Engineer On a Disk

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1. TABLE OF CONTENTS

Quality Control and Methods

2. QUALITY CONTROL

2.1 INTRODUCTION TO QUALITY

• The quality of a product is determined by how well it suits your needs.
 - reliability
 - durability
 - safety
 - maintainability
 - cost
 - ?

• Where do we have to change production in an industry to improve quality?
 - EVERYWHERE !
  - Specifications - clarify what is important in a product, the rest is second priority
  - Design - Only design a product to meet specifications, any more is a waste of time and resources. For example, if a chemical company 'tunes' their production for a certain impurity in a raw material, a sudden improvement might hurt their product quality.
  - Production - to meet the specifications
  - Inspection - ensure conformance to the specifications, and correct problems.
  - Review of Specifications - make sure the specs. describe the product well, the specs are useful to customers, etc.

• Two main approaches to quality,
 - inspection - accept/reject
 - process control - constantly examine input and output and refine process.

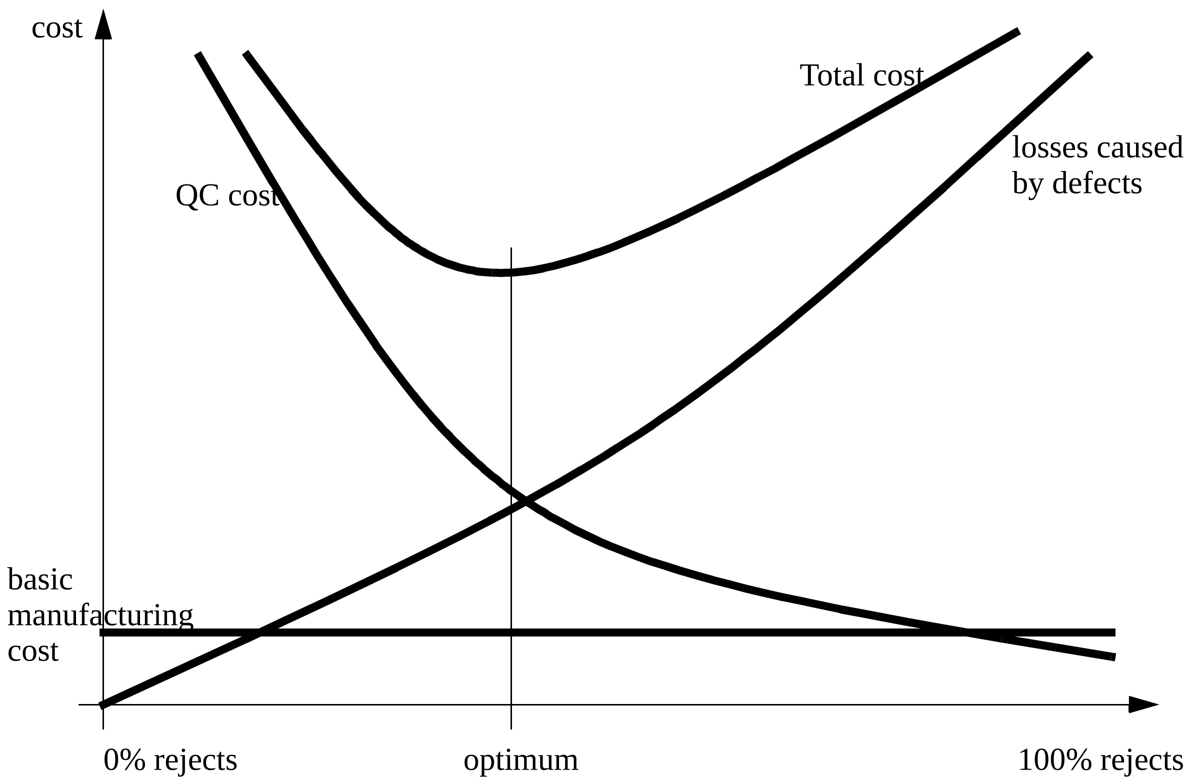
• Typical options when products fail inspection.
 - Reworks (high cost)
 - Scrap (high cost)
 - Sell anyway (upset customers, poor reputation)
 - Downgrade (lower returns), e.g. try to get largest chicken eggs, but when smaller eggs are produced, sell for less.

• What are some of the different ways to inspect processes?
 1. Gating - Only examine final product for pass/fail. Not very effective for correcting problems.
 2. Design of Experiments - Various process parameters can be varied (e.g. speeds, feeds) and the effects can be examined to determine the best settings for a process.
 3. Statistical Process Control (SPC) - Various measurements may be done on a part after

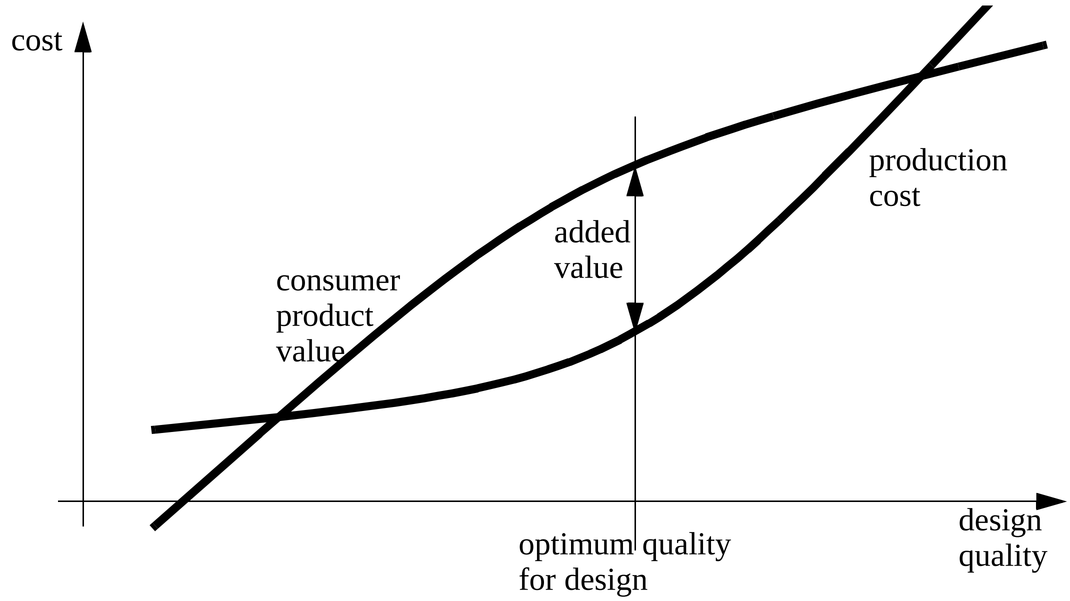
processing, and the process can be adjusted to keep it within spec.

4. Total Quality Management (TQM)- Try to improve employee attitude (e.g. Friday cars)

• Does it cost more to inspect each process instead of the final product?
- RARELY
- The use of statistics allow small population samples to produce enough data for a process. And, it is much cheaper to adjust a process before problems occur, than it is to fix a completed product.
- Consider the graph below, there is a basic manufacturing cost per part associated with any piece. If we consider what happens when selecting quality levels, we see that to improve quality to get 0% rejects (all parts good) our costs rise significantly. On the other hand if more rejects are produced, the economic losses rise. There is an optimal point to choose where the quality level of the product will give the optimal economic sense.



• What about the cost of quality?
- All products are the results of trade-offs - the most common factor is cost, others include size weight, etc. These vary between industries and products.



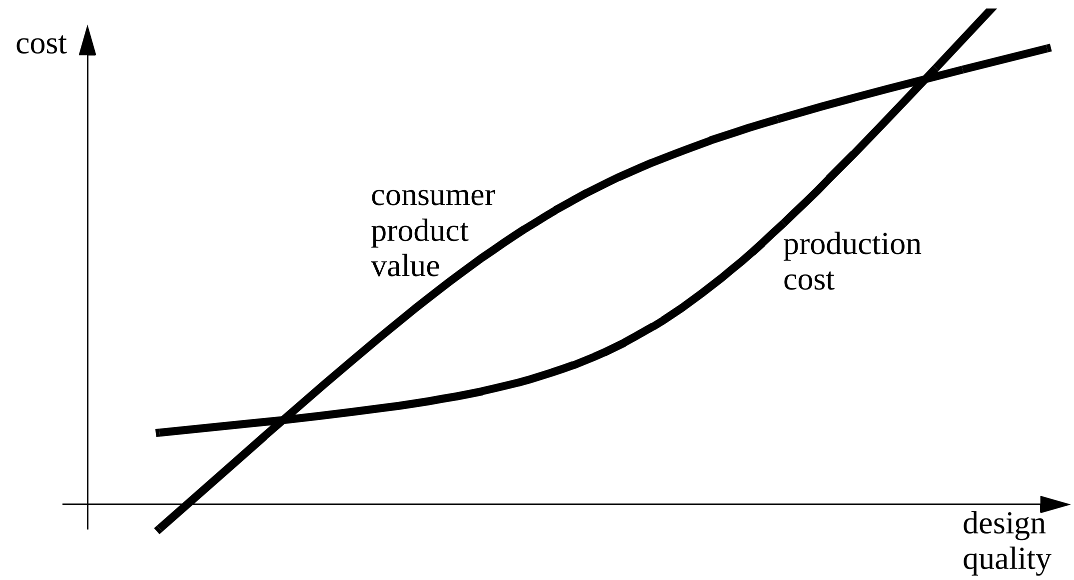
- We can use (and must in many companies) money as one factor, but we must justify quality for its other benefits also.
    - customer satisfaction (e.g. no caps on bolts caused Pintos to explode)
    - employee moral
    - no reworks
    - etc.

• What roles do various departments play in quality?
- Marketing
    - customer standards
    - current market
    - competition
    - liability
    - government standards
    - independent lab standards
    - customer surveys
    - dealers and store surveys
- Design
    - Specifications
    - standards
    - tolerances
    - keep it simple
    - evaluate production capabilities
    - safety
    - models
    - life testing
    - engineering changes
- Purchasing
    - select materials, components

    - evaluate suppliers (rating, distances, etc)
    - single/multiple suppliers
    - follow up rejected goods
    - schedules
- Manufacturing Engineering
    - processes
    - equipment
    - standards
    - layout
- Manufacturing
    - employee attitude
    - training
- Inspection
    - Incoming
    - Equipment
- Packaging and Shipping
    - Packing
    - Shipping
- Product Service
    - Install
    - Repair
    - Part supply
- CEO
    - support
    - funding, staffing, training
    - evaluate

2.2 PRACTICE PROBLEMS

1. The graph below shows two curves that relate the cost of a product to the expected value.



a) What are the sources for the two curves on this graph?

ans. Consumer Product Value - typically developed by marketing with survey and research data.
Production Cost - a result of design and manufacturing engineering based on machines, materials, etc.

b) How can this graph be used when setting engineering specifications?

ans. By selecting values that fall between the curves the product will be cost effective. The point where the vertical distance between the consumer and production curves is maximum determines the largest per unit profit.

3. STATISTICAL PROCESS CONTROL

3.1 CONTROL CHARTS

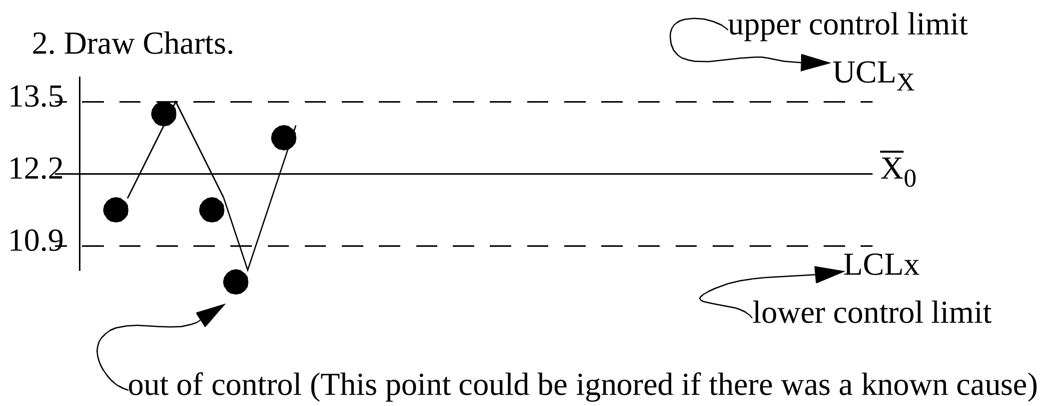
• Basic plots of statistical variation to show trends. Uses basic values like,
- average
- standards deviation
- range

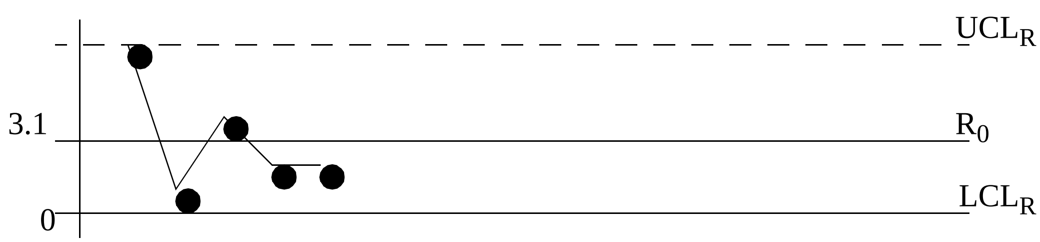
e.g.

1. Take samples from the shop floor.

Time	Samples (X_i)	$\bar{X}$	R
12:15	12 15 10 9	11.5	6
2:45	13 14 13 14	13.5	1
3:15	14 13 10 11	12	4
5:30	11 12 9 10	10.5	3
6:00	12 15 13 12	13	3

2. Draw Charts.





• the uses for control charts,
- these give a measure of performance, and therefore we can estimate the benefits of process parameter adjustment.

- process capability can be determined
- process specifications can be made greater than process capability
- can indicate when a process is out of control, and be used to reject a batch of product.

3.1.1 Sampling

• values used for control charts should be numerical, and express some desired quality.

• selecting groups of parts for samples are commonly done 2 ways.

INSTANT-TIME METHOD - at predictable times pick consecutive samples from a machine. This tends to reduce sample variance, and is best used when looking for process setting problems.

PERIOD-OF-TIME METHOD - Samples are selected from parts so that they have not been presented consecutively. This is best used when looking at overall quality when the process has a great deal of variability.

• Samples should be homogenous, from same machine, operator, etc. to avoid multi-modal distributions.

• Suggest sample group size can be based on the size of the production batch

LOT SIZE	SAMPLE SIZE
66-110	10
111-180	15
181-300	25
301-500	30
501-800	35
801-1300	40
1301-3200	50
3201-8000	60
8001-22000	85

(e.g. from MIL-STD-414)

therefore, for a batch of 200 parts, we should have 25 samples. If we take 5 samples every time we would need to visit 5 times to get the samples.

3.1.2 Creating the Charts

• The central line is an average of ‘g’ historical values.

$$\overline{\overline{X}} = \frac{\sum_{i=1}^{g} \overline{X}_i}{g} \qquad \overline{R} = \frac{\sum_{i=1}^{g} R_i}{g}$$

• The control limits are +/-3 σ of the historical values

$$UCL_{\overline{X}} = \overline{\overline{X}} + 3\sigma_{\overline{X}}$$
$$LCL_{\overline{X}} = \overline{\overline{X}} - 3\sigma_{\overline{X}}$$

$$UCL_R = \overline{R} + 3\sigma_R$$
$$LCL_R = \overline{R} - 3\sigma_R$$

note: not zero

• At start-up these values are not valid, but over time it is easy to develop a tight set of values.

• For the non-technical operators there are a couple of techniques used.
 - to simplify calculation of the control limits we can approximate σ with

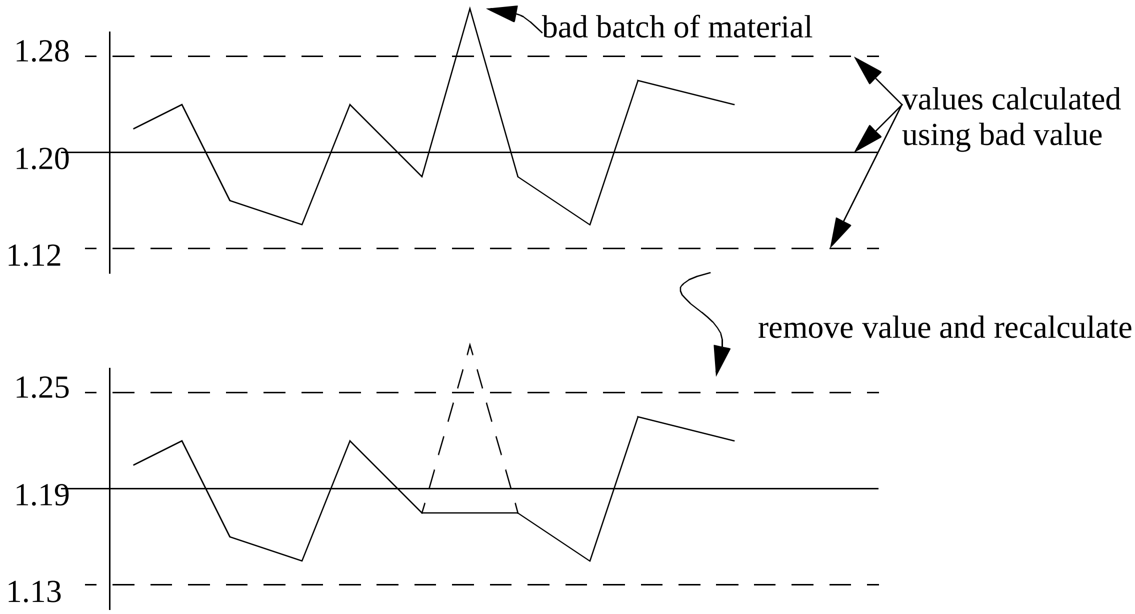
$$3\sigma_{\overline{X}} = A_2\overline{R}$$
$$3\sigma_R = D_4\overline{R}$$

from table in back of text

3.1.3 Maintaining the Charts

• Over time σ_R and $\sigma_{\overline{X}}$ should decrease.

• If some known problems occurred that created out of control points, we can often eliminate them from the data and recreate the chart for more accurate control limits.



