FINAL PORTFOLIO- BEER FACTORY

PRODUCTIVITY AND QUALITY ENGINEERING

MFE 634

GROUP # 3

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CONTENTS

1. INTRODUCTION TO BEER & QUALITY CONCEPTS

Beer is the *most popular alcoholic beverage* in this world. The origin of this beverage dates back to 6th millennium B.C and its production and distribution is also recorded in the writings of an ancient Egyptian history. Beer was first produced by women and was sold directly from their homes to support their livelihood. It was later produced and sold by European monasteries. During 19th century, Industrial revolution made domestic manufacturing less significant and Industrial manufacturing became more dominant.

Beer is *manufactured by the fermentation of sugars* which are derived from starch and usually comprises of wheat, malt, corn, rice and barley. The starch molecules are then broken down by the enzymes present which leads to production of sugary liquid know as Wort. This liquid is then mixed with flavored hops, which acts as a natural preservative. Along with the above ingredients, herbs and fruits may be added. Yeast is then used to cause fermentation which leads to production of alcohol. This process of production of beer is called Brewing. The invention of hydrometers and thermometers has helped in controlling the brewing process more accurately.

Brewing process consists of **seven main steps**: Mashing, Lautering, Boiling, Fermentation, Conditioning, Filtering, and Packaging.

Mashing is the process where all the ingredients (grains) are mixed with water and heated to a pre-specified temperature. The temperature should be conducive for the enzymes so that it breaks down the starch into sugars such as maltose.

Lautering is the process of separating the wort extracts from the spent grain after the mashing. This comprises of two stages: First, extraction of wort in an undiluted state and secondly, Sparging, in which the wort extract is rinsed off with hot water. The wort is then filtered in a mash filter.

Boiling is the stage where the filtered wort extracts are heated to a certain temperature to maintain the sterility which later helps in preventing the extract from infections. During this stage, hops are added which in turn add flavor and aroma to the brew. The boiling of the extract also helps in coagulation of proteins present in the wort and in lowering its pH. Boiling must be even and highly intense. This stage lasts for 50 – 120 minutes depending on the intensity, hop addition schedule, and volume of the wort the brewer expects to evaporate.

The wort is later cooled down to 20 degree Celsius before moving on to fermentation stage.

Fermentation commences as soon as yeast is added to the cooled wort. Yeast acts as a catalyst in metabolizing the malt into alcohol and carbon dioxide. This is the stage where the product can be first called as Beer.

Conditioning is the stage where the beer is cooled down to freezing temperature as this temperature is conducive for settling of the yeast and also causes proteins to coagulate. Phenolic compounds which are bad in taste become insoluble in chilled beer and thereby smoothens the beer's flavor.

Filtering is the process of stabilizing the beer flavor and filters out any remaining hops, grain particles and yeast in the beer. This stage also makes beer crystal clear by wiping out any traces of microorganisms thus giving beer its ultimate luster.

Packaging is the process of filling the beer into the containers such as bottles, aluminium cans and kegs. It is also filled into large containers for higher volume customers.

Today, the brewing industry is a huge global business, comprising of many multinational companies and smaller players ranging from brewpubs to regional breweries. Around 35 gallons of beer were sold worldwide amounting to total global revenues of $ 294.5 billion during the year 2006.

InBev is the largest beer producing company in the world, followed by SABMiller, which became the second largest when South African Breweries acquired Miller Brewing. Anheuser – Busch is placed at third position.

QUALITY CONCEPTS

Quality in everyday life and business has impact on both sales revenue and costs and hence it is considered more of a business issue rather than a technical issue. Quality has been described by many techniques over a period of time in terms of inspection, metrology in early times to statistical process control, supplier certification, quality audit, quality function deployment, Taguchi methods, competitive benchmarking, six sigma and many more during the 20th century.

Quality is defined in more than one way. Many different definitions of quality prevalent in industries are:

- "Fitness for use" – as described by Joseph M. Juran
- "Conformance to requirements" – Philip B. Crosby
- "Degree to which a set of inherent characteristics fulfills requirements" – as per ISO 9000
- "Value to some person "– Gerald M. Weinberg
- "Costs go down and productivity goes up, as improvement of quality is accomplished by better management of design, engineering, testing and by

improvement of process. Better quality at lower price has a chance to capture a market. Cutting costs without improvement of quality is futile" – W. Edwards Deming.

Quality in short can be described as "Customer satisfaction and loyalty".

Quality has two components or in other words, Customer satisfaction and loyalty are achieved through two dimensions:

- Features of the product or services which have major impact on sales income.
- Products or Services free from deficiencies which have major effect on cost.

Quality has important relationships with *few parameters* such as productivity, costs, cycle time, and value.

- Increase in quality increases productivity
- As the quality of features increases, costs increase. But as the quality of conformance increases, reduction in rework, complaints, scrap result in decreased costs.
- Reduction of rework and redundant operations due to quality improvement reduces cycle time.
- Providing better quality to customers without an increase in price result in better "value".

In the subsequent topics, we will study in detail all the quality aspects involved in a beer manufacturing firm, discussing the older techniques such as inspection, gage measurement et al. to the modern techniques such as six sigma and statistical process control.

2. ANALYSIS OF COST OF POOR QUALITY (COPQ)

Cost of poor quality is the *annual monetary loss* of products and processes that are not achieving their quality objectives. This highlights the fact that COPQ is not *just limited to quality* but it is more of cost of waste associated with poor performances of processes.

Experts say that COPQ in any manufacturing and service industries is *5-30% of gross revenue.* Many studies have revealed that COPQ is costing companies in millions of dollars annually and the reduction of the same can transform marginally successful companies into highly profitable ones. But still, many managers believe that their company's COPQ is below 5% or they just don't know what COPQ is. Many companies strongly believe that quality is an absolute necessity to survive and succeed in this highly competitive business world. Further, calculating the COPQ assists the organization to figure out the extent to which the organizational resources have been utilized for the activities which are the result of the deficiencies that occur in its processes. Such information helps the organization in determining the potential savings to be made by implementing the process improvements.

COPQ is an important tool which can be put to use in the following manner:

- **Identify all the activities which occur due to the cost of poor quality**: Carry out a brainstorming session involving those personnel who have the knowledge of the process and involve in day to day activities, to capture the information which can help in coming out with a remedial solution.
- **Identify the location where the organization is experiencing much of the costs**: Costs may appear in one area or in multiple areas.
- **Determine the method which can lead to a suitable remedy:** To use the *total resources method*, the total resources consumed in a category and the percentage of those resources used for activities associated with remediating effects of the poor quality have to be identified. To use the *unit cost method*, number of deficiencies occurring and the average cost for correcting those deficiencies has to be determined.

- **Collect the data and estimate the costs**.
- **Chart out an improvement path**: Once the costs are determined, one has to determine the ways to overcome these COPQ in the future and try and *maintain the improved process.* The concerned personnel have to be trained to use the improved methods to incorporate the same in their daily routine.
- **Celebrate and restart the process**: The parameters involved in manufacturing process keep changing frequently and hence the relevant COPQ too changes. In order to bring the changed process back to normalcy, one has to keep monitoring COPQ regularly and repeat the above steps frequently.

From the manufacturing or service industries perspective, *COPQ consists of three main components:*

- Cost of nonconformities
- Cost of inefficient processes
- Cost of lost opportunities for sales revenue

Many organizations, be it manufacturing or service, briefly sum up the costs in four categories: *Internal failures*, *External Failures*, *appraisal* and *prevention*. COPQ comprises of first two categories and the last categories are viewed as investments to achieve quality objectives.

COPQ analysis not only helps in analyzing financial benefits, but allows identifying ROI (Return on Investment) from the improvements efforts put in. As illustrated by DuPont financial model, ROI can be calculated by

Return on assets / Investments = Profit margin * Asset turnover

Hence it is necessary for all the companies to seriously work on this subject, result of which will catapult them to the list of the most profitable companies.

The following table describes the four different categories of quality costs in the context of beer factory:

COST ITEM	INTERPRETATION / Effect on COPQ
INTERNAL COSTS	
Inefficient Process	
• Proper timing of the brew	Timing affects taste, causing rework or scrap
• Quality of the ingredients (Malt, Hop, etc)	Inspection of coarseness of malt, taste of hop, etc
• Exact acidity of water	Improper acidity or calcium content will require rework to bring it to proper standard
• Controlled temperature (Ex. mash mixer)	Maintaining temp./temp. changes required for various processes
• Fermentation	To maintain the beer flavor
• Packaging and storage	Final inspection of packaging and storage
Rework on brewing process	Obviously resulting in increase of COPQ
Scrap due to brewing process	Waste of material, time, etc
Re-inspection due to rework	Non-value adding activity increasing COPQ
Implementing another manufacturing process	Investment in manufacturing process
Non-value added activities	Inspection, re-inspection, redundant activities, etc
Uncontrolled downtime of the equipment	Loss of capacity and investment in new equipment
Failure analysis	A non-value added activity, analyzing causes of failure
EXTERNAL COSTS	
Returned Material	Increase COPQ due to replacement of defective beer products
Fines due to poor quality	Eventually increase COPQ
Poor support operations	Correcting errors on other external processes
Loss of market share	Result in lost opportunities of sales revenue
APPRAISAL COSTS	
Incoming inspection and test (Ex. Harvest, malt, etc)	Non-value adding activity increasing COPQ
Maintaining accuracy of test equipment	Calibrating instruments such as hydrometer and thermometer on a regular basis further help in maintaining accuracy of process control. If not done, it may lead to improper inspection of the beer product and increase in Non-value added activity.
Evaluation of stocks	Finished products beer should be checked frequently for their stability and shelf life else it will lead to scrap
Final Inspection and Tests	Post production tests and inspection of the beer product has to be carried in order to conform to the specifications else it will again lead to scrap or reprocessing
PREVENTION COSTS	
Performing product quality audits	These parameters fall under the category of prevention costs which are incurred by beer manufacturing firm to keep failure and appraisal costs at a minimal level. These parameters have to be checked on a regular basis, failing of which may lead to unskilled labor, low productivity, scrap, rework, maintenance costs and Non-value addition.
Quality Planning	
Process Control and New Products review	
Calibration of equipments	
Process planning	
Supplier Quality evaluation	
Training	

3. ROAD MAP FOR IMPROVEMENT

The road map for improvement in enterprise quality was developed by Dr. Joseph Juran to direct and bring about a *sustainable change* in an enterprise. This process helps an enterprise in gaining more profits through implementation of leaner processes, continuous improvements, and employee involvement with value and value-driven leadership taking a centre stage. Quality is considered as everyone's job.

