‘Quality means never having to say you are sorry.’

Farhad Kashani

Quality & Reliability

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Introduction

This is not a book! At least that was not the intention. I decided to publish three presentations that I had from my younger days. It turned out that the only way I could post them was to make it to look like a book and publish it in that fashion.

Here is my related experience in the fields of quality & reliability.

I hold an AA degree from De Anza College in quality.

I am a certified Reliability Engineer. I am a certified Quality Engineer. The highest quality title I held was Director of Quality and as a CEO have had VP of Quality reporting to me.

Farhad Kashani

COST of QUALITY

Cost of Not Having Quality

HISTORY & REASON

- The Cost of Quality concept was first described by Dr. Armand V. Feigenbaum in Harvard Business Review in 1956. Up until then the common understanding was that the more the quality the more the cost. The cost of quality concept showed that it should not be the case.
- The South West Airlines is the proof that the higher the quality the cheaper the cost.

SOUTHWEST AIRLINES

- The highest quality reliability airline in the world established in 1967.
- Has over 550 airplanes. Never lost any to any crash.
- No passenger has ever died.
- Never lost a penny not even after 9/11.
- Pays the highest salary to 737 pilots!
- Always uses two ATP pilots as opposed to one ATP and one CPL (cost more).

SOUTHWEST AIRLINES

- Has 3500 scheduled flights per day.
- Each airplane flies over 11 hours/day.
- The closest competition does 8 hours.
- Has 46,000 employees
- The first/best cheap airline in the world.

DEFINITION

- Cost of Quality: Any cost related to not having quality.
- In a perfect world you can design a product that does not require any prevention, any appraisal (inspection), does not produce any failures in the factory and never fails in the field.
- In a real world you need to spend money to prevent problems from happening.

DEFINITION continued

- You need to spend money to inspect the product at each and every stage, you will have some internal process failures that you need to fix, and you will have field failures. These are all called Cost of Quality. If your Total Cost of Quality is less than 2.5% of your revenue, you are doing great. If it is more than that you need to review it and see where you are spending too much.

ELEMENTS of COST of QUALITY

- There are four major categories:

1- Prevention

2- Appraisal

3- Internal Failure

4- External Failure

1- PREVENTION

- Any activity related to preventing failures from happening. For example hiring a quality engineer, spending any money on ISO certification, having any kind of training for the staff, workers, or suppliers, will be considered as Cost of Prevention.

2- APPRAISAL

- Any activity related to inspection of the material or product from source inspection, to receiving inspection, process inspection, final product inspection is considered as Cost of Appraisal. This cost is not limited to the quality department. Anywhere the material or product gets inspected it is cost of appraisal even if done by manufacturing people. All inspection machines such as optical, X-Ray, brake test in a car are included in this cost.

3- INTERNAL FAILURES

- Any repair done in manufacturing, any scrap material, any rework or repair labor, any equipment purchased for repair, any location dedicated for rework, any electricity used for rework, they all count as the Cost of Internal Failures. The time spent in Material Review Board to dispose the rejected items also is a cost of Internal Failures.

4- EXTERNAL FAILURES

- Any cost related to products failing in the field such as issuing Return Material Authorization (RMA), call center, repairing the returned units, sending mobile service to repair such items, transportation cost for the returned items, if paid by the company, Product recalls, product upgrades, the time spent by president of the company to apologize to the customer, is considered as Cost of External Failures.

CONFORMANCE vs. NONCONFORMANCE

- In general the first two costs, Prevention and Appraisal are called Cost of Conformance , and the last two, meaning, Internal and External Failures are called Cost of Nonconformance.
- The more money you spend on the first two the less you will spend on the last two.

QUALITY DECISION

- If you were the VP of Quality of a newly formed hardware or software company and your boss gave you a $1,000,000 budget , to spend it however you like on the Cost of Quality, how would you do it?
- It definitely makes sense to spend most of it on the first two so that you do not need to do much for the last two.

QUALITY DECISION

As a matter of fact this is how you need to spend the money.

Prevention>Appraisal>I. failures> Ex. Failures

The companies that do not spend enough money on the first two end up spending much more than what they wish, on the last two items.

REAL CASE

- In 1983 in my first hi tech job in the Silicon Valley, I was asked to measure the actual Cost of Quality of the company because the VP of Operations was interested to see what is going on.
- They gave me 45 days to measure the CoQ for this $500M company with multiple products and 2000 employees in 15 buildings.

REAL CASE

- In that process I discovered some $700,000 worth of rejected boards collecting dust. A simple money interest calculation convinced the VP of Operations to hire two extra technicians to repair the boards. The final cost number was 5% of the revenue which was not that bad but showed that improvements could be made.

TYPES of COSTS

1- Tangible Costs: The ones that can be measured scientifically. Such as material cost, Labor cost, etc.

2- Intangible Costs: The ones that require a lot guess work. How much does it cost to lose a customer? How much does it cost to lose market share due to quality issues?

The 1-10-100 RULE

- It is said that if you catch a problem at Prevention level it may cost you 1. The same thing caught in the final stages of production it may cost 10. Once it leaves the door and if caught later it may cost you 100.
- An Airbus A340-600 was being delivered to an airline in Toulouse, France. The final inspection was being done by the airline test pilot. Testing the full power with the brakes on.

The 1-10-100 RULE

- All of a sudden the airplane started rolling and hit a noise barrier. 10 crew and ground members got injured. You can categorize this as Cost of Inspection (if pilot error) or Internal Failure (if airplane error). The airplane was wrecked but it was much cheaper than having a similar accident with over 300 passengers aboard.

SOUTHWEST CASE

- Prevention Costs:
- Pays the highest 737 salaries to its pilots so that they do not need to migrate to other airlines with bigger airplanes to make more money.
- Due to using two ATP pilots vs. one ATP and one CPL, it pays more money, but benefits from two experienced pilots vs. one.

SOUTHWEST
Case Continued

- Appraisal Cost: Let's assume it is like the other airlines.
- Internal Failure Cost: Much less due to operating one type of airplane only.
- External Failure: Almost ZERO

Farhad Kashani

- Certified Reliability Engineer (CRE) 1984
- Certified Quality Engineer (CQE) 1985

PRACTICAL RELIABILITY ENGINEERING

"Given enough time everything will fail whether electronics, or human beings"

Definition of Reliability: Probability that a system does its intended function in a defined environment during a defined period of time.

QUALITY vs. RELIABILITY

- When we talk about our first impression of the product or Plug & Play, we are talking about quality.
- When we talk about the long term performance or performance in time, we are talking about reliability.
- It is a common mistake that customers call both issues as quality issues.
- The manufacturer has to always separate these two issues and deal with each one appropriately.

