of-control process into control before permanent control chart parameters are established. Deming (1986) stated the reason for using control chart in industry is to determine whether a process or system is stable or in a state of statistical control. If a process is not in statistical control, its variability is called 'common cause.'

Special cause variation is a cause of variation that can be assigned to a specific or special condition that does not apply to other events. It occurs because something has happened that should not have happened such as use of wrong material, an inaccurate measuring device, a worn-out tool, a sick employee, the weather conditions, an accident, a stage omitted, etc. This kind of variation, as they are not always present, needs to be searched for the cause immediately and get eliminated. Eliminating the special causes is part of quality control (Hoyle, 2003) – taking corrective action to prevent the recurrence of a problem.

Random variation is inherent to the capability (Benbow et al, 2003) of a process and includes a wide range of variation; however the total sum of these random or common causes is measurable. Random variation can not be eliminated without modifying the process, i.e. the system itself must be changed to increase its capability.

3.3 Types of control charts

Shewhart control charts are basically of two types: variables control charts and attributes control charts. Figure 3 illustrates a decision tree of the types of available control charts, on which the choice depends upon the type of data, the size of the sample, and whether the sample size is constant or variable.



For each of the control charts, there are two distinct situations:

- (i) *When no standard values are given-* the purpose here is to discover whether observed values of the plotted characteristics, such as subgroup average value (\bar{X}), subgroup range (R) or any other statistic, vary among themselves by an amount greater than that which should be attributed to chance alone. Control charts based entirely



on the data collected from samples are used for detecting those variations caused other than by chance, and

- (ii) *When standard values are given-* The standard values are some specified requirement or target values. The purpose here is to identify whether the observed values of \bar{X} , etc., for several subgroups of n observations each, differ from the respective standard values X_0 , etc. by amounts greater than that expected to be due to chance causes only. The difference between charts with standards given and those where no standards are given is the additional requirement concerning the location of the centre and variation of the process for no-standard case.

Variable control charts

Variable data represent observations obtained by measuring and recording the numerical magnitude of a characteristic for each of the units in the subgroup under consideration. Examples of variables measurements are length in meters, resistance in ohms, noise in decibels, etc. Variables charts - and especially their most customary forms, the \bar{X} and R charts - represent the classic application of control charting to process control.

Control charts for variables are particularly useful for several reasons (ISO 8258:1991). These are:

- (i) Most processes and their output have characteristics that are measurable, so the potential applicability is broad.
- (ii) A measurement value contains more information than a simple yes-no statement.
- (iii) The performance of a process can be analyzed without regard to the specification. The charts start with the process itself and give an independent picture of what the process can do. Afterwards, the process may or may not be compared with the specification.
- (iv) Although obtaining one piece of measured data is generally more costly than obtaining one piece of go/no go data, the subgroup sizes for variables are almost always much smaller than those for attributes, and so are more efficient. This helps to reduce the total inspection cost in some cases and to shorten the time gap between the production of parts and corrective action.

Mean (\bar{X}) chart and Range (R) or Standard deviation (s) chart

Variables charts can describe process data in terms of both spread (piece-to-piece variability) and location (process average). Because of this, control charts for variables are almost always prepared and analyzed in pairs - one chart for location and another for spread. The most commonly used pair is the \bar{X} and R charts.

Table 1 and Table 2 give the control limit formulae and the factor for variables control charts respectively (ISO 8258:1991).

Table 1- Control limit formulae for Shewhart variable control charts

Statistic	No standard values given		Standard values given	
	Central line	UCL and LCL	Central line	UCL and LCL
\bar{X}	$\bar{\bar{X}}$	$\bar{\bar{X}} \pm A_2 \bar{R} \text{ or } \bar{\bar{X}} \pm A_3 \bar{s}$	$X_0 \text{ or } \mu$	$X_0 \pm A\sigma_0$
R	\bar{R}	$D_3 \bar{R}, D_4 \bar{R}$	$R_0 \text{ or } d_2 \sigma_0$	$D_1 \sigma_0, D_2 \sigma_0$
s	\bar{s}	$B_3 \bar{s}, B_4 \bar{s}$	$s_0 \text{ or } c_4 \sigma_0$	$B_5 \sigma_0, B_6 \sigma_0$

Note- X_0, R_0, s_0, μ and σ_0 are given standard values.

Table 2- Factors for computing control charts lines

Observations in subgroup n	Factors for control limits											Factors for central line			
	A	A_2	A_3	B_3	B_4	B_5	B_6	D_1	D_2	D_3	D_4	C_4	$1/C_4$	d_2	$1/d_2$
2	2,121	1,880	2,659	0,000	3,267	0,000	2,606	0,000	3,666	0,000	3,267	0,797 9	1,253 3	1,128	0,886 5
3	1,732	1,023	1,954	0,000	2,568	0,000	2,276	0,000	4,358	0,000	2,574	0,806 2	1,120 4	1,083	0,590 7
4	1,500	0,729	1,628	0,000	2,266	0,000	2,068	0,000	4,608	0,000	2,282	0,921 3	1,085 4	2,059	0,485 7
5	1,342	0,577	1,427	0,000	2,089	0,000	1,984	0,000	4,918	0,000	2,114	0,940 0	1,063 8	2,326	0,429 9
6	1,225	0,483	1,287	0,030	1,970	0,029	1,974	0,000	5,078	0,000	2,094	0,951 5	1,051 0	2,534	0,394 6
7	1,134	0,419	1,182	0,118	1,882	0,113	1,886	0,204	5,204	0,076	1,924	0,959 4	1,042 3	2,704	0,369 8
8	1,061	0,373	1,090	0,185	1,815	0,179	1,751	0,388	5,306	0,136	1,964	0,965 0	1,036 3	2,847	0,351 2
9	1,000	0,337	1,032	0,239	1,761	0,232	1,707	0,547	5,393	0,184	1,816	0,989 3	1,031 7	2,970	0,338 7
10	0,949	0,308	0,975	0,284	1,716	0,276	1,669	0,687	5,469	0,223	1,777	0,972 7	1,028 1	3,078	0,324 9
11	0,905	0,285	0,927	0,321	1,679	0,313	1,637	0,811	5,535	0,256	1,744	0,975 4	1,025 2	3,173	0,315 2
12	0,868	0,268	0,886	0,354	1,648	0,346	1,610	0,922	5,594	0,283	1,717	0,977 6	1,022 9	3,258	0,306 9
13	0,832	0,249	0,850	0,382	1,618	0,374	1,585	1,025	5,647	0,307	1,693	0,979 4	1,021 0	3,336	0,299 8
14	0,802	0,235	0,817	0,406	1,594	0,399	1,563	1,118	5,696	0,328	1,672	0,981 0	1,019 4	3,407	0,293 5
15	0,775	0,223	0,789	0,428	1,572	0,421	1,544	1,203	5,741	0,347	1,653	0,982 3	1,018 0	3,472	0,288 0
16	0,750	0,212	0,763	0,448	1,552	0,440	1,526	1,282	5,782	0,363	1,637	0,983 5	1,016 8	3,532	0,283 1
17	0,728	0,203	0,739	0,468	1,534	0,458	1,511	1,358	5,820	0,378	1,622	0,984 5	1,015 7	3,588	0,278 7
18	0,707	0,194	0,718	0,482	1,518	0,475	1,496	1,424	5,856	0,391	1,608	0,985 4	1,014 8	3,640	0,274 7
19	0,688	0,187	0,698	0,497	1,503	0,490	1,483	1,487	5,891	0,403	1,597	0,986 2	1,014 0	3,689	0,271 1
20	0,671	0,180	0,680	0,510	1,490	0,504	1,470	1,540	5,921	0,415	1,585	0,986 9	1,013 3	3,735	0,267 7
21	0,655	0,173	0,663	0,520	1,477	0,518	1,459	1,605	5,951	0,425	1,575	0,987 6	1,012 6	3,778	0,264 7
22	0,640	0,167	0,647	0,534	1,466	0,528	1,448	1,659	5,979	0,434	1,566	0,988 2	1,011 9	3,819	0,261 6
23	0,626	0,162	0,633	0,545	1,455	0,538	1,438	1,710	6,006	0,443	1,557	0,988 7	1,011 4	3,858	0,259 2
24	0,612	0,157	0,619	0,555	1,445	0,549	1,429	1,759	6,031	0,451	1,548	0,989 2	1,010 9	3,895	0,256 7
25	0,600	0,153	0,606	0,565	1,435	0,558	1,420	1,806	6,056	0,459	1,541	0,989 6	1,010 5	3,931	0,254 4

Source: ISO 8258(1991)

Control chart for individuals (\bar{X})

In some process control situations, it is either impossible or impractical to take rational subgroups. The time or cost required to measure a single observation is so great that repeat observations cannot be considered. This would typically occur when the measurements are expensive (e.g. in a destructive test) or when the output at any time is relatively homogeneous.

