Learning Objectives for Midterm 2

– Chapter 5: Strategic Capacity Planning –

LO1: Define capacity, explain the importance of long-term capacity, know how to measure capacity and understand two related performance measures, and describe factors influencing effective capacity

LO2: Describe the strategic capacity planning process in organizations, know how to forecast demand and calculate capacity requirements, and discuss major considerations for developing capacity alternatives

LO3: Describe the break-even analysis approach for evaluating capacity alternatives, and use it to solve problems

– Chapter 9: Management of Quality –

LO1: Define the term quality, describe evolution of quality management, discuss dimensions and determinants of quality, describe various costs associated with quality, and discuss philosophies of quality gurus

LO2: Discuss quality certifications

LO3: Describe HACCP and apply it

LO4: Describe and apply Canada Awards for Excellence and TQM

LO5: Give an overview of problem solving and process improvement, describe and use various quality tools

– Chapter 10: Statistical Quality Control –

LO1: List and briefly explain the elements of the statistical process control process

LO2: Explain how control charts are designed and the concepts that underlie their use, and solve problems that involve control chart design and use

LO3: Assess process capability, and solve problems involving process capability

LO4: Describe Six Sigma quality and design of experiments

– Chapter 10 Supplement: Acceptance Sampling –

LO1: Explain acceptance sample, contrast single & multiple sampling plans

LO2: Construct and use an operating characteristic curve

LO3: Determine single sampling plans

LO4: Determine the average quality of inspected lots, and determine a related sampling plan

Chapter 5: Strategic Capacity Planning

– LO1 –
capacity: the upper limit on the load that any operation unit can handle
design capacity: maximum obtainable output rate under ideal conditions
effective capacity: maximum output rate given work breaks, product mix, scheduling difficulties, delays, and other realities (standard output rate)
actual output: rate of output actually achieved—cannot exceed effective capacity

$$\text{Efficiency} = \frac{\text{Actual output rate}}{\text{Effective capacity}} \qquad \text{Utilization} = \frac{\text{Uptime}}{\text{Available time}}$$

Example: Capacity

Actual production last week = 32,000 units
Effective capacity = 35,000 units
Design capacity = 250 units/hour
Factory operates 7 days/week, 3-8 hour shifts
Maintenance is 20 hours/week and other downtime is 12 hours/week

Solution:

Available hours = 7 days x 3 shifts x 8 hours = 168 hours
Design capacity = 168 hours x 250 units = 42,000 units
Efficiency = $\frac{\textbf{Actual production}}{\textbf{Effective capacity}} = \frac{\mathbf{32,000}}{\mathbf{35,000}}$ = 91.4%
Utilization = $\frac{\textbf{Uptime}}{\textbf{Available time}} = \frac{\mathbf{168-(20+12)}}{\mathbf{168}}$ = 81%

Factors influencing capacity

→facilities, products or services, human, planning and operational, external

– LO2 –

Capacity planning process

1. Forecast demand one to five years ahead
2. Determine capacity requirements
3. Measure the capacity now and decide how to bridge the gap
    a. Generate feasible alternatives
    b. Evaluate alternatives considering economic and non-economic aspects
    c. Choose the best alternative and implement it

Example: Calculating capacity requirements

1 – 8 hour shift, 250 days/year, how many machines (with the given processing times) would be needed to handle the required volume?

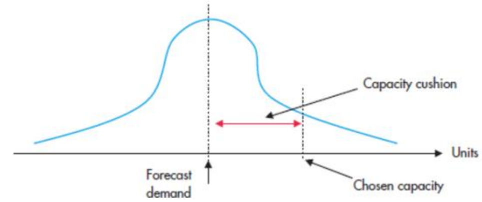
Product	Annual Demand	Standard Processing time per unit	Processing time needed
A	400	5.0	2,000
B	300	8.0	2,400
C	700	2.0	1,400

Solution:

8 x 250 = 2,000 machine hours/year
Machines needed = $\frac{\mathbf{2,000+2,400+1,400}}{\mathbf{2,000}}$ = 2.9 machines needed

Major considerations for developing capacity alternatives

1. Design flexibility into the system
2. Differentiate between new and mature products
3. Take a "big picture" approach to capacity changes
   bottleneck operation: an operation in a sequence of operations whose capacity is lower than that of the other operations
4. Choose capacity timing and increments
5. Prepare to deal with capacity "chunks"
6. Attempt to smooth out capacity requirements
7. Use capacity cushion
   capacity cushion: the excess of capacity over the average
8. Identify the optimal operating level



economies of scale

→fixed costs (facilities, equipment, management) spread out over more units
→volume purchase discounts

diseconomies of scale

→worker fatigue, equipment breakdown, less room for error, difficulties in coordination

evaluating alternatives

economic considerations
→ cost, useful life compatibility, revenue

non-economic considerations
→ public opinion, reactions from employees, community pressure