• If we recalculate values from the beginning there is no problem, but if we are using the numerical approximation (using constants from table B)

already calculated

$$\bar{\bar{X}}_{new} = \frac{\left(\sum \bar{X}\right) - \left(\sum \bar{X}_d\right)}{g - g_d} \qquad \bar{R}_{new} = \frac{\left(\sum R\right) - \left(\sum R_d\right)}{g - g_d}$$

$\bar{X}_d$ = the discarded averages

g = the number of sample groups used

g_d = the number of groups discarded

R_d = the discarded ranges

find the new σ using

$$\sigma_0 = \frac{R_0}{d_2}$$ from table B

therefore,

$$\bar{X}_0 = \bar{\bar{X}}_{new}$$

$$R_0 = \bar{R}_{new}$$

$$UCL_{\bar{X}} = \bar{X}_0 + A\sigma_0$$

$$LCL_{\bar{X}} = \bar{X}_0 - A\sigma_0$$

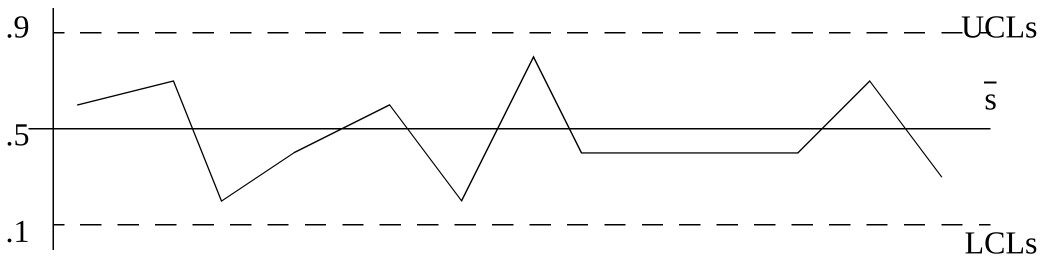
$$UCL_R = D_2\sigma_0$$

$$LCL_R = D_1\sigma_0$$

3.1.4 The s-Chart

• Instead of an R-chart we can use an s-chart to measure variance

• This chart will reduce the effect of extreme values that will occur with R charts. And, as the number of samples grows, so does the chance of extreme values to throw off the R-chart.



$$UCL_s = \bar{s} + 3\sigma_s$$

$$LCL_s = \bar{s} - 3\sigma_s$$

• the approximate technique is,

$$\bar{s} = \frac{\sum_{i=1}^{g} s_i}{g} \qquad \bar{\bar{X}} = \frac{\sum_{i=1}^{g} \bar{X}_i}{g}$$

$\bar{X}_i, s_i$ = standard deviation and average for sample group

g = number of sample groups

$$UCL_{\tilde{X}} = \bar{\bar{X}} + A_3\bar{s}$$

$$LCL_{\bar{X}} = \bar{\bar{X}} - A_3\bar{s}$$

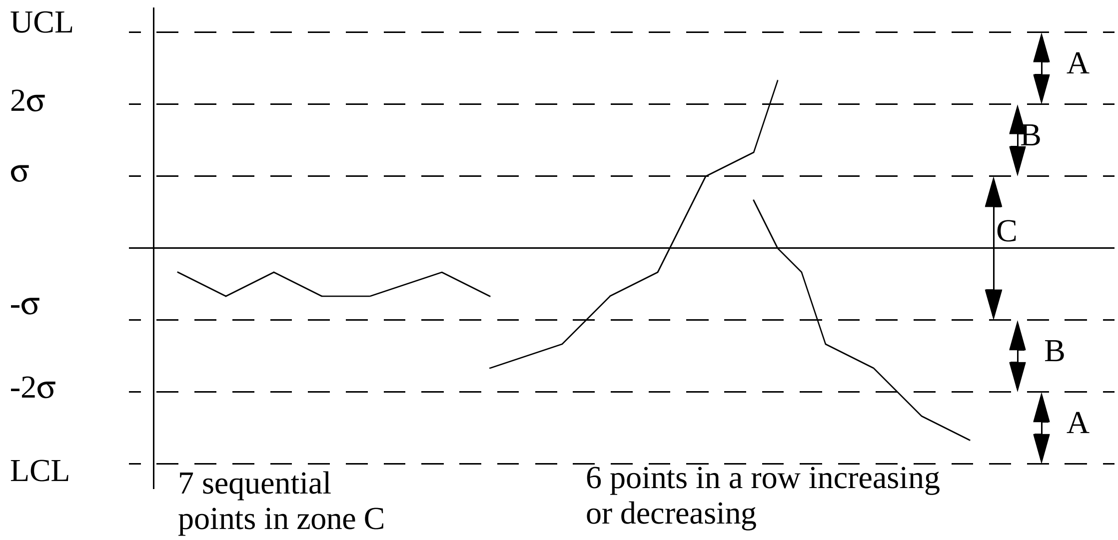
$$UCL_s = B_4\bar{s}$$

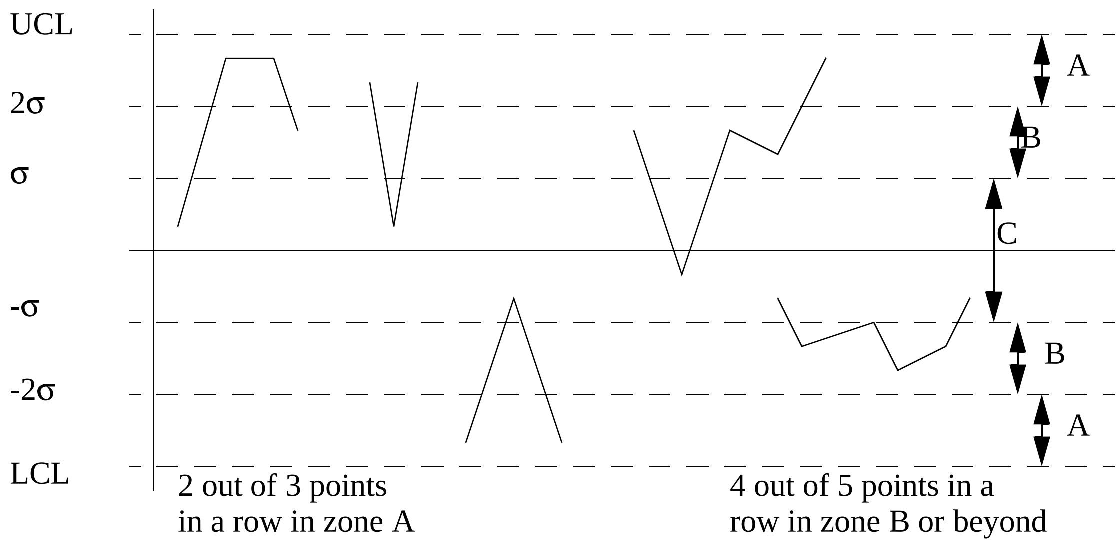
$$LCL_s = B_3\bar{s}$$

3.1.5 Interpreting the Control Charts

• We consider a point that lies outside of the 3σ control limits to be very unlikely, therefore the process is ‘out of control’

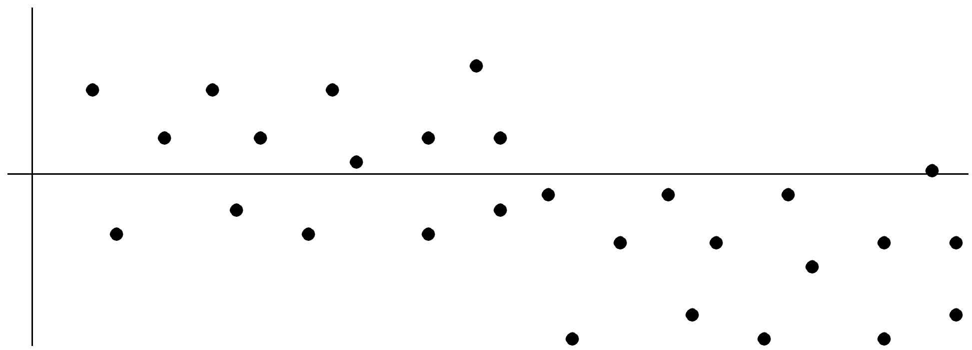
• In some cases a process may have points within the control limits, but in highly unlikely trends that indicate a process is out of control





3.1.6 Using the Charts for Process Control

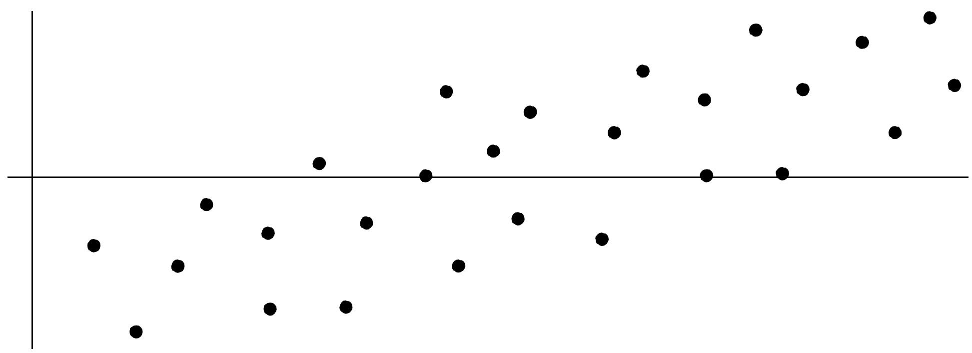
1. change or jump in level ($\overline{X}$)



- indicates a discontinuity in the process, could be caused by material, new operator, etc.
- e.g. measurement gauge has slipped.

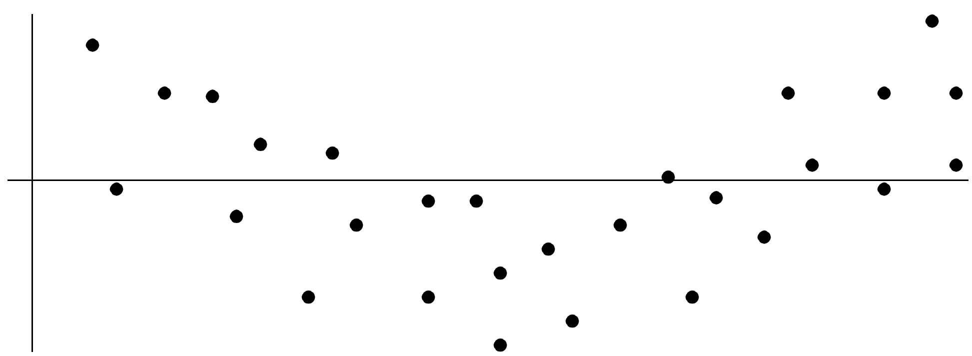
2. Change or jump in level (R)
   - indicates a change in process accuracy, caused by failure of small parts, material, etc.
   - e.g. measurement gauge has stretched

3. trend, or steady change in level ($\overline{X}$ and R)



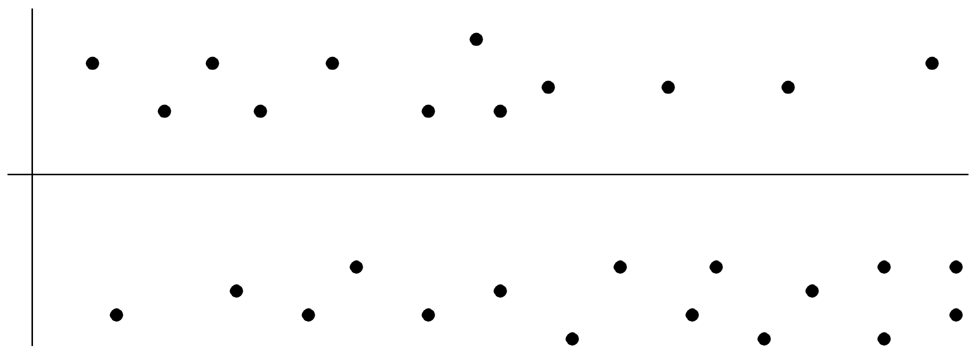
- indicates a gradual change in the process caused by wear, aging, etc.
- e.g. a tool is aging

4. Cycles



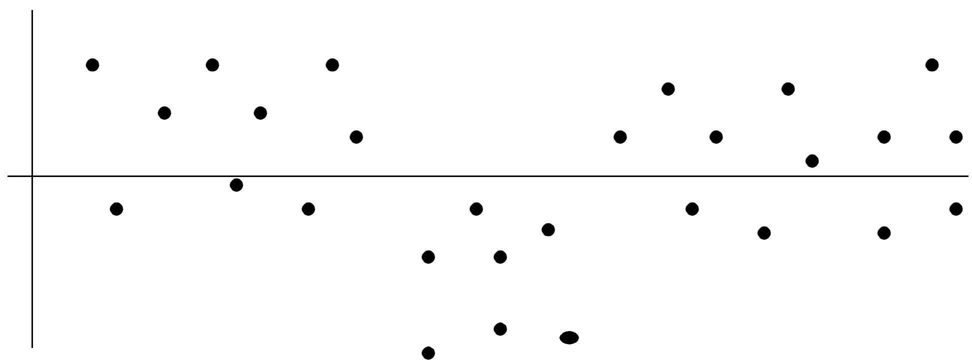
- indicates time variance in process
- e.g. shift change, day-night temp changes, etc.

5. Mixed Data



- indicates multimodal distributions caused by mixed material batches, alternate operators, etc.
- e.g. steel from scrap dealer, and from steelco is used.

6. Error



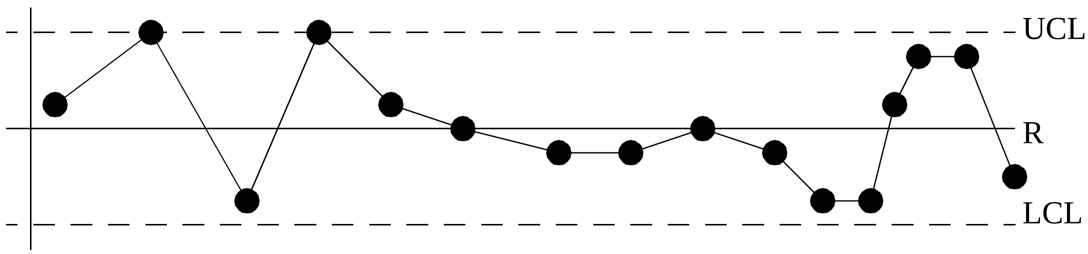
- readings are incorrect because of misreadings, transcription error, etc.
- e.g. a new operator measured the wrong dimension

3.1.7 Practice Problems

#1 Draw the detailed $\overline{X}$, R, and s charts for the data below.

Sample 1	Sample 2	Sample 3
1.6	0.1	2.7
1.3	2.5	2.7
1.9	2.1	4.9
1.9	3.3	1.5

#2 What problems can be seen in this control chart?



#3. Draw the Pareto diagram for the data below. The data indicates the number of reported errors made when taking fast food orders by telephone

Day \ Operator	Tom	Dick	Harry
Monday	12	8	3
Tuesday	9	7	7
Wednesday	7	9	9
Thursday	8	4	2
Friday	21	9	24
Saturday	28	12	9

3.2 CONTROL CHARTS FOR ATTRIBUTES

******** Clarify section

• ATTRIBUTE - a nonconformity that cannot, or will not be measured

• NONCONFORMITY- A flaw in a product that will not always make it unsellable.

• p-chart (for nonconforming units)

Select attributes, same as if constructing a Pareto chart or using matrix analysis → Select a subgroup size large enough to get a reasonable count → Collect Data → Calculate and construct chart

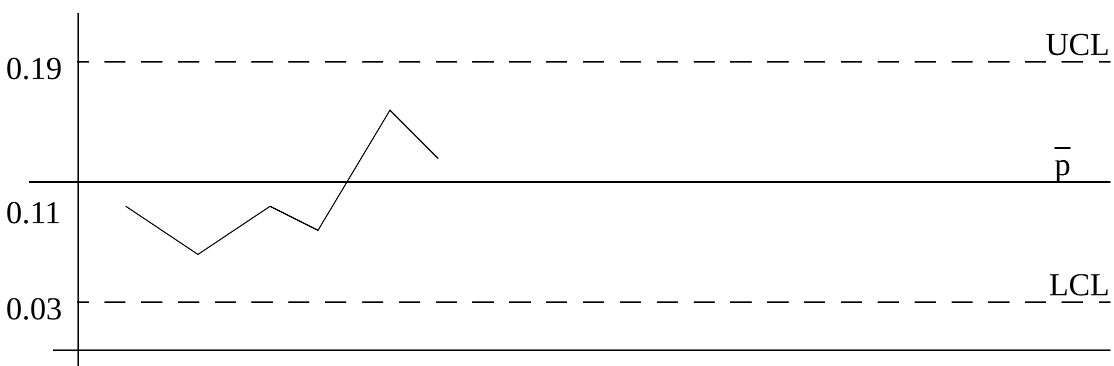
sub-group	size(n)	nonconform. (np)	proportion (p)
1	10	1	.1
2	20	1	.05
3	30	3	.1
4	30	2	.067
5	30	5	.17
6	30	4	.13
	150	16	

$$\bar{p} = \frac{\sum np}{\sum n} = \frac{16}{150} = 0.11$$

$$UCL = \bar{p} + 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}} = 0.11 + 3\left(\frac{0.3}{12.4}\right) = 0.19$$

$$LCL = \bar{p} - 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}} = 0.03$$

(not less than 0)   (*note based on Binomial distribution)



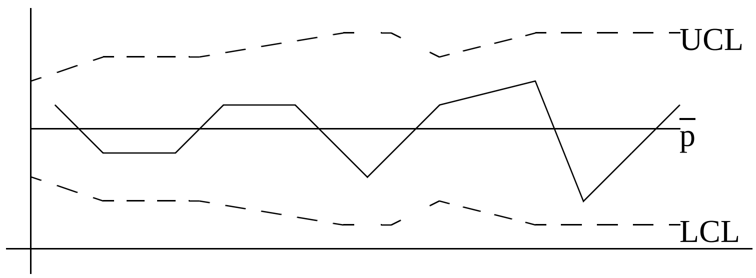
p-chart

• p-chart control limits can vary if the sample size varies.

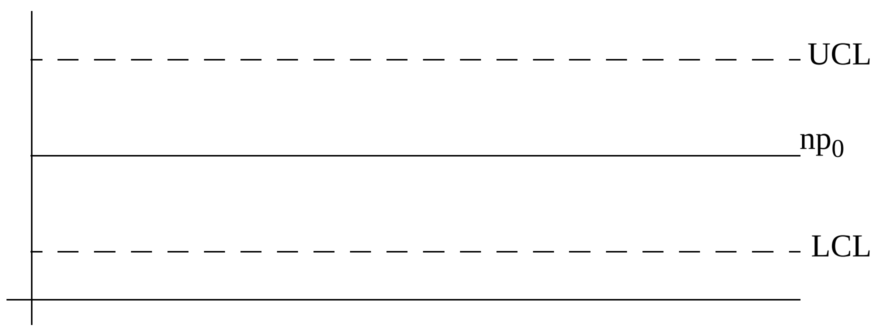
$$\bar{p} = \frac{\sum np}{n}$$ stays the same

varies for each sample

$$UCL, UCL = \bar{p} \pm 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n_i}}$$



• np-chart (nonconforming units) - almost identical to p-chart, except not normalized to 0 to 1 scale, so it is more sensitive to sample size changes, but it is easier to maintain.

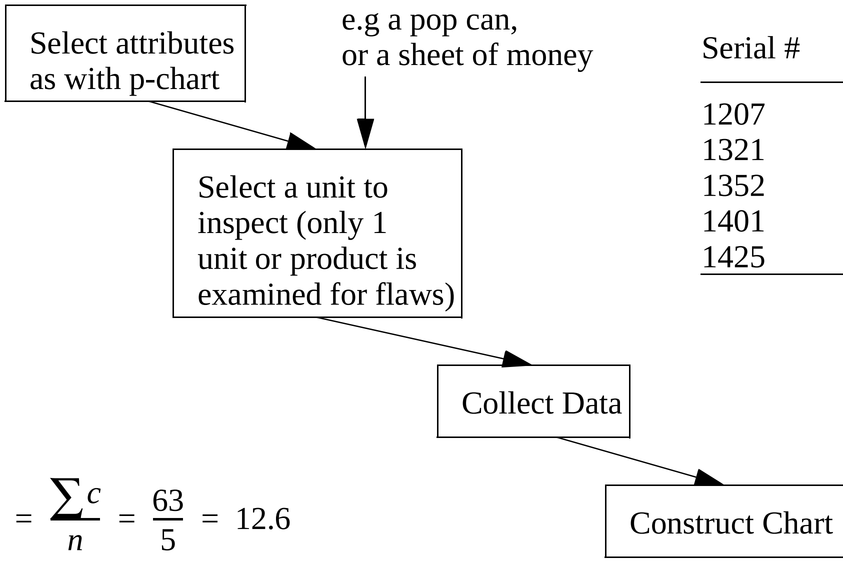


$$np_0 = \frac{\sum np}{\sum n}$$

$$UCL, LCL = np_0 \pm 3\sqrt{np_0(1-p_0)}$$

p_0 - the historical value for fraction nonconforming

• c-chart (for count of nonconformities) - Best used when there is a small number of errors in a huge sample space, and the nonconforming events are independent.