In the case of charts for individuals, since there are no rational subgroups to provide an estimate of within-batch variability, control limits are based on a variation measure obtained from moving ranges of, often, two observations. A moving range is the absolute difference between successive pairs of measurements in a series; i.e. the difference between the first and second measurements, then between the second and third, and so on. From the moving ranges, the average moving range R is calculated and used for the construction of control charts. Also, from the entire data, the overall average \bar{x} is calculated. Table 3 gives the control limit formulae for control charts for individuals (ISO 8258:1991).

Table 3- Control limit formulae for control charts for individuals

Statistic	No standard values given		Standard values given	
	Central line	UCL and LCL	Central line	UCL and LCL
Individual, X	\bar{X}	$\bar{X} \pm E_2 \bar{R}$	X_0 or μ	$X_0 \pm 3\sigma_0$
Moving range, R	\bar{R}	$D_4 \bar{R}, D_3 \bar{R}$	R_0 or $d_2 \sigma_0$	$D_2 \sigma_0, D_1 \sigma_0$

Notes

1. X_0, R_0, s_0, μ and σ_0 are given standard values.
2. \bar{R} denotes the average moving range of $n=2$ observations.
3. The values of the factors d_2, D_1, D_2, D_3, D_4 and, indirectly, $E_2 (=3/d_2)$ can be obtained from table 2 for $n=2$.

Source: ISO 8258(1991)

Procedure for developing variable control charts

ES ISO 8258 (2004) describes the following control procedure is followed to prepare variable control charts.

- (1) Gather and analyze data, calculating averages and ranges.
- (2) Plot the R chart first. Check the data points against the control limits for points out of control or for unusual patterns or trends. For each indication of an assignable cause in the range data, conduct an analysis of the operation of the process to determine the cause; correct that condition and prevent it from recurring.
- (3) Exclude all subgroups affected by an identified assignable cause; then recalculate and plot the new average range (\bar{R}) and

control limits. Confirm that all range points show statistical control when compared to the new limits, repeating the identification/ correction/ recalculation sequence if necessary.

- (4) If any subgroups are dropped from the R chart because of identified assignable causes, they shall also be excluded from the \bar{X} chart. The revised \bar{R} and \bar{X} values shall be used to recalculate the trial control limits for averages, $\bar{X} \pm A_2 \bar{R}$.

NOTE- The exclusion of subgroups representing out-of-control conditions is not just “throwing away bad data”. Rather, by excluding the points affected by known assignable causes, we have a better estimate of the background level of variation due to chance causes. This, in turn, gives the most appropriate basis for the control limits used to detect most efficiently future occurrences of assignable causes of variation.

- (5) When the ranges are in statistical control, the process spread (the within-subgroup variation) is considered to be stable. The averages can then be analyzed to see if the process location is changing with time.
- (6) Now plot the x chart and check the data points against the control limits for points out of control or for unusual patterns or trends. As for the \bar{X} chart, analyze any out-of-control condition and take corrective and preventive action. Exclude any out-of-

control points for which assignable causes have been found; recalculate and plot the new process average (\bar{X}), and control limits. Confirm that all data points show statistical control when compared to the new limits, repeating the identification/correction/recalculation sequence if necessary.

- (7) When the initial data to establish control limit reference values are consistently contained within the trial limits, extend the limits to cover future periods. These limits shall be used for ongoing control of the process, with the responsible individuals (operator and/or supervisor) responding to signs of out-of-control conditions on either \bar{X} or R chart with prompt action.

Interpreting the chart

A set of eight supplementary tests used for interpreting patterns in Shewhart charts is schematically presented in Table 4 (ISO 8258:1991). Although this can be taken as a basic set of tests, analysts should be alert to any unique patterns of points that might indicate the influence of special causes in their process. These tests should therefore be viewed as simply practical rules for action whenever the presence of assignable causes is indicated. An indication of any of the conditions stipulated in these tests is an indication of the presence of assignable causes of variation that must be diagnosed and corrected.

The upper and lower control limits are set at a distance of 3σ above and below the central line. For the purpose of applying the tests, the control chart is equally divided into six zones, each zone being 1σ wide. These are labeled A, B, C, C, B, A with zones C placed symmetrically about the central line.

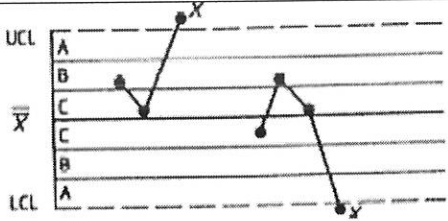
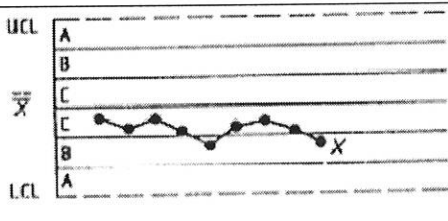
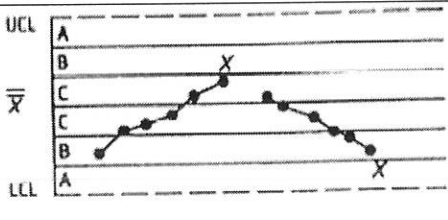
Zone A: The area defined by the average $\pm 1\sigma$

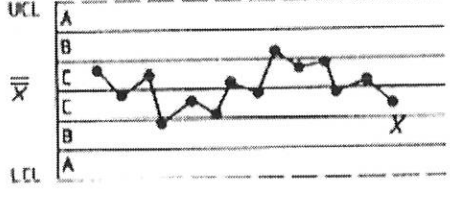
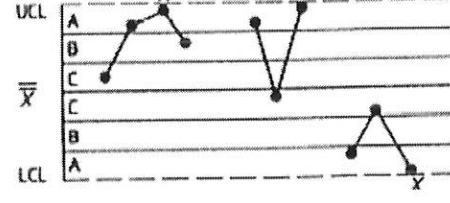
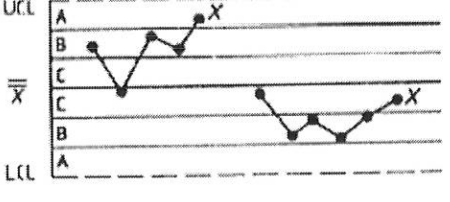
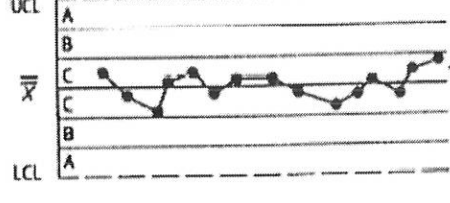
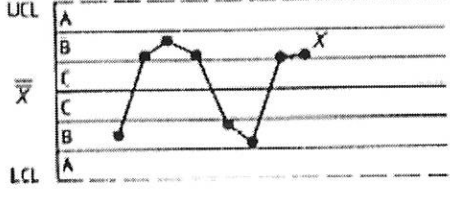
Zone B: The area defined by the limits of $\bar{X} - 1\sigma$ to $\bar{X} - 2\sigma$ and $\bar{X} + 1\sigma$ to $\bar{X} + 2\sigma$

Zone C: The area defined by the limits of $\bar{X} - 2\sigma$ to $\bar{X} - 3\sigma$ and $\bar{X} + 2\sigma$ to $\bar{X} + 3\sigma$

These tests are applicable to x charts and to individual (X) charts.