Quality or Reliability
Real Case

- A customer sued our computer company in 1984 for $1,300.000 for having 25% failure rate in one year.
- It turned out that the plug & play number was better than 99% (quality) and we were meeting and exceeding our specified MTBF (reliability) for one year of usage.
- The case was dropped and I received an unspecified raise (25%)!

DEFINITION of MTBF

- MTBF (Mean Time Between Failure): The average time that a population of systems will fail. i.e. if 5 systems had a total of 2000 hours logged on them and they had 2 failures. The MTBF would be 2000/2= 1000 hours.
- MTTF or Mean Time To Failure is used for such things as a light bulb and things that only fail once and are not reparable.
- Failure Rate: Inverse of MTBF or MTTF.
- If MTBF is 1000 hours the Failure Rate is 1/1000

TYPES OF MTBF

- CALCULATED MTBF: Based on Military Hand Book.
  Mil-HDBK-217G or specification of the manufacturer.
- DEMONSTRATED MTBF: Based on Mil-STD-781D.
- FIELD MTBF: Based on the field observations.
- SPECIFIED MTBF: Based on your definition or requirement.

CALCULATED MTBF

If we build a product that has three components with the following MTBF's What would be the MTBF of the system?

- Component A MTBF=5,000 Hours
- Component B MTBF=1,000 Hours
- Component C MTBF=2,000 Hours
- System Failure Rate=1/5000+1/1000+1/2000
- System Failure Rate=17/10,000
- System MTBF=10,000/17= 588 Hours
- The MTBF of a system cannot be greater than its sub-components. It will be less than its lowest component.
- In the above example it cannot exceed 1000 hours.

DEMONSTRATED MTBF

- You put a number of systems under test. Statistically speaking there is no difference in results between flipping one coin 1,000 times, and 1,000 coins one time. In reality none of the extreme cases help.

- Lets assume we put 20 units under test and after a month we have collected 14,400 Hours. Also let's assume we have seen 5 failures total. The Demonstrated MTBF will be 14,400/5 = 2,880 Hours. Of course by continuing the test the MTBF number can go higher until it reaches the point of maturity where you do not get a higher MTBF number.

FIELD MTBF

- Let's assume we have 2000 units in the field. Some were delivered last week and some during the last few years from the first introduction of the product. We add up all hours accumulated and count all failures accumulated except the ones that have been positively fixed.
- Let's assume we have accumulated 2,000,000 hours and we have had 15 failures. 5 of the failures were the same kind that were positively fixed by a hardware ECO, therefore we have 10 failures left. The Field MTBF will be 2,000,000/10=200,000 hours.

SPECIFIED MTBF

- You are creating a new product and you feel the MTBF should be 100,000 Hours. You just need to demonstrate that number by testing a population of products. By selling such system with high MTBF numbers you are liable to produce the results.

MTBF IMPROVEMENT

- What is a good MTBF number?
  It depends on your customer's expectations, your specification, your competition, or your goal.

- How do you improve your MTBF number? Either better design, better software, better components, better manufacturing process or periodic replacement of suspected parts.
- An oil filter in a car has a much lower MTBF than the rest of the car, therefore the manufacturer recommends that you replace them regularly. In that case it does not count against MTBF.

TYPES of FAILURES

- Are there any differences between hardware and software failures? Is re-setting the system as bad as a hardware failure?
- It depends on how you define the failure based on your customer requirement.
- You can also come up with two different MTBF numbers. One for hardware failures and one for software failures.
- Does “No Problem Found” count as a failure? Again It depends on your definition. I think they are worse than “Problem Found ”. The unit has failed and you do not know why?

RELIABILITY

- The more a system is used the more it may fail no matter what the MTBF is.
- What is the reliability of a 5 hour flight from San Jose to New York if the MTBF of the plane is 1000,000 hours? How about a 2 hour flight to Denver?
- Reliability (chances of not failing)=
- 1-(Intended time of usage/MTBF)
- To New York= 1-(5/1000,000)=99.9995%
- To Denver = 1-(2/1000,000)=99.9998%

MTTR

- MTTR: Mean Time To Repair
- MTTR= Average Repair Time + Administrative Lead Time+ Shipping Time + Disassemble Time + Install Time + Parts Acquisition.
- If we have a system in a remote location that takes one hour to disassemble + One hour to assemble + One hour to repair + Three shipping days each way and one day to get the parts, what would be the MTTR?
- MTTR=1+1+1+72+72+24=171 Hours

SYSTEM AVAILABILITY

- Now that we know how to do MTBF and MTTR calculations. How are they utilized?
- SYSTEM AVAILABILITY= 1-(MTTR/MTBF)
- If in our last example the MTBF was 10,000 hours what would be the System Availability?
- SYSTEM AVAILABILITY= 1-(171/10,000)=98.29%
- Conclusion: If you are selling to an availability sensitive customer you either need a very high MTBF or a very low MTTR (7X24 service, on-site service, available parts, regular maintenance or parts on site, better design for disassembly etc.).

SYSTEM AVAILABILITY

- In the previous example you can have a lower MTBF with a much lower MTTR and yet you will have a better System Availability.
- If MTBF was 5,000 hours but MTTR was 5 hours:
- System Availability= 1-(5/5000)=99.9%

SYSTEM AVAILABILITY

- While formal larger organizations know how to do the System Availability calculations and they demand certain numbers, regular customers do the same calculation in their heads without knowing the formula. The more their system is down the less they like your product!

SYSTEM AVAILABILITY
REAL CASE

- AD is a heavy tractor truck manufacturer overseas. Its service policy says that customers can bring their truck for service or repair at any time with no prior appointment till 4PM and receive their truck back the same day. AD's competitions use a different rule.
- 1- Appointments are necessary.
- 2- Trucks will not be accepted for repair toward the weekend.
- 3- Time to bring in trucks is from 7-8AM only.

SYSTEM AVAILABILITY
Real Case continued

- In a conversation with a famous local bank that finances all trucks from all brands, the VP of the bank asks President of AD whether they have a credit screening system. AD president responds no, why? The bank VP says because your customers have the best track record on payments with our bank!
- It was the lower MTTR that kept the AD trucks on the roads and money in the pocket of owners that they could afford to pay their payments.

SYSTEM AVAILABILITY
Real Case #2

- Selling some computer hardware to the Air force in 1985 since the System Availability was not meeting the requirements and we could not increase the MTBF we had to give them some free spare parts to cut the MTTR to a more reasonable number.

RELIABILITY ORGANIZATION

Q: Where does the Reliability Engineering function fit in an organization?

A: Somewhere between Engineering and Manufacturing.