Techniques used for evaluation:

1. Break even analysis
2. Payback period
3. Net present value

– LO3–

Break even analysis	
TC = FC + VC VC = Q x v TR = Q x r P = TR – TC = Q x r – (FC + Q x v) $Q_{BEP} = \frac{FC}{r-v}$ *For a specific profit:* $Q = \frac{P+FC}{r-v}$	TC = Total cost FC = Total fixed cost VC = Total variable cost TR = Total revenue v = variable cost per unit r = revenue per unit Q = volume of output Q_{BEP} =break even volume P = profit

make-or-buy decision: $Q = FC/(v_b - v_m)$ **cost-vs.-cost decision:** $Q = (FC_A - FC_B)/(v_B - v_A)$

step costs: costs that increase stepwise as a range of outputs increase

Example: Break-even problem with step fixed cost

A manager has the option of purchasing one, two, or three machines. Fixed costs and range of output are as follows:

Number of Machines	Total Annual Fixed Cost	Corresponding Range of Output
1	$ 9,600	0 to 300
2	$ 15,000	301 to 600
3	$20,000	601 to 900

d

Variable cost is $10 per unit, and revenue is $40 per unit.

a. Determine the break-even point (if any) for each range.

b. For any value of annual demand between 0 and 900 units, determine how many machines the manager should purchase.

Solution:

a. Calculate the break-even point for each range

For 1 machine: $Q_{BEP} = \frac{\$9,600}{\$40-\$10}$ = 320 units (not in range, so there is no BEP)

For 2 machines: $Q_{BEP} = \frac{\$15,000}{\$40-\$10}$ = 500 units

For 3 machines: $Q_{BEP} = \frac{\$20,000}{\$40-\$10}$ = 666.67 units

b. For demand ≤ 499 → use 0 machine (because the first feasible break-even point is 500)

For 500 ≤ demand ≤ 600 → use 2 machines

For 601 ≤ demand ≤ 766 → (don't use 3 machines), but use 2 machines to produce 600 units because:

profit = 600($40-$10) - $15,000 = $3000 is greater than profit (Q), 601 ≤ demand ≤ 766.

For example, profit(766) = 766($40-$10) – 20,000 = $2,980

For 767 ≤ demand ≤ 900 → use 3 machines

break-even point in dollars = $FC/(1 - v/R)$

more than one type of output = $$Q_{BEP\$} = \frac{FC}{\sum\left[\left(1-\frac{v_i}{R_i}\right)W_i\right]}$$:re W = proportion of revenue of product

i = product

Chapter 9: Management of Quality

– LO1 –

quality: the ability of a good/service to consistently meet or exceed customer expectations

→ North American marketplace tended to focus on quantity, cost, and productivity rather than on quality—many Japanese manufacturers that focused on quality were able to catch a significant share of the North American market because of this

quality control: monitoring, testing, and correcting quality problems after they occur

quality assurance: providing confidence that a product's quality will be good by preventing defects before they occur

total quality management (TQM): a strategic management approach to quality created in the 1980s, places greater emphasis on customer satisfaction, and involves all levels of management as well as workers in a continuing effort to increase quality

continuous improvement: never-ending improvements to key processes as part of TQM

<u>Dimensions of quality of goods</u>

→ performance – main characteristics or function of the product
→ aesthetics – appearance, feel, smell, taste
→ special features – extra characteristics or secondary functions
→ conformance – how well a product corresponds to design specifications
→ reliability – consistency of performance over time (not failing for a certain length of time)
→ durability – long life
→ perceived quality – subjective evaluation of quality (reputation, image)
→ serviceability – handling of complaints or repairs

<u>Service quality</u>

→ tangibles, convenience, reliability, responsiveness, time, assurance, courtesy, consistency

<u>Determinants of quality</u>

1. Product design
2. Process design
3. Production

conformance to design specifications: the degree to which produced goods or services conform to the specifications of the designers

<u>Benefits of quality</u>

→ improved quality of product design → better reputation → premium prices and increased market share → higher profitability
→ improved conformance to design specifications → lower manufacturing and warranty expenses → higher profitability

<u>Costs of quality</u>

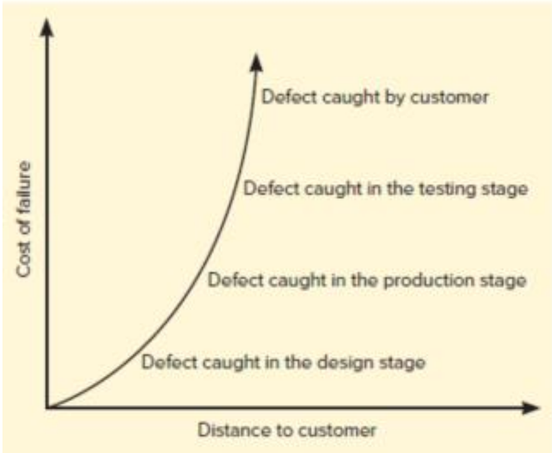
failure costs: incurred by defective parts or products

internal failures: discovered during production

external failures: discovered after delivery to the customer

appraisal (detection) costs: relate to inspection, testing, and other activities intended to uncover defective products

prevention costs: relate to attempts to prevent defects from occurring, including training, standard operating procedures, working with vendors, etc