Table 4: Tests for assignable causes

<p>Test 1: One point beyond zone A</p>	 <p>A control chart with a central line labeled \bar{X}. The chart is divided into six zones labeled A, B, C, C, B, A from top to bottom. The upper control limit (UCL) is at the top and the lower control limit (LCL) is at the bottom. A data point is plotted in zone A above the UCL, and another data point is plotted in zone A below the LCL. The points are connected by a line.</p>
<p>Test 2: Nine points in a row in zone C or beyond on one side at central line</p>	 <p>A control chart with a central line labeled \bar{X}. The chart is divided into six zones labeled A, B, C, C, B, A from top to bottom. The upper control limit (UCL) is at the top and the lower control limit (LCL) is at the bottom. Nine data points are plotted in a row, all within zone C or beyond on one side of the central line. The points are connected by a line.</p>
<p>Test 3: Six points in a row steadily increasing or decreasing</p>	 <p>A control chart with a central line labeled \bar{X}. The chart is divided into six zones labeled A, B, C, C, B, A from top to bottom. The upper control limit (UCL) is at the top and the lower control limit (LCL) is at the bottom. Six data points are plotted in a row, showing a steady increase or decrease. The points are connected by a line.</p>

<p>Test 4: Fourteen points In a row alternating up and down</p>	 <p>A control chart with a central line labeled \bar{x} and control limits UCL and LCL. The chart is divided into zones A, B, and C above and below the center line. The data points show a clear alternating up-and-down pattern for 14 consecutive points, with the 14th point marked with an 'X'.</p>
<p>Test 5: Two out of three points In a row In zone A or beyond</p>	 <p>A control chart with a central line labeled \bar{x} and control limits UCL and LCL. The chart is divided into zones A, B, and C above and below the center line. The data points show two consecutive points in zone A (above zone C) and two consecutive points in zone A (below zone C), with the 4th and 7th points marked with an 'X'.</p>
<p>Test 6: Four out of five points in a row in zone B or beyond</p>	 <p>A control chart with a central line labeled \bar{x} and control limits UCL and LCL. The chart is divided into zones A, B, and C above and below the center line. The data points show four out of five consecutive points in zone B or beyond (above zone C and below zone B), with the 5th and 10th points marked with an 'X'.</p>
<p>Test 7: Fifteen points In a row In zone C above and below central line</p>	 <p>A control chart with a central line labeled \bar{x} and control limits UCL and LCL. The chart is divided into zones A, B, and C above and below the center line. The data points show 15 consecutive points in zone C, alternating above and below the center line, with the 15th point marked with an 'X'.</p>
<p>Test 8: Eight points in a row on both sides of central Line with none In zone C</p>	 <p>A control chart with a central line labeled \bar{x} and control limits UCL and LCL. The chart is divided into zones A, B, and C above and below the center line. The data points show 8 consecutive points on both sides of the center line, with none in zone C, and the 8th point marked with an 'X'.</p>

Attribute control charts

Anything we must measure with whole number is an attribute. These include nonconformance (rejects, rework and scrap) and nonconformities (defects). Attributes data are generally rapid and inexpensive to obtain and often do not require specialized collection skills. A single chart will suffice, unlike that of control charts for variables, since the assumed distribution has only one independent parameter, the average level.

Table 5: Control limit formulae for attribute control charts

Statistic	No standard values given		Standard values given	
	Central line	UCL and LCL	Central line	UCL and LCL
p	\bar{p}	$\bar{p} \pm 3\sqrt{\bar{p}(1-\bar{p})/n}$	p_0	$p_0 \pm 3\sqrt{p_0(1-p_0)/n}$
np	$n\bar{p}$	$n\bar{p} \pm 3\sqrt{n\bar{p}(1-\bar{p})}$	np_0	$np_0 \pm 3\sqrt{np_0(1-p_0)}$
c	\bar{c}	$\bar{c} \pm 3\sqrt{\bar{c}}$	c_0	$c_0 \pm 3\sqrt{c_0}$
u	\bar{u}	$\bar{u} \pm 3\sqrt{\bar{u}/n}$	u_0	$u_0 \pm 3\sqrt{u_0/n}$

Note- p_0 , np_0 , c_0 and u_0 are given standard values.

Source: ISO 8258(1991)

Table 6: Data plotted and application of attribute control chart

Chart	Data plotted	Application
np	Nonconformance (reject, scrap, rework) count, np	Shows whether the nonconformance rate has changed.
p	Nonconformance fraction, or percent, p	Same.
c	Defect count	Shows whether the average defect rate has changed.
u	Defect density (defects per part)	Same.

Source: Levinson and Tumbelty (1997). SPC essentials and productivity improvement- A manufacturing approach. ASQ Press

Process Capability and Indices

Once assignable causes are systematically eliminated and the process is operating under a state of statistical control, its performance is predictable and its capability to meet specifications can be assessed.

As defined by equation set in Table 7, Process capability indices measures a process' ability to meet specifications.

Table 7: Process capability indices

Symbol	Equation	Description
C_p	$C_p = \frac{USL - LSL}{6\sigma}$	C_p is the ratio of the specification width to the process width. The process width is 6σ , where σ is the process standard deviation. This is also the width of the Shewhart control limits ($\pm 3\sigma$).
CPL	$CPL = \frac{\mu - LSL}{3\sigma}$	CPL measures the process' ability to meet the lower specification.
CPU	$CPU = \frac{USL - \mu}{3\sigma}$	CPU measures the process' ability to meet the upper specification.
C_{pk}	$\min [CPL, CPU]$	C_{pk} is the minimum of CPL and CPU. When the process is at the target or nominal, $CPL=CPU= C_{pk}= C_p$, and the yield is at its maximum.

Source: Levinson and Tumbelty (1997). SPC essentials and productivity improvement- A manufacturing approach. ASQ Press

σ is estimated from the average within the subgroup variability and is given by \bar{s}/c_4 or \bar{R}/d_2 , where \bar{s} is the average value of the subgroup sample standard deviation.

The interpretations of these indices are elaborated under Table 8.

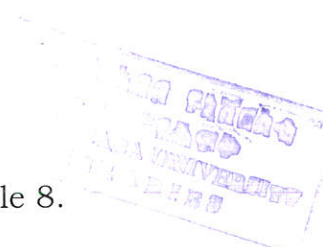


Table 8: Guidelines for process capability

C_p	Process status
$C_p < 1$	Poor. The Shewhart control limits are wider than the specification limits. The process can make bad parts even when it is in control.
$C_p < 1.33$	Fair.
$1.33 < C_p$	Acceptable. 1.33 is the basic standard (because there is always some sampling variation and no process is ever fully in statistical control).
$2 \leq C_p$	Excellent. The process will make less than 2 parts per billion nonconformances.