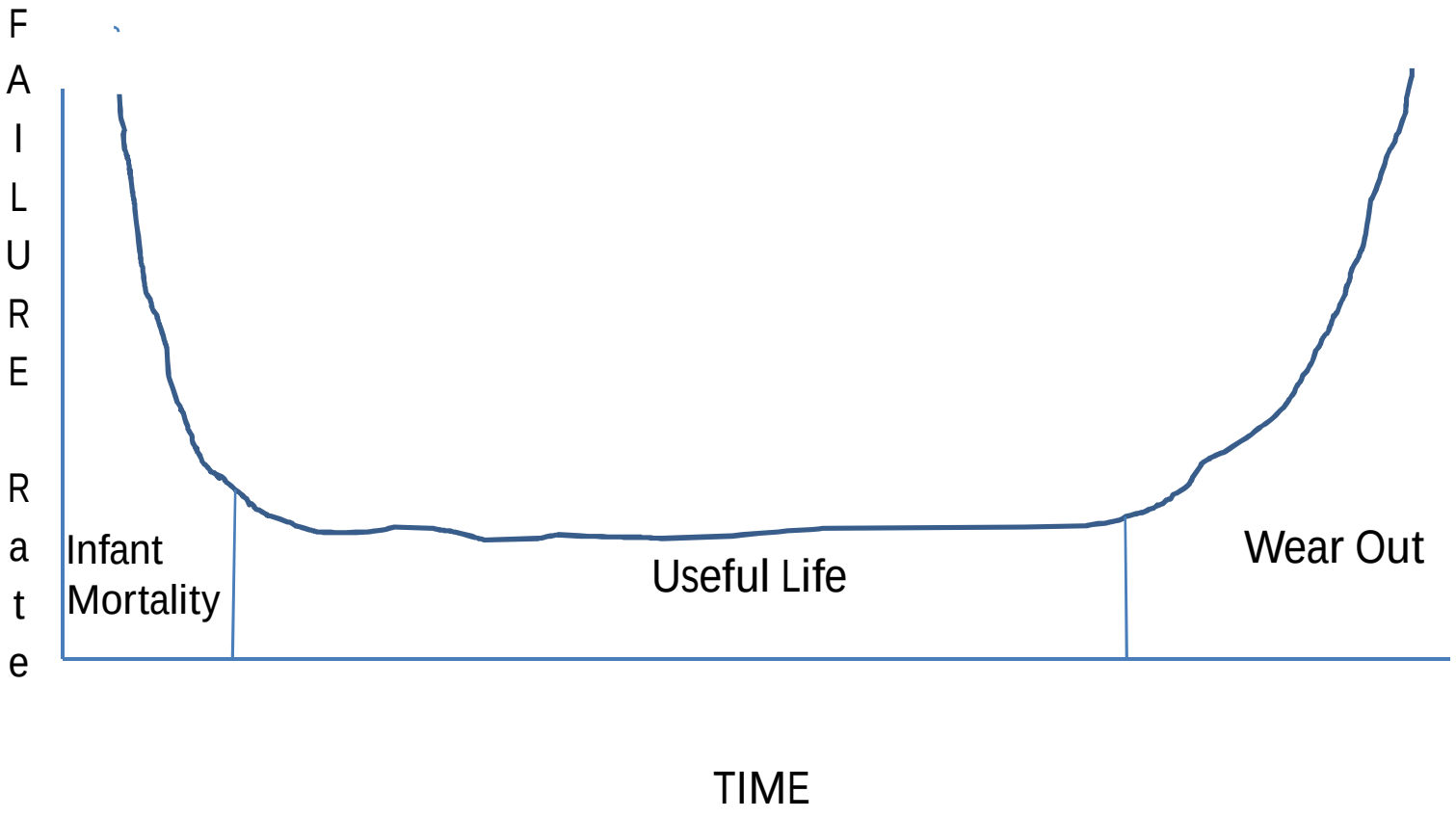
RELIABILITY DEPARTMENT

- How does it work?
- After engineering releases the product, manufacturing builds as many samples as budget allows for reliability testing. After reliability proved the theoretical MTBF number with a demonstrated test, the product will be released to manufacturing.
- This test catches a lot of problems that otherwise customers will see.

USEFUL LIFE

- It should be noted that the Calculated and Demonstrated MTBF only apply to the Useful Life period of a system. It does not apply to Infant Mortality period or Wear Out period.
- Also it should be noted that the discussions so far were about the Life Test. There are other tests in Reliability Department such as drop test, shock test, humidity test, pressure test, brown out test etc. that we will discuss later.

BATH TUB CURVE



ACCELERATED TESTING

- Accelerated Testing: Any abnormal environment that can accelerate failures in a system such as elevated temperature (Burn-In), shock, or vibration. There are tables such as Arrhenius Table that show the effect of temperature on time. For example if you raise the temperature from 25 Celsius to 40 the time multiplies by 3.

ACCELERATED TESTING

- Accelerated Testing: Has two applications:

- In production it can accelerate the Infant Mortality period to deliver the product at the beginning of Useful Life.

- In reliability testing it is a multiplier for time to demonstrate the MTBF faster during Useful Life period.

ORT

- Ongoing Reliability Testing: Let's say you have demonstrated certain MTBF number before you introduce the new product to the market. What happens if some components are changed, or the manufacturing process has changed? Wouldn't those changes impact the reliability of a system? They do, therefor by taking periodic samples from production line and running them for extended amount of time would help to understand the issues.

RELIABILITY QUALIFICATION TESTING

Depending on the product and its living environment there are other tests that can be done to assure that the product will not fail under those conditions.

A Drop Test for a packaged product shows the strength of the design of the package to withstand drops and not transfer all the G Force to the product.

A Vibration Test for a packaged product can simulate the road vibrations and its impact on the product.

A Vibration Test for the product itself can show its survivability when a drawer is slammed to a desk and the vibration that follows.

RELIABILITY QUALIFICATION TESTING

- A Humidity Test shows how a product will perform in a humid environment.
- A Tilt Test shows how far a product can tilt before it drops on its side (a server or car).
- A Brown Out Test shows how low the voltage can go before it causes a hardware failure or catching fire.
- A Pressure/Altitude Test shows how a product will perform in mountains or high altitudes.

RELIABILITY QUALIFICATION TESTING

- A Thermal Shock Test will show how a product will perform if taken from a very cold environment to a very hot environment or reverse (airplane taking off or landing). Also what is the temperature tolerance of the system .
- A Salt Test will show how a system performs near sea or in a ship (a car or computer).
- A Lightning Test will show how a product performs under lightning (airplanes)

RELIABILITY QIUALIFICATION TESTING

- A Freeze Test shows how a product performs when it accumulates ice on it (airplane).

- There are many more tests depending on the product and environment these were just some samples.