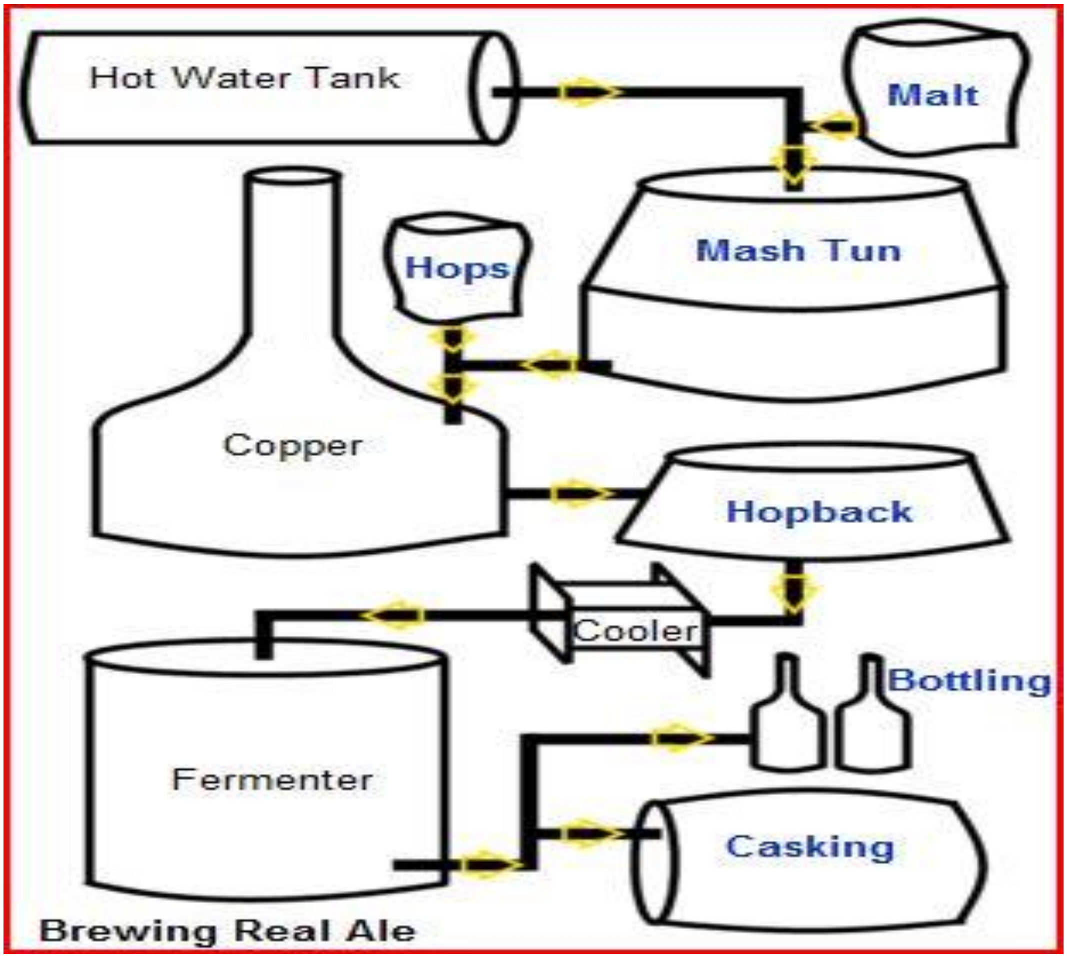
The road map for improvement comprises of five stages with each stage being independent of each other. These phases act as a managerial guide rather than a prescription.

Five stages in deploying the Road Map for Enterprise Quality are:

- Decide
- Prepare
- Launch
- Expand
- Sustain

Phase I: Decide

The brewing process consists of seven main steps: Mashing, Lautering, Boiling, Fermentation, Conditioning, Filtering and Packaging. The company should assess the organization status to identify the goals. The goals to improve the quality of beer and reducing the cost of poor quality are identified, integrated and aligned into the business plan. An executive panel is setup to study the areas such as customer satisfaction, strengths of the company and key business processes. The executive panel then identifies the stages where a new quality process or changes have to be implemented. The *goals* and objectives framed by the panel in a beer manufacturing environment are to *improve customer satisfaction – by controlling significant factors, cost reduction – by reducing COPQ, and hence revenue improvement.*



Beer Manufacturing Process

Phase II: Prepare

The executive team begins to prepare *necessary infrastructure*, *especially measurement gauges*, that have to be established to obtain the quality goals. The initiative goals are established with respect to the company goals and financial issues are addressed. The metrics such as pH of the water used and other aspects of raw material which play an important part in achieving the goals of improved quality are identified and so are the pilot projects. Pilot project selection involves the employing of quality experts, training employees with necessary quality tools and methodologies and finalizing the deployment plan.

Phase III: Launch

Training, mentoring and coaching of the executives, champion and employees takes place at the launch stage. A *particular brand of beer is selected* from the varieties manufactured to conduct the pilot project. For example Anheuser-Busch brews various brands of beer and can select a particular brand say Budweiser to conduct the pilot project. The *process is measured and reviewed at this stage* and a review of lessons learned is prepared. The executive panel reviews the lessons learned and make a decision either to abandon their efforts or change the plan and expand it throughout the organization (say to brands such as Bud Light, etc).

Phase IV: Expand

The original plan developed in the decide phase is modified based on the *lessons learned* in the launch phase. A revised deployment plan is developed and the projects are *expanded to other products, organizational units and geographic locations.* More projects imply more experts being hired and additional training given to employees. Based on the results of the previous brand, the process is implemented to other beer brands, production units, etc.

Phase V: Sustain

The *four dimensions* for successful integration of the intended change into the life of an organization are Goals, Review & Audits, Key Business Process and People. Audits are conducted and appropriate actions are to be taken. Steps must be taken to make sure quality systems are maintained regularly. The organization should stay focused on improving customer satisfaction. Variance in the quality system has to be monitored, analyzed and rectified.

4. SIX SIGMA / DMAIC/ DFSS ANALYSIS:

Six Sigma is a set of practices in order to systematically improve processes by eliminating defects. A defect is defined as nonconformity of a product or service to its specifications.

Six Sigma asserts the following:

1) *Continuous efforts* to reduce variation in process outputs is key to business success
2) Manufacturing and business processes can be defined, measured, analyzed, improved and controlled
3) Succeeding at achieving sustained quality improvement requires commitment from the entire organization, particularly from top-level management

Six Sigma's implicit goal is to improve all processes to that level of quality or better.

DMAIC:

It is one of the six sigma methodologies and it is used to improve an existing business process. It is based on the following five steps.

Define the process improvement goals that are consistent with customer demands and enterprise strategy.
Measure the current process and collect relevant data for future comparison.
Analyze to verify relationship and causality of factors. Determine what the relationship is, and attempt to ensure that all factors have been considered.
Improve or optimize the process based upon the analysis using techniques like Design of Experiments
Control to ensure that any variances are corrected before they result in defects. Set up pilot runs to establish process capability transition to production and thereafter continuously measure the process and institute control mechanisms.

IMPLEMENTATION OF SIX SIGMA INA BEER FACTORY

Define:

- Identify potential projects for improvement.
- To reduce variation in the beer from various manufacturing units
- To reduce the cost of poor quality.

- To conduct a customer survey to identify customer needs which could be translated into *Critical to Quality Characteristics(CTQ's)*
- This data should be reviewed.
- We should review the previous records of the factory to understand the defects in history.
- The data is then ranked and prioritized as the "What" matrix in the *Quality Function Deployment (QFD).*

  E.g.: Fattening property, aroma, bitter taste and flavor in case of the customer requirements for a beer.

- The factors could be qualitative such as odor, taste, color, fermentation.

Measure:

- The goals of this phase are to establish a baseline process performance, narrow the focus of the project scope and quantify the factors mentioned above. The above qualitative factors can be converted to quantitative ones such as follows:

  Temperature -> 10 – 77 C

  Pressure -> 50 – 70 Kpa

  Turbidity -> Maximum 1 NTU

  Viscosity -> 1.32 – 2.20 Mpa-S

  pH -> 4.0 to 4.6

  Alcoholic Strength -> 17.75 ml to 20.0 ml

- In order to test whether the measuring system was reliable enough, a *Gauge R&R study* can be done to confirm it. Secondly a *process capability test* can be done to test the amount of variation involved in the process. Thirdly in order to find the source of the variations *fishbone charts* and *process maps* can be used.

Analyze:

- The goals of the analyze phase to find out the root causes of the process that directly affect the critical to quality (CTQ's) customer requirements. Theories are tested and validated with data and outputs of this phase are verified causes that lead to a solution development in the next phase.
- Conduct a QFD analysis of the relationships between process variables and CTQ's
- *Analyze the relationships in the QFD*

  E.g.: In case of a beer factory there is a strong relationship between Fattening property and alcohol content and a weak relationship between Fattening property and beer color.
- Narrow the focus to the most significant relationships

  E.g.: Here we narrow down to the relationships which have a very strong relationship between them. We take into consideration only the relation between fattening property and alcohol content and neglect the relationship between fattening property and beer color as it of less significance.
- Identify new techniques to improve the significant few.

  E.g.: In case of a Pareto analysis chart we arrange the selected few relationships in their decreasing order of importance and find their cumulative percentages and draw a graph between the causes and their cumulative percentages.
- Conduct hypothesis testing on certain relationships to verify our assumptions.

Improve:

- The goals of the improve phase is to develop and pilot proposed solutions, validate that they address the root causes of the process issues and achieve or exceed the expected benefits. Once validated plans are developed for a full scaled implementation of solutions
- Use benchmarking to improve the standards.
- Redesign a solution
- Prove the effectiveness of the solution.
- Conduct a Design of Experiments (DOE) to find out whether there existed a relationship between other inputs and variations.
- Put the solution into operations.

Control:

- The aim of the control phase is to evaluate the process performance and to compare it to the baseline values. Standards; documentation and training in the new process are completed. Process Controls are institutionalized to maintain the current performance and to identify further opportunities for process improvement.