Source: Levinson and Tumbelty (1997). SPC essentials and productivity improvement- A manufacturing approach. ASQ Press

3.4 Introducing plastics and its manufacturing process

The term 'plastic' is as common as are the articles made from plastic material. It would be difficult indeed to go through an average day without coming into contact with at least one plastic article. The word "plastic" means soft and pliable, or, capable of being shaped or molded. From a more scientific standpoint, the characteristics, which taken together denote the plastics of modern industry, are as follows (Anderson and Thompson, 1950):

- (1) synthetically produced;
- (2) composed mainly of a resin or a similar organic binder;

the following: (1) a hardening agent, usually formaldehyde; (2) a plasticizer or softening agent, commonly a phosphate, phthalate or castor oil; (3) a solvent, such as alcohol, ether or acetone; (4) a coloring agent, which may be either a dye or a pigment; and (5) a filler, or bulking agent as it is sometimes called. In the case of laminated or coated products, plywood, glass, cloth, paper or metal are commonly used. After the materials are mixed or combined, the plastic mass is given shape by molding, pressing, rolling, or extruding. The shapes, usually known as standard in the plastics market, are mainly rods, tubes, bars, strips and sheets, each varying in dimension and other detail. Baking, tempering or curing, as well as burnishing or polishing, may also be necessary to give permanence and proper finish to the various shapes. The operations in this stage are mechanical and thermal in nature, rather than chemical, and do not differ greatly from those carried on in the ceramic and metallurgical industries.

The fourth or fabricating stage consists in cutting, punching, drilling, machining and polishing the plastic materials as may be needed in the various parts and preparing them for assembly into the ultimate product. These operations are mechanical in nature and quite similar to those performed in the woodworking plants and the machine shops of other industries. Many of the standard machines and the ordinary occupational skills of these plants and shops can be adapted to the processing of plastics without extensive changes.

Plastic materials are usually divided into two classes based upon their reaction to heat, namely, thermosetting and thermoplastic. A thermosetting plastic is one which does not return after setting to a plastic or liquid state upon the application of heat. Thermoplastic materials, on the other hand, are those which may be changed back into a plastic state, repeatedly, if desired, by the application of heat.

Thermoplastic materials, the only type that is being produced by Ethiopia Plastic S.C., are capable of being molded when heated and they harden when cooled. No chemical change takes place during the molding process as in the thermosetting material. Only a physical change takes place and the chemical structure of the compound is not altered. Since no chemical change has taken place, the molded material can be reground into powdered form, reheated, and remolded. This characteristic of thermoplastic materials has been compared to the melting and re melting of wax. Thermoplastic products, after having served their original purpose, may be returned to the scrap pile to compete with virgin materials in the manufacture of new products. Since this material does not corrode or lose any of its qualities perceptibly with the passage of time, stock piles may be counted upon to grow as the industry approaches maturity. Situations will develop, no doubt, similar to those which existed in the case of many metals during the depression, when over half of the annual production was supplied from previously used material.

Some of plastic manufacturing processes as discussed by Spaak (1975) are as follows:

Blow Molding- The blow molding process is used to make hollow articles especially bottles, drums and other liquid containers. The blow molding process itself consists basically of heating a hollow tube of a particular plastic to its softening point, placing it between the faces of a cold mold and forcing high pressure air into the center of the hollow tube or parison to conform to the contour of the mold. The hot plastic is expanded against the cavity of the mold and allowed to cool, in place. When the cooling process is completed, the mold is opened and the blow-molded article is removed. The blow molding process follows four basic steps: production of parison, positioning of the mold halves to entrap the parison, forming the neck of the container, and injection of air and cooling of the mold.

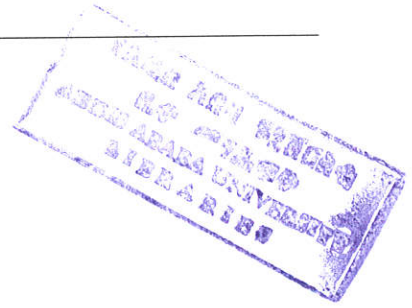
Film Blowing- Thermoplastics raw material of low-density polyethylene is fed on the hopper. The poured raw material enters in the film blowing extrusion machine with the help of screw rotation. The material is heated in the feeding zones of the extruder up to 115-170°C. After complete homogenizations, the melt is changed into films by the help of external and internal air blowing system. The film is cooled by air and the tubular film

produced taken to the store while others to the printing section. After printing it goes to the cutting and sealing section. The finished product is weighed & taken into the store. The scraps of film products are sent into recovery unit.

Extrusion- Thermoplastics are converted from raw granular or powdered material to continuous pin lengths of finished products through the extrusion process. These products include pipes, conduits, shutter profiles and hoses. Wide use of the extruder is made in the application of insulation and jacketing used in wire and cable, where a crosshead die with the wire travels at right angles to the flow of PVC insulation.

Injection Molding- In injection molding, thermoplastic polymers or pellets are heated to a molten state and are forced under pressure into a relatively cooled mold where the polymer solidifies to form the object. Time, pressure and temperature are basic variables that need to be controlled. Normal scrap generated in the injection molding of thermoplastics materials can be ground into small particles and reused. This adds to the economical features of the process. The products requiring intricate shapes and tight tolerances most readily lend themselves to injection molding.

Chapter Four



4. Research Findings

4.1 Method of analysis

To find out the objective evidence on the status of quality assurance activities of the company the strategic plan, annual plans, reports, operation manuals and procedures were analyzed. Semi-structured interviews were also conducted with the planning expert, the quality control service head, quality control experts, heads of film blowing and extrusion production sections, and operators in different production lines.

Three rounds of observations were made during actual production and inspection activities in blowing and extrusion productions. In addition, a quality control personnel and an operator were assigned to collect data from a batch of PVC pipes of which the outer diameter and wall thickness are measured. The data were analyzed and the graphs plotted using SPSS software.

4.2 Company Profile

The Ethiopian Plastic Factory was established in 1960 by five Italian share holders with an initial capital of 270 000 Birr to produce plastic conduits and insulated electrical cables. Four years later, the capital of the factory rose to 370 000 Birr, the number of shareholders-including the two Ethiopians-to seven, and the total number of shares to 370. In

1967 the capital increased to 2 220 000 Birr, and the type of products to seven. Partially nationalized in 1975, the government owned 55% of the shares and administered by a board of management, until it was fully nationalized in 1978.

The factory is sited in Kirkos and Bole Woredas and lied on total area of 24 500 m². With a capital of Birr 29 670 000 and nearly 380 employees, the factory is currently being administered by a board of directors accountable to the Privatization and Public Enterprises Supervisory Agency.

Vision

To maintain leadership and larger market share in the plastic industry based on product and service quality.

Mission

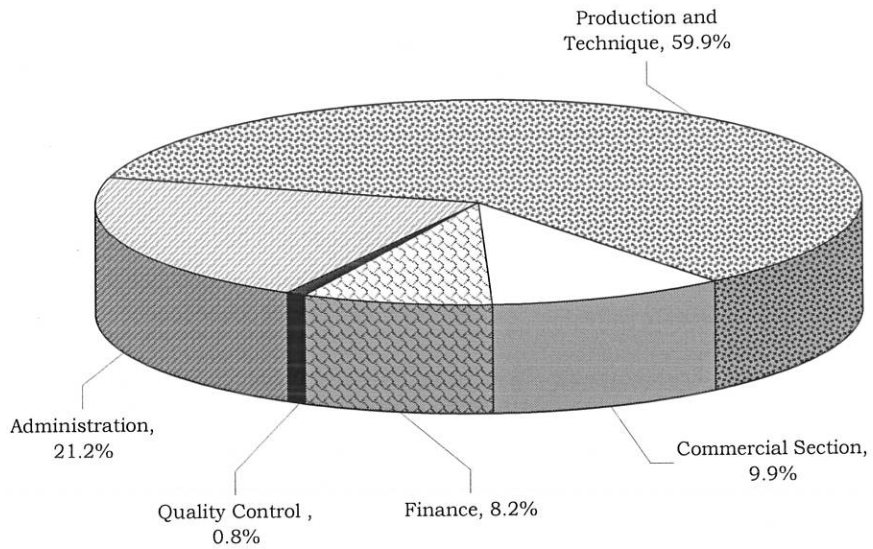
To manufacture and supply, making use of latest technology and creativity of its employees, high quality plastic products for construction, packaging, and household purposes that satisfy customers' requirements.