DERATING

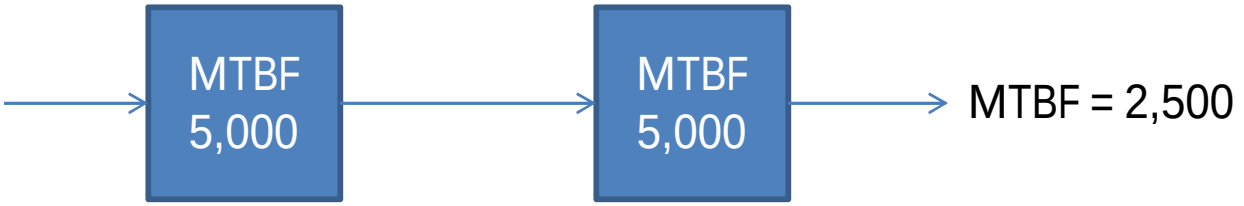
- It means not pushing every capability up to 100%. Imagine a car can go a maximum of 100MPH but you use maximum 70% of that meaning 70MPH. By de-rating you increase the life and reduce the chances of failure.

REDUNDANCY

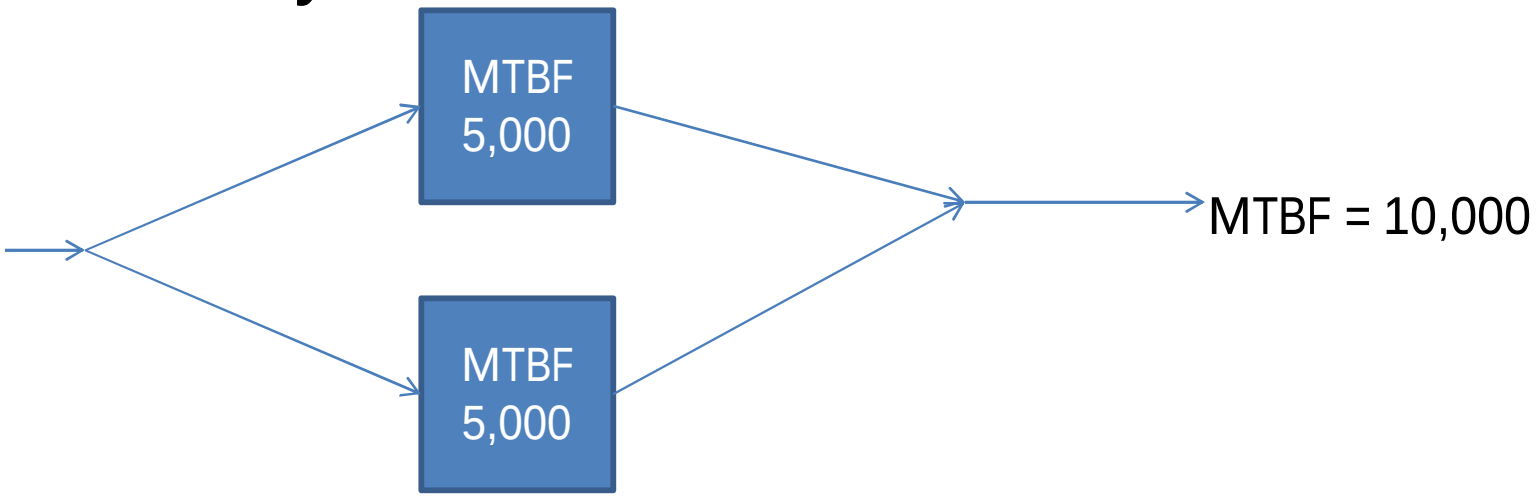
- Imagine an airplane that can fly with 2 engines may have 4. This is called Redundancy. Redundancy will increase the MTBF of the product. If you put two parts in parallel with each other where each one can do the job you are doubling the MTBF.

PARALLEL vs. SERIES SYSTEMS

- Series Systems



- Parallel Systems



Prepared by Farhad Kashani

- Certified Reliability Engineer 1984
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STATISTICAL PROCESS CONTROL

This method was invented by Dr. Walter Shewhart in 1924 and was perfected by Dr. Edward Deming years later. It basically gives you warning when your process goes out of control and does things that 99.7% of the time it does not do.

STATISTICAL PROCESS CONTROL

If you cannot measure it you cannot improve it.

Lord Kelvin

STATISTICAL PROCESS CONTROL

- What does it do for you?
- You have a car that every time you fill up the gas tank and you measure its gas consumption. You get 20+_2 MPG but one day you get 15 MPG don’t you want to know what is wrong with your car?
- What if it usually gives you 20+_2 but one day it gives you 25MPG. What is right with it?

RANDOM vs. ASSIGNABLE

- When you measure your gas consumption and 99.73% of the time you get between 18-22 MPG the reasons for these small variations are due to random reasons that you do not need to investigate. These are chance related reasons.

ASSIGNABLE CAUSE

- When all of a sudden you get 15 or 25 MPG these are the events that do not happen 99.73% of the time so you really need to investigate and find out why. There must be assignable causes for these two behaviors. Whether you hate the change (15 MPG), or you love it (25 MPG).

LOOKING FOR ASSIGNABLE CAUSES

- In the first example what are the possible assignable causes?
  - –Clogged air filter, carrying too many passengers or load, a lot of uphill driving, a lot of fast driving, using the wrong type of gas, mechanical problems.

LOOKING FOR ASSIGNABLE CAUSES

- In the second example what are the possible assignable causes?
- Wrong measurement, better fuel, recent oil change, lot of level driving, better driving skills and habits.

BEING OUT OF CONTROL

- Now using the formula you will figure out what are the numbers that happen 99.73% of the time.
- Then you look for any number that is out of the 99.73% range. Now you are looking for assignable causes not chance related causes. When your gas consumption was varying from 18-22 MPG the numbers varied because of chance. When it jumps to 25 or 15 it is not chance anymore and you need to find the cause.

ATTRIBUTE CHARTS
(Counting Defective Units)

- P Chart: You inspect 100 units. 10 are defective. For P chart purposes you enter 10% defective. Your sample can vary each time.

- NP Chart: You inspect 10 units 2 are defective. For NP chart purposes you enter 2 defective units. Sample size should be constant.

ATTRIBUTE CHARTS
(Counting Defects)

- C Chart: You inspect 15 units and find 10 defects overall. For C chart purposes you enter 10 defects. Your sample size must be constant.

  U Chart: You inspect one product and write down the number of defects found.

VARIABLE CHARTS

- X Bar & R Chart: You take actual measurements of let's say 4 products and write down the average (X bar) and Range (difference between highest and lowest numbers.
- X Bar & S Chart: You take actual measurement of let's say 4 products and write down the average X Bar and Standard Deviation.