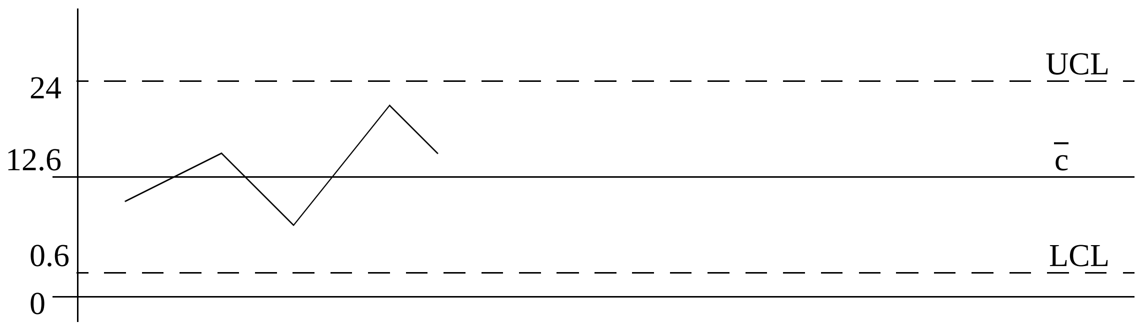
Serial #	count of nonconformities
1207	12
1321	13
1352	10
1401	15
1425	13
	63

$$\bar{c} = \frac{\sum c}{n} = \frac{63}{5} = 12.6$$

$$UCL = \bar{c} + 3\sqrt{\bar{c}} = 12.6 + 3\sqrt{12.6} = 24$$

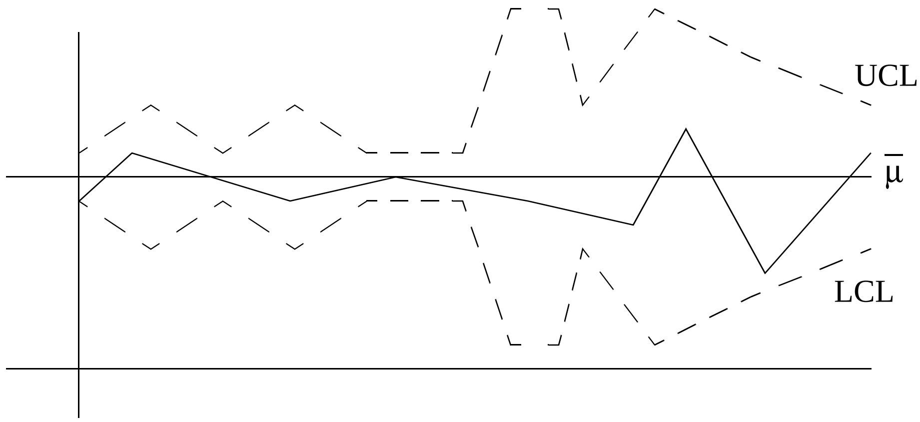
**Note based on Poisson distribution

$$LCL = \bar{c} - 3\sqrt{12.6} =$$



- u-chart - similar to c-chart, except it can handle different sample group sizes (e.g. a rivet department dealing with different sizes of riveted parts).

$$\mu = \frac{c}{n} \qquad \bar{\mu} = \frac{\sum c}{\sum n} \qquad UCL, LCL = \bar{\mu} \pm 3\sqrt{\frac{\bar{\mu}}{n}}$$



• choosing an attribute chart

	CHART	nonconforming units	nonconformities
Sample size	constant	np	c (n=1)
	constant or varies	p	u

READING: chapter 7, pg. 235-273
PROBLEMS: pg 273- #1, 4, 6, 9, 13, 18, 19, 21, 24

4. INSPECTION FOR QUALITY

4.1 ACCEPTANCE OF LOTS

• What ? screening of arriving product lots to ensure adequate quality for use

• Why? Because putting parts into production when they are out of spec. will probably result in out of spec. product. This will cost much more.

• Advantages,
  - focuses quality problems on source
  - reduces inspection required
  - can use destructive testing
  - rejection of entire lots increases supplier quality incentives
  - uses known risks and probabilities

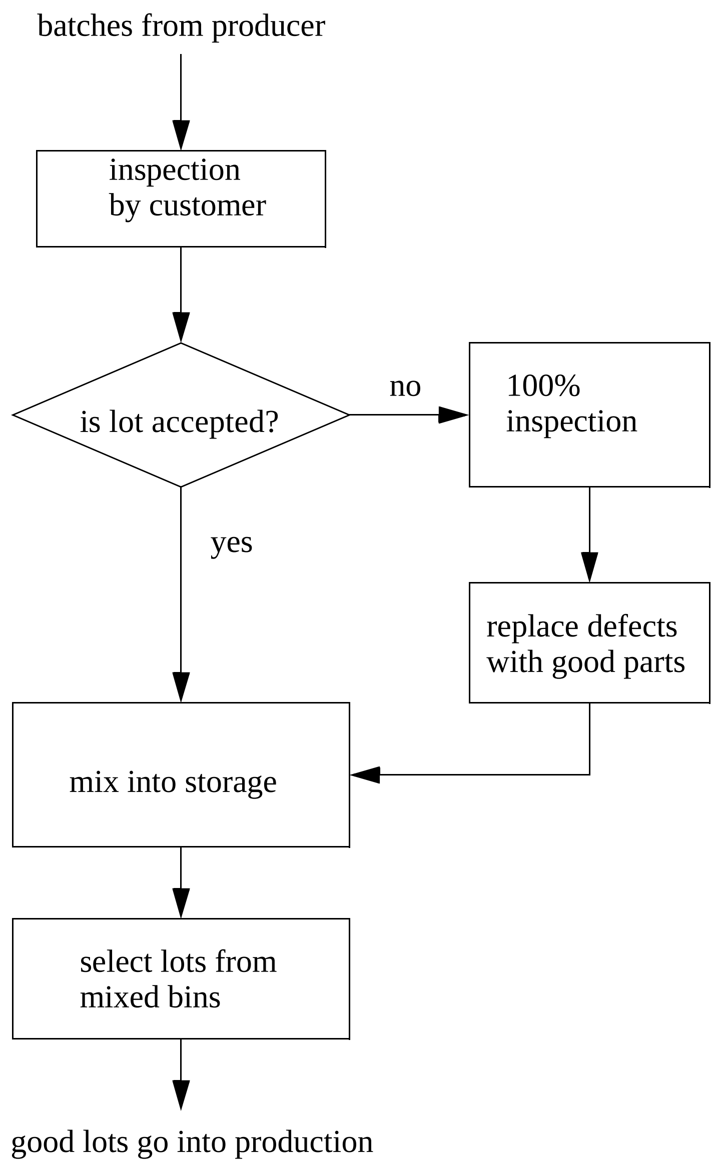
• Disadvantages,
  - good/bad lots may be rejected/accepted without reason
  - planning and documentation required
  - only describes part of a lot

4.2 SCREENING

• When every part in an incoming lot is checked, this is called screening.

• The non-conforming parts can be removed, and replaced with good parts

• Screened lots can be mixed with good lots to improve the AOQ



4.3 THE COST OF SAMPLING

• A simplified economic comparison of inspection versus screening can be made with the following method,

$$C_I = nC_{I_n} + (N-n)pC_D$$

where,

C_I = the total inspection cost

C_{I_n} = the cost to inspect each individual part

C_D = the average cost resulting from each defective part

p = the proportion of defective parts

n = the number of parts in sample

N = the number of parts in a lot

Consider that for 100% inspection, n=N. Therefore, when choosing between screening, or sampling, consider the break even point detailed below. If the equation given is not true, then 100% inspection should be used, otherwise, sampling may be a better plan.

cost 100% > cost sample (for sampling type inspection)

$$\therefore NC_{I_N} + (N-N)pC_D > nC_{I_n} + (N-n)pC_D$$

$$\therefore NC_{I_n} - NpC_D > nC_{I_n} - npC_D$$

$$\therefore \frac{N(C_{I_n} - C_D)}{(C_{I_n} - pC_D)} > n$$

For example: a defective gear costs an automotive manufacturer $350 to replace once a vehicle is in service, and is costs $2.25 per gear to inspect it. It is known that one in a thousand gears will be defective, what inspection policy should be used if the parts arrive in batches of 10,000?

here,

$$C_{I_n} = \$2.25$$

$$C_D = 350$$

$$p = \frac{1}{1000} = 0.001$$

$$N = 10000$$

$$\therefore n < \frac{N(C_{I_n} - C_D)}{(C_{I_n} - pC_D)} = \frac{10000(2.25 - 350)}{(2.25 - 0.001(350))} =$$

Therefore, as a result we should XXXXXXXXXXXX

4.4 SINGLE/DOUBLE/MULTIPLE SAMPLED PLANS

• SINGLE - just take a sample from the lot, examine, and reject. e.g. a lot of 5000 has 200 samples removed, if more than 2 non-conforming samples found, the lot is sent back.

• DOUBLE - One sample is taken. If it conforms, keep the lot. If there are too many non-conforming send back the lot, otherwise take a second sample. If the combined first and second samples have too many rejects, then send the lot back.

• MULTIPLE - like the double sampled plan, but extended for a larger number of tests.

• the accept/retest/reject limits are set by statistical methods.

• Lot Sample Selection, must be as random as possible,
  - use a random number generator,
  - use a paper based method (e.g. pg. 288 in text)

• What to do when a lot is rejected

time shortage

- Have your employees sort the parts

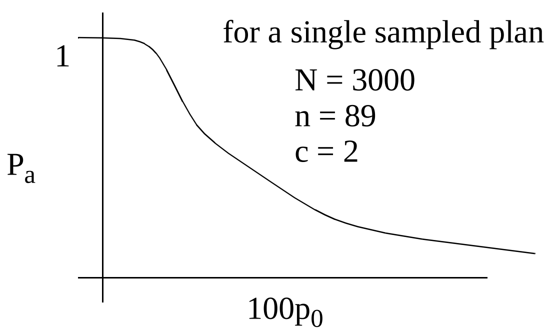
- have your suppliers employees sort the parts at your facility

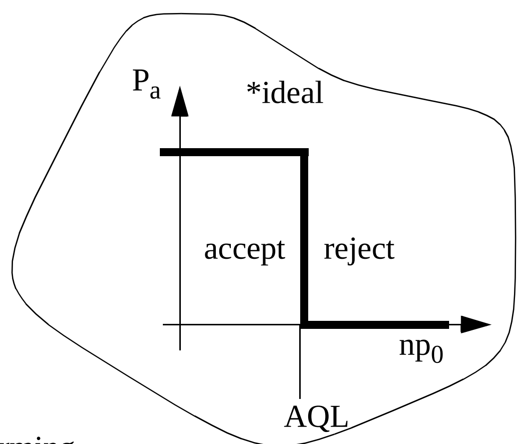
- send the parts back to the supplier

image and moral important

4.5 OPERATING CHARACTERISTIC (OC) CURVES

• Used to estimate the probability of lot rejection, and design sampling plans.





P_a - the probability the lot is accepted
p_0 - the fraction of the lot that is nonconforming
N - the number in the lot
n - the size of the test sample
c - the maximum number nonconforming for acceptance

• Drawing the single sampling curve (assuming Poisson distribution)

getting the numbers
$P_a = P_0 + P_1 + ... + P_n$
or easier use the values in table C

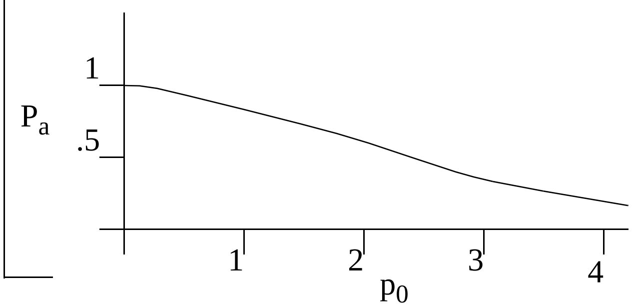
******INLCUDE TABLE C OR EQUIVALENT

make a table of values

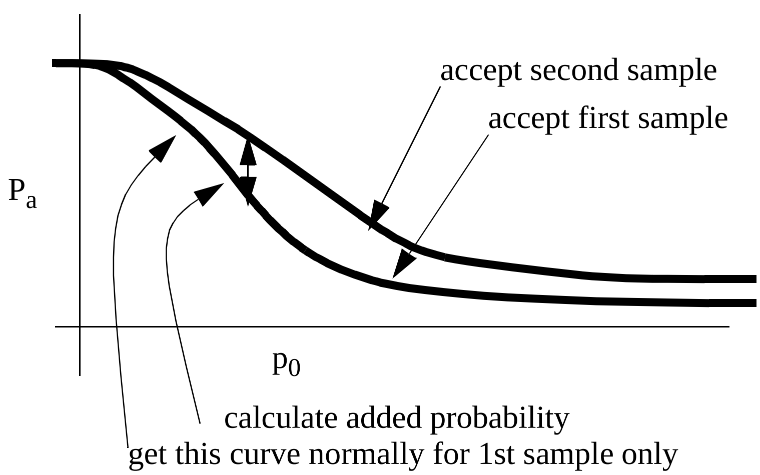
p_0	$100p_0$	np_0	P_a
.01	1	.9	.938
.02	2	1.8	.731
.03	3	2.7	.494
.	.	.	.
.	.	.	.
.	.	.	.

given
$c = 2$
$n = 89$

graph and
interpolate



• Double sampling curves



- Assume for the first sample

0 fails
1 fails — accept ($c_1 = 1$)
2 fails
3 fails — another sample
4 fails
etc... — reject ($r_1 = 4$)

- for the second sample (assume 5 is the upper limit, $r_2 = 6$)

for 2 fails in the first sample (P_{a2})

$\Delta Pa = (P_{a2})(P_3$ or less this time)

from first table

from table C

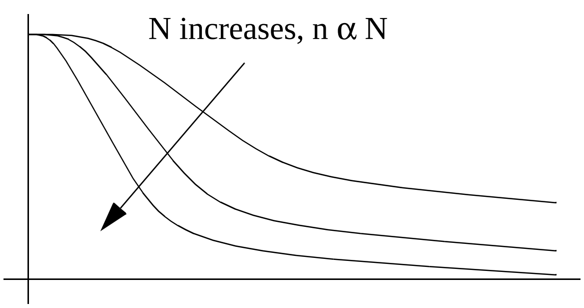
for 3 fails in the first sample (P_{a3})

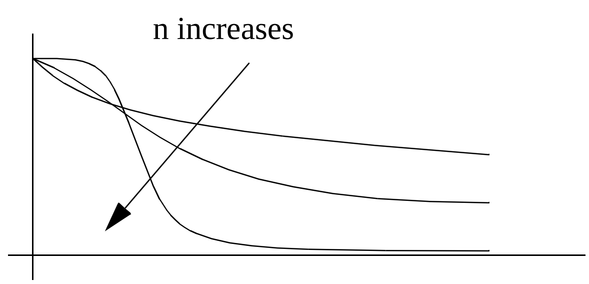
$\Delta P_a = (P_{a3})(P_2$ or less this time)

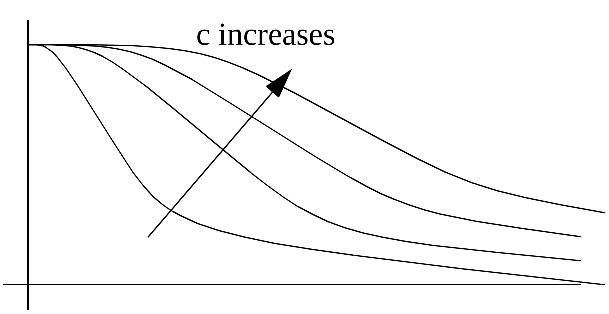
add together for difference

- for multiple sampling, continue from above

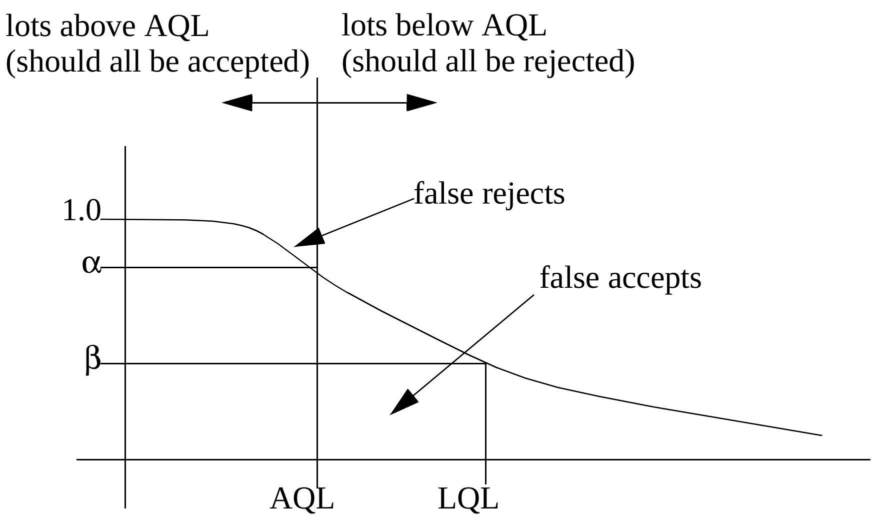
• Factors that vary OC curves







• Producers/Consumers risk

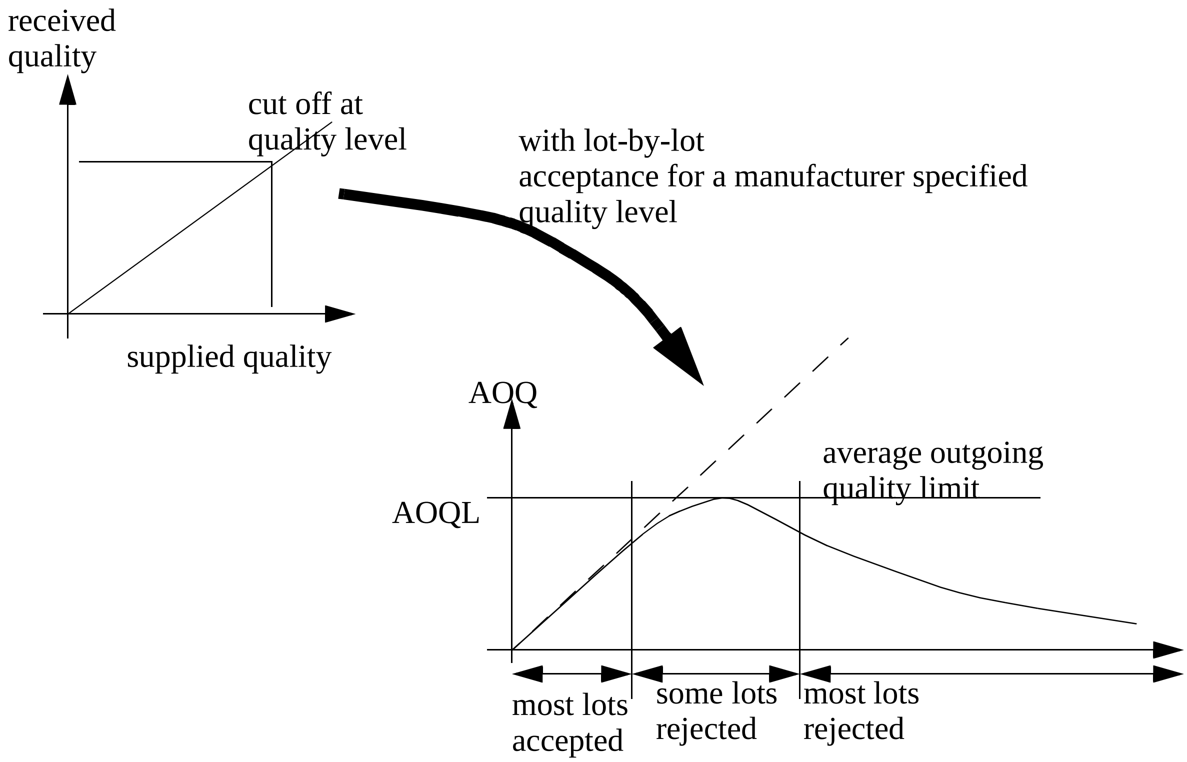


α = producers risk of rejection
β = consumers risk of acceptance
LQL = Limiting Quality Level
AQL = Acceptable Quality Level

• The basic trade-off to be considered when designing sampling plans.