  E.g.: The following are the parameters which we will measure in a beer factory

  Temperature of the beverage
  Operating Pressure
  Test of Water Quality
  Composition of Ingredients
  Raw-Material Analysis
  pH
  Viscosity

- Document the process and conduct training
- Implement a Statistical Process Control (SPC) and Control charts to monitor the processes.

DFSS:

Design for Six Sigma is used to determine the needs of the customers and aiming at driving those needs into the final product. It is one of the six sigma methodologies and consists of the following 5 steps.

Define the goals of the design activity that are consistent with customer demands and enterprise strategy.
Measure and identify CTQs (critical to qualities), product capabilities, production process capability, and risk assessments.
Analyze to develop and design alternatives, create high-level design and evaluate design capability to select the best design.
Design details, optimize the design, and plan for design verification. This phase may require simulations.
Verify the design, set up pilot runs, implement production process and handover to process owners.

5. QUALITY FUNCTION DEPLOYMENT (QFD)

QFD is a method to *transform user demands* into design quality, to deploy the functions forming quality, and to deploy methods for achieving the design quality into subsystems and component parts, and ultimately to specific elements of the manufacturing process.

QFD is designed to help planners focus on characteristics of a new or existing product or service from the viewpoints of market segments, company, or technology-development needs. The technique yields graphs and matrices.

The QFD technique involves three main steps:

1. Identify customer needs and wants as *voice of the customer* (VOC)
2. Identify the engineering characteristics of products or services that meets VOC
3. Setting development targets and test methods for the products or services

QFD helps transform customer needs (the voice of the customer [VOC]) into engineering characteristics (and appropriate test methods) for a product or service, prioritizing each product or service characteristic while simultaneously setting development targets for product or service. It is a comprehensive quality design method that seeks out spoken and unspoken customer needs from fuzzy Voice of the Customer verbatim; Uncovers "positive" quality that wows the customer; Translates these into designs characteristics and deliverable actions; and builds and delivers a quality product or service by focusing the various business functions toward achieving a common goal—customer satisfaction.

Voice of Customer:

- Consumers are worried about the fattening properties of beer
- Low alcohol and low calorie beers have traditionally been viewed as a compromise
- Beer packing must appear fresh, bright Formation of a stable head of foam when the beer is poured

- Aroma and Flavor
- Appearance and Visual appeal
- Package

Engineering Characteristics:

One good definition for a quality beer is therefore simply "a beer that consistently meets specification." The *idea of a specification* immediately requires that someone, at sometime and someplace, has decided what the beer's defining character(s) should be and how it should be measured. The idea of consistency immediately requires a system of people, plant, and process who are able to repeat exactly what they do time and again. Brewers generally behave in consistent ways when making beer. For example they *repeat quite exactly the weights of malts and hops used*, and the times and temperatures at which they are brewed. The rate and extent of yeast growth intimately affects beer flavor.

Beer specifications and the analyses that go with them are of two general kinds:

- Those that can be perceived by the human senses
- Those that require instrumental analysis.

Sensory methods are not necessarily easy to apply (and often ill used) but are useful and quite cheap to do. They include an analysis of beer flavor (beer's most important attribute), beer clarity, color, and foam.

Beer color, on the other hand, can be measured in a comparator (the human eye is much better at this than most instruments). A standard beer set aside for color matching remains stable for quite a long time if kept cold and in the dark.

One of the most important qualities of a beer in the marketplace is that it should remain clear (bright) until consumed. Cycling a beer on some regular schedule (e.g. daily) between a warm place (60° C) and a cold one (40° C) will create haze; more stable beers withstand more cycles than less stable ones.

High on this list of "invisible" specifications has to be the *original gravity (OG)* and the degree of ferment ability (hence alcohol content) of beers. The wort OG and ferment ability are fundamental specifications for a beer, because beer is made from the fermentable portion of the wort. Beer bitterness would be a nice measure to have but requires a good spectrophotometer and involves solvent extraction. Package beer, on the other hand, must be analyzed for CO_2 content (carbonation) and bottle "air" for flavor stability.

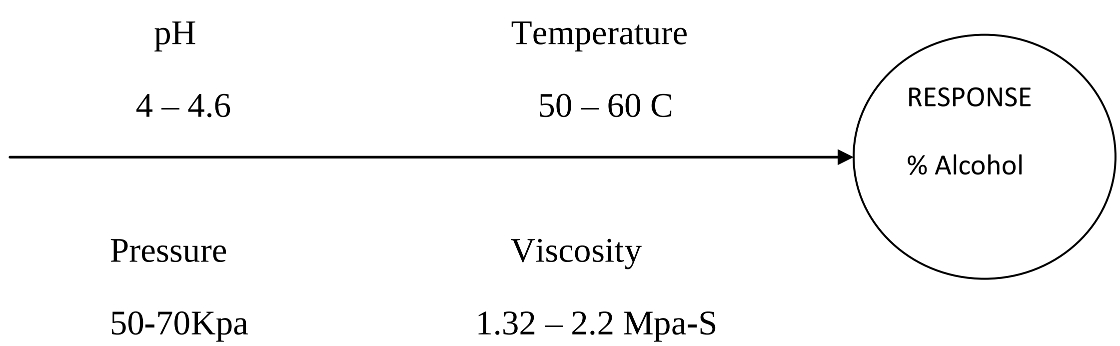
The degree of ferment ability can be determined by a rapid fermentation test in which a high population of yeast cells, with frequent agitation, rapidly ferments out the wort. The difference between the starting and ending gravity in this test tells the degree of attenuation to be expected in the brewery fermentation and is a good predictor of the alcohol content of the beer.

6. DESIGN OF EXPERIMENTS (DOE)

In general, the trial model that will fit to *DOE data should be consistent with the goal of the experiment* and has been predetermined by the goal of the experiment and the experimental design and data collection methodology. Design of experiments includes the design of all information gathering exercises where variation is present, whether under the full control of the appraiser or not. DOE is a *method to maximize the knowledge gained from experimental data.* Most experimentation involves several factors and is conducted in order to optimize processes and or investigate and understand the relationships between the factors and the characteristics of the process (responses) of interest.

Process model for a Design of Experiment

DOE begins with determining the objectives of an experiment and selecting the process factors for the study. An Experimental Design is the laying out of a detailed experimental plan in advance of doing the experiment. Well chosen experimental designs maximize the amount of "information" that can be obtained for a given amount of experimental effort. A process is a combination of *several discrete and continuous input factors that can be controlled by the experimenter to get one or more measured output.* The output responses are assumed to be continuous.



In general, a linear model with two factors, X_1 and X_2, can be written as –

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_{12} X_1 X_2 + \text{error}$$

Where, Y is the response because of the main effects of X1, X2 and their interaction.

DOE in Manufacturing of Beer:

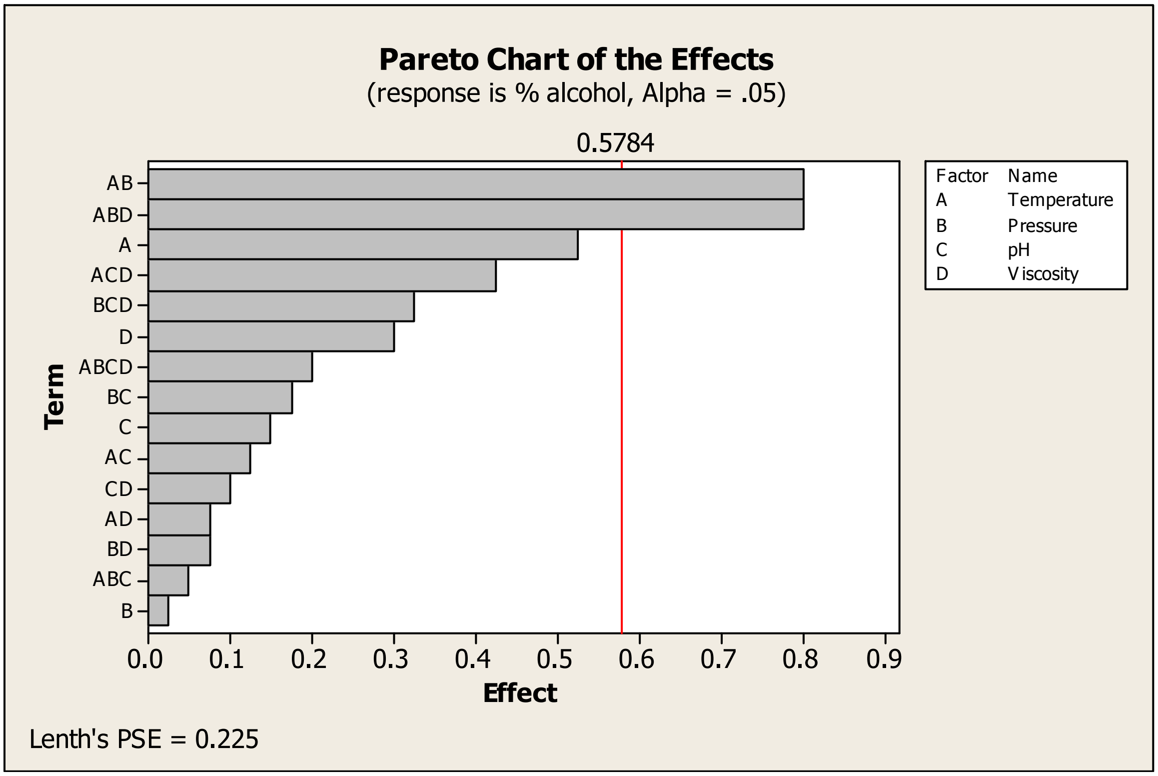
We have analyzed this case taking into *4 factors* into consideration; Temperature, Pressure, pH and viscosity, each having *two levels.* The factors that affect the process or the factors that can be significant are generally, in any industry should be, found out from the employees that are in direct contact with the process.

We have provided random data to study our response variable, % Alcohol. The data for this analysis has been provided in the appendix.