HOW TO PLOT A CHART

- No matter what kind of chart, you come up with some numbers that need to be plotted.
- After plotting the points based on the scale you connect the dots. Now you have a kind of broken line which is your trend line.
- Then you calculate the average of all points on the chart to come up with the average line.
- You plot the average line

TREND CHART

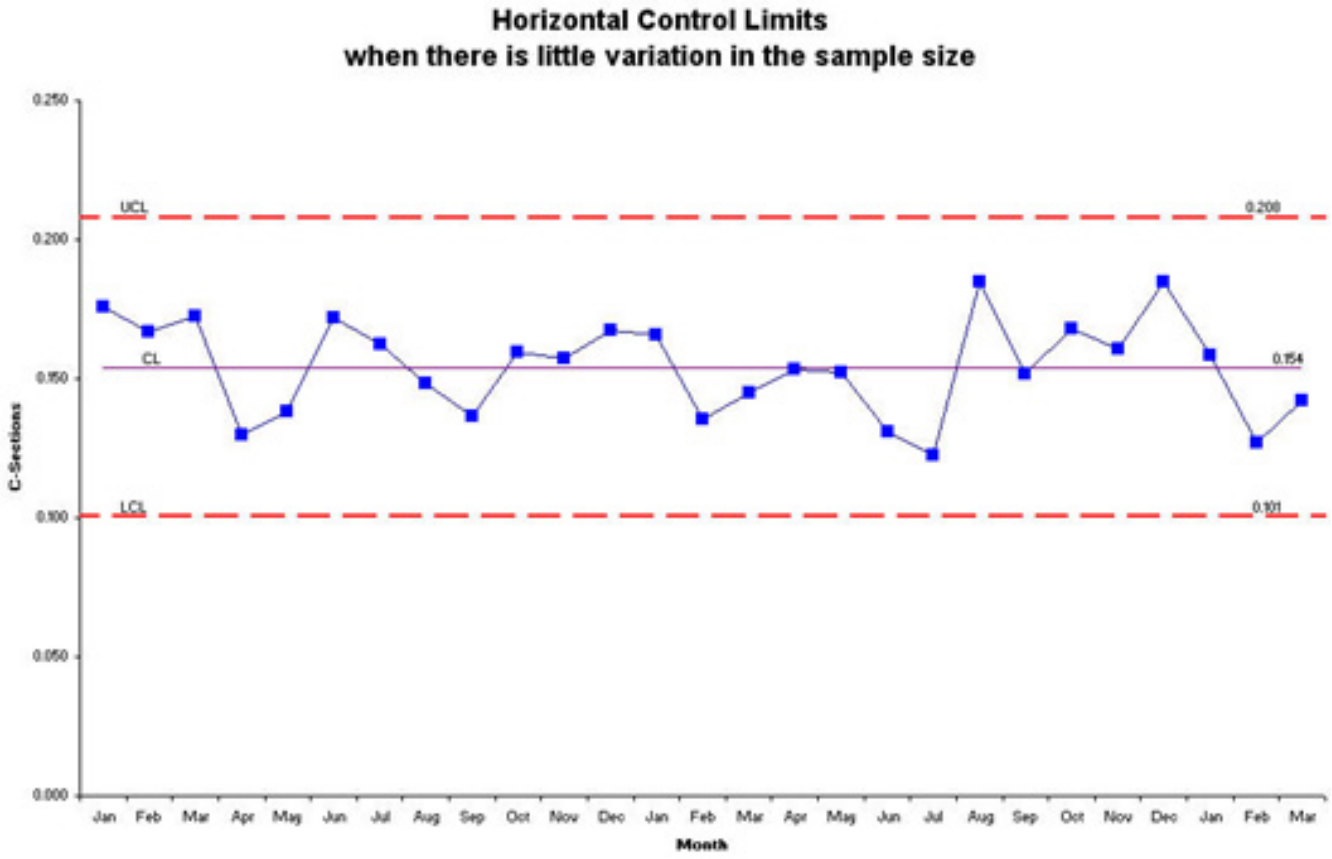
- Looking at our trend line and comparing it with the average line we may have situations where the trend line is sometimes above the average line and sometimes below.
- Now we calculate the Upper and Lower Control limits based on the formula.
- Any point above the UCL or below LCL is out of control and we need to find the assignable cause.

ASSIGNABLE CAUSE

- Another situation where you may find an out of control situation is when 8 points fall on one side of the average line. This means either a shift in process has happened or the process is out of control. Why? because chances of a point falling on either side is 50%. Having 8 consecutive ones can mean 4 in 1000 situation.
- 0.5X0.5X0.5X0.5X0.5X0.5X0.5X0.5=0.4%