- The producer does not want to have lots with higher rejects than the AQL to be rejected. Typically lots have acceptance levels at 95% when at AQL. This gives a producers risk of α = 100% - 95% = 5%. In real terms this means if products are near the AQL, they have a 5% chance of being rejected even though they are acceptable.
- The consumer/customer does not want to accept clearly unacceptable parts. If the quality is beyond a second unacceptable limit, the LQL (Lower Quality Level) they will typically be accepted 10% of the time, giving a consumers risk of β = 10%. This limit is also known as the LTPD (Lot Tolerance Percent Defective) or RQL (Rejectable Quality Level).

• AOQ (Average Outgoing Quality)



• AOQ (Average Outgoing Quality) - a simple relationship between quality shipped and quality accepted.

$$AOQ = (\text{supplied quality})P_a$$

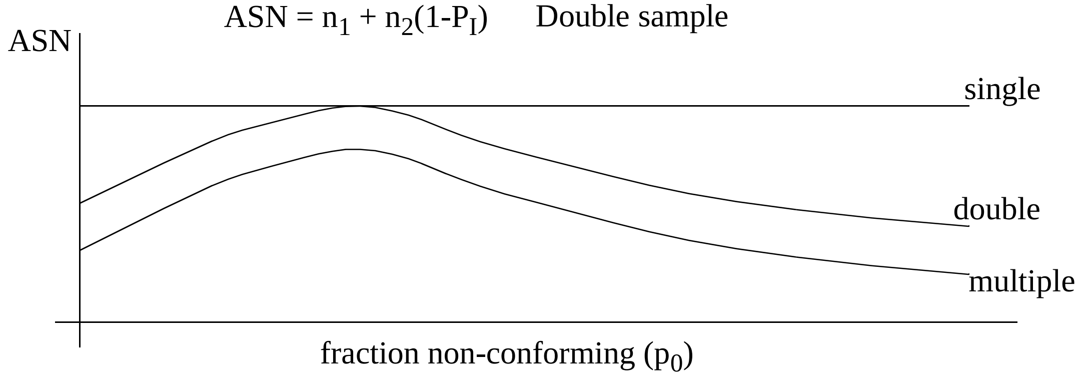
* Note: this does not account for discarded units, but is close enough.

• ASN (Average Sample Number) - the number of samples the receiver has to do

The chance a second sample is taken

ASN = n_1 Single sample

ASN = $n_1 + n_2(1-P_I)$ Double sample



DESIGNING A SAMPLE PLAN

e.g. when only concerned with the producers risk

1. get producers risk of α (given)
2. get AQL (given)
3. refer to table of values to start (e.g. pg.314)
    - given: α=0.5, therefore P_a=.95
    - look at c (Pass/Fail sample size)
    - for c=1, np = .355
        - given AQL = 1.5% = .015
        - n = .355/.015 = 23.67 = 24
    - for c=5, np=2.613
        - n=2.613/.015 = 174.2 = 175
4. Select a sample from acceptable list e.g.

c	n
1	24
5	175

• On the other hand, given consumers risk (β) and Lower Quality Level (LQL), we can follow a similar approach, still using the table on pg. 314

• Given α and AQL, and β and LQL we can also find a best fit plan through trial and error.

c	np for α	n for α	np for β	n for β
1				
2				
3				
4				
5				
.				
.				
.				
.				

from table   calculate until close

READING: chapter 8, pg. 283-320
PROBLEMS: pg. 321- #1, 4, 7, 14, 17, 22

4.5.1 Practice Problems

1. Show the effect of lot screening if the sample size is n=100 and the reject limit is c=1.

2.

a) Develop a double sampling plan OC curve given that,

N = 1000
n1 = 50
c1 = 2
r1 = 4
n2 = 100
c2 = 3

b) What is the AOQL?

3. a) Develop Operating Characteristic (OC) curves for the three cases below,

a) N = 1000, n = 20, c = 4
b) N = 1000, n = 40, c = 8
c) N = 1000, n = 80, c = 16

b) For each curve indicate the AQL and RQL for a producer risk of 5% and a consumer risk of 10%

(ans. for n=20,c=4, AQL=10%, RQL=40%, for n=40,c=8, AQL=11.8%,RQL=33%, for n=80,c=16, AQL=13.8%,RQL=N.A.)

4.6 MIL-STD-105D AND ANSI/ASQC Z1.4-1981

******** ADD MORE ABOUT ANSI STANDARDS ABOVE

• Began development 1942

• A set of tables for single, double and multiple inspections.

• These tables are designed to favor producers risk.

• Three types of inspection levels,

(III) Tightened - for new suppliers, or suppliers with poor quality history
(II) Normal - for poor quality history
(I) Reduced - for suppliers with a good quality history

• AQL (Acceptable Quality Level) - chosen by experience and requirement

e.g.
critical components approx. 0.1%
major components approx. 1%
minor components approx. 2.5%

1. Sample size code can be found on table (pg. 329) using lot size and inspection level.

	Inspection Level		
batch size	I	II	III
2-8	A	A	B
9-15	A	B	C
16-25	B	C	D
.	.	.	.
.	.	.	.
.	.	.	.

2. Using AQL, and sample size code, find the appropriate sample plan table, and look up the values. (plan varies by single, double, multiple sampling)

include mil-std plans here

- see page 336 for a multiple sampling plan.

3. Start at normal inspection level, then tighten or loosen as required.

NORMAL to TIGHTENED
when: 2 out of 5 lots rejected
TIGHTENED to NORMAL
when: 5 batches in a row accepted
NORMAL to REDUCED
when:
10 batches in a row accepted
and the total number of rejects for these 10 batches is less
than specified in table pg.333**********************ADD
and production is constant
and the purchaser is willing to handle additional effort and risk
HALT PRODUCTION
when: On tightened inspection more than 10 batches rejected
REDUCED TO NORMAL
when:
one batch rejected
one lot is marginal
production is erratic
other conditions threaten quality

• An example of use for these tables is an aerospace manufacturer is receiving batches of parts in batches of 5000. These parts will be used in the landing gear, and are considered critical. Find sampling plans (single, double, and multiple) for this batch. Find a single sampling plan if the two last batches were rejected.

READING: chapter 9, pg. 325-338
PROBLEMS: pg. 379 #1, 3, 5

4.6.1 Practice Problem

1. Given a lot of 3000 and an AQL of 1%, compare level I, II, and III plans using OC curves on the same graph.

4.7 ANSERED QUESTIONS

#1 Draw the $\overline{X}$, R, and s charts for the data below, using exact calculations: Then calculate the Control Limits using approximate techniques.

Sample 1	Sample 2	Sample 3
12.6	10.1	12.7
12.3	12.5	12.7
12.9	12.1	9.9
12.9	13.3	13.5
13.8	10.5	13.2
13.2	13.0	12.8
11.6	12.6	12.5

#2 The data below was collected for a factory that manufactures telephones. Each day they make 10,000 phones, inspect 500, and expect to find 4 nonconforming (e.g. sometimes a button is put in upside down). The chart below lists nonconformity data for the previous week. Select the appropriate type of control chart, and plot the data.

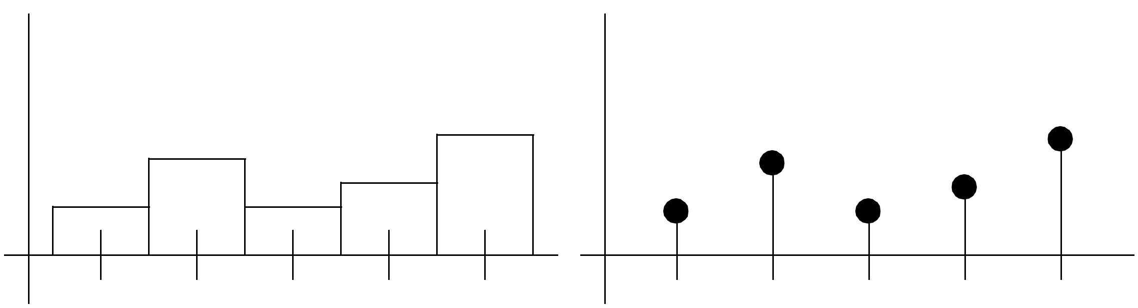
Date	nonconforming
Nov., 15	6
Nov., 16	3
Nov., 17	10
Nov., 18	5
Nov., 19	2
Nov., 20	4

#3 Use a Frequency Division Analysis Sheet and 2 other methods to determine if the data listed below is normal.

5, 7, 4, 3, 5, 9, 6, 4, 6, 7, 2, 3

#4 Very Short answers

a) what is the difference between the two histograms below?



b) Give a practical example of what a bi-modal distribution would indicate in quality control.

c) Describe the difference between Cp and Cpk.

d) How can Design of Experiments help an engineer improve a process?

e) Why would a single sampled plan be preferred to a double sampled Lot Acceptance Plan. Use an example in your answer.

f) Give a single sampling plan for a sample of 188 with an Acceptance Quality Level (AQL) of 0.4.

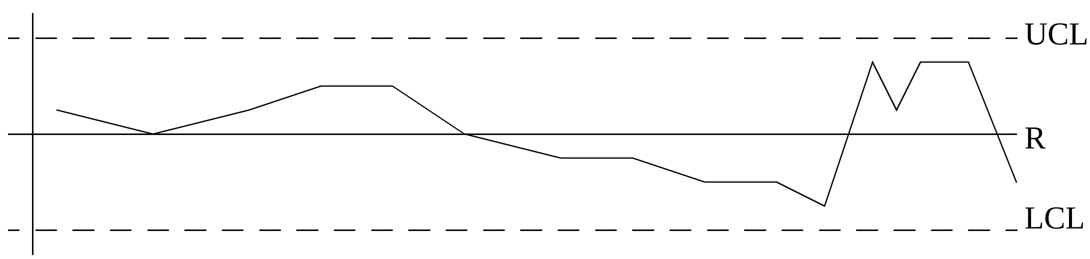
#5 Draw the Operating Characteristic (OC) curve for a batch of 10,000 with a sample size of 30, and a non-conforming reject level of 2. Identify the producers risk when a quality of 2% non-conforming is produced.

#6

a) Develop an Ishikawa diagram to identify problems when painting a house.
b) make a tally sheet based on your Ishikawa diagram, and suggest some data.
c) Draw a Pareto chart of the data.

#7 Short Answer Questions

a) What is meant by grouped and ungrouped data?
b) What is a mode? Give an example.
c) Describe the Instant Time Method
d) What problems can be seen in this control chart?



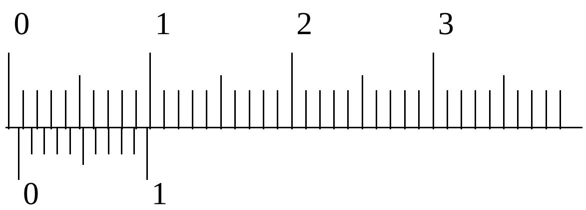
#8 Is this data normal?

sample number	data
1	134 165 144 148
2	139 155 148 143
3	148 160 145 140
4	163 155 139 147

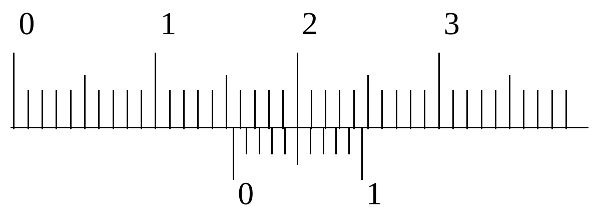
#9 For the data in question #8 draw an $\overline{X}$ and R chart

4.8 UNANSWERED PROBLEMS

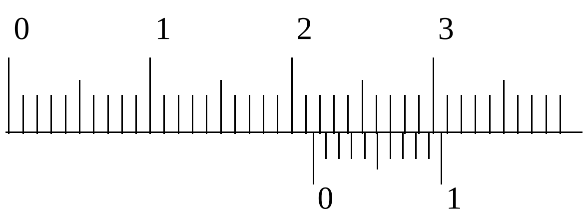
1. Write the values displayed on the vernier scales below.



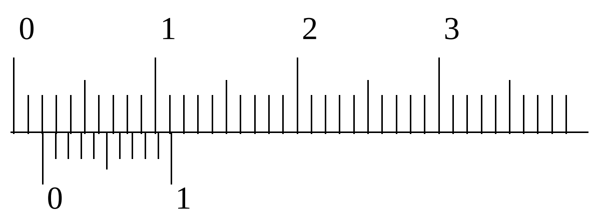
Value: ______________________



Value: ______________________



Value: ______________________



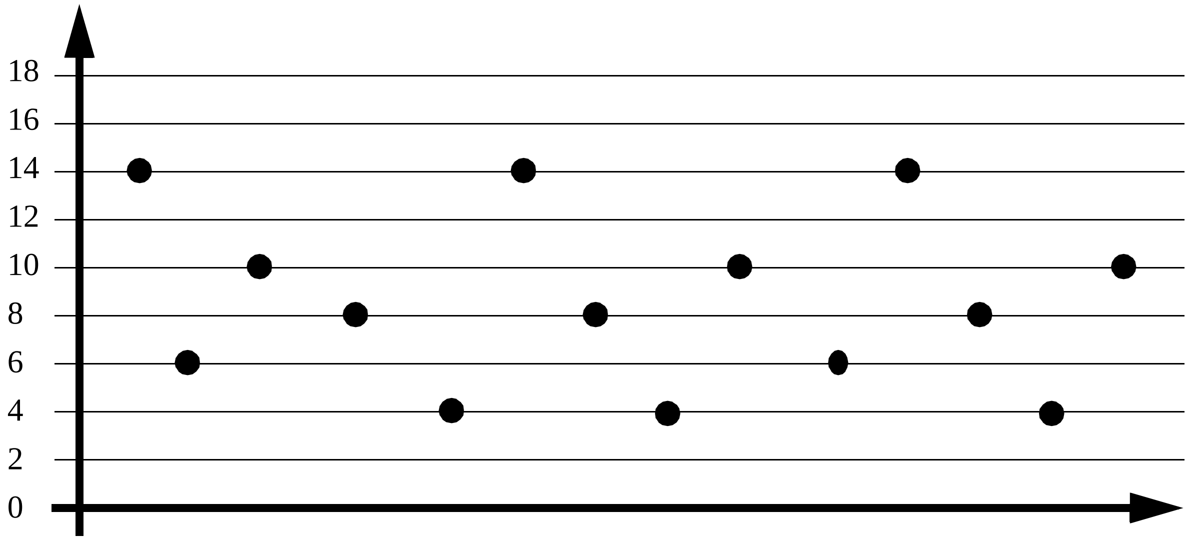
Value: ______________________

2. Draw the appropriate diagram for the data below. The data indicates sources of photocopy problems.

Operator / Defect	Mary	Pete	Ahmed	Meiling
paper jam	5	18	2	8
toner falls off	1	2	2	0
too light	2	8	10	2
unknown	3	4	1	12

3. a) The data below has been plotted from QC samples, add the lines required to complete the $\overline{X}$

chart.



b) We are designing a new product and want to produce it on the process described in #3 a). What tolerance is required to obtain 6 sigma quality?(6%)

4. XXXXXXXXXXXXXXXXXXXXX

5. Given the attached “Frequency Distribution Analysis Sheet”

a) What is the average?
b) What value is at +2 sigma?
c) What is the mode?
d) What is the median?

6. Are the ISO9000 quality standards part of SPC? Justify your answer.(5%)

7. a) Given the results from a Designed Experiment, as listed below, what are the main effects of A and B?

Run	A	B	Samples
1	10	1	3.2, 9.8, 5.5
2	8	1	5.0, 6.7, 2.1
3	10	3	11.3, 7.2, 8.5
4	8	3	7.7, 6.0, 8.9

b) Draw a graph from the data in a), and explain the significance of the effects.(5%)

8. At Joe’s Barbatorium a once a day inspection is done of one customer at random. The QC

inspector checks 1000 hairs for length, any over 1” are considered defective. For the last week the counts have been 10, 2, 25, 0, 7.

a) Select the correct type of attribute chart to track quality.(4%)
b) Draw the chart selected in a).(11%)

9. Develop a double sampling plan OC curve given that, (20%)

N = 1000
n1 = 50
c1 = 2
r1 = 4
n2 = 100
c2 = 3

10. Generally, why should production try to meet specifications, not exceed them?

11.

a) Draw a fishbone diagram for the production of cookie dough. The quality to be measured is the ratio of chocolate chips to dough per cubic meter. Note: the components are weighed separately, and then mixed together in a large tub.
b) Select the most reasonable causes from a), make up a tally sheet, fill it with some data, and draw a Pareto chart. You must consider that there are three different operators that may do the weighing and measuring.

12.

a) We have found a box of gum for practical jokes. Most of the gum is normal, but some pieces will result in purple tongues when chewed. Would inductive, or deductive statistics be used to determine how many of the sticks are for jokes without chewing them all?
b) Assume we are counting the number of fish in a pet store aquarium. Give an example of a grouped, and ungrouped count.

13. Four samples have been taken at the start of a new process run. But, one of the values, X_1, was accidentally erased after the calculations were done. Using the data below, find the missing value.

$\overline{X}_0 = 10.23$ $\qquad$ $UCL_{\bar{x}} = 12.54$
$\overline{X}_1 = ?$ $\qquad$ $LCL_{\bar{x}} = 9.26$
$\overline{X}_2 = 9.98$
$\overline{X}_3 = 11.75$

14. Is the data below normal? Justify your answer.

.0021
.0015
.0014
.0023
.0018
.0027

15. The data below was measured over a two week period for a 1.000” shaft with a tolerance of +/- 0.010” .

Date	Samples			
Nov., 1, 1994	1.0034”	0.9999”	0.9923”	1.0093”
Nov., 2, 1994	0.9997”	1.0025”	0.9993”	0.9938”
Nov., 3, 1994	1.0001”	1.0009”	0.9997”	1.0079”
Nov., 4, 1994	1.0064”	0.9934”	1.0034”	1.0064”
Nov., 5, 1994	0.9982”	0.9987”	0.9990”	0.9957”
Nov., 6, 1994	0.9946”	1.0101”	1.0000”	0.9974”
Nov., 7, 1994	1.0033”	1.0011”	1.0031”	0.9935”
Nov., 8, 1994	1.0086”	0.9945”	1.0045”	1.0034”
Nov., 9, 1994	0.9997”	0.9969”	1.0067”	0.9972”
Nov., 10, 1994	0.9912”	1.0011”	0.9998”	0.9986”
Nov., 11, 1994	1.0013”	1.0031”	0.9992”	1.0054”
Nov., 12, 1994	1.0027”	1.0000”	0.9976”	1.0038”
Nov., 13, 1994	1.0002”	1.0002”	0.9943”	1.0001”
Nov., 14, 1994	0.9956”	1.0001”	0.9965”	0.9973”

a) Draw accurate $\overline{X}$, R and s control charts.
b) Determine if all the data values are normal (56 in total) using the normal distribution graph paper.
c) Determine Cp and Cpk.
d) What would the tolerance have to be if we required 6 sigma quality?

16. A manufacturer ships 10,000 balloons a day to McDonalds. A daily sample of 50 are removed and tested. The table below lists the number that burst when inflated.