Factorial Fit: % alcohol versus Temperature, Pressure, pH, Viscosity

Parameter	**Effect**	**Coefficient**
Temperature	0.5250	0.2625
Pressure	0.0250	0.0125
pH	0.1500	0.0750
Viscosity	0.3000	0.1500
Temperature*Pressure	0.8000	0.4000
Temperature*pH	0.1250	0.0625
Temperature*Viscosity	0.0750	0.0375
Pressure*pH	-0.1750	-0.0875
Pressure*Viscosity	0.0750	0.0375
pH*Viscosity	-0.1000	-0.0500
Temperature*Pressure*pH	0.0500	0.0250
Temperature*Pressure*Viscosity	-0.8000	-0.4000
Temperature*pH*Viscosity	0.4250	0.2125
Pressure*pH*Viscosity	0.3250	0.1625
Temperature*Pressure*pH*Viscosity	-0.2000	-0.1000

Effects Pareto for % alcohol



The chart shows the absolute effect, 0.5784, as shown by the read line.

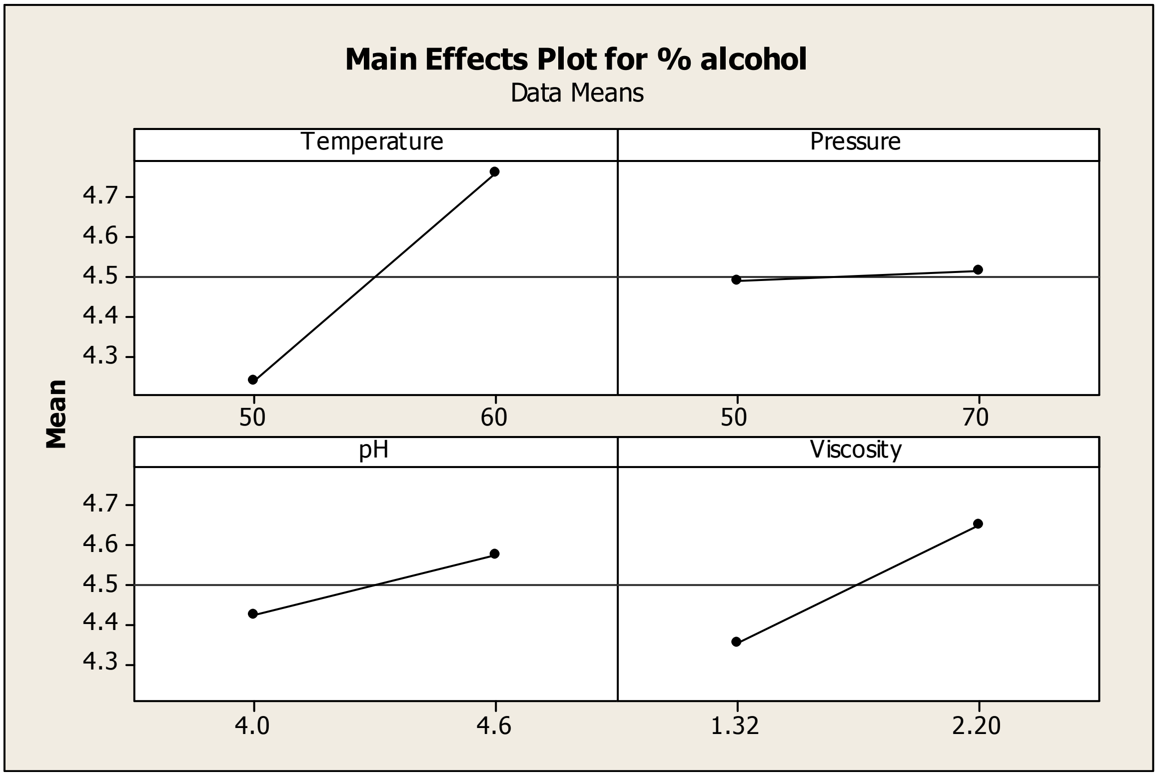
So, *the factors that cross or touch this line have a significant effect or potentially important on our response*.

The reference line takes into consideration α = 0.05

In our case these factors are: Temperature and Pressure combined

Temperature, Pressure and Viscosity combined

Main Effects Plot

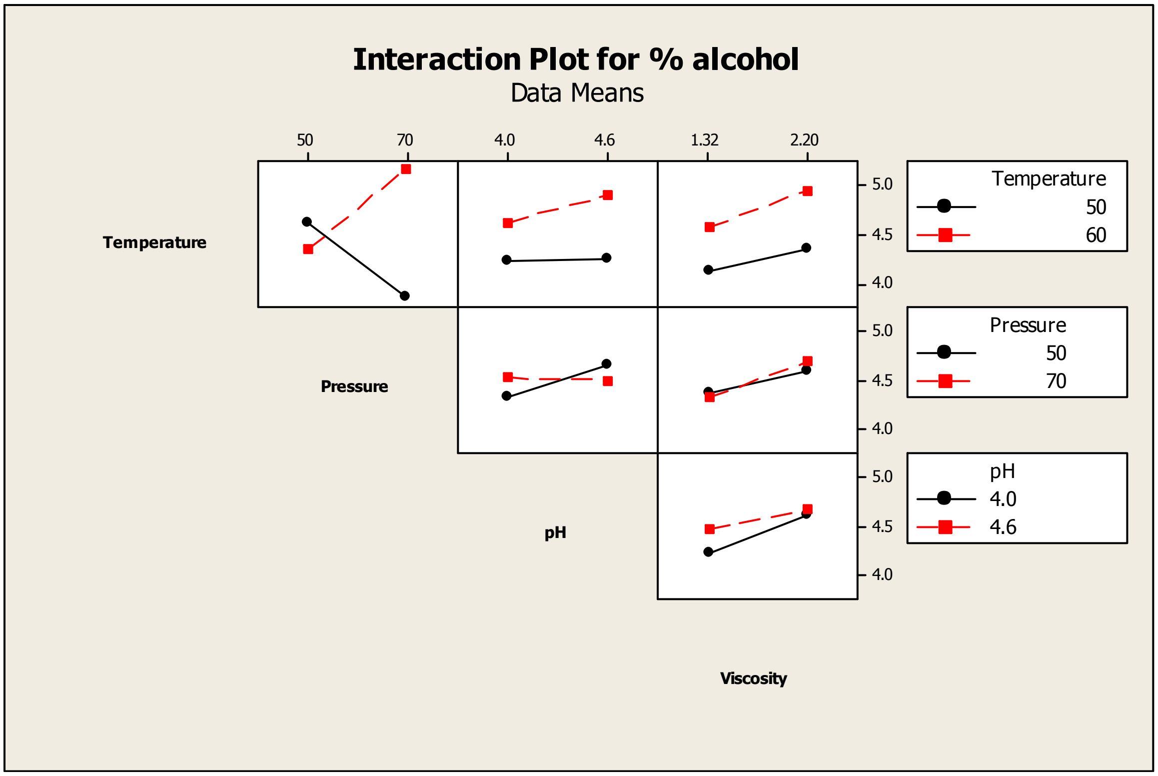


This Main effects plot shows that, amongst the individual factors, temperature has a more significant effect on our response, % Alcohol.

So, changing temperature from 50 to 70 will have a nominal effect on our response, where as changing temperature from 50 to 60 will have a significant on our response.

In general, response in this case is more sensitive to temperature, rather than pressure.

Interaction Plot



An interaction plot is a plot of means of each level of the factor, considering the second factor as constant. An interaction may occur when the change in response form the low level to the high level of the factor is not same as the change in response of the two levels of the second factor.

As indicated from the above plot, the following factors have interactions with each other:

Temperature and Pressure

Pressure and pH

Pressure and Viscosity

pH and Viscosity

Consider the first case: The change in response (% Alcohol) is not the same if we keep temperature constant at 50C, and change pressure and the if we keep temperature at 60C and then change pressure.

Hence, the interaction occurs.

7. SUPPLY CHAIN AND LEAN MANUFACTURING

Supply Chain is the *movement of materials* as they flow from their source to the end customer. It includes purchasing, manufacturing, warehousing, transportation, customer service; demand planning, supply planning and Supply Chain management. It is made up of the people, activities, information and resources involved in moving a product from its supplier to customer. Supply chain management (SCM) is the oversight of materials, information, and finances as they move in a process from supplier to manufacturer to wholesaler to retailer to consumer. Supply chain management involves coordinating and integrating these flows both within and among companies.

Supply Chain in a beer factory aims at analyzing with its retail customers the optimal product mix and assortment for the beer categories within stores. This results in enhanced space productivity, reduced out-of-stocks, and increased shopper satisfaction which leads to improved category sales and profitability. The ability to collaborate with retailers in information based decision process for assortment leads to improved shelf conditions, lower out-of-stocks and better overall performance.

Supply chain includes *five basic components*

1. **Plan** – This is the strategic portion of SCM. You need a strategy for managing all the resources that go toward meeting customer demand for your product or service. A big piece of planning is *developing a set of metrics to monitor the supply chain* so that it is efficient, less costly, delivers high quality product and value to customers.

2. **Source** – Choose the suppliers that will deliver the goods, malt and services you need to create your product. Develop a set of pricing, delivery and payment processes with suppliers and create metrics for monitoring and improving the relationships. And put together processes for managing the inventory of goods and services you receive from suppliers, including receiving shipments, verifying them, transferring them to your manufacturing facilities and authorizing supplier payments.

3. **Make** – This is the manufacturing step. Schedule the activities necessary for production, testing, packaging and preparation for delivery. As the most metric-intensive portion of the supply chain, measure quality levels, production output and worker productivity.

4. **Deliver** – This is the part that many insiders refer to as logistics. Coordinate the receipt of orders from customers, develop a network of warehouses, pick carriers to get products to customers and set up an invoicing system to receive payments.

5. **Return** – This is the problem part of the supply chain. Create a network for receiving defective and excess products back from customers and supporting customers who have problems with delivered products.