Organizational structure and man power

As shown on Annex 1, the factory comprises of five departments and two services that are directly accountable to the general manager.

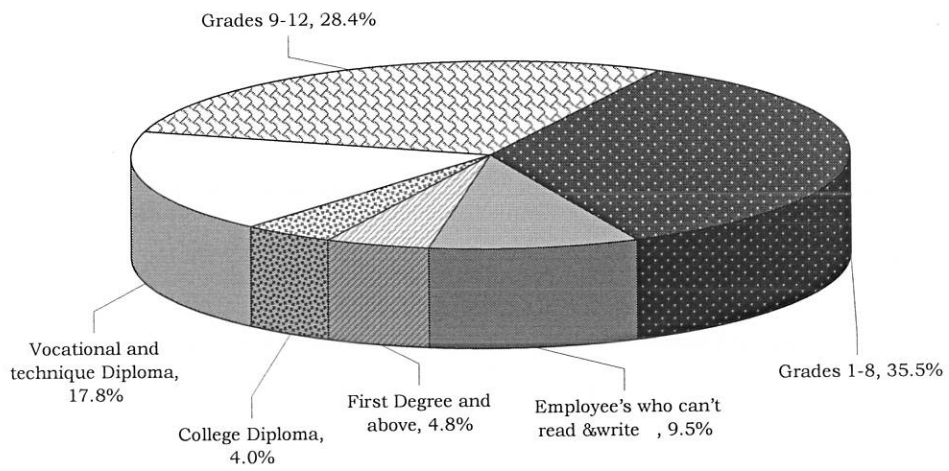
The man power distribution by function and education is illustrated under Figure 4 and Figure 5.

Figure 4: EPSC Man power distribution by function



Source: EPSC information brochure (2006)

Figure 5: EPSC Man power distribution by education



Source: EPSC information brochure (2006)

Products and production technology

Products of the Ethiopian Plastic S.C. include:

- Polyethylene products: film bags, wrapping materials, sacks (both heavy and light-duty);
- Insulated electric copper wires: twin insulated and cables;
- PVC products: boots, garden hose, pipe, shutter profile, plastic bottles, rigid and soft conduit, ribbon band, ball point pen, floor tiles, bottle stopper, water jugs, electric wires and cables insulation, etc.

The company works on a three shift basis per day using manual, semiautomatic and automatic machines of the following category and quantity:

- Film blowing machine 8
- Extrusion machine 7
- Blow molding machine 1
- Injection molding machine 5
- Recovery machine 3

Suppliers and customers

The company has no specific suppliers of raw materials, which it depend upon. Any trader which accept the bid agreement can participate by providing samples of raw materials according to the specification described in bid announcement. The sample raw materials are tested for their critical quality parameters in the factory's laboratory

or external laboratories. The test results, i.e. degree of compliance of the specimen with the specification are the basis for acceptance or rejection of suppliers. Following acceptance, financial evaluation of the bid will be processed. Records indicate that 99% of the raw materials is imported from Middle East countries and only 1% (socks for boots is locally available).

Textile industries, construction industries, food and agro industries, the Ethiopian Electrical Light and Power Corporation, laundries, distributors and Individual household users comprise majorities of customers of the company.

Quality system objective

The company has an objective to implement ISO 9001:2000 Quality Management System and be certified by mid 2008.

4.3 Quality control practice of the company

The quality control department is the pioneer of quality related issues in the company. Its main responsibilities include ensuring the quality of raw materials complies to specification before a shipment is ordered, the required quality level is maintained during production, and the final product conforms to specification set by the company and/or customers.

The company has developed a quality control policy to guide the activities concerning quality. The policy, as stated in the quality control manual, has the following aims:

- To keep and maintain the quality standards of the plastic products produced by the factory;
- To compare the raw material quality specifications with International Standards quality specifications for their compliance; and
- To produce quality products by avoiding the problems that may encounter during production process and by keeping the proper functioning of production machineries and auxiliaries.

Customer complaints related to product characteristics are also forwarded to this function for investigation, i.e. to find out root causes of the complaint and propose corrective actions.

As a component of the ISO 9001:2000 QMS project rounds of training are being conducted to employees to upgrade their knowledge on general concepts of quality and importance of meeting customer requirements.

The company has organized quality circles for the purpose of generating improvement ideas in any process or part of the company, and solving specific problems directed from management.

The actual quality control practice can be evaluated in three

consecutive stages: incoming (raw material), in-process, and final product phases.

Incoming quality control phase includes controlling raw material parameters such as melt flow rate, heat stability, working temperature, processability, toxicity, color, and light fastness. However, due to technical failure and unavailability of testing machines, melt-flow index, processability and visual inspection on packaging are the only parameters being tested.

The in-process quality parameters are generally controlled by machine settings and adjustments except the blending of raw materials and handling of finished products which is done manually. The variables in this stage are material temperature, mold temperature, injection pressure, mold adjustment, curing speed, and chilling. The majority of machines, sick with old age, are observed to cause production interruption and scrap. For some machines, the control/adjustment knobs are not functional which make control of critical parameters difficult.

The quality control personnel have a regular daily routine to control the processes in every shift. The person in charge of this inspection task, monitor the process to verify absence of non conformity in the production process. If nonconformance products or process are observed, the quality control personnel will propose counteractive

measures that may include interruption of production until the problem is solved. This is usually done in agreement with production supervisors. Besides, the defects observed, the causes and corrective action taken are all recorded on a daily record sheet.

Some of the quality related nonconformance, as indicated in daily record sheet, is:

- Film bag – oversize, thickness, poor seal poor print, shrink poor surface finish, cutting machine problem.
- Bottle stopper – excess flash, mold wear
- Wire – overweight, under weight
- Switch box – flash, mold wear
- Pipe – burning, mechanical failure on machines

In this stage, despite the fact frequent measurements are made primarily by operators and quality control personnel, the data are not formally recorded. With the exception of recorded data on weekly scrap level, quantitative data analysis on critical process parameters are not carried out. In other words, neither the quality control personnel nor production operators are observed using statistical process control tools. Every time a product parameter is seen to get out of the specification limit, operators are observed making adjustments on the machine to control the observed variation.

The interview with quality control personnel, production heads and operators revealed the following major potential causes of variations which directly or indirectly affect the quality of products:

Material

- Contamination during handling
- Moisture
- Poor blending
- Inadequate inspection of raw materials
- Mix of virgin raw material with recycled material

Machine

- Machine setup for new batches
- Wrong mold adjustment
- Mold temperature
- Injection speed
- Frequency of preventive maintenance
- Wear and tear of components
- Machine breakdown

Method

- Existence of clear quality policy and objectives
- Availability of procedures and work instructions
- Use of sampling methods/techniques
- Labeling/identification of different batches
- Use of different standards for setting product specification

People (Man power)

- Insufficient competence
- Lack of hands-on training on new machines and quality control techniques
- Motivation
- Health of employees
- Alertness during long working hours and night shifts

Measurement

- Calibration status of measuring devices
- Zero setting for digital measuring devices

Environment

- Room temperature during day and night shifts
- Cleanliness of production and storage rooms
- Power fluctuation and interruptions

At the final product stage variables such as length, thickness, strength, and color are the variable quantities that need to be controlled before the product is ready for delivery to customers. Although quality control personnel check final products at the end of production line on random basis for conformance with specification, no standardized statistical method for sample size and acceptable quality level is applied. If the quality personnel have some doubt of whatever on the product quality, a 100% visual inspection may be made before transferring the product to store.

A daily production report, describing the amount of raw materials, the final product and scrap level in weight is prepared by the production supervisor and communicated to quality control service on weekly basis. Based on these the quality control service summarizes the weekly production, comparing amount of input, output, scrap and cost of each. Whenever the percentage of cost incurred due to scraps happened to be above the standard limit acceptable by the company, the cause is indicated on the weekly production report.