Date	Failures Per Sample
Dec., 10	3
Dec., 11	5
Dec., 12	1
Dec., 13	3
Dec., 14	2
Dec., 17	4
Dec., 18	5
Dec., 19	2
Dec., 20	3
Dec., 21	0

a) Select the correct type of control chart, and draw it accurately.
b) If McDonalds sets a maximum of 3 rejects in 50 samples, draw the OC curve.
c) For the OC curve drawn in b), identify the consumers risk when 3% of the balloons are non-conforming.

17. List some material and process variables that can affect quality.
ans. Quality can be affected by speeds, feeds, hardness, surface contamination, purity, temperature, etc.

18. Why is standard devistion important for process control?
ans. Standard deviation is a measure of distribution in a process that varies randomly with a gaussian distribution.

19. Describe SPC (Statistical Process Control).
ans. Statistical process control uses statistical methods to track process performance, and then probability to estimate when it is undergoing some non-random or systematic change. When this occurs the process is no longer under control.

20. What is the purpose of control limits in process monitoring?
ans. Control limits are hard boundaries that the process should not work outside. If a value is outside these limits the process should be stopped.

21. What is process capability and how is it used?
ans. Process capability is used to measure the precision of a machine.

22. What would happen if the SPC control limits were placed less than +/-3 standard devistions.
ans. There will be more of the distribution outside the limits, and hence more rejects.

23. What factors can make a process out of control.
ans. Factors can put a process out of control. A sudden jump will be caused by a change in tools/operators/components/materials. A slow change in the mean will result from slipping gages/tools, or tool wear. A single anomaly can lead to a single control point outside the range (e.g. somebody drops their gum in the machine).

24. What is acceptance sampling and when should it be used?
ans. Acceptance sampling is used for parts that are being made by another manufacturer who does not provide process quality information. This technique uses random inspection of parts as they arrive to ensure conformance to quality limits.

4.9 QUALITY CONTROL PROJECTS

4.9.1 Measuring for Quality Control

Objectives:
• You will be expected to gain practice using the Metrology equipment. Beyond this the students will be expected to make sense of the numbers collected, as well as how they relate to variations caused by processes. The student should also gain an appreciation for software support tools.

Suggested Procedure:
1. Students will be assigned a set of similar parts.
2. Each part will be measured for specified dimensions/features during normal laboratory time. EACH part is to be measured by EACH student 5 times. Each measured dimension will be measured using at least two different Metrology methods.
3. The results may be analyzed using methods, such as,
   - distribution for individuals, parts, overall, etc.
   - calculation of parameters; σ, mean, etc.
   - process capability.
   - etc.
4. TurboSPC is used on the measured data, and is available on a number of computers.
5. A report and presentation (10 minutes) will be prepared for the lab session

4.9.2 Evaluation of Metrology Equipment

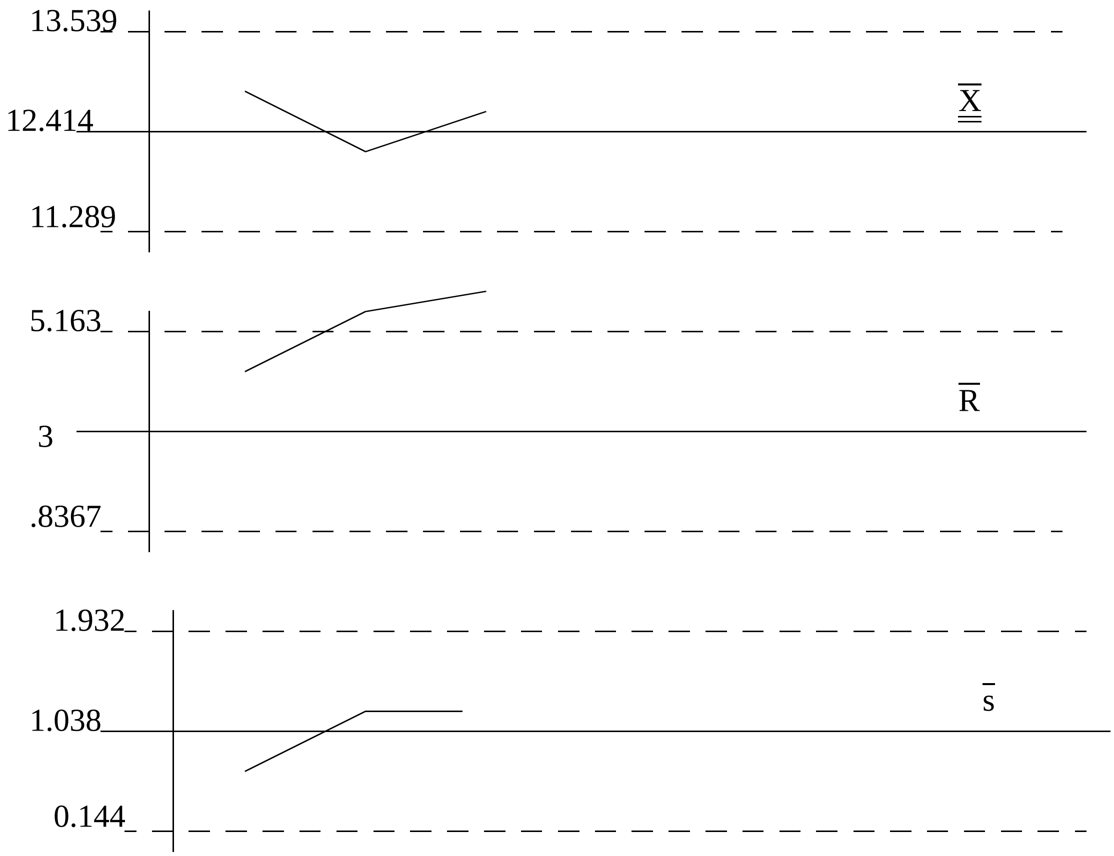
Objectives:
• To understand the limitations in the equipment used for Metrology.

Suggested Procedure:
1. Select a measuring machine used in Project 1. This should not have been used by any other groups in your section.
2. Measurement standards will be used to make repeated measurements, as in Project 1.
3. The capabilities of the process will be determined using known methods.
4. Comparison to results in Project 1 can be made.

5. A report and presentation will be completed.

4.10 ANSWERS TO SELECTED PROBLEMS:

1. Based on exact calculations



Approximate control limits
$UCL_{\bar{X}} = 13.671$
$LCL_{\bar{X}} = 11.157$
$UCL_R = 5.772$
$LCL_R = 0.228$
$UCL_s = 1.954$
$LCL_s = 0.122$

2. We have nonconforming units with a constant sample size, therefore select an np chart.

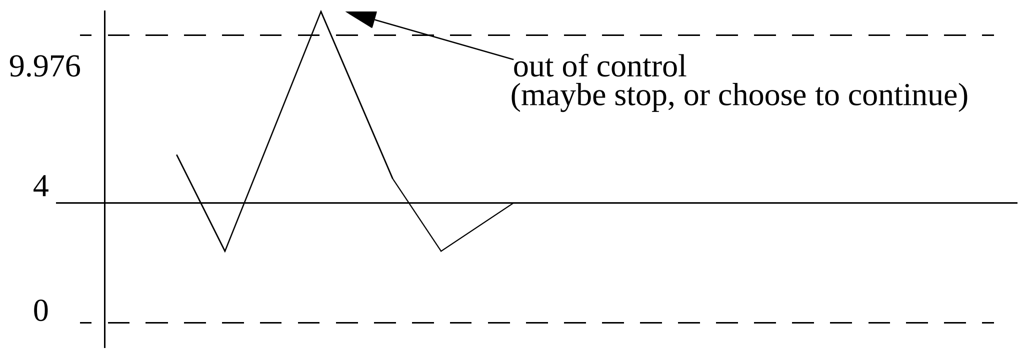
sub-group	n	np
1	500	6
2	500	3
3	500	10
4	500	5
5	500	2
6	500	4
	3000	30

$p_0 = 4/500 = .008$

$np_0 = 4$

$$UCL = 4 + 3\sqrt{4(1 - 0.008)} = 9.976$$

$$LCL = 4 - 3\sqrt{4(1 - 0.008)} = -1.976$$



Data	tally/histogram	Count	Rank	%
2	I	1	1	4.17
3	II	2	2,3	12.5, 20.83
4	II	2	4,5	29.2, 37.5
5	II	2	6,7	45.8, 54.2
6	II	2	8,9	62.5, 70.8
7	II	2	10,11	79.2, 87.5
8		0		
9	I	1	12	95.8
		n=12		

method 1

data appears slightly platykurtic, and slightly skewed to right

$\bar{X} = 5.083$

$\sigma = \sqrt{\frac{44.917}{12.1}} = 2.021$

method 2

$a_3 = \frac{25.809}{12(2.021)^3} = 0.26$

$a_4 = \frac{394.57}{12(2.021)^4} = 1.971$

method 3: use data in table above to draw line in Frequency Distribution Analysis Sheet. Look for straightness of line, and slope.

3. Short answers

a) The histogram on the left indicates grouped data, the histogram on the right indicates ungrouped data.

b) Bimodal distributions indicate a mixture of two sample populations, as if a box of parts has been filled by two different machines.

c) Cp indicates process variance to tolerance only, while Cpk incorporates the shift of the process centre also.

d) DOE allows the most sensitive process parameters to be controlled first.

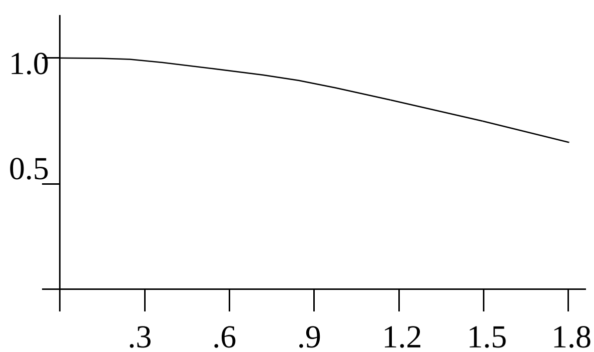
e) Double sampled plans are good when we have something like a good supplier, and destructive testing. Single sampled plans are better when quality must be very high.

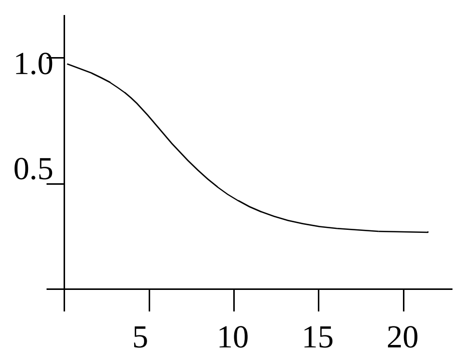
f) Look at charts in book. sample = 188, 2 or less must fail for acceptance.

5.

N = 10000, n = 30, c = 2

p_0	$100p_0$	sample size(n)	np_0	Probability of acceptance (P_a)
.005	.5	30	.15	.999
.01	1	30	.3	.996
.02	2	30	.6	.977
.03	3	30	.9	.938
.04	4	30	1.2	.879
.05	5	30	1.5	.809
.06	6	30	1.8	.731
.07	7	30	2.1	.650
.08	8	30	2.4	.570
.09	9	30	2.7	.494

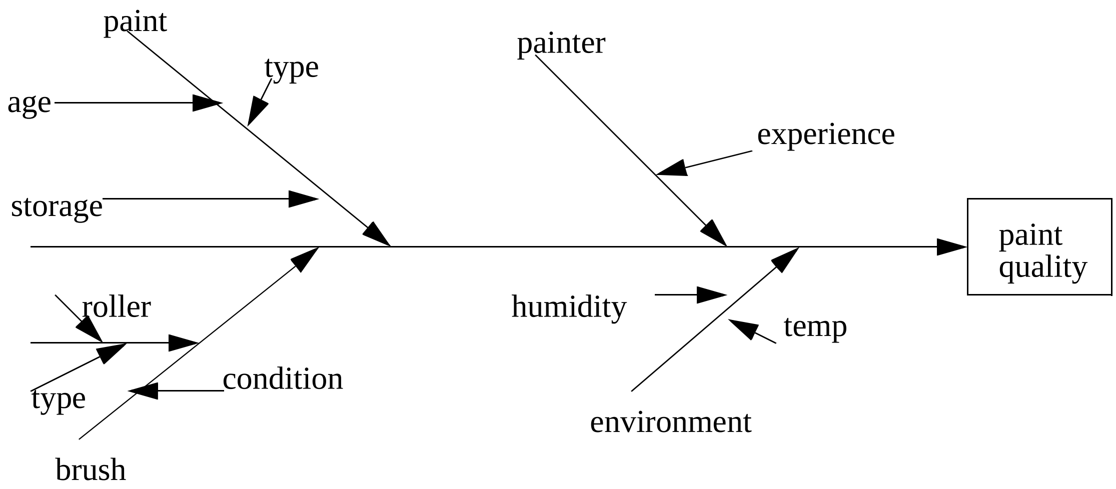




from table C for p_0 = .02, therefore np_0 = .02(30) = .6, α = 1-0.997=2.3%

6.

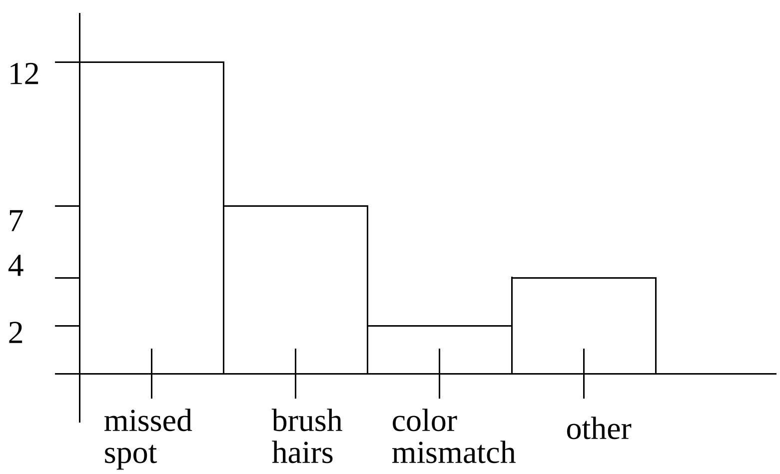
a)



b)

Problem	count
Brush hairs	IIIII II
missed spots	IIIII IIIII II
color mismatch	II
other	IIII

c)



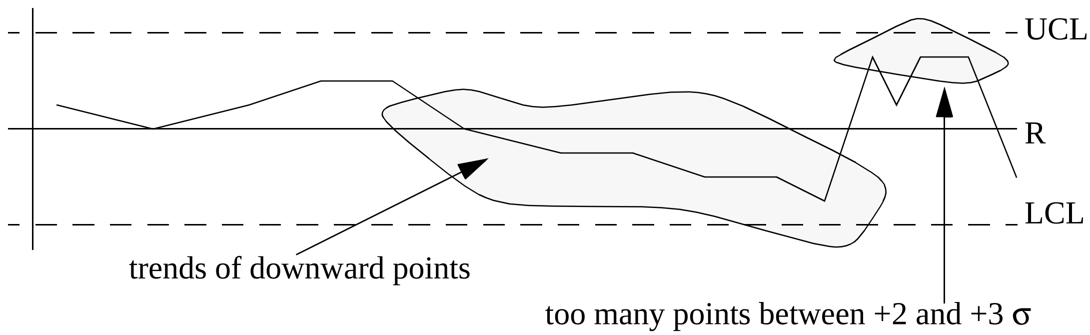
7. Short answer questions

a) Ungrouped data is continuous, and can be grouped into “slots”

b) It is a value in a set of grouped data that reoccurs the most. It tends to indicate where a distribution is centred, or some unnatural patterns. e.g., 10 out of 30 students get a mark of 85% on the test, indicating copying.

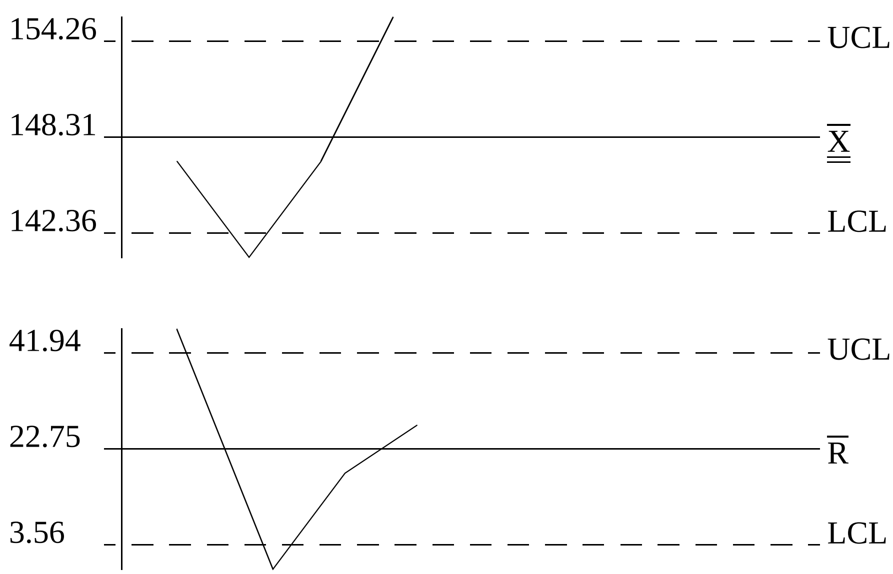
c) A set of samples are taken from a process in one instant in time. The samples are all from a very short period of production time.

d)



8. May as well use a3 and a4, but other methods could be used. $\overline{X}$ = 148.3125, s = 9.0459, a3 = .3900 (skewed to right, positive direction), a4 = 1.958 indicates mesokurtic.

9.



4.11 QUALITY CONTROL FORMS

1. Frequency Distribution Analysis Sheet

5. QFD (QUALITY FUNCTIONAL DEPLOYMENT)

• Basically this relates the customer requirements (i.e., product specifications) to the product design parameters (i.e., final designs) mathematically. The result is a mathematically driven product redesign.