The choice of the right software in setting up an effective SCM system is crucial. There are *two major classes* of SCM software, i.e., supply chain planning (SCP) software and supply chain execution (SCE) software. SCP software is used to determine the best or most logical way to fill customer orders, while SCE software is used to track the physical location or status of goods and materials, and manage their flows effectively. The SCM software package selected must include both the aspects of planning and execution.
Common obstacles to setting up an SCM system include:

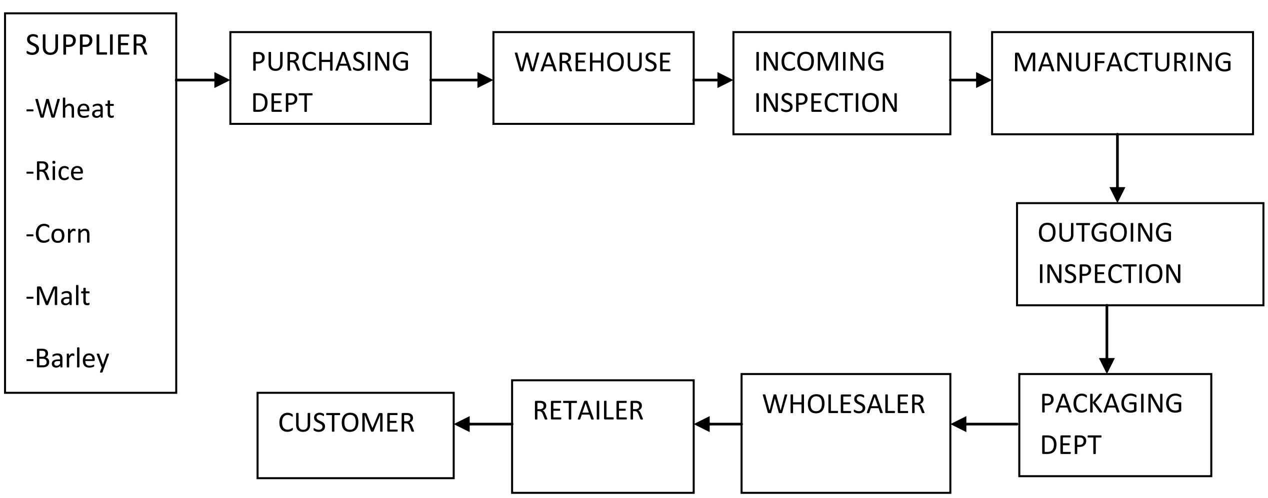
1) Gaining the trust of suppliers and partners to participate in the SCM program;

2) Difficulty of integrating various processes and systems along the supply chain;

3) Internal resistance to change due to the perceived additional work that comes with the program;

4) Possible discouragement and loss of confidence in the system due to early mistakes during the learning curve.

Here is a sample of the supply chain flow in case of a beer manufacturing unit



LEAN

Lean Manufacturing is the systematic elimination of waste – overproduction, waiting, transportation, inventory, motion, over-processing, defective units – and the implementation of the concepts of continuous flow and customer pull.

Five areas drive lean manufacturing/production:

1. Cost
2. Quality
3. Delivery
4. Safety
5. Morale

To solve the problem of waste Lean has several tools including continuous process improvement (kaizen), the "5 Whys" and mistake-proofing (Poke-yoke). There is a second approach to Lean in which the focus is upon implementing the flow or smoothness of work through the system and not upon waste reduction. Techniques to improve flow include production leveling, "pull" production.

The difference between these two approaches is not the goal but the prime approach to achieving it. The implementation of smooth flow exposes quality problems which always existed and thus waste reduction naturally happens as a consequence. The advantage claimed for this approach is that it naturally takes a system-wide perspective whereas a 'waste' focus has this perspective assumed

The lean principles include

- *Specify value* from the standpoint of the end customer by product family.
- Identify all the steps in the *value stream* for each product family, eliminating every step and every action and every practice that does not create value.
- Make the remaining value-creating steps occur in a tight and integrated sequence so the product will *flow smoothly* toward the customer.
- As flow is introduced, let customers *pull* value from the next upstream activity.
- As these steps lead to greater transparency, enabling managers and teams to eliminate further waste, pursue perfection through continuous improvement.

STEPS FOR IMPLEMENTING LEAN IN A BEER FACORY:

- ***Find a change agent.*** This could be you—or anyone of the organization: the key is that this must be a leader who will take personal responsibility for the lean transformation.
- ***Get the lean knowledge***. It's important to draw from a true and thorough source of lean, whether from an ex-Toyota sensei or some other reputable source, so your internal change agents master lean thinking to the point where it becomes second nature. And always implement lean techniques as part of a system, not as isolated programs.
- ***Find or create a crisis***. Unfortunately, few if any firms will take the necessary steps to adopt lean thinking across the board unless they are facing a crisis.
- ***Forget grand strategy for the moment***. Start by simply eliminating waste everywhere possible.
- ***Map the value streams***, beginning with the current state of how material and information flow now, then drawing a leaner future state of how they should flow and creating an implementation plan with timetable
- ***Begin as soon as possible*** with an important and visible activity.
- ***Demand immediate results***.
- ***As soon as you've got momentum, expand your scope***. Link improvements in the value streams and move beyond the shop floor to office processes. Practice kaizen, or constant improvement, relentlessly

8. GAGE R&R AND METROLOGY STUDY

Metrology is defined by the International bureau of Weights and Measures (BIPM) as "the science of measurement, embracing both experimental and theoretical determinations at any level of uncertainty in any field of science and technology. Thus it is needed to assess and maintain regular surveillance of the manufacturing operations and ensure that desired parameters are measured to get the required accuracy through the usage of statistical and management techniques.

Metrology in Beer Manufacturing

The measurement of quantities can be classified *into Qualitative and Quantitative.* In beer manufacturing, features such as Odor, Taste, Color and Fermentation are classified as Qualitative variables. The Quantitative variables are those measured on a numeric scale. Quantitative variables in beer manufacturing are Temperature of the beverage, Operating Pressure, Test of water quality, Composition of ingredients, Raw material analysis, pH and viscosity.

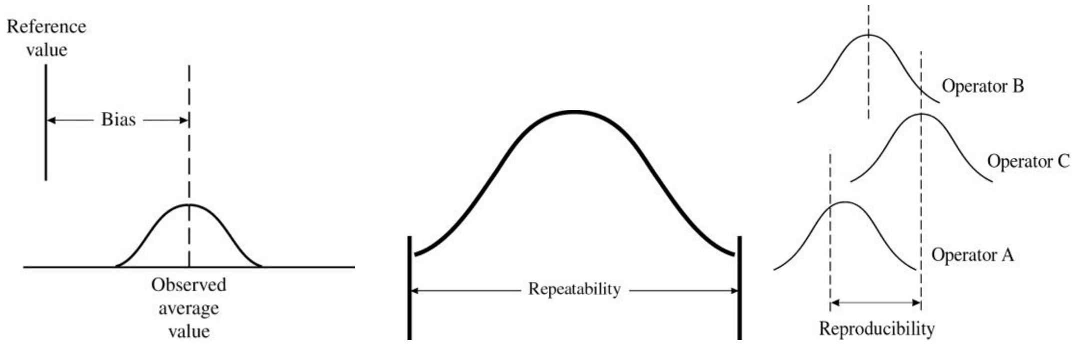
Gauge R & R

Gauge is an instrument used to make measurements. Factors that affect measurement system variation can be studied using the gauge repeatability and reproducibility (Gauge R&R) technique. Measurement system variation can be characterized by location (stability, bias, linearity) and *width or spread* (repeatability and reproducibility).

Bias is the difference between the observed average of measurements and the reference value. The reference value, also known as the accepted reference value or master value, is a value that serves as the accepted reference for measured values.

Repeatability is the variation in measurements obtained with one measurement instrument when used several times by an appraiser while measuring the identical characteristic on the same part.

Reproducibility is the variation in the average of the measurements made by different appraisers using the same measuring instrument when measuring the identical characteristic on the same part.



Gage repeatability and reproducibility (GR&R) study can be applied in most manufacturing related measurement systems. It may be used as:

- A criterion for judging new measuring equipment.
- A comparison among measuring devices.
- A means for improving performance of measuring instruments.
- A comparison for measuring equipment before and after repair.
- A required component for calculating process variation and the acceptability level for a production process.
- A measure of the need for training in how to use measuring instruments.

Following are the Gauge measurement with regard to Beer Manufacturing.

- Temperature Gauge – measuring temperature of beverage at various stages of manufacturing
- Pressure Gauge – maintaining the pressure during manufacturing depending on specifications
- Nephlometer (NTU) – to measure the turbidity of the beverage
- Weights – measure the composition of ingredients
- Viscometer – to measure the viscosity of the beverage
- pH Meter or pH Indicator or pH Paper – acidity of beverage
- Hydrometer- determine specific gravity of beer, thus determining the alcohol content

Data hand book is a manual which consists of all standard units of measurement of a parameter in SI (International Standard) system. It also consists of the information pertaining to equipment used in the processing of beer. The information includes calibration procedure and includes the training module to train the operators who are involved in the operation of respective machines. Operating specifications of all parameters involved in manufacturing process are mentioned in the manual.

The equipments used in the manufacturing process are:

- Mashing System
- Fermenting System
- Filter System
- Cooling and Pipeline System
- Packing System
- Heat and Air Supply System
- Electrical System
- Water Treatment System

The parameters which have to be measured periodically and their respective operating ranges are:

- Temperature: 10 – 77 C
- Pressure: 50 – 70 Kpa
- Turbidity: Maximum 1 NTU
- Viscosity: 1.32 – 2.2 Mpa-S
- pH: 4.0 – 4.6
- Alcoholic Strength: 17.75 – 20.0 ml

Measurement assurance is a technique which helps in determining whether a parameter is within the operating range and if not what is the difference or measurement error. This can be done by using control charts and other measurement variation methods such as bias error, reproducibility and reproductivity.

9. ACCEPTANCE SAMPLING PLAN

Beer is manufacturing in huge containers, thus the raw material and the treatment of a lot is same and the *output of this lot is also the same*. The probability that a sample is accepted will be depending on sampling a portion of the beer lot manufactured. The Go-No Go rule is that if the sample passes the acceptance test it is packaged and sent to the market, or further treatment is carried out to get the desired result and testing is carried out again. Qualitative variables such as odor, taste, color and alcohol content in beer play major in determining whether the sample is accepted and Quantitative variable plays a major role during the manufacturing.