Nonconforming (defective) items are reported into two categories as recyclable, which can be reprocessed as raw material, and non-recyclable which can not possibly be reprocessed and remain as scrap/waste. In both cases cost is inevitable as reprocessing also incurs additional labor, machine, and overhead costs.

As an illustration the nonconforming summary report on selected products for the year 2005/2006 (1998 ET) is shown under Table 9.

Table 9: Extracted summary report of nonconforming items for the year 2005/2006

Material	Input (kg)	Output (kg)	Nonconforming items ¹		Cost of nonconforming items (Birr)
			(kg)	(%)	
PE Film	355488	337429	18059	5.1	56573
PVC Pipe	314148	294873	19275	6.1	18245
Electric Wire	897867	894326	3541	0.4	15334
Garden Hose	53107	51875	1232	2.3	65319
Plastic Boots	204003	191215	12788	6.3	74138
Flexible Conduit	32357	29190	3167	9.8	41630

Source: EPSC 2005/2006 annual report (2006)

4.4 Analyzing applicability of control charts

In order to analyze the applicability of control charts data is collected from a sample of PVC pipe of single batch. The company standard of the PVC products is listed under Table 10.

¹ Nonconforming items include both recoverable and non-recoverable items

Table 10: Dimensional specification of PVC pipe (set by the company)

Designation	Weight ² (kg/m)	Outside diameter (mm)	Wall thickness (mm)	Nominal length (m)
PVC pipe 50	0.33	50	1.5	6
PVC pipe 75	0.63	75	2.0	
PVC pipe 110	1.02	110	2.5	
PVC pipe 125	1.33	125	3.0	
PVC pipe 160	2.25	160	3.6	
PVC pipe 200	3.70	200	4.5	

Source: EPSC quality control manual

Twenty samples with subgroup size of five are measured using calipers of resolution 0.01 mm. The data are organized in two sets, i.e., outside diameter measured in mm, and wall thickness measured in mm.

Making use of the decision tree model for choice of control chart (see Fig 3), \bar{X} and R chart is selected as appropriate model for the analysis. Accordingly, the subgroup averages and ranges are calculated and plotted (see Table 11, Table12, Figure 6 and Figure 7).

² The weights are for PVC pipes designed for a pressure of 4 bar.

Figure 6: Average and range chart - outer diameter

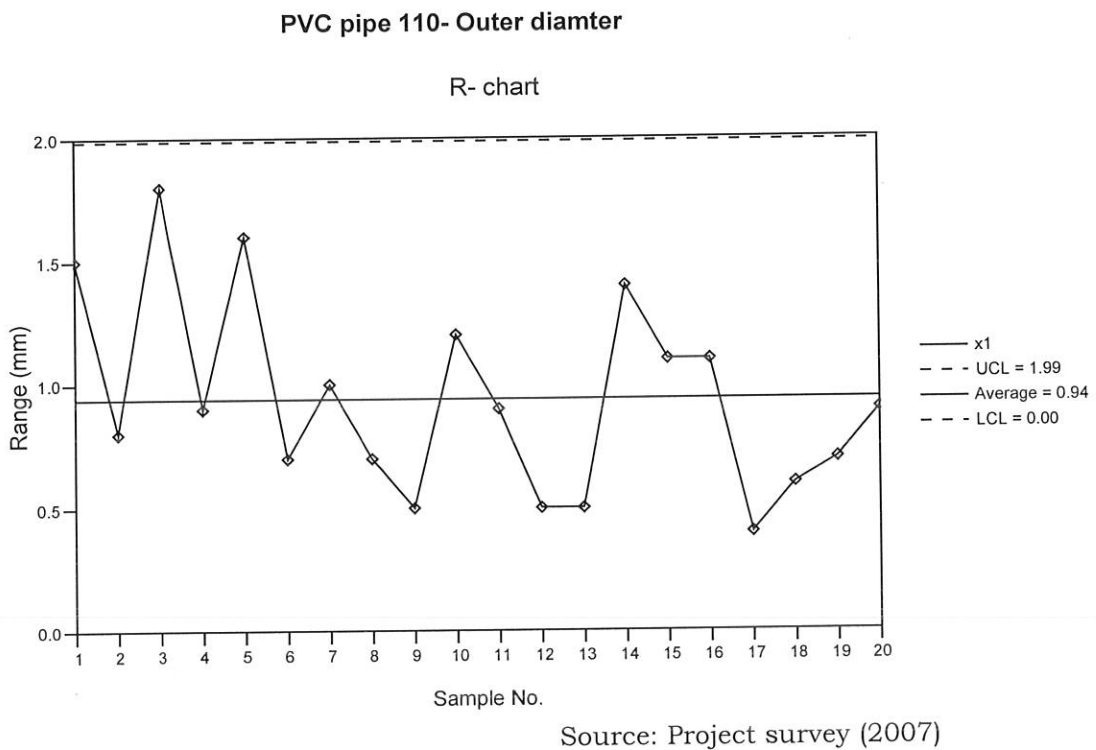
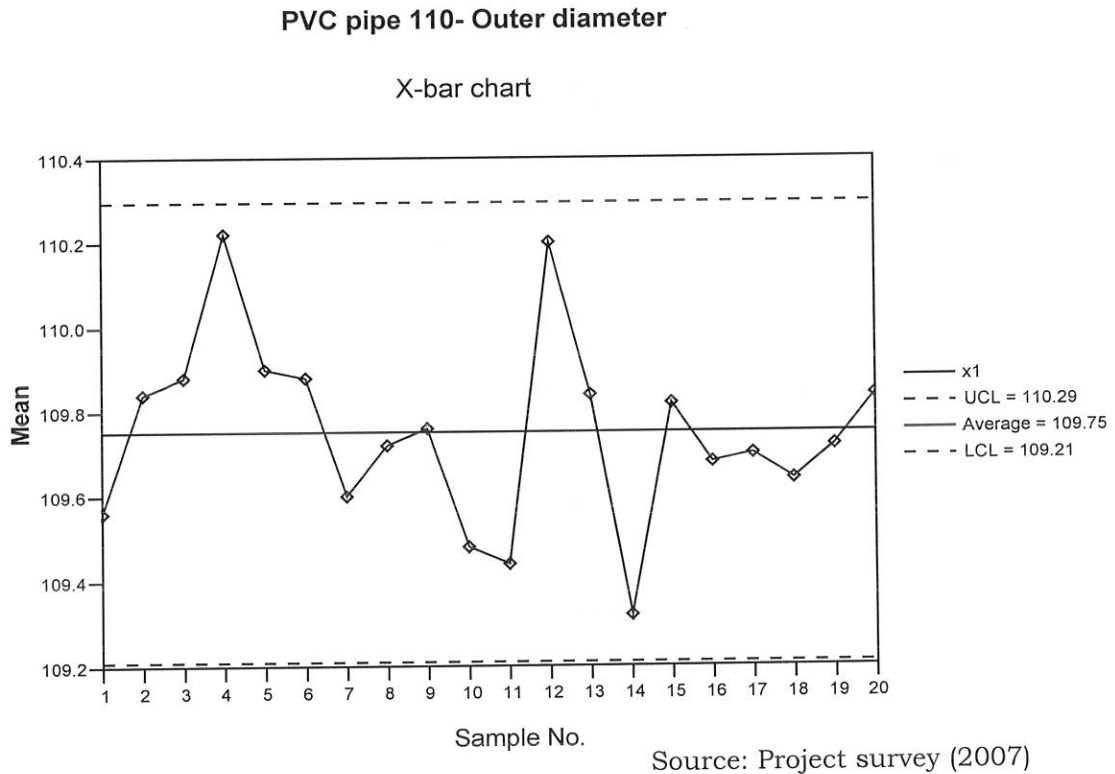