• Also known as House of Quality

• Advantages,
  - reduction of the product design time
  - cost reduction
  - exposes design trade-offs early
  - provides written documentation of design decisions
  - design errors and corrections reduced
  - provides clarity for decisions

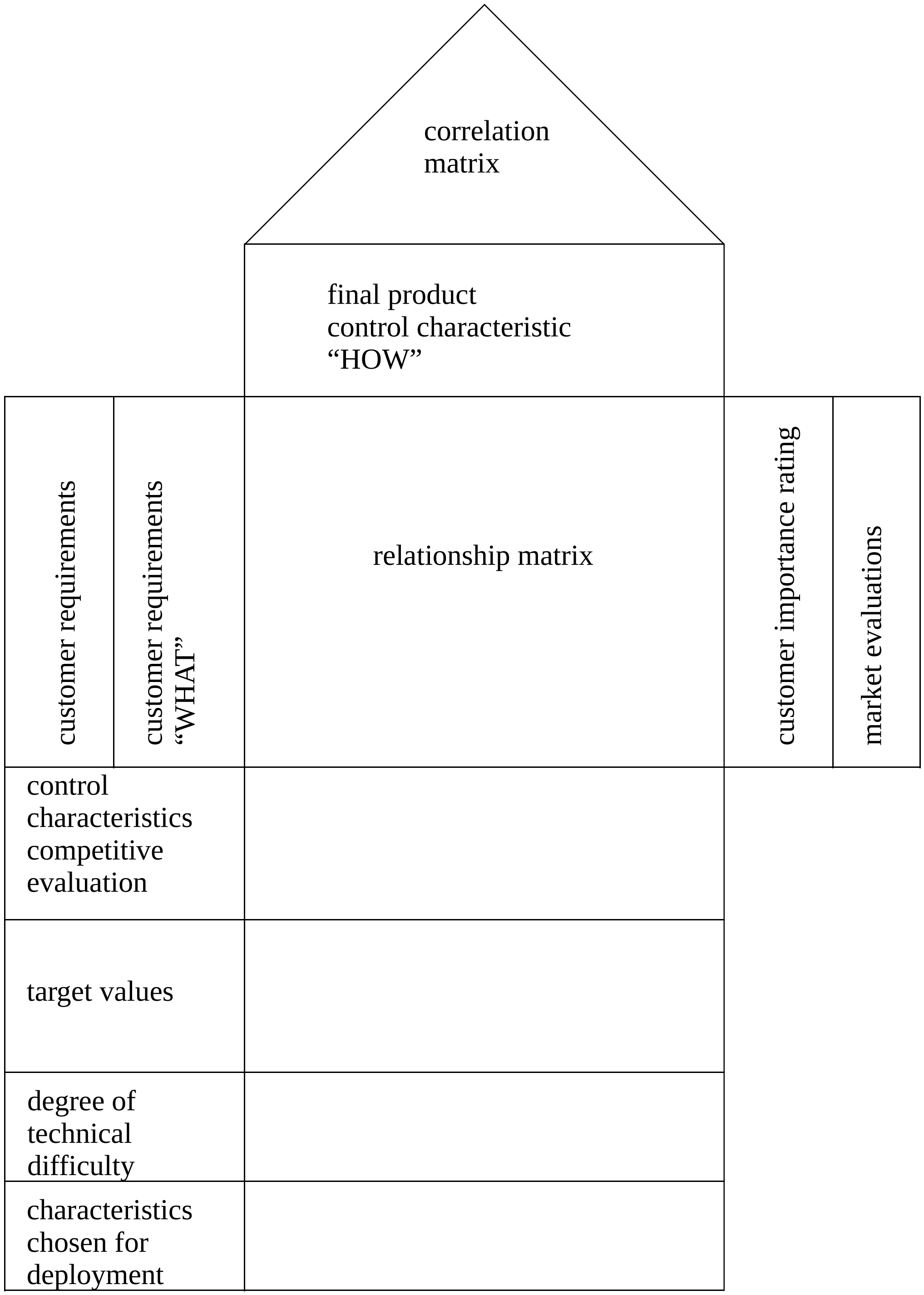
• STEP 1: Voice of the Customer
  • Identify the customers needs, wants and requirements, also known as the Voice Of the Customer (VOX).
  • This ensures that the product design decisions are based on the customer and not just on the perceived customer needs.
  • this should involve all groups in a company that get any feedback from customers. Special programs may also be set up to poll customers.
  • the relative value that customers place on these items should also be identified.

• STEP 2: Customer Requirements Refinement
  • take customer requirements and expand it to more specific points.
  • this can be done with a What-to-How technique.
    • for each requirement ask “What must be accomplished?”, “How will this be accomplished?”
  • a chart can be constructed,

REQUIIREMENTS	WHAT	HOW
dependable	trouble free	no breakdowns
		non-critical parts don’t break
	long life	
	simple fast repairs	
economical		

- The how list should be expanded until each point is a measurable quantity (called the final-product-control-characteristic)

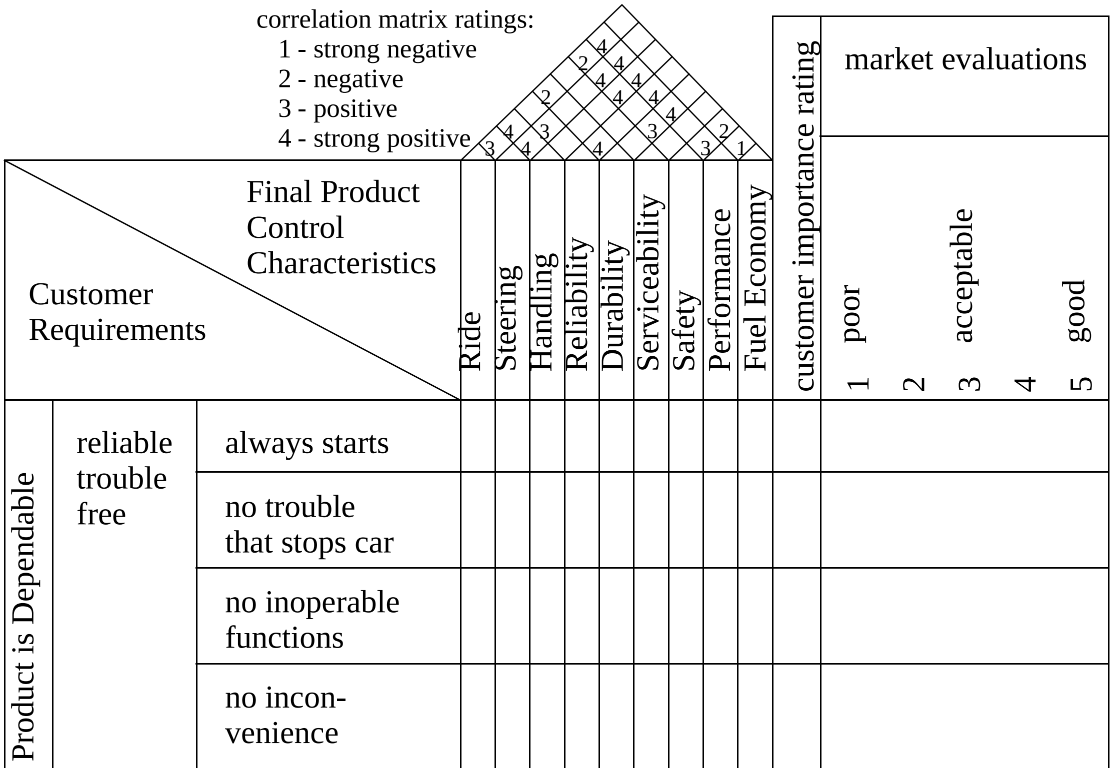
- Step 3: Begin Laying out the Planning Matrix



- ************ INCLUDE FIGURE FROM pg 76 Eureka, W.E., "Quality Functional Deployment Simplified", Technical Report, American Supplier Institute, Michigan, 1987.

Customer Requirements		Final Product Control Characteristics	Ride	Steering	Handling	Reliability	Durability	Serviceability	Safety	Performance	Fuel Economy	customer importance rating	market evaluations: 1 poor, 2, 3 acceptable, 4, 5 good
Product is Dependable	reliable trouble free	always starts											
		no trouble that stops car											
		no inoperable functions											
		no incon-venience											
	lasts a long time	no unexpected component fails											
		no unexpected body deterioration											
	easily and quickly serviced	fast servicing											
		parts available service effective											

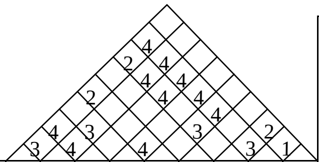
• STEP 4: Fill out the Correlation Matrix to determine how factors relate,
  - relate positive changes to any one of the Control Characteristics to the others. In this case 1 is a very negative effect, up to 4 which is a very positive effect. Unrelated factors have no entry.
  - If too many, or too few of these spots are filled, the customer requirements should be reexamined for accuracy, etc.
  - The product and process should be reconsidered if in general there are more negative than positive effects.



STEP 5: Complete the relationship matrix and importance rating values.

- The relationships between the “WHATS” and “HOWS” are made in this matrix by assigning weights. For example 0-9 where 0 is none and 9 in very strong.
- The column values are then summed to give an importance rating
- This should result in a few clearly important features, and a few that are clearly not important.

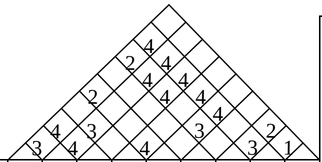
Relationship matrix ratings:
* - strong (value = 9)
o - medium (value = 3)
x - weak (value = 1)



Customer Requirements		Final Product Control Characteristics	Ride	Steering	Handling	Reliability	Durability	Serviceability	Safety	Performance	Fuel Economy	customer importance rating	market evaluations: 1 poor	2	3 acceptable	4	5 good
Product is Dependable	reliable trouble free	always starts				*	*	x		*							
		no trouble that stops car				*	*	x	x	*							
		no inoperable functions				*	*			*							
		no incon-venience				*	*	o		o							
	lasts a long time	no unexpected component fails				*	*		o	*							
		no unexpected body deterioration					*										
	easily and quickly serviced	fast servicing						*									
		parts available service effective						*									
importance rating			0	0	0	45	54	23	4	39	0						

STEP 6: Customer Importance Rating and Market Evaluations

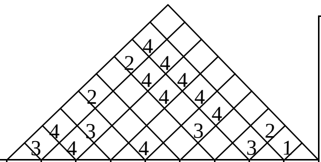
- The opinions of the customer (as collected in step 1) are quantified in terms of importance of the requirements “WHAT”s, these numbers are entered in the customer importance rating column.
- The overall ratings for the competitors products, as well as yours are ranked for each requirement “WHAT” as poor to good. These values are derived from information gathered in step 1, and entered in the Market Evaluations column.
- these sections will clearly identify the strengths and weaknesses of the product within the consumers objectives and compared to the competition.
- if these values have a reasonable distribution, the customer requirements should be reexamined.



Customer Requirements		Final Product Control Characteristics	Ride	Steering	Handling	Reliability	Durability	Serviceability	Safety	Performance	Fuel Economy	customer importance rating	1 poor	2	3 acceptable	4	5 good
Product is Dependable	reliable trouble free	always starts				*	*	x		*		2	A	X		B	
		no trouble that stops car				*	*	x	x	*		2		B	X	A	
		no inoperable functions				*	*			*		3		X	A	B	
		no incon-venience				*	*	o		o		3		X	B	A	
	lasts a long time	no unexpected component fails				*	*		o	*		2		A	B	X	
		no unexpected body deterioration					*					1	A			B	X
	easily and quickly serviced	fast servicing						*				1	B	X	A		
		parts available service effective						*				2		A	B	X	
importance rating			0	0	0	45	54	23	4	39	0						

market evaluations

• STEP 7: Control Characteristics Competitive Evaluation
  - Competitors products, and the internal product are compared technically. The performance criteria are done in terms of the Final Product Control Characteristics.
  - Values are entered in the Control Characteristics Competitive Evaluation section of the chart, and are ranked good to poor.
  - when these numbers are compared to the numbers in the Importance rating row, the technical deficiencies of the product, and it’s importance are clear.



Customer Requirements		Final Product Control Characteristics	Ride	Steering	Handling	Reliability	Durability	Serviceability	Safety	Performance	Fuel Economy	customer importance rating	market evaluations: 1 poor	2	3 acceptable	4	5 good
Product is Dependable	reliable trouble free	always starts				*	*	x		*		2	A	X		B	
		no trouble that stops car				*	*	x	x	*		2		B	X	A	
		no inoperable functions				*	*			*		3		X	A	B	
		no inconvenience				*	*	o		o		3		X	B	A	
	lasts a long time	no unexpected component fails				*	*		o	*		2		A	B	X	
		no unexpected body deterioration					*					1	A			B	X
	easily and quickly serviced	fast servicing						*				1	B	X	A		
		parts available service effective						*				2		A	B	X	
importance rating			0	0	0	45	54	23	4	39	0						
control characteristics competitive evaluation		poor 1				X				A							
		2	B	B	A		X			B	B						
		3	A	X	B	A	A	X	B		A						
		4	X			B		A	X		X						
		good 5		A	X		B	B	A	X							

Technical difficulty ratings:
- 1 - easily achieved
- 2 - limited technical difficulty
- 3 - limited technical problems, but higher cost
- 4 - high technical difficulty and cost
- 5 - very highly technical and costly

• STEP 8: Evaluate the Chart
- the chart at this point contains enough information to do some critical evaluations.
- the control characteristics competitive evaluation, and the importance rating should indicate candidates for change. Primarily a high importance rating, where the competitors product is rated better.

- the candidates selected should be checked to see how the correlate to the Customer Importance Rating and market evaluations. If the choice is not considered important to the customer, or less important then consider it less important. (Use the planning matrix to find effects).
- If any of the customer requirements are unanswered, then the requirements/control characteristics list must be reconsidered.

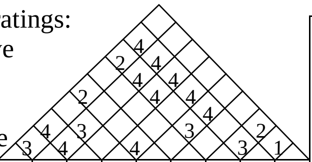
STEP 9: Develop new target values

- using current implemented design parameters, and the relative importance exposed in the last step, new target values should be selected.
- the values determined for the competitors products should be used as well as in-house data for the product.
- a separate sheet, or document may be used here because descriptions may become bulky.

STEP 10: Technical Difficulty

- considering the target values and previous production performance, the difficulty of achieving the target value should be estimated.
- a ranking for this is entered in the “Degree of Technical Difficulty” row.

correlation matrix ratings:
1 - strong negative
2 - negative
3 - positive
4 - strong positive



Customer Requirements		Final Product Control Characteristics	Ride	Steering	Handling	Reliability	Durability	Serviceability	Safety	Performance	Fuel Economy	customer importance rating	market evaluations: 1 poor	2	3 acceptable	4	5 good
Product is Dependable	reliable trouble free	always starts				*	*	x		*		2	A	X		B	
		no trouble that stops car				*	*	x	x	*		2		B	X	A	
		no inoperable functions				*	*			*		3		X	A	B	
		no incon-venience				*	*	o		o		3		X	B	A	
	lasts a long time	no unexpected component fails				*	*		o	*		2		A	B	X	
		no unexpected body deterioration					*					1	A			B	X
	easily and quickly serviced	fast servicing						*				1	B	X	A		
		parts available service effective						*				2		A	B	X	
importance rating			0	0	0	45	54	23	4	39	0						
control characteristics competitive evaluation		poor 1				X				A							
		2	B	B	A		X			B	B						
		3	A	X	B	A	A	X	B		A						
		4	X			B		A	X		X						
		good 5		A	X		B	B	A	X							
target values																	
degree of technical difficulty			3	3	4	1	2	4	3	5	5						
characteristic chosen for deployment							X										

Technical difficulty ratings:
1 - easily achieved
2 - limited technical difficulty
3 - limited technical problems, but higher cost
4 - high technical difficulty and cost
5 - very highly technical and costly

Relationship matrix ratings:
* - strong (value = 9)
o - medium (value = 3)
x - weak (value = 1)

- STEP 11: Deployment Selection
    - quality has a cost, and at this point the cost/benefit trade-off is made.
    - one or more factors can be selected. If there are not a few clear choices, the process should be reexamined
    - the main objectives here are to select the elements with the lowest technical difficulties, but the greatest importance ratings
    - this decision will be slightly arbitrary, but it should not be far outside of what the chart suggests.

- STEP 12: Deployment Matrices
    - for each control characteristic selected in the last step a deployment matrix is developed
    - the top of the matrix is developed using factors discussed in development of the planning matrix
    - the relationship between testable components and the “WHAT”s of durability are put here.
    - the control characteristics measured for all products, and the target values are positioned below.
    - the bottom matrix is system components that can be affected by design. On the left are the systems they affect, and the components in those systems. On the right are the measurable variables, and in the centre are the locations to track the relative quality of the components.

strong effect = x mild effect = o		power train		body			front end		
		cold weather operation	hot weather operation	salt environment	humid environment	scratch resistant	rough road surface	impact resistance	
durability	power train	x	o						
	body			x		o			
	front end						x	x	
control characteristics competitive evaluations	vehicle X A B	95 105 110	95 105 110	90 105 100	90 105 100	90 105 100	105 110 110	105 110 110	
control charateristics targets		115%	115%	115%	115%	115%	115%	115%	
subsystem	component								finished comp-onent characteristic
front suspension	springs								rate
									free height
	shocks								damping
carburetor	choke								choke spring tension
									thermal reaction

- STEP 13: Design and test
  - the deployment matrix is used to do design work, test the results, and compare them to

the target values

• Note that this process is involved, and will require some period of time, but will improve competitiveness of products.

5.1 REFERENCES

Ullman, D.G., The Mechanical Design Process, McGraw-Hill, 1997.

6. DETERMINING CAUSES OF PROBLEMS

• Can be done by an individual, or a team

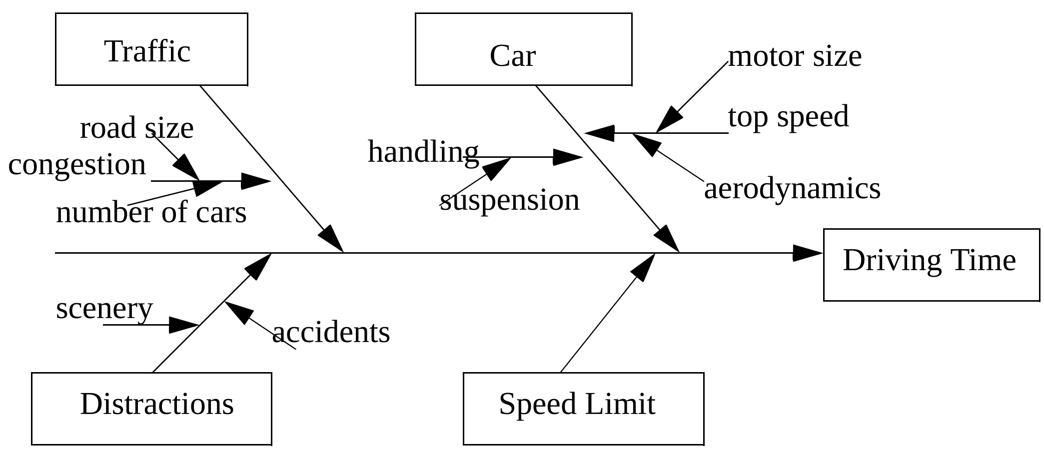
• Can be done by
  - looking at problems
  - thinking about process

6.1 CAUSE AND EFFECT DIAGRAMS

• Consider a production team about to launch a new product. They must anticipate factors that will affect the final product
  APPROACH - Use a Cause and Effect Diagram

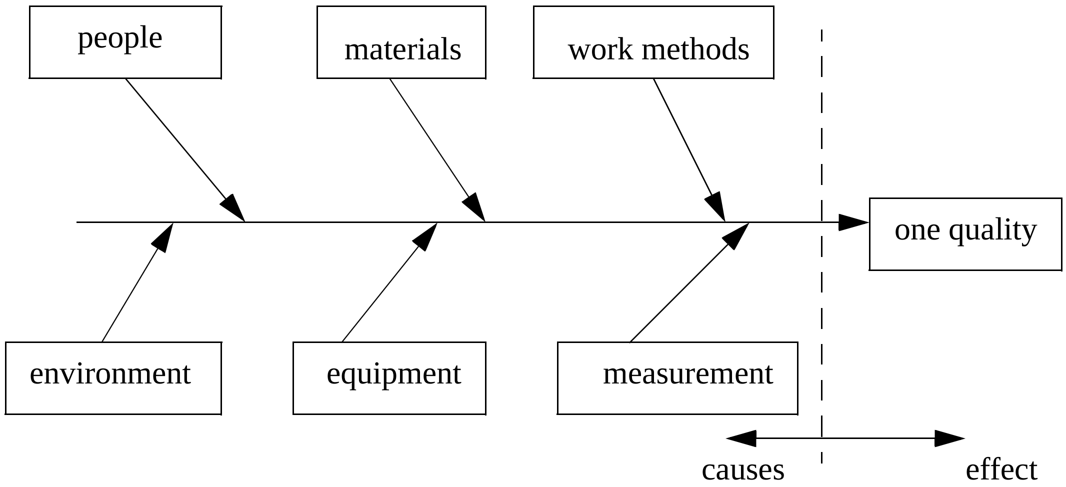
• The cause and effect diagram was developed by Kaoru Ishikawa in 1943.
  - Commonly called - Cause and Effect (CE), Ishikawa Diagram or Fishbone diagram

• In quality we use these to find factors that have some role in a good/bad quality.