Acceptance sampling is *"the middle of the road" approach* between no inspection and 100% inspection. There are two major classifications of acceptance plans: by *attributes* ("go, no-go") and by *variables*. The attribute case is the most common for acceptance sampling, and will be assumed for the rest of this section. A point to remember is that the main purpose of acceptance sampling is to decide whether or not the lot is likely to be acceptable, not to estimate the quality of the lot. Acceptance sampling is employed when one or several of the following hold:

- Testing is destructive
- The cost of 100% inspection is very high
- 100% inspection takes too long

Types of acceptance sampling plans

Sampling plans can be categorized across several dimensions:

- **Sampling by attributes vs. sampling by variables**: When the item inspection leads to a binary result (either the item is conforming or nonconforming) or the number of nonconformities in an item are counted, then we are dealing with sampling by attributes. If the item inspection leads to a continuous measurement, then we are sampling by variables.
- **Incoming vs. outgoing inspection**: If the batches are inspected before the product is shipped to the consumer, it is called outgoing inspection. If the inspection is done by the consumer, after they were received from the supplier, it is called incoming inspection.

- **Rectifying vs. non-rectifying sampling plans**: Determines what is done with nonconforming items that were found during the inspection. When the cost of replacing faulty items with new ones, or reworking them is accounted for, the sampling plan is rectifying.

- **Single, double, and multiple sampling plans**: The sampling procedure may consist of drawing a single sample, or it may be done in two or more steps. A double sampling procedure means that if the sample taken from the batch is not informative enough, another sample is taken. In multiple sampling, additional samples can be drawn after the second sample.

Acceptance sampling for a Beer Manufacturing

Operating Characteristic Curve: Describes the discriminatory power of an acceptance sampling plan. The OC curve plots the probabilities of accepting a lot versus the fraction defective. Thus OC curve is helpful in determining the sample size for a given lot size when the consumer and producer risk are known.

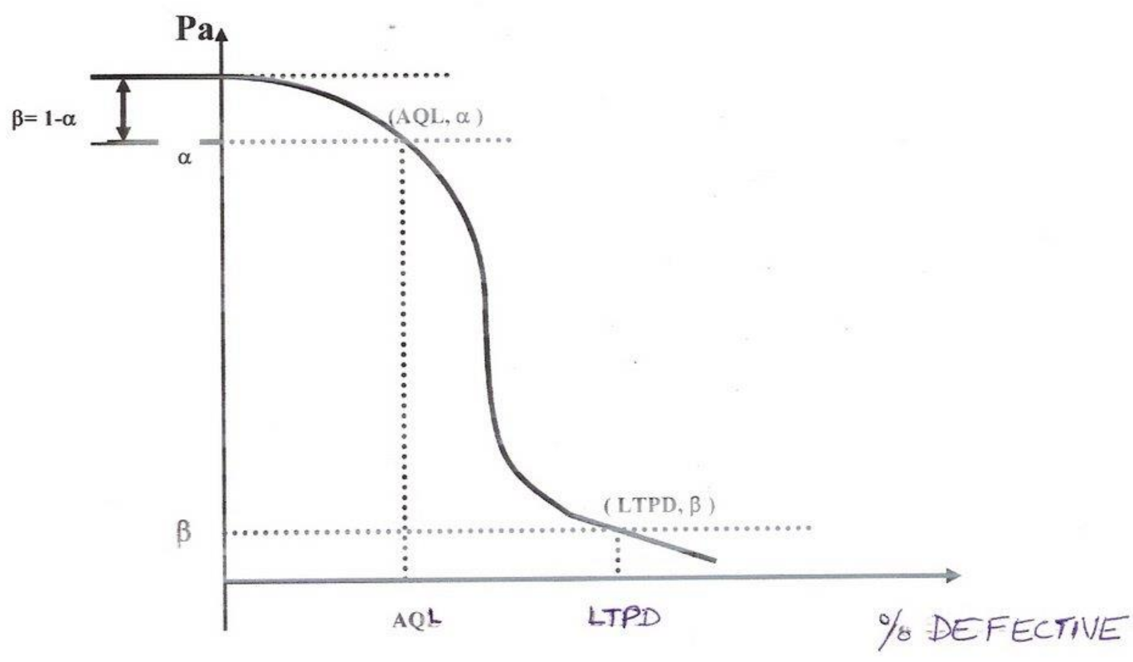


Fig (): OC curve

Where, α= producer's risk

β= consumer's risk

AQL= Acceptance Quality Level

LTPD= Lot Tolerance Percent Defect

For beer manufacturing we considered a lot size of 10,000 bottles having producer risk, α= 0.05 and consumer risk, β=0.10 which showed that the sample size for that lot should be 1158 bottles with acceptance criterion of not more than 5 defective samples.

(Note: determined using MINITAB)

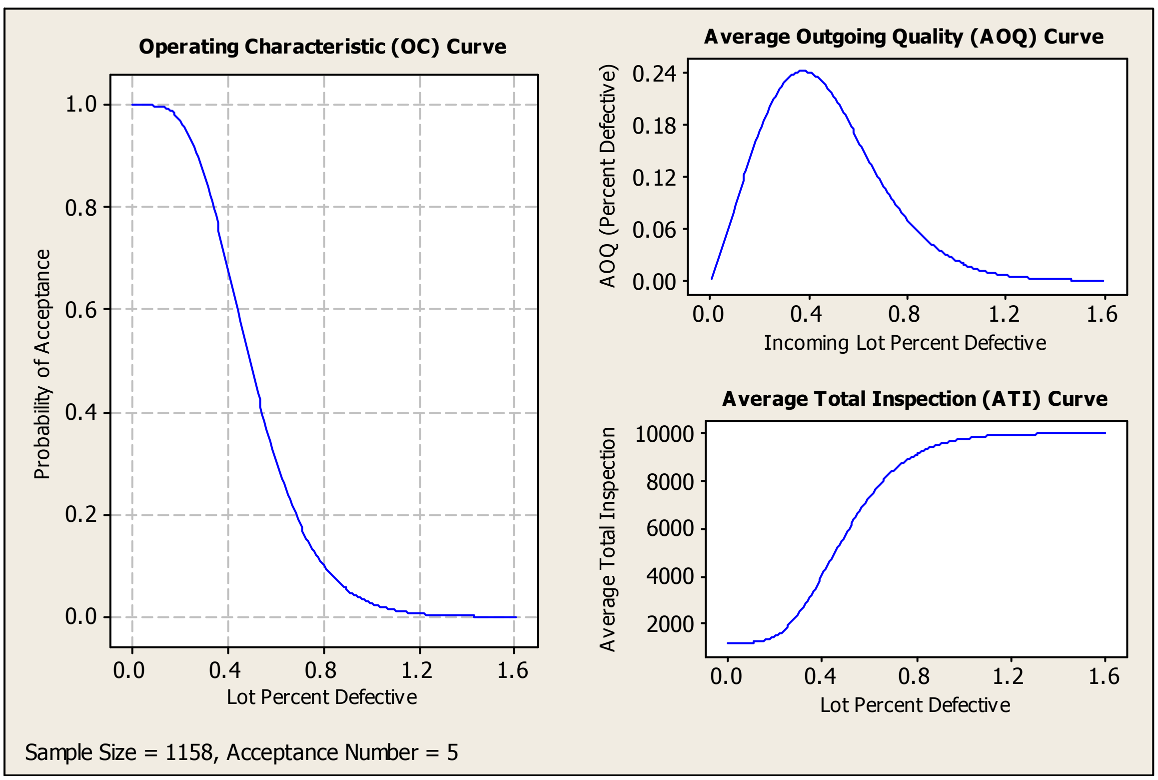


fig (): OC curve, AOQ curve, ATI plot for the given sample (Appendix: OC Curve.MPJ in CD)

The above figure is done using MINITAB; however OC curve can be constructed manually using the plot [λ vs. OC (λ)].

10. STATISTICAL PROCESS CONTROL AND CONTROL CHARTS

Statistical Process Control (SPC) is an effective method of monitoring a process through the use of control charts. Much of its power lies in the ability to monitor both process centre and its variation about that centre. By collecting data from samples at various points within the process, variations in the process that may affect the quality of the end product or service can be detected and corrected, thus reducing waste and as well as the likelihood that problems will be passed on to the customer. With its emphasis on early detection and prevention of problems, *SPC has a distinct advantage over quality methods*, such as inspection, that apply resources to detecting and correcting problems in the end product or service.

In addition to reducing waste, SPC can lead to a reduction in the time required to produce the product or service from end to end. This is partially due to a diminished likelihood that the final product will have to be reworked, but it may also result from using SPC data to identify bottlenecks, wait times, and other sources of delays within the process. Process cycle time reductions coupled with improvements in yield have made SPC a valuable tool from both a cost reduction and a customer satisfaction standpoint.

Among the many tools for quality improvement, the following are the most commonly used tools of SPC:

- Histograms
- Cause-and-Effect diagrams
- Pareto diagrams
- Control charts
- Scatter or correlation diagrams
- Run charts
- Process flow diagrams

Cause and Effect Diagram

The cause and effect diagram is used to explore all the potential or real causes (or inputs) that result in a single effect (or output). Causes are arranged according to their level of importance or detail, resulting in a depiction of relationships and hierarchy of events.

This can help you search for root causes, identify areas where there may be problems, and compare the relative importance of different causes.