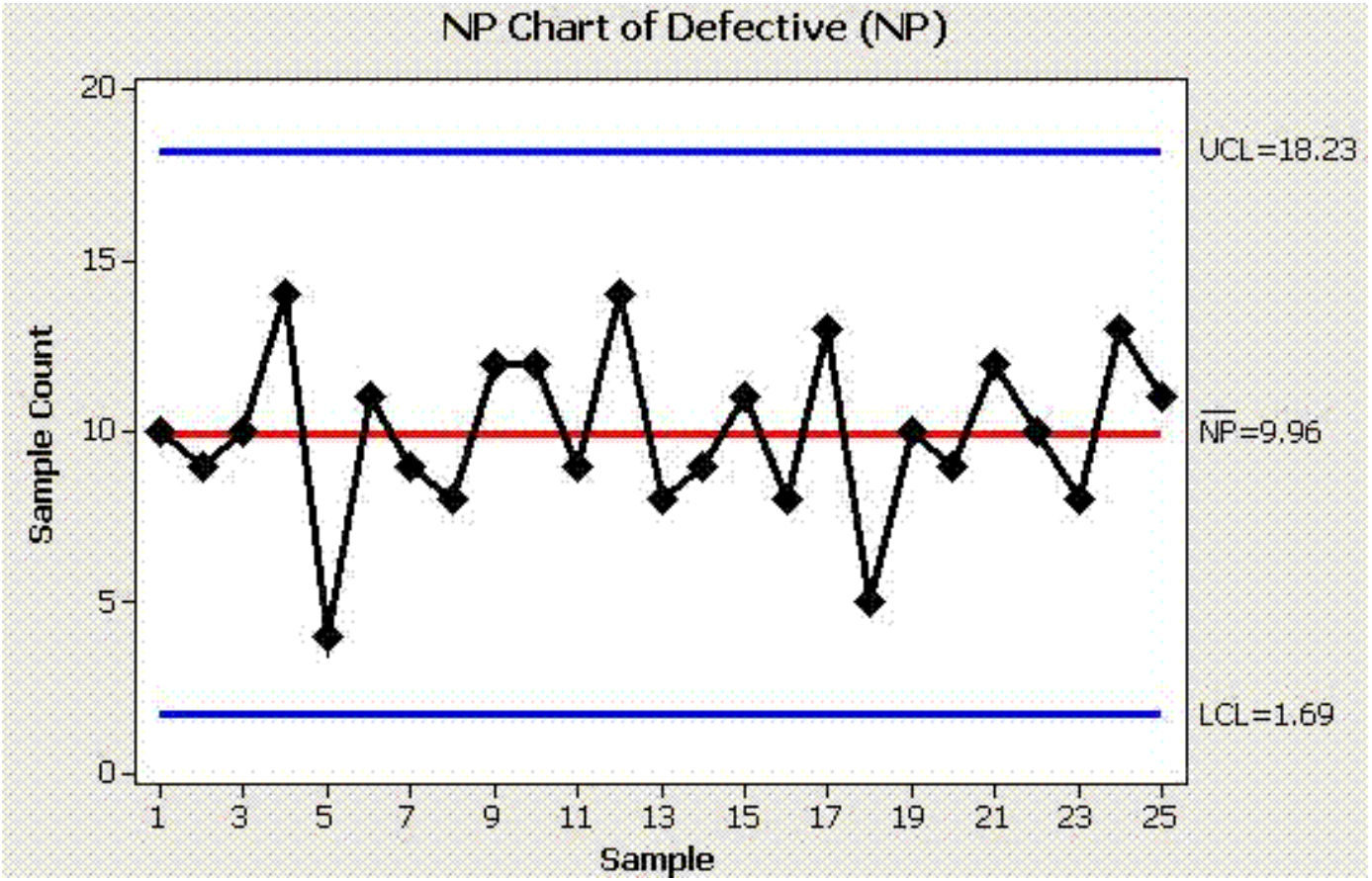
P CHART SAMPLE

P CHART



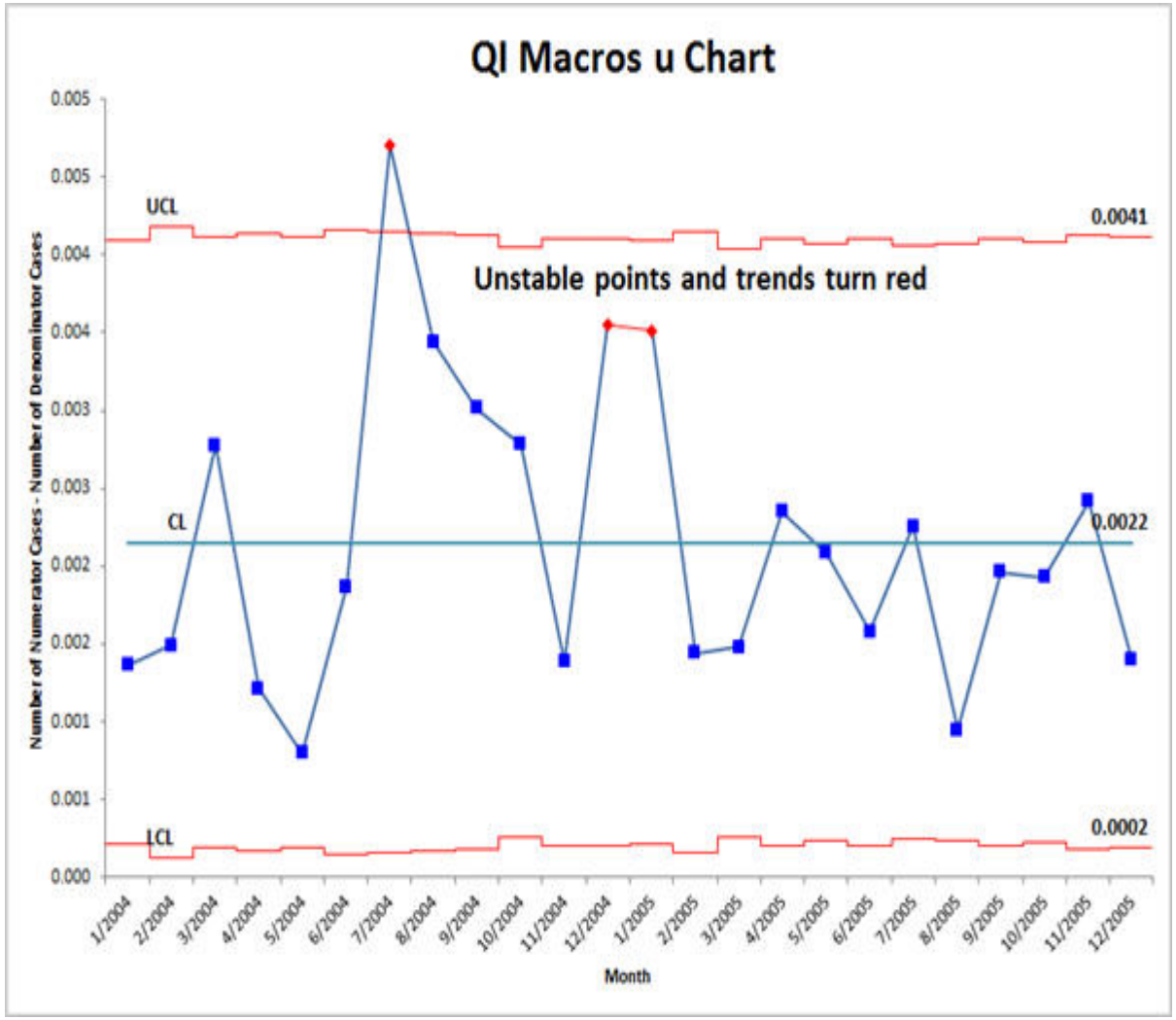
NP CHART

- NP CHART



U CHART

- U


QI Macros u Chart
Unstable points and trends turn red
UCL