** Think about how some of these factors will change the driving time, also consider that long driving times can be good, as well as short driving times.

• For manufacturing there are some more standard causes to consider.



• How can a CE diagram be made up?
- use a team for more ideas
- use brainstorming techniques

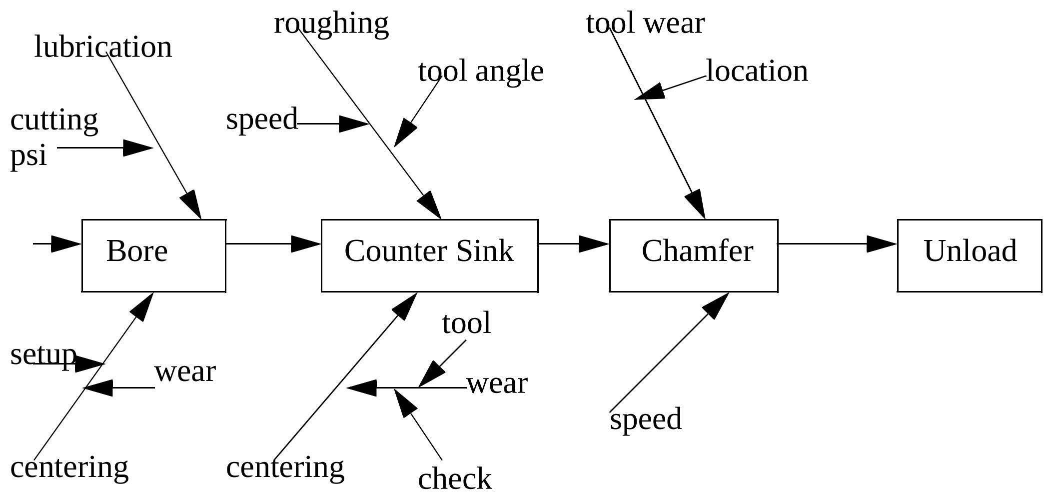
• Brainstorming is a two stage process
Step 1: As a group, have each team member contribute ideas. If an idea is not good it doesn't matter. Add ideas to the diagram. Exhaust all ideas! NO CRITICISM!!!
Step 2: Review the diagram critically as a group. Voting will help to narrow down what are the most important factors.

• What use is a CE diagram?
- Post it in visible spots for common reference by all the workgroups.
- Use it to anticipate, or find the cause of problems.
- Keeps workers involved and informed.

• Advantages of CE diagram
- Analysis - allows tracking of errors, efficient use of resources, lower costs.
- Elimination of unwanted causes.
- Standardization of existing and proposed operations.
- Education and training to allow personnel to make decisions and correct problems autonomously.

6.1.1 Process Diagrams

• Another type of CE diagram is the Process-Analysis diagram. This is used when there are a number of operations or factors involved.



• When considering CAUSES, there are two main types, assignable and chance.
chance - normal, or natural variations that occur in a system (e.g. dice)
assignable - controllable parameters such as material, process parameters, operator skill, etc.

6.2 PARETO DIAGRAM

• After the CE diagram is constructed we can start to trace the cause of problems.

• Assume
1. We have collected data from defects on the factory floor.
2. We have identified the causes of each of the defects (could also use problems, type of problems, etc)

e.g. bad photocopies

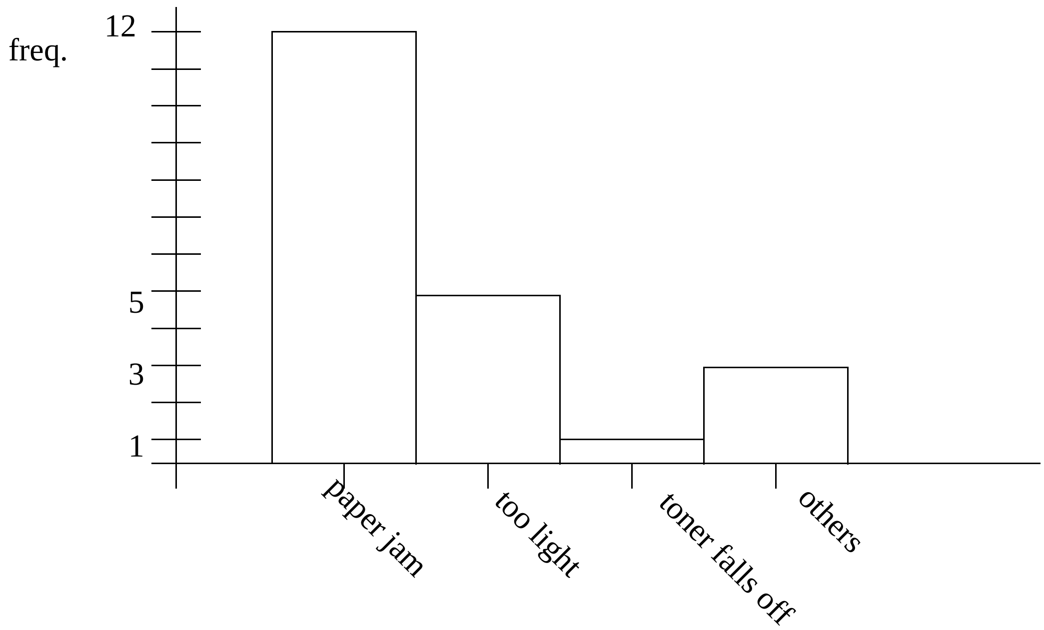
Frequency	Defect
12	Paper Jam
1	Toner falls off
5	too light
3	Others

3. We can rank the list)

e.g. bad photocopies

Frequency	Defect
12	Paper Jam
5	Too light
1	toner falls off
3	Others

4. Draw the graph (** This is a Pareto diagram)



5. Tackle the problem on the left first. Paper jams are the most significant problem that comes up.

6.3 MATRIX ANALYSIS

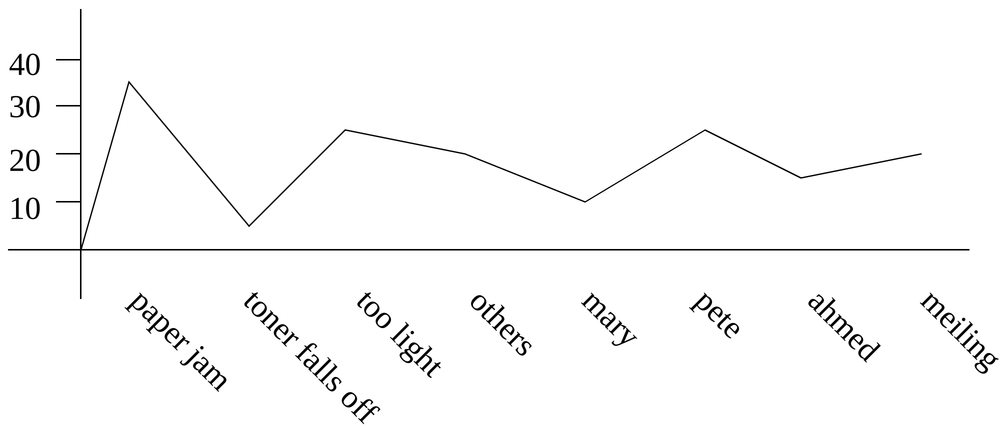
• It is also possible to use the concept in the Pareto Diagram, in a setting with multiple processes.

1. Take data concerning quality.

2. Assign causes and make a table, then sum columns and rows

Defect \ Operator	Mary	Pete	Ahmed	Meiling	
paper jam	5	18	2	8	33
toner falls off	1	0	2	0	3
too light	2	8	10	2	22
others	3	4	1	12	20
	11	30	15	22	

3. Draw graph



<u>7. TOTAL QUALITY CONTROL</u>

• Developed by Dr. A.V. Feigenbaum in the 1950's at G.E.

• Includes all level of management.

• quality should be first and foremost in everybodies minds

• In the production cycle the quality control activities are defined as,

1. New design
   - selling quality products
   - engineering quality products
   - planning quality processes
2. Incoming material control
   - buying quality material
   - receiving and inspecting quality material

3. Product Control,
    - Manufacturing quality parts and products
    - inspecting and testing quality products
    - shipping quality products
    - installing and servicing quality products

• Basic requirements for implementation,
    1. Management must re-emphasize the quality responsibilities, and accountabilities of each employee, regardless of position
    2. Create a Quality Department that will be responsible for the maintenance of quality.

8. W. EDWARD DEMING'S 14 POINTS

• These set the tone for the modern concern with quality [get source]

1. Innovate and allocate resources to fulfill the long-term needs of the company and customer rather than short-term profitability.
2. Discard the old philosophy of accepting nonconforming products and services.
3. Eliminate dependance on mass inspection for quality control; instead, depend on process control, through statistical techniques.
4. Reduce the number of multiple source suppliers. Price has no meaning without an integral consideration for quality. Encourage suppliers to use statistical process control.
5. Use statistical techniques to identify the two sources of waste -- system (85%) and local faults (15%); strive to constantly reduce this waste.
6. Institute more through, better job related training.
7. Provide supervision with knowledge of statistical methods; encourage use of these methods to identify which nonconformities should be investigated for solution.
8. Reduce fear throughout the organization by encouraging open, two-way, non-punitive communication. The economic loss resulting from fear to ask questions or reporting trouble is appalling.
9. Help reduce waste by encouraging design, research, and sales people to learn more about the problems of production.
10. Eliminate the use of goals and slogans to encourage productivity, unless training and management support is also provided.
11. Closely examine the impact of work standards. Do they consider quality or help anyone do a better job? They often act as an impediment to productivity improvement.
12. Institute rudimentary statistical training on a broad scale.
13. Institute a vigorous program for retraining people in new skills, to keep up with changes in materials, methods, product designs and machinery.
14. Create a structure in top management that will push every day for continuous quality improvement.

9. TOTAL QUALITY MANAGEMENT (TQM)

• A quality philosophy that reaches all levels of an organization.

• There is no well defined standard.

• One tool to help assessment of problems is the list of questions below, [Nordeen, 1993]

1. Why does the product have poor quality and/or why does the service of the product have poor quality?
2. Why was the product not correct and/or why was the service of the product not correct?
3. Why was the total process for developing and producing the product and its relatedd systems not capable, and why did the people not have the required knowledge and skills?
4. Why is the importance of the organizational processes, knowledge, and skills not recognized in the business plan and management of the organization?
5. Why does senior leadership not understand?

Nordeen, D.L., "Total Quality Management in Industry", Automotive Engineering, June 1993, pp. 35-41.

10. PROCESS CAPABILITY

• After control charts ($\overline{X}$ and R) have been developed, and the process is in control, the process capability is 6σ

• The capability index can be calculated for a design

$$C_p = \frac{U-L}{6\sigma_0}$$

C_p = Capability Index

$U - L$ = the difference between the upper and lower tolerance

$6\sigma_0$ = the process capability

$C_p = 1$ is OK

$C_p < 1$ is bad (not an acceptable process)

$C_p > 1$ is good (1.33 is standard)

• The capacity Ratio can also be calculated

$$C_r = \frac{1}{C_p}$$

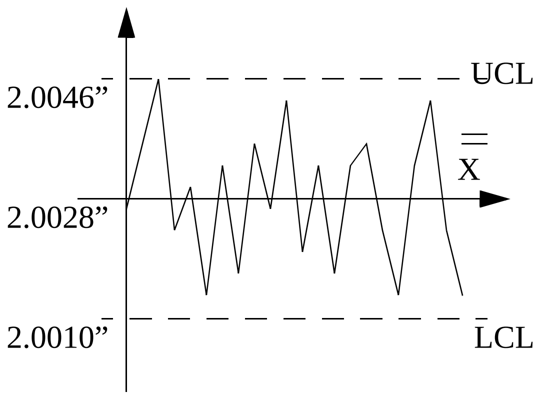
• The Capability Index is another useful measure

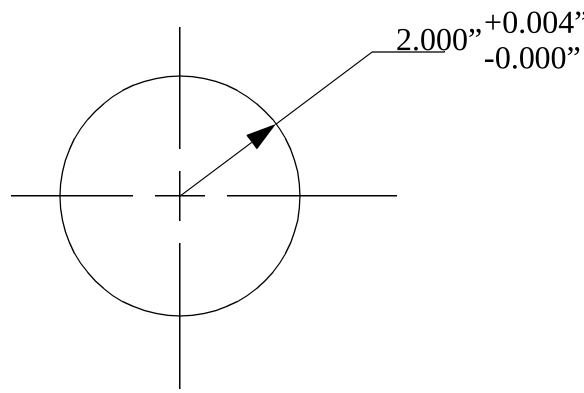
$$C_{pk} = min(Z_1, Z_2)$$

$min(Z_1, Z_2)$ is the smallest value of $\frac{(U-\bar{X})}{3\sigma}, \frac{(\bar{X}-L)}{3\sigma}$

• Some general notes about these indices
- C_p is independent of process centre
- $C_p = C_{pk}$ when the process is centered
- $C_{pk} <= C_p$
- C_{pk} of 1 means the process is OK
- $C_{pk} < 1$ means product out of spec
- $C_{pk} = 0$ process centre at a tolerance limit
- $C_{pk} < 0$ process centre is outside the tolerance range

e.g., Given the control chart for the a process, and a feature to be turned on the process, determine if the tolerances specified are reasonable.





GOOD

$$C_p = \frac{(U - L)}{UCL - LCL} = \frac{2.004 - 2.000}{2.0046 - 2.0010} = \frac{0.004}{0.0036} = 1.11$$

$$Z_1 = \frac{2.004 - 2.0028}{\left(\frac{2.0046 - 2.0010}{2}\right)} = 0.667 \qquad Z_2 = \frac{2.0028 - 2.000}{\left(\frac{2.0046 - 2.0010}{2}\right)} = 1.556$$

$$C_{pk} = min(0.667, 1.556) = 0.667$$

BAD

• If C_p or C_{pk} are both too large (>>2) the process may be too good, suggesting less expensive, easier processes could be considered.

• A good rule of thumb for using C_p and C_{pk} is that if new equipment is being purchased, try to get values above 1.5, if the equipment is already available, 1.33 is acceptable.

• Try Probs #6 pg124, #32,33 pg128

11. SIX SIGMA QUALITY

• Developed by Motorola

• A strategy to target quality problems

• In simple terms,

$$C_p = 2$$

$$C_{pk} = 1.5$$

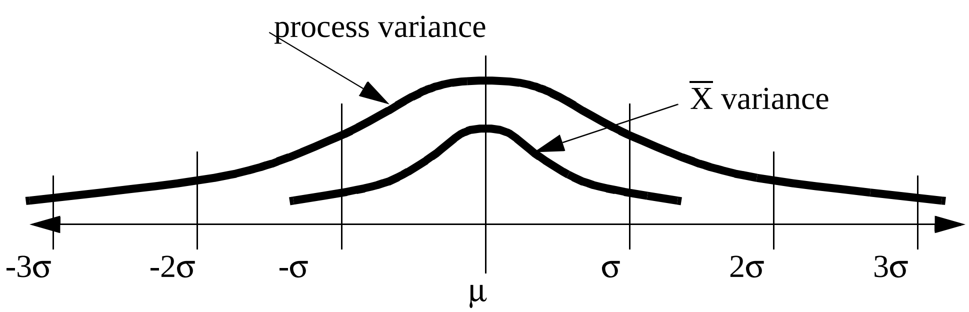
* Recall,
- if Cp = Cpk then $\overline{X} = \mu$, and the process is always centered

$$C_p = \frac{U - L}{6\sigma}$$

$$C_{pk} = \left(\frac{U - \mu}{3\sigma}\right) \text{or} \left(\frac{\mu - L}{3\sigma}\right)$$ select the smaller of the two

the mean typically drifts about 1.5σ, as established by historical means

and, +/-6σ quality gives 2 defaults in 1 million with no variation.
with a 1.5σ variation in mean the reject rate is 3.4 in 1 million



• This can be summarized as 6σ of variance alone ignores the drift of the process centre. Assuming the process centre varies by +/-1.5σ results in a more accurate model of production.

• The steps in implementation are,
1. Identify critical characteristics through such functions and activities as marketing, industrial design, R&D engineering, etc.
2. Identify the product elements that influence the critical characteristics defined in step 1.
3. Define the process elements that influence the critical characteristics defined in step 2.
4. Establish maximum tolerances for each product and process element defined in steps 2 and 3.
5. Determine actual capability of the elements presented in steps 2 and 3.
6. Assume $C_p >= 2$ and $C_{pk} >= 1.5$.

12. DESIGN OF EXPERIMENTS

• WHAT? combinations of individual parameters for process control are varied, and their effect on output quantities are measured. From this we determine the sensitivity of the process to each parameter.

• WHY? Because randomly varying (trial and error) individual parameters takes too long and the results are not mathematically conclusive.

12.1 OVERVIEW

• e.g. A One-Factor-At-A-Time-Experiment

Effect: We are finding the causes of cracks in steel springs.
Causes:

1. Steel temperature before quenching 1450F or 1600F
2. Carbon Content .5% or .7%
3. Oil quench temperature 70F or 50F

Experiments 1 and 2:

Run 1:

1. 1450F
2. 0.5%
3. 70F

yield(%) 72 70 75 77, $\bar{X}$=73.5%

Run 2:

1. **1600F
2. 0.5%
3. 70F

yield(%) 78 77 78 81, $\bar{X}$=78.5%

Observation: 1600F before quench gives higher yield.

Run 3:

1. 1600F
2. **0.7%
3. 70F

yield(%) 77 78 75 80, $\bar{X}$=77.5%

Observation: Adding more carbon has a small negative effect on yield.

Run 4:

1. 1600F
2. 0.5%
3. **50F

yield(%) 79 78 78 83, $\bar{X}$=79.5%

Observation: We have improved the quality by 6%, but it has required 4 runs, and we could continue.

• The example shows how the number of samples grows quickly.

• A better approach is designed experiments

12.2 n-FACTORIAL

• These experiments vary parameters with the basic procedure below,

1. Identify process variables (inputs) and dependant variables (outputs). Outputs should be continuous values.
2. Select discrete values for the inputs. The most basic approach is to pick a high and low value for each.
3. Create a data collection table that has parameters listed (high/low) in a binary sequence. Some of these tests can be left off (fractional factorial experiment) if some relationships are known to be insignificant or irrelevant.
4. Run the process using the inputs in the tables. Take one or more readings of the output variable(s). If necessary, average the output values for each of the experiments.
5. Graph the responses varying only one of the process parameters. This will result in curves that agree or disagree. If the curves agree then the conclussion can be made that process variables are dependent. In this case the relationship between these variables requires further study.
6. Calculate the effects of the process variable change.
7. Use the results of the experiment to set process parameters, redesign the process, or to design further experiments.

• e.g. 3-factorial DOE for springs in last section

Overview: In this case the problem uses the yield of good springs from a manufacturing process. (Note: It would be better to measure individual parameters such as spring force.) The process has three variables that are varied between high and low, thus giving 8 possible combinations. The yield is measured over four batches, and the average yield is used. The process variables and yield are determined by somebody very familiar with the process. The purpose of this experiment is to determine what the effect of the variables are, and if there are and interdependancies between process varaibles.