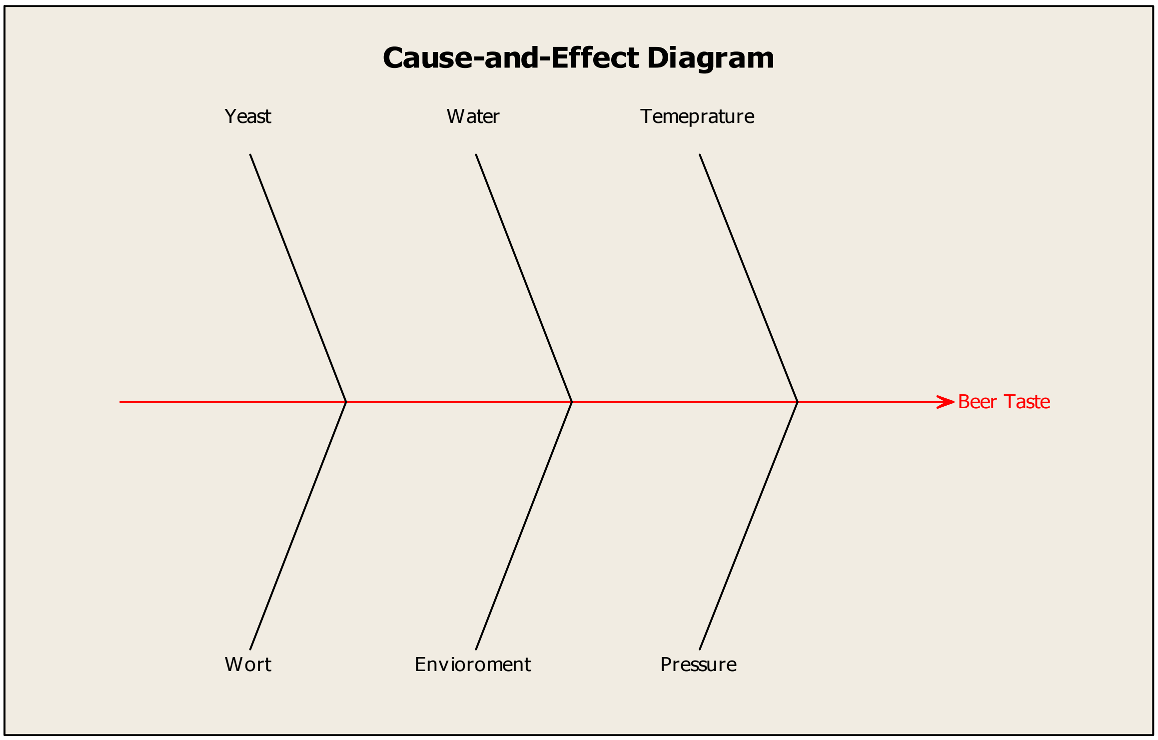


fig (): Cause and Effect Diagram for Beer Taste (Appendix SPC.MPJ)

Process Capability

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

A process capability index uses both the process variability and the process specifications to determine whether the process is "capable"

A *capable process* is one where almost all the measurements fall inside the specification limits. This can be represented pictorially by the following plot:

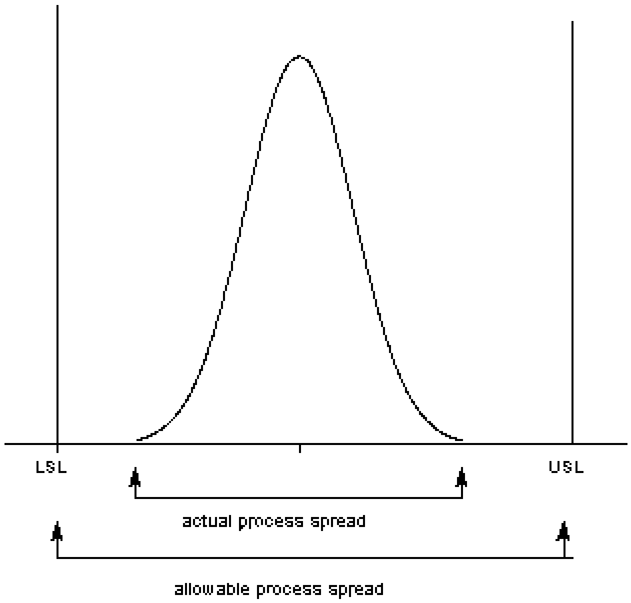


Fig (): Capable process pictorial presentation

There are several statistics that can be used to measure the capability of a process: C_p, C_{pk}, *and Cpm.*

The C_p, C_{pk}, *and* C_{pm} statistics assume that the population of data values is normally distributed. Assuming a two-sided specification, if μ and σ are the mean and standard deviation, respectively, of the normal data and USL, LSL, and T are the upper and lower specification limits and the target value, respectively, then the population capability indices are defined as follows:

Definitions of various process capability indices

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

$$Cpk = \min[\frac{USL - \mu}{3\sigma}, \frac{\mu - LSL}{3\sigma}]$$

$$Cpm = \frac{USL - LSL}{6\sqrt{\sigma^2 + (\mu - T)^2}}$$

Control Charts:

The control chart is a graph used to study how a process changes over time. Data are plotted in time order. A control chart always has a central line for the average, an upper line for the upper control limit and a lower line for the lower control limit. These lines are determined from historical data. By comparing current data to these lines, you can draw conclusions about whether the process variation is consistent (in control) or is unpredictable (out of control, affected by special causes of variation).

Type of control charts:

Common Control Charts for Continuous (or Variable) Data:

- X-Bar and R Chart
- X-Bar and S Chart
- X-mR Chart
- Z-mR Chart

Common Control Charts for Attribute (or Categorical) Data:

- P Chart
- nP Chart
- C Chart
- U Chart

We considered the Variable chart (X-Bar and R Chart) to measure the consistency of the beer taste at *ten manufacturing stations*. To measure the number of defects in a given sample we used the attribute charts (C chart).

Our interest factor in consideration is % Alcohol. *We want it to lie between 4% and 5%.*

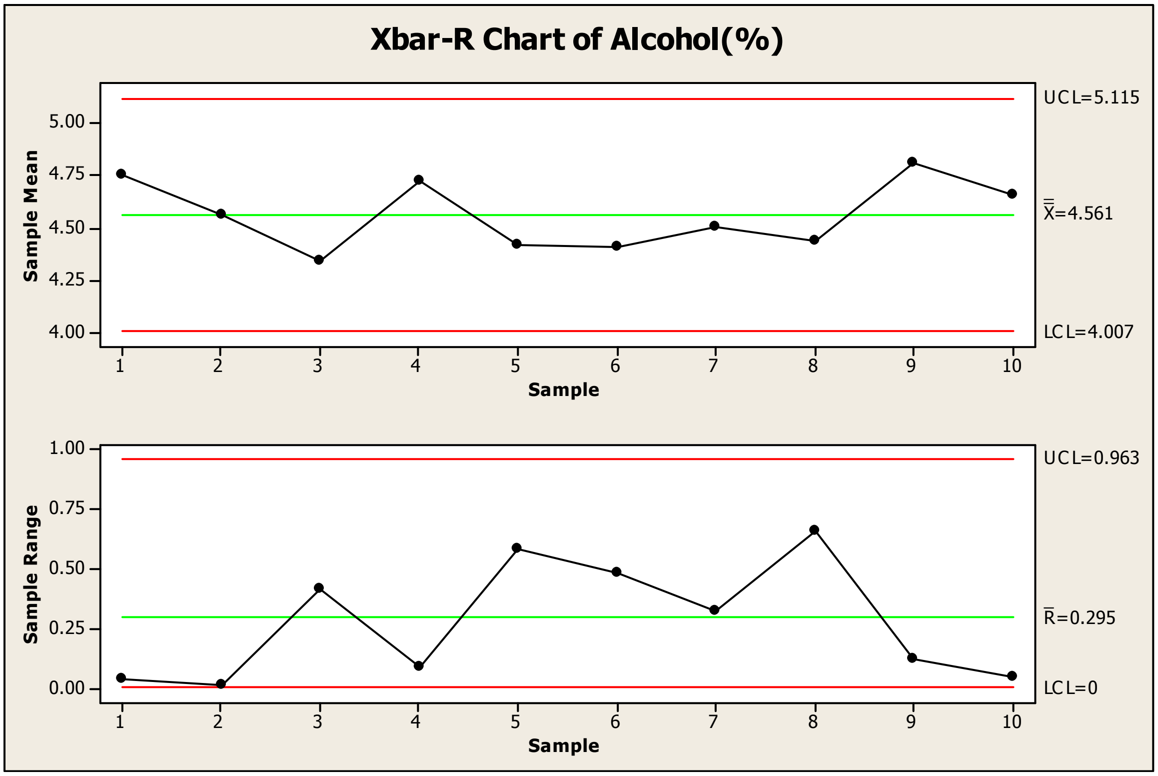


Fig (): X-Bar Chart for measurement of same taste at different places (Appendix SPC.MPJ)

From the X-Bar chart it can be seen that the process is stable and hence the beer taste would be the same at all the stations

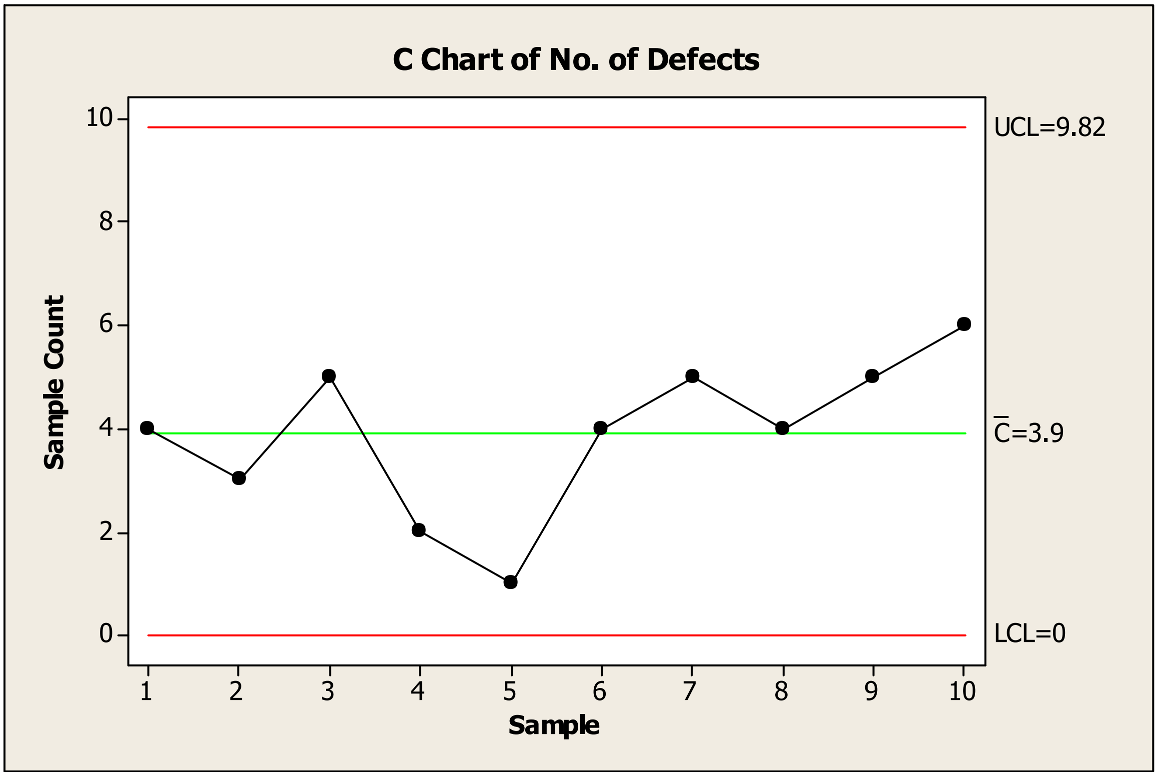


Fig (): C Chart for measurement of no. of defects in a sample (Appendix SPC.MPJ

The C – chart deals with the number of defects in a sample.