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Number of Numerator Cases - Number of Denominator Cases
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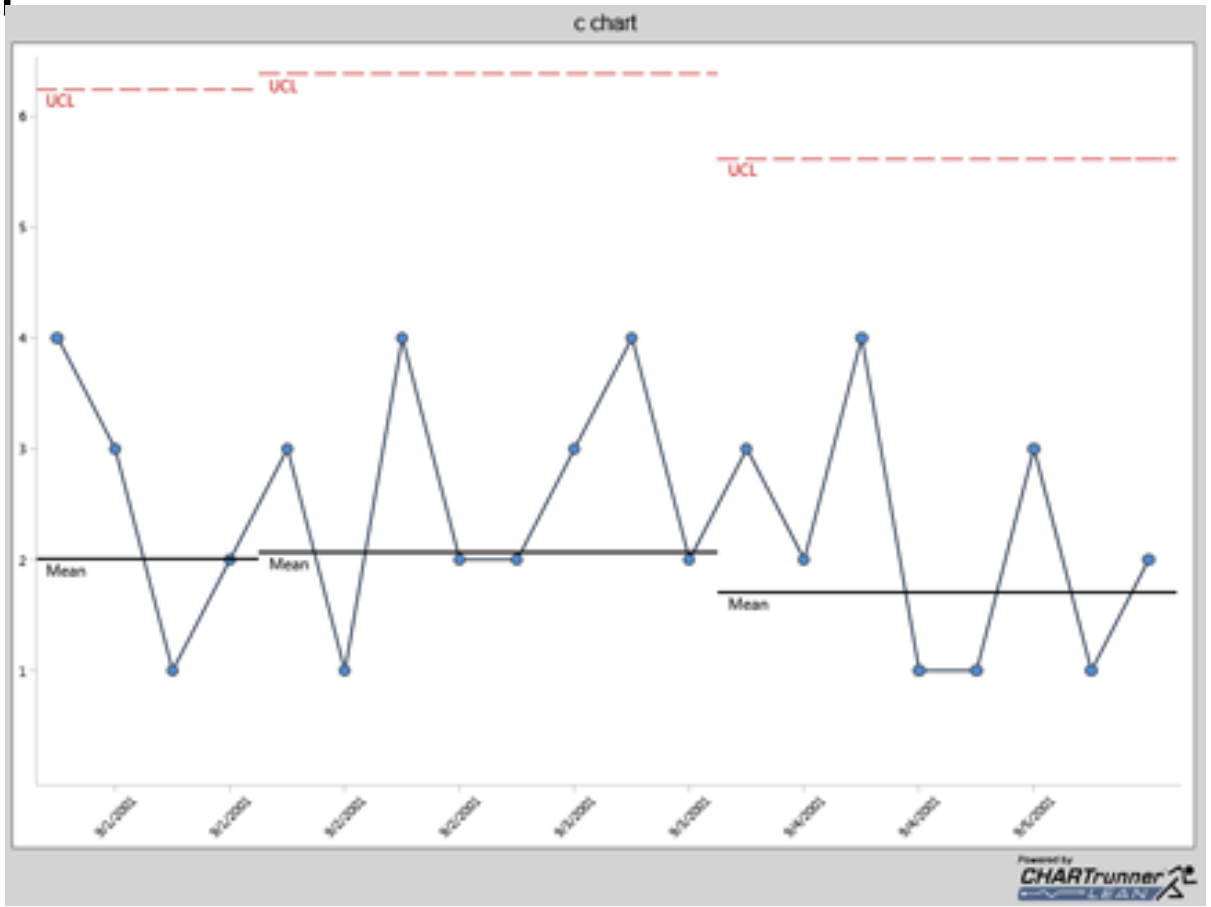
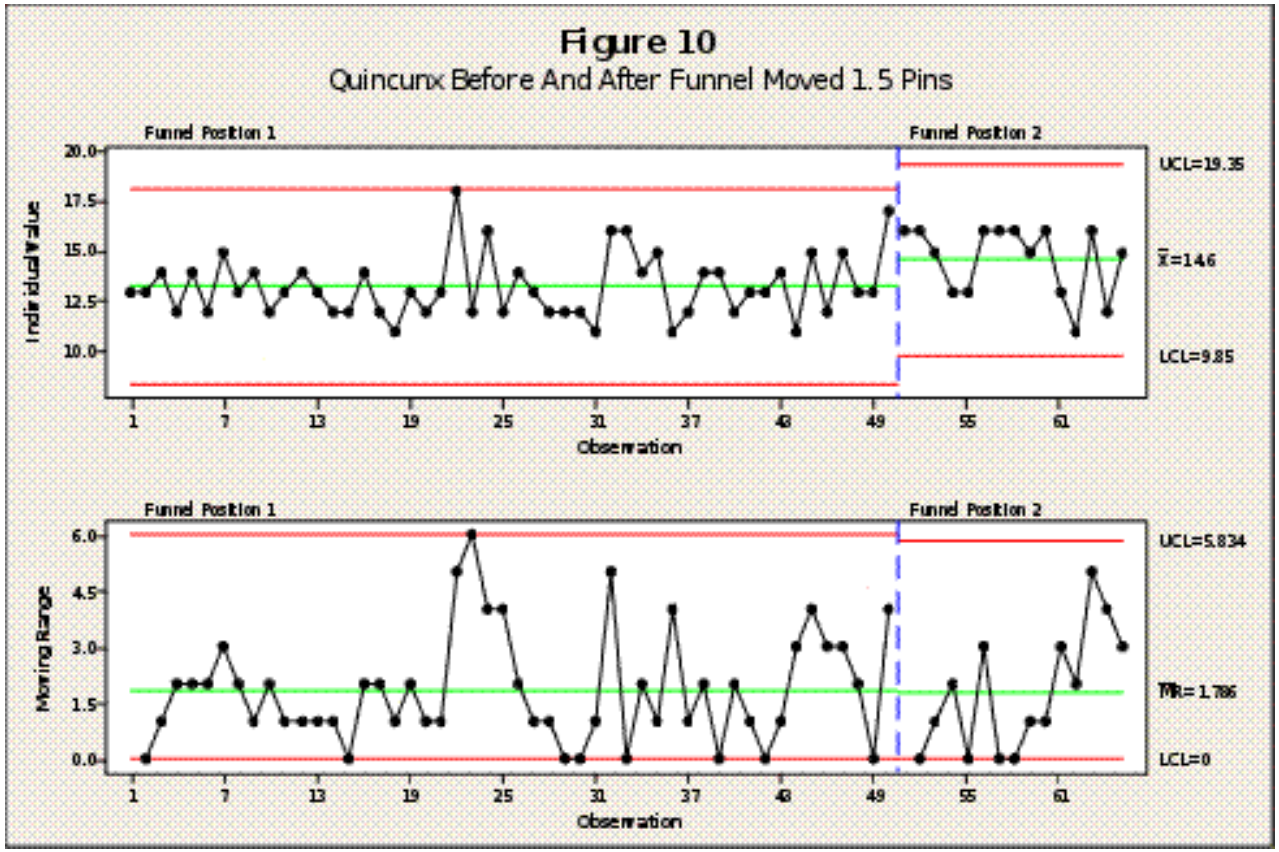
C CHART