Table 12: PVC Pipe wall thickness in mm

Sample No.	Subgroup					\bar{X}	R
	X1	X2	X3	X4	X5		
1	2.3	2.3	2.1	2.8	2.7	2.4	0.7
2	2.9	2.5	2.7	2.3	2.4	2.6	0.6
3	2.2	2.5	2.5	2.9	2.5	2.5	0.7
4	2.5	2.3	2.8	2.5	2.5	2.5	0.5
5	2.4	2.2	2.0	2.0	2.3	2.2	0.4
6	2.5	2.7	2.8	2.8	2.2	2.6	0.6
7	3.0	2.5	2.8	2.7	2.7	2.7	0.5
8	2.2	2.8	2.1	2.4	2.3	2.4	0.7
9	2.4	2.5	2.4	2.8	2.7	2.6	0.4
10	2.3	2.3	2.5	2.1	2.0	2.2	0.5
11	2.2	2.4	2.1	2.1	2.2	2.2	0.3
12	2.4	2.3	2.4	2.6	2.2	2.4	0.4
13	2.3	2.2	2.9	2.7	2.7	2.6	0.7
14	2.4	2.4	2.7	2.6	2.4	2.5	0.3
15	2.7	2.4	2.5	2.5	2.4	2.5	0.3
16	2.5	2.7	2.3	2.3	2.7	2.5	0.4
17	2.3	2.4	2.4	2.2	2.9	2.4	0.7
18	2.7	2.5	2.8	2.5	2.3	2.6	0.5
19	2.3	2.2	2.3	2.5	2.5	2.4	0.3
20	2.9	2.4	2.3	2.2	2.6	2.5	0.7
					$\bar{\bar{X}} =$	2.46	
					$\bar{\bar{R}} =$		0.51

Source: Project survey (2007)

From the table, the central line, UCL and LCL for both \bar{X} and R is calculated as:

$$UCL_{\bar{x}} = \bar{\bar{X}} + A_2 \bar{\bar{R}} \quad LCL_{\bar{x}} = \bar{\bar{X}} - A_2 \bar{\bar{R}}$$

$$UCL_{\bar{x}} = (2.46 \text{ mm}) + (1.88)(0.51 \text{ mm}) = 3.42 \text{ mm}$$

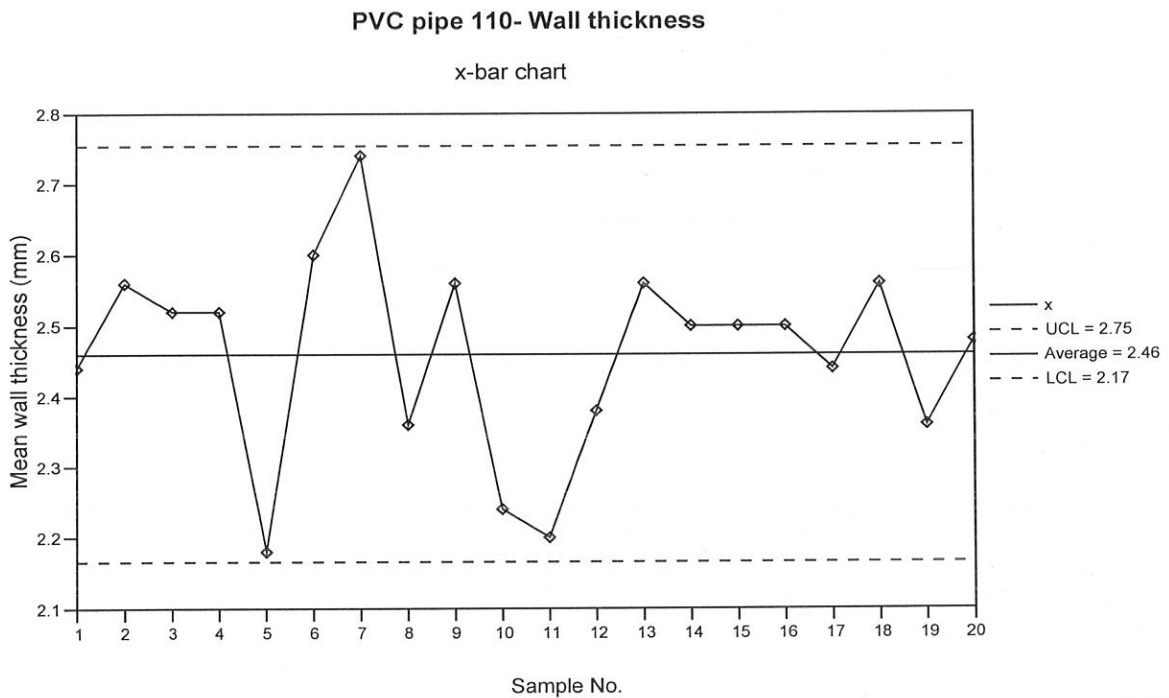
$$LCL_{\bar{x}} = (2.46 \text{ mm}) - (1.88)(0.51 \text{ mm}) = 1.50 \text{ mm}$$

$$UCL_R = D_4 \bar{\bar{R}} \quad LCL_R = D_3 \bar{\bar{R}}$$

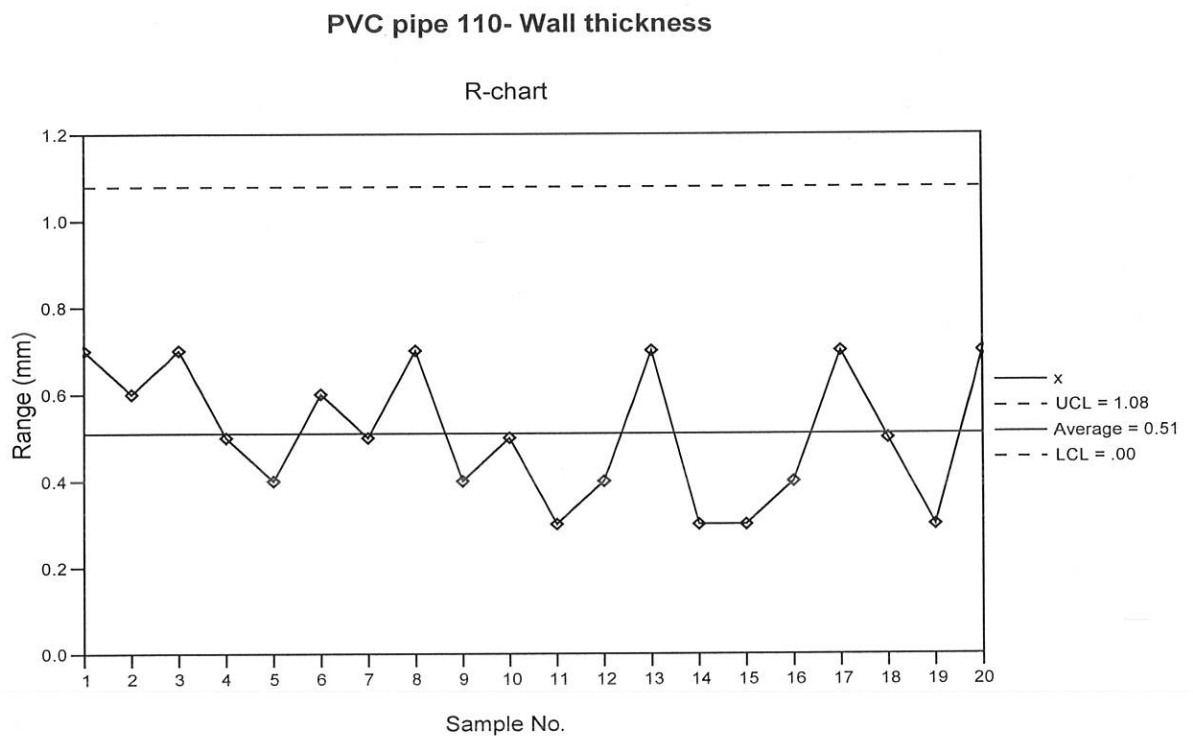
$$UCL_R = (2.114)(0.51 \text{ mm}) = 1.08 \text{ mm}$$

$$LCL_R = (0.00)(0.51 \text{ mm}) = 0.0 \text{ mm}$$

Figure 7: Average and range chart - wall thickness



Source: Project survey (2007)



Source: Project survey (2007)

Examining the graphs against tests for assignable causes (see Table 4), it can be seen that process is in a state of statistical control.