The number of ways in which a product can be damaged gives the number of defects.

Since our product form is liquid, it is very obvious and safe that we should deal with the defects, rather than the number of defectives.

11. RELIABILITY AND ESTIMATION OF MTTF AND FR

Reliability is the *ability of a product* to perform a required function under the stated condition for a stated period of time. Reliability is the probability that a product will work for the required amount of time.

Overall reliability goals require a meeting of the minds on reliability as a number, environmental conditions and successful product performance. *The major equipments involved in beer manufacture are:*

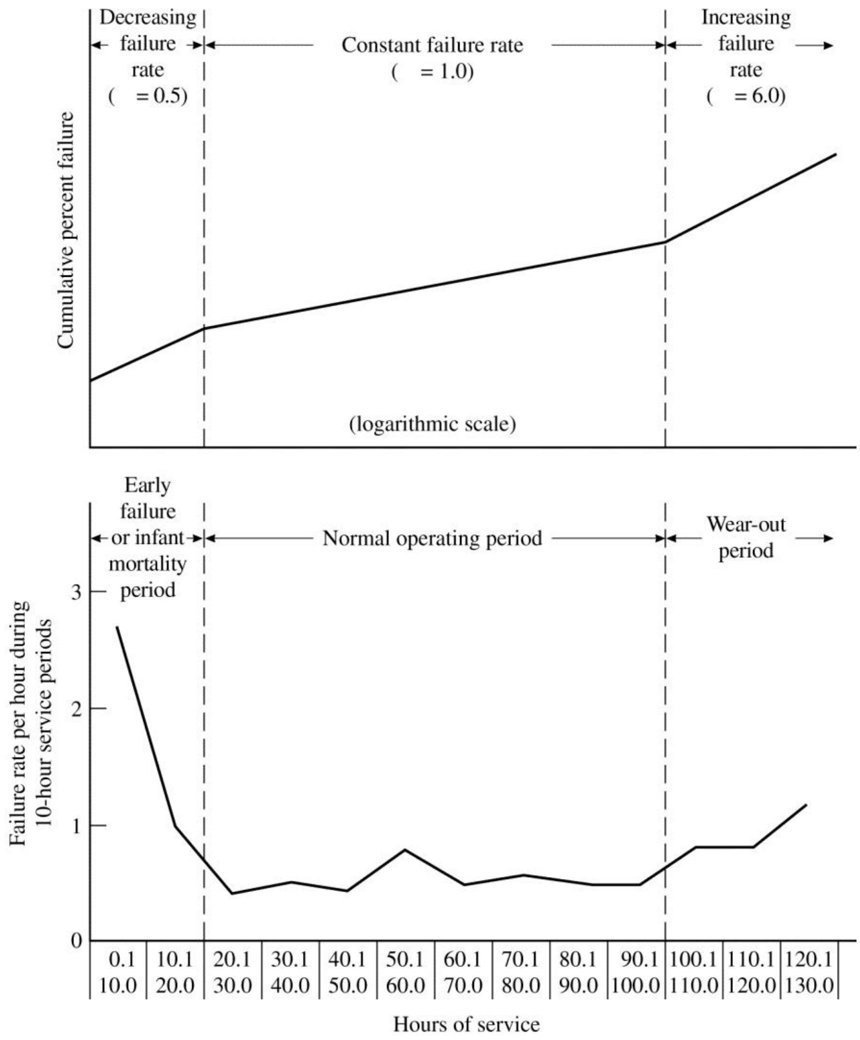
- Heater in the processes of Mashing and Boiling
- Cooler in the process of Conditioning
- Packaging machinery in the process of Packaging
- Metrology instruments such as Temperature gauges, Pressure gauges, Viscometer.

It is very important for all the above mentioned *machines and instruments to be functioning at all times to get the required beer qualities.*

To quantify reliability, the piece of equipment is placed on test and when it fails, the time of failure is recorded. The equipment is repaired and again placed on test and the next time of failure is recorded. The procedure is repeated to obtain the data namely time of failure in infant mortality period, constant failure-rate-period and wear-out period. When the failure rate is plotted against time, the result often follows a familiar pattern of failure known as the *Bathtub curve.*

The bathtub curve shows how the periods differ in the frequency of failure:

1. Infant mortality period
   This period shows the high failure rates that show up early in the use of the machinery. The results that are identified in this case are primarily due to mistakes in design or manufacturing of the machinery.



2. <u>Constant failure-rate period</u>
   The limitations in design, changes in the environment and accidents caused by use or maintenance will result in failures in this period. Good control of operating and maintenance procedures will reduce the accidents rate, but design changes are required for a basic reduction in failure.

3. <u>Wear-out period</u>
   The old-age of any equipment will cause failures in wear-out period. A reduction in failure rates requires preventive replacement of these dying components before they result in a failure.

For repairable products such as the heaters and cooler used in the manufacture of beer the *Time Between Failures (TBF)* is critical characteristic.

The corresponding characteristic for non-repairable products such as temperature and pressure gauges is usually called the Time to Failure (TTF).

Time Between Failures follows exponential distribution and indicates the chance of failure-free operation for the specific time period. When the failure rate is constant, the probability of survival (or reliability).

$$P_s = R = e^{-t/\mu} = e^{-t\mu}$$

$P_s = R =$ Probability of failure-free operation for a time period equal to or greater than t

$t =$ Specified period for failure-free operation

$\mu =$ Mean time between failures (the mean of TBF distribution)

$\lambda =$ Failure rate (the reciprocal of μ)

The Mean Time Between Failures (MTBF) is the mean or average time between successive failures of a repairable product such as the heaters or cooler used in beer manufacturing. Mean Time To Failure (MTTF) is the mean time to failure of a non-repairable product or the time to first failure of a repairable product. Mean life of any equipment is the mean value of life related of major overhead, wear-out time and is the inverse of mean time to failures or mean time between failures. Longevity is the wear out time for any equipment such as heater, container used for fermentation, etc.

Availability is defined as the probability that a product, when used under given conditions, will perform satisfactory when called upon. Total downtime includes active repair, preventive maintenance time and logistics time. When total downtime is used, the resulting ratio is operational availability A_o.

$$A_o = \frac{MTBF}{MTBF + MTTR}$$

$MTBF =$ Mean time between failures

$MDT =$ Mean Downtime

$MTTR =$ Mean time to repair

The process of reliability quantification involves three parts:

1. Apportionment or Budgeting – The process of allocating (aligning) reliability objectives among various elements that collectively make a higher quality product
2. Prediction – The use of data of performance from prior instances plus probability theory to calculate the expected various failure rates for temperature and pressure gauges.
3. Analysis – The identification of the *strong and weak portions* of the design to serve the basis of improvement.

Estimation of MTTF and FR from data

The 15 exponentially distributed times to failure of a temperature gauge used in brewing of beer are mentioned below

72.878	91.997	12.507	51.566	120.536
7.047	49.106	37.151	111.858	1.118
110.878	1.504	181.624	110.757	78.724

Sum of time to failure = T = 1039.251

Estimated time to failure = T/n = 69.2834

Failure rate = $\frac{1}{MeanLife}$ = 1 / 69.2834 = 0.0144

a) 90% Confidence Interval for Mean time to failure (MTTF)
For n = 15 and α = 0.1

$$\chi^2_{2n,1-\alpha/2} = \chi^2_{30,\,0.95} = 43.77$$

$$\chi^2_{2n,\alpha/2} = \chi^2_{30,\,0.05} = 18.49$$

$$\left(\frac{2T}{\chi^2_{2n,1-\alpha/2}}, \frac{2T}{\chi^2_{2n,\alpha/2}}\right) = \left(\frac{2*1039.251}{43.77}, \frac{2*1039.251}{18.49}\right) = (47.49,\ 112.41)$$

b) 90 % Confidence Interval for Failure rate

Failure Rate = $\frac{1}{MeanLife}$

$(\frac{1}{112.41}, \frac{1}{47.49})$ = (0.009, 0.02)

c) Now we consider the 10th temperature gauge fails at time t(10)- 91.99

Obtain the 90 % Confidence Interval for Mean time to failure (MTTF)

The times to failures of temperature gauge before the 10th failure are

1.118	1.504	7.047	12.507	37.151
49.106	51.566	72.878	78.724	

Sum of times to failure = T = 403.598 + 5 * 91.99 = 771.551

$\chi^2{}_{2k,1-\alpha/2} = \chi^2{}_{20,\,0.95} = 31.41$

$\chi^2{}_{2k,\alpha/2} = \chi^2{}_{20,\,0.05} = 10.85$

For k = 10 and α = 0.1

Confidence Interval for MTTF

$(\frac{2T}{\chi^2{}_{2k,1-\alpha/2}}, \frac{2T}{\chi^2{}_{2k,\alpha/2}})$ = $(\frac{2*771.551}{31.41}, \frac{2*771.551}{10.85})$ = (49.122, 142.22)

MTTF point estimator is T/k = 77.155

d) Obtain 90 % Confidence Interval for Failure Rate (FR)

Failure Rate = $\frac{1}{MeanLife}$

$$(\frac{1}{142.22}, \frac{1}{49.122}) = (0.00703, 0.0203)$$

e) Compare two sets of results and conclude

From the above confidence intervals obtained above, it can be concluded that the C.I.'s for both mean time to failure and failure rate are approximately the same after truncating at the 10^{th} failure.

Our MTTF point estimator is observed to fall in the 90 % confidence interval.

12. CONCLUSION

- 'You can improve it, if and only if you measure it'
- There have been dramatic change in the field of managing for quality in the recent years
- Customers demanding perfection in quality, cost and reliability have become a norm
- SPC, if applied properly, can play a very critical role in improving process in virtually any industry … service and manufacturing
- Input to identifying significant factors affecting the process should always come from those who handle the process
- Standardize, then apply DMAIC … otherwise you are working with garbage, just that you don't want !!!

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