- C CHART



X BAR & R CHART

- X BAR & R CHART



X BAR & S CHART

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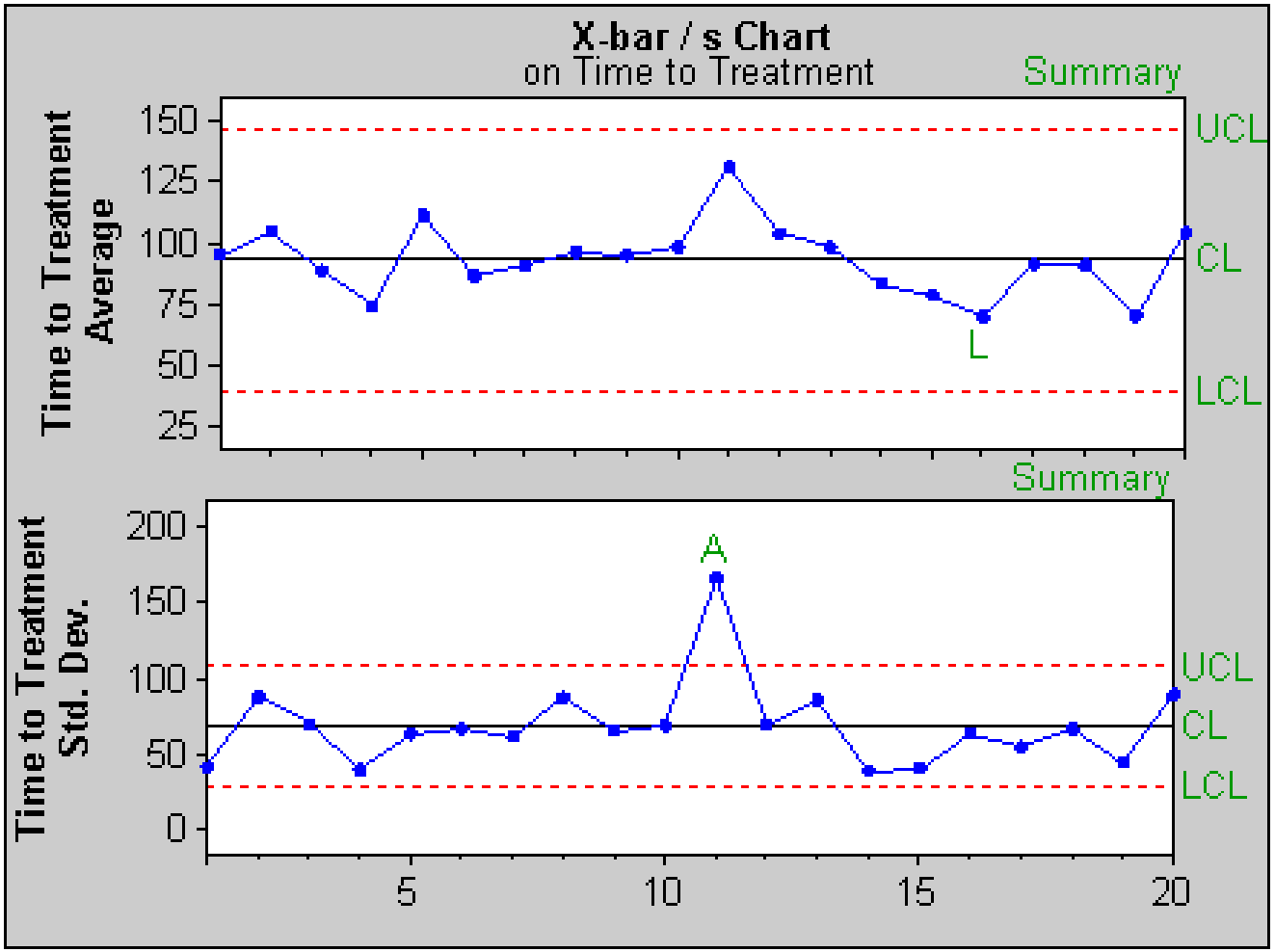
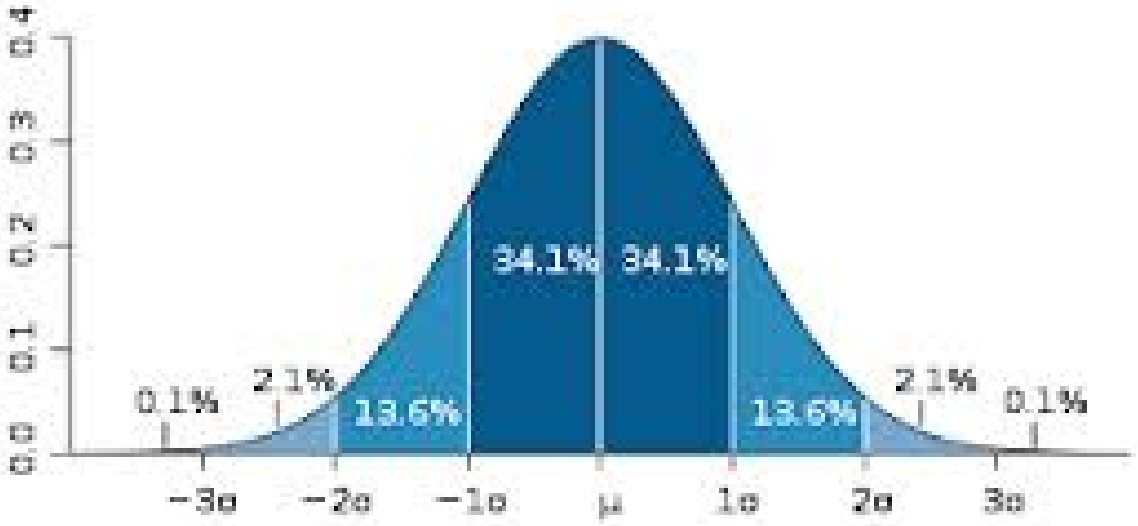


Normal Curve
Bell Shaped Curve

Normal Curve



Normal Population

- A normal population which is represented by Bell Shaped Curve has many applications and every statistical control chart is using it as the main assumption.
- If we assume that the average height of the men in the world is 170 CM, based on this curve, number of people who are taller than 170 would be equal to the ones that are shorter than 170. Also there will be equal number between 160-170 and 170-180.

3 SIGMA
ON EACH SIDE OF BELL

- On a Bell Shaped Curve the following numbers are vey important:
- 1 Standard Deviation from the mean=34.1%
- 2 Standard Deviation from the mean=34.1+13.6%=47.7%
- 3 Standard Deviation from the mean=34.1+13.6%+2.1%=49.8% of population
- 3 Sigma on both sides of Bell=2X49.8%=99.6%

3 SIGMA vs. 6 SIGMA

- While 3 sigma covers 99.6%-99.7% of the population and is used in Statistical Process Control, there is a quality goal invented by Motorola in 1985 and made famous by Jack Welsh of GE in 1995 called 6 sigma. It means a quality level of 99.99966%, which leaves 3.4 defects per million.
- The above goal is almost as equal as Phillip Crosby's Zero Defect goal.

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