Making use of the data, process capability for the machine producing PVC pipe 110 is determined as follows:

	Outer diameter	Wall thickness
USL	115.0 mm	3.00 mm
LSL	105.0 mm	2.00 mm
UCL	111.4 mm	2.75 mm
LCL	108.0 mm	2.17 mm
μ or \bar{X}	109.7 mm	2.46 mm
R_{av}	0.9 mm	0.51 mm
St. dev, σ ($=\bar{R}/d_2$)	0.387 mm	0.219 mm
$C_p = \frac{USL - LSL}{6\sigma}$	4.3	0.76
$CPL = \frac{\mu - LSL}{3\sigma}$	4.0	0.70
$CPU = \frac{USL - \mu}{3\sigma}$	4.6	0.82
C_{pk} [min (CPL, CPU)]	4.0	0.70

The process capability indices indicate that the process is highly capable of meeting the outer diameter requirements, but has limitation

in complying with the wall thickness specification. The observed low capability in wall thickness is caused mainly, according to the opinions of quality personnel, due to fluctuation of air pressure inside the pipe during extrusion process.

Although a major virtue of the control chart is its ease of use and construction, it would be appropriate to highlight some of the difficulties that may be faced by companies like Ethiopia Plastic S.C. applying SPC for the first time (Shaw and Burgess, 2001). These are:

- Educating and training the work force to use SPC, which must also be preceded by the expertise to design and install the necessary control schemes.
- Up-front cost and the less tangible, longer term benefits of quality improvement.

These hurdles can be overcome through a carefully laid plan and management's commitment to allocate necessary resource before taking measures to implement across the board in all processes.

- iii. Employ computers and appropriate statistical analysis software for collection and analysis of production and quality related data, instead of aggregate information, so that sound improvement objectives can be set.

- iv. Build the capacity of management and shop floor operators through continuous training program in quality management systems, quality assurance and improvement tools.

- v. Taking into consideration the level of importance it plays, a study on the awareness of employees on basic quality concepts and tools is recommended for future researchers.

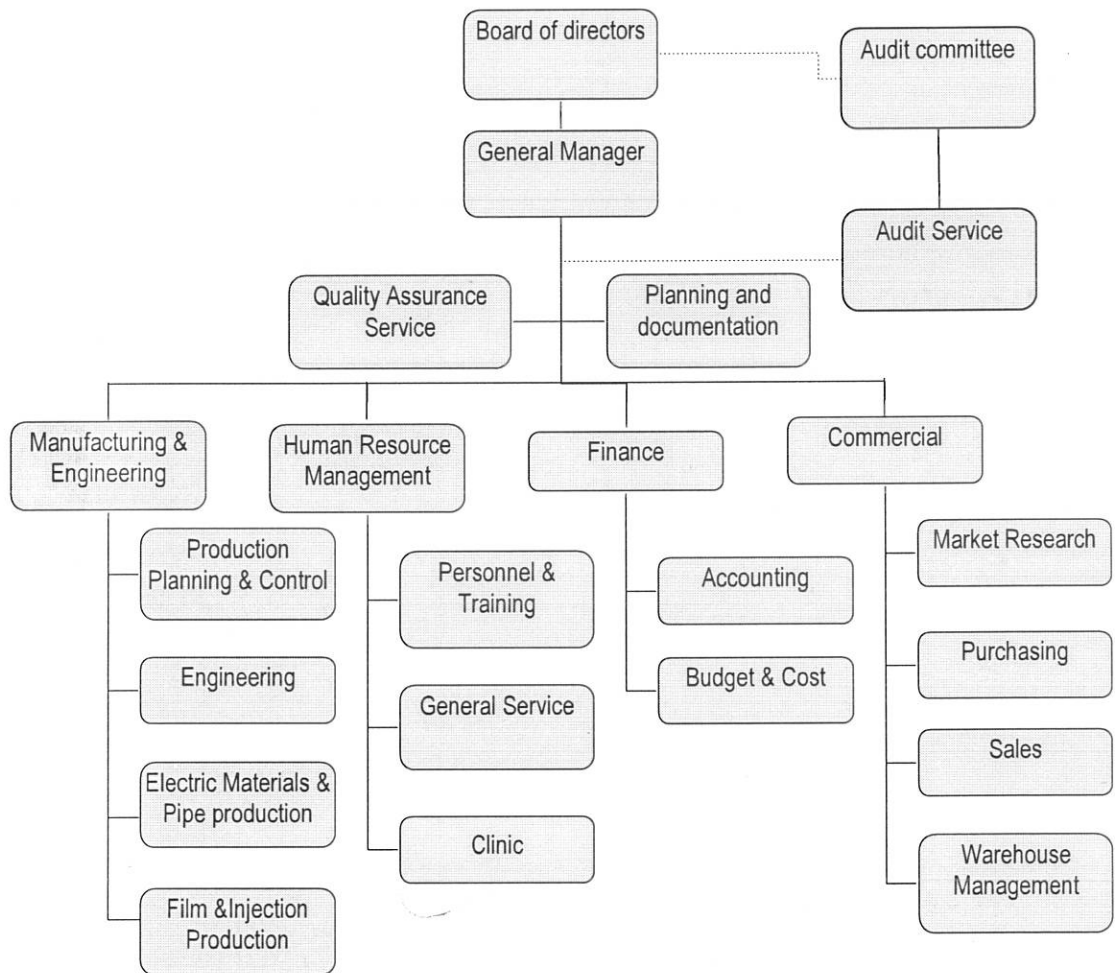
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Annex 1

Organizational Structure of EPSC



Annex 2

EPSC Daily Product Quality Control form

ETHIOPIA PLASTIC SHARE COMPANY		Document No: EPOF/CRD									
NON-CONFORMING PRODUCT REPORT /NCR/FORM		Page No: Page 1 of 1									
Date	Shift No.	Product type	Inspection time interval					Product process quality problems	Corrective action taken	Observed result	Remark
			1	2	3	4	5				

SIGN OF QC QARSH COMMENT.....

Annex 4

Cover page of ES ISO 8258

**ETHIOPIAN
STANDARD**

ES ISO 8258:2004

First edition
2004-03-06

Shewhart control charts

(Identical with ISO 8258:1991)

ICS : 03.120.30

Descriptors: Statistical analysis, quality control, process control charts,
specifications.

Price based on 30 pages.

Reference number
OES ISO 8258 2004

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Declaration

This is to declare that this project report entitled "Evaluating the applicability of SPC tools- Control Charts: The case of Ethiopia Plastic S.C." is my own effort and study. I have conducted it independently except for the guidance of my research advisor. This study has not been submitted for any degree of diploma in this or any other university. It is offered here in partial fulfillment of the requirements for the Degree of Masters in Business Administration.

Mesfin Teklehaimanot



Date 2007.07.27

Annex 3

Cover page of ES ISO 7870³

**ETHIOPIAN
STANDARD**

ES ISO 7870:2004

First edition
2004-03-09

**Control charts — General guide and
introduction**

(Identical with ISO 7870:1993)

ICS : 03.120.30

Descriptors: Statistical analysis, quality control, statistical quality control,
production control, control charts, generalities.

This based on 9 pages.

Reference number:
ES ISO 7870:2004

³ Full text is available at QSAE documentation center