- set up orthogonal array

Run	1.	2.	3.	Yield%	Ri = $\overline{X}$
1	1450	0.5	50		
2	1600	0.5	50	79 78 78 83	79.5
3	1450	0.7	50		
4	1600	0.7	50		
5	1450	0.5	70	72 70 75 77	73.5
6	1600	0.5	70	78 77 78 81	78.5
7	1450	0.7	70		
8	1600	0.7	70	77 78 75 80	77.5

more readings required for this experiment

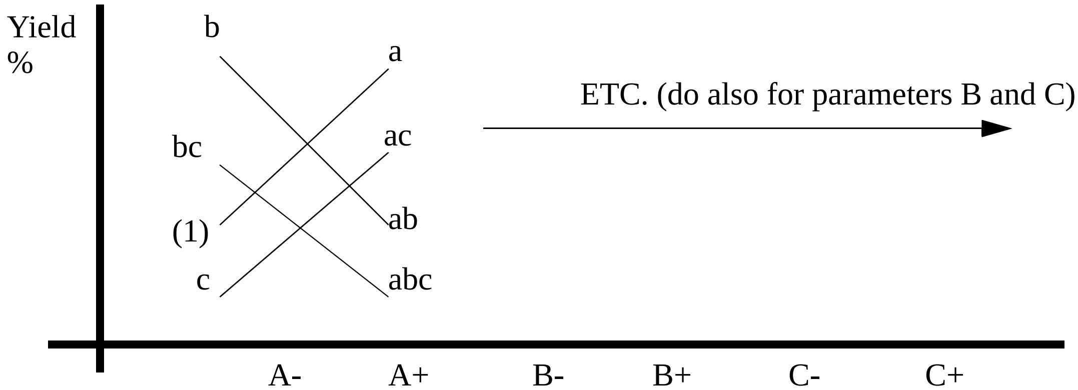
Note the binary sequence

-(optional) This can also be shown in a more generic form.

Run	a	b	c	Yield%	Ri = $\overline{X}$
(1)	L (-1)	L (-1)	L (-1)		
a	H (1)	L (-1)	L (-1)	79 78 78 83	79.5
b	L (-1)	H (1)	L (-1)		
ab	H (1)	H (1)	L (-1)		
c	L (-1)	L (-1)	H (1)	72 70 75 77	73.5
ac	H (1)	L (-1)	H (1)	78 77 78 81	78.5
bc	L (-1)	H (1)	H (1)		
abc	H (1)	H (1)	H (1)	77 78 75 80	77.5

In this case we change the notation. So the input parameters become a, b and c. And the process values are indicated as high or low H or L. This can also be shown as (1) and (-1)

- these can be drawn on an effect graph



Note: As shown here, we see all four cases where only a is changed. If we look at the curves 'c-ac' and '(1)-a'they both have the same trend, so the variables are independant. But, both of the curves that include 'b' reverse the trend, so process parameter 'b' (in this case the carbon content) interacts with the temperature.

- Find effects of each factor

$$\text{Main Effect} = (\text{Average at High}) - (\text{Average at Low})$$

$$\text{Main Effect of A} = \frac{(R_2 + R_4 + R_6 + R_8)}{4} - \frac{(R_1 + R_3 + R_5 + R_7)}{4}$$

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The values of the effects will indicate the influence of a given parameter on the process. output. These equations are specific to an experiment with three inputs, but the other forms are quite similar.

13. TAGUCHI METHODS

See attached

14. REFERENCES

Besterfield,

Harry, M.J., “The Nature of Six Sigma Quality”, A booklet published by the Motorola Inc. Government Electronics Group,

Toper, W.G., “The ISO9000 Quality System Standards and Their Implication for Global Business”, A tutorial presented at the third annual IIE Four-chapter Conference at the Sheraton Falls view Hotel & Convention Centre, Niagara Falls, Ontario, Canada, June 14, 1993.

15. DESIGN OF EXPERIMENTS

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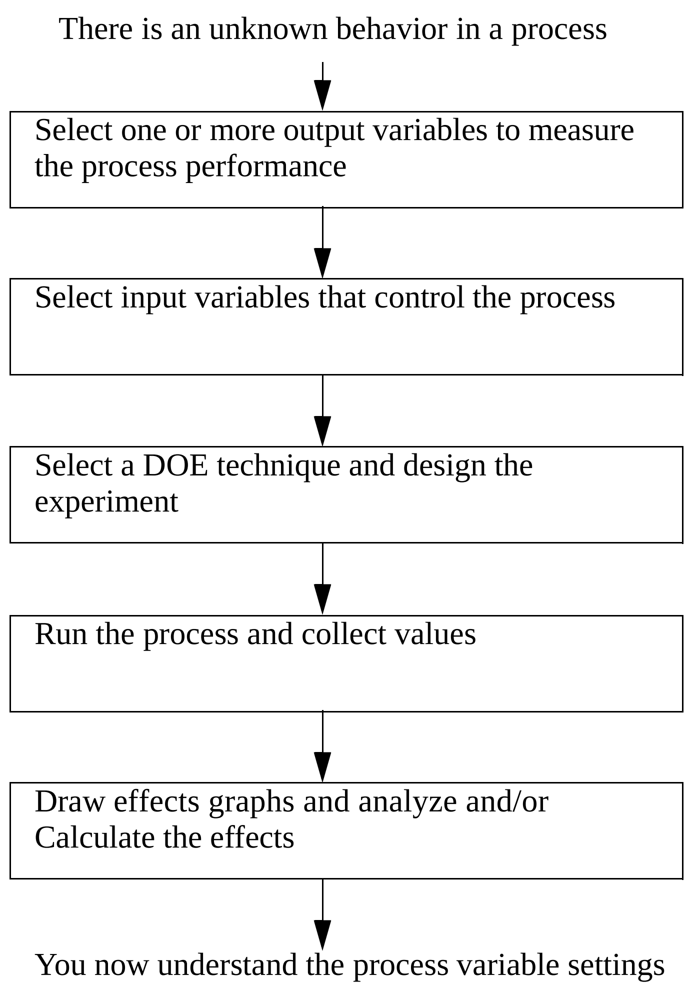
• WHY? Because randomly varying (trial and error) individual parameters takes too long and the results are not mathematically conclusive.

15.1 OVERVIEW

• The basic process for analysis is shown below.



- The purpose of DOE is to prove a relationship between given outputs and inputs. Cases that are possible include:
    - no relationship
    - positive relationship
    - negative relationship
    - interaction between inputs

- e.g. A One-Factor-At-A-Time-Experiment

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Overview: In this case the problem uses the yield of good springs from a manufacturing process. (Note: It would be better to measure individual parameters such as spring force.) The process has three variables that are varied between high and low, thus giving 8 possible combinations. The yield is measured over four batches, and the average yield is used. The process variables and yield are determined by somebody very familiar with the process. The purpose of this experiment is to determine what the effect of the variables are, and if there are and interdependencies between process variables.

- set up orthogonal array

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more readings required for this experiment

Note the binary sequence

-(optional) This can also be shown in a more generic form.

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c	L (-1)	L (-1)	H (1)	72 70 75 77	73.5
ac	H (1)	L (-1)	H (1)	78 77 78 81	78.5
bc	L (-1)	H (1)	H (1)		
abc	H (1)	H (1)	H (1)	77 78 75 80	77.5

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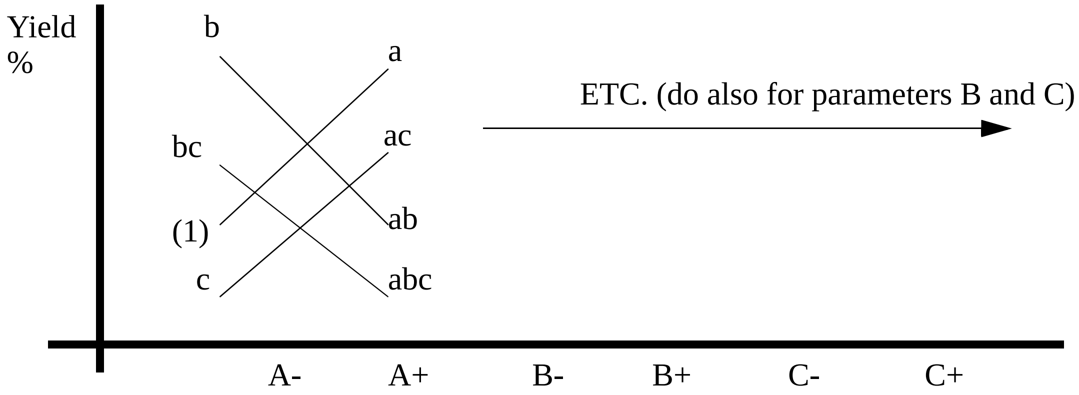

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- Find effects of each factor

$$\text{Main Effect} = (\text{Average at High}) - (\text{Average at Low})$$

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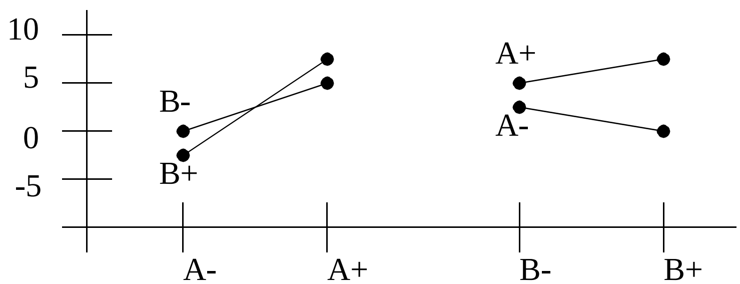
The values of the effects will indicate the influence of a given parameter on the process. output. These equations are specific to an experiment with three inputs, but the other forms are quite similar.

15.3 PRACTICE PROBLEMS

1. You have collected the data below as part of a 2-n factorial experiment for making slush. There are two process variables you control, a quantity of sugar and a quantity of salt that is added to the water, these modify the freezing temperature of the slush. Draw effects graphs and calculate the effects of changing the parameters. State whether they are dependant or independent.

sugar (g)	salt (g)	freezing temp (C)
40	3	2
40	5	-4
60	3	6
60	5	7

ans.



$$\text{Main Effect of A} = \left(\frac{6+7}{2}\right) - \left(\frac{2+(-4)}{2}\right) = 7.5$$

$$\text{Main Effect of B} = \left(\frac{-4+7}{2}\right) - \left(\frac{2+6}{2}\right) = -2.5$$

Using the slopes of the graphs,
- The effect of B(salt) is dependant on A(sugar)
- The effect of A(sugar) is independent of B(salt)

A(sugar) generally increases the freezing temperature while B(salt) decreases it.

15.4 REFERENCES

16. ISO9000

• Originally developed by the ISO Technical Committee TC 176.

• A standard aimed at certifying products for quality (e.g., when taking a drivers licence test, they don't care how you learned to drive, only if it conforms to the legal requirements).

• This is the first Globally accepted quality designation, and it is replacing many existing quality certification programs, such as those of,

- GM, Chrysler, and Ford
- NATO,
- Telecommunication companies
- US Department of Defense
- etc

• There are designated certification agencies throughout the world.

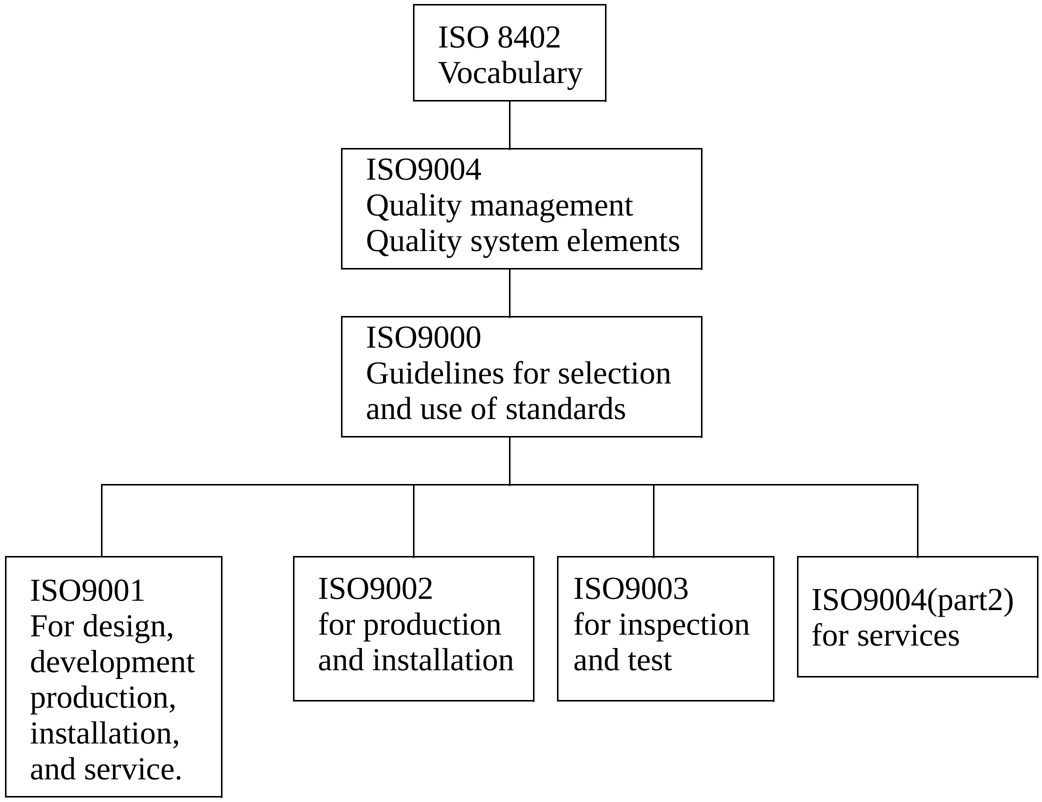
• The philosophy,

- should be open about all processes, no hiding, no "back-rooms" where 'skeletons' are hidden.
- common agreement about quality objectives between suppliers, producer, customers.
- a product, and quality responsibility should be traceable from start to end.
- documentation is required to indicate how production goes from the front end to the customer.
- the documents are to be signed and copies given to everybody responsible. It becomes a "quality bible" for a product.

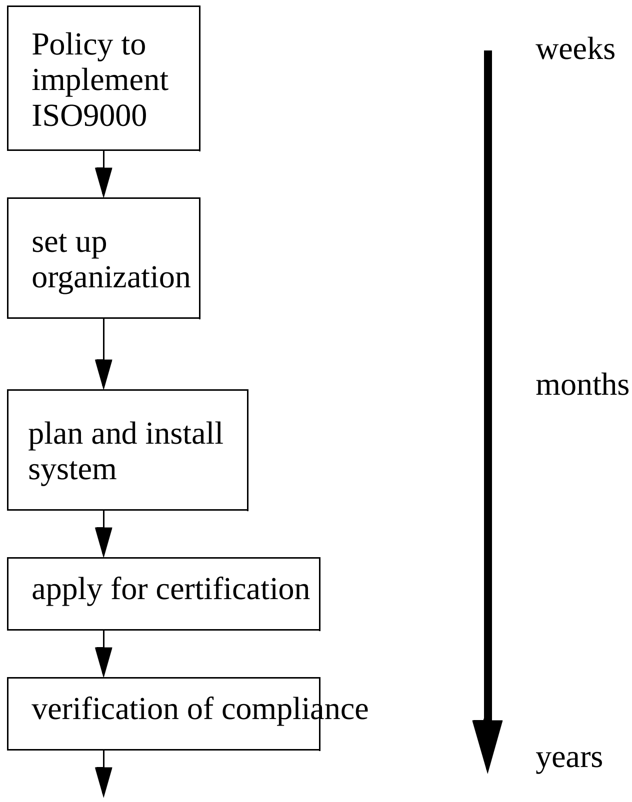
• The standards,

- ISO9000 - directs the selection of the other ISO900x standards and general management policies.
- ISO9001 - The most stringent quality standard requiring conformance from design to service.
- ISO9002 - Looser than ISO9001, requiring excellence in production and installation.
- ISO9003 - Best when only capable of inspection and testing. Even easier than ISO9002.

• Overview



• Approach to certification.



• Information is available from,
  - (USA) the National Institute of Science and Technology (NIST), the Department of Commerce, Phone:(301) 975-4031, Fax:(301) 963-2871

• What is required for an effective quality system?
  - Organizational Structure and Responsibilities
  - Processes and Procedures
  - Documentation and Implementation of Quality Policy

• Standard compliance can be determined by,
  - Second party - a customer may audit the suppliers quality system, and verify compliance to one of the standards, with periodic reviews.
  - Third party - The accreditation body certifies the program, and conducts periodic monitoring of procedures.

• Basic steps for implementation
  1. Make a decision to seek certification
     - is it required for commercial needs?
     - is the organization committed to certification?

2. Determining the state of the existing facility
    - assess and identify gaps in processes and documentation
    - determine existing compliance
    - begin promoting and training for compliance
    - select a registration body
3. Compliance
    - continue training
    - conduct internal and external audits
    - close quality gaps
4. Registration
    - auditors will visit and review the application, and the state of the document, etc.
    - continued monitoring

• ISO 9001 is the most stringent standard, and the ISO 9002, and ISO 9003 standards are subsets of this, as shown in the table below,

item #	item description	ISO 9001	ISO 9002	ISO 9003
1	Management responsibility	3	2	1
2	Quality system	3	3	2
3	Contract review	3	3	0
4	Design control	3	0	0
5	Document control	3	3	2
6	Purchasing	3	3	0
7	Purchaser supplied product	3	3	0
8	Product identification and traceability	3	3	2
9	Process control	3	3	0
10	Inspection and testing	3	3	2
11	Inspection, measuring and test equipment	3	3	2
12	Inspection and test status	3	3	2
13	Control of nonconforming product	3	3	2
14	Corrective action	3	3	0
15	Handling, storage, packaging and delivery	3	3	2
16	Quality records	3	3	2
17	Internal quality audits	3	2	0
18	Training	3	2	1
19	Servicing	3	0	0
20	Statistical techniques	3	3	2

Legend
3 = important
1 = some importance
0 = not included

• The principles that must be applied to the above areas are,
    - each element must be addressed

- the process must be defined
- process documentation
- develop and maintain evidence of implementation

• The most typical initial impacts on a company are,
  - a culture change where procedures must now be followed
  - addition of a system for controlling documents

• Significant long term impacts on a company are,
  - use of documents to direct work
  - ongoing review of quality methods

17. ISO 14000

• A set of standards that address environmental issues. This initiative began in 1993 when the ISO formed TC207 (technical committee).

• This set of standards is designed to be administered like the ISO9000 quality standards. Basically, documenting the process, and ensuring that the documented process is followed. - “say what you do, do what you say”.

• ISO 9000 and 14000 are compatible and can be integrated.

• The standards include,
  - environmental management
  - environmental auditing
  - environmental labeling
  - environmental performance evaluation
  - life cycle assessment
  - environmental standards

• The standard includes the following sections,
  14000 - the main guide to the 14000 standards
  14001 - the most stringent environmental certification
  14010-14019 - guidelines for auditing
    14010 - the general principles of environmental auditing
    14011-1 - auditing of environmental management systems
    14011-2 - audits to check for compliance
    14012 - qualification of auditors
    14014 - a guide to performing an initial environmental review
  14020-14024 - environmental labelling
    14020 - basic principles for environmental labelling
    14021 - terms and definitions for labelling

- 14022 - symbols used in labelling
- 14023 - testing and verification methods for labelling
- 14024 - methods used by labelling teams

14031 - methods for evaluating environmental performance
14041-14044 - life cycle assessment
- 14041 - code of practice
- 14042 - inventory
- 14043 - impact analysis
- 14044 - improvement analysis

14050 - terms and definitions
14060 - inclusion of environmental aspects in product standards

• As with ISO9000 the basic process is,
1. Make a decision to obtain certification.
2. Plan the preparation process (possibly hire a consultant).
3. Assess current practices.
4. Make required changes.
5. Document the corrected system.
6. Request a certification visit.
7. The certification team visits to ensure compliance.
8. Certification may be granted.
9. Internal audits and updates done as called for in ISO14000 documents.
10. Occasional visits to ensure compliance to renew certification.

17.1 PRACTICE PROBLEMS

1. Give examples of local companies that would be well suited to different ISO certifications.
a) ISO 9001
b) ISO 9002
c) ISO 9003

2. List 5 types of companies that might seek ISO 14000 certification. State why they would need the certification.