Quality gurus

W. Edwards Deming

- → 14 points
- → management must fix system
- → reduce variation by distinguishing between special and common causes of variation
- → statistical process control (SPC), plan-do-stucy-act (PDSA)

Joseph M. Juran

- → fitness-as-use
- → trilogy: planning, control, improvement
- → continuous improvement
- → first to measure the cost of quality

Armand Feigenbaum

- → "total field", when one improvement was made in a process, other areas of the company also achieved improvements
- → quality at the source – every worker is responsible for his own work

Philip B. Crosby

- → zero defects
- → "do it right the first time"
- → quality is free – costs of poor quality are much greater than traditionally recognized

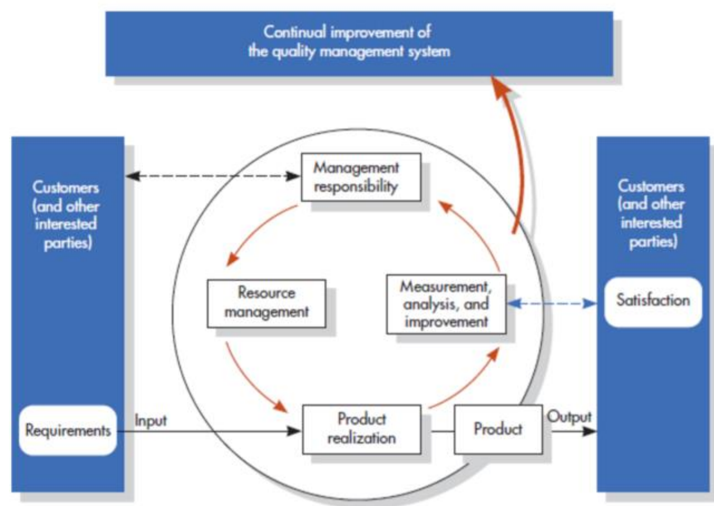
– LO2 –

International Organization for Standardization (ISO)

- → purpose is to promote worldwide standards that will improve operating efficiency and productivity, and reduce costs

ISO 9001: the international standard for a quality management system, critical to international business

- → usually 3 types of documents created: a quality manual, a procedures manual, and detailed work instructions and other supporting documents
  - → system requirements
  - → management responsibilities
  - → resource management
  - → product realization
  - → measurement, analysis, and improvement



ISO 14000: a family of standards related to environmental management, concerned with what an organization does to minimize harmful effects to the environment caused by its operations

- → management systems – system development and integration of environmental responsibilities into business planning
- → operations – consumption of natural resources and energy
- → environmental systems – measuring, assessing, and managing emissions, effluents, and other waste streams

– LO3 –

Hazard Analysis Critical Control Point (HACCP): a quality management system designed for food processors, enforced by the Canadian Food Inspection Agency (CFIA)

1. Perform hazard analysis
    - → identify potential hazards for each ingredient/processing step
    - → determine if the potential hazard is significant and provide justification
    - → provide preventative measures for significant hazards in process design
2. Determine the Critical Control Points (CCPs)
    - → for ever ingredient/processing step with one or more significant hazards, if there will not be a subsequent step that would eliminate the hazard, the this step is a CCP
    - → i.e receiving point of raw material, closing point of cans, sterilization points
3. Establish the HACCP plan
    - → for each CCP, determine a control/preventative measure, critical limits, monitoring procedure, corrective action and records, and the verification procedures

– LO4 –

Canada Awards for Excellence (CAE)

→ recognizes outstanding quality achievement by Canadian organizations
- → leadership and governance
- → planning and environmental sustainability
- → customer/citizen/client focus
- → people focus and healthy workplace
- → process management
- → supplier/partner focus

<u>Progressive Excellence Program</u>
1. Foundation
2. Transformation
3. Role model – silver certificate or bronze certificate
4. World class – gold trophy

Total quality management (TQM)

<u>3 key features</u>
1. Continuous improvement
2. Involvement of everyone
3. Ever-increasing customer satisfaction

<u>Approach</u>
1. Find out what the customer wants
2. Design a product/service that meets or exceeds customer wants
3. Design processes that facilitates doing the job right the first time
4. Keep track of results
5. Extend these concepts to suppliers

– LO4 –

<u>Basic problem solving steps</u>
1. Define the problem
2. Collect data
3. Analyze the problem
4. Generate potential solutions
5. Choose a solution and implement it
6. Monitor the solution to see if it accomplishes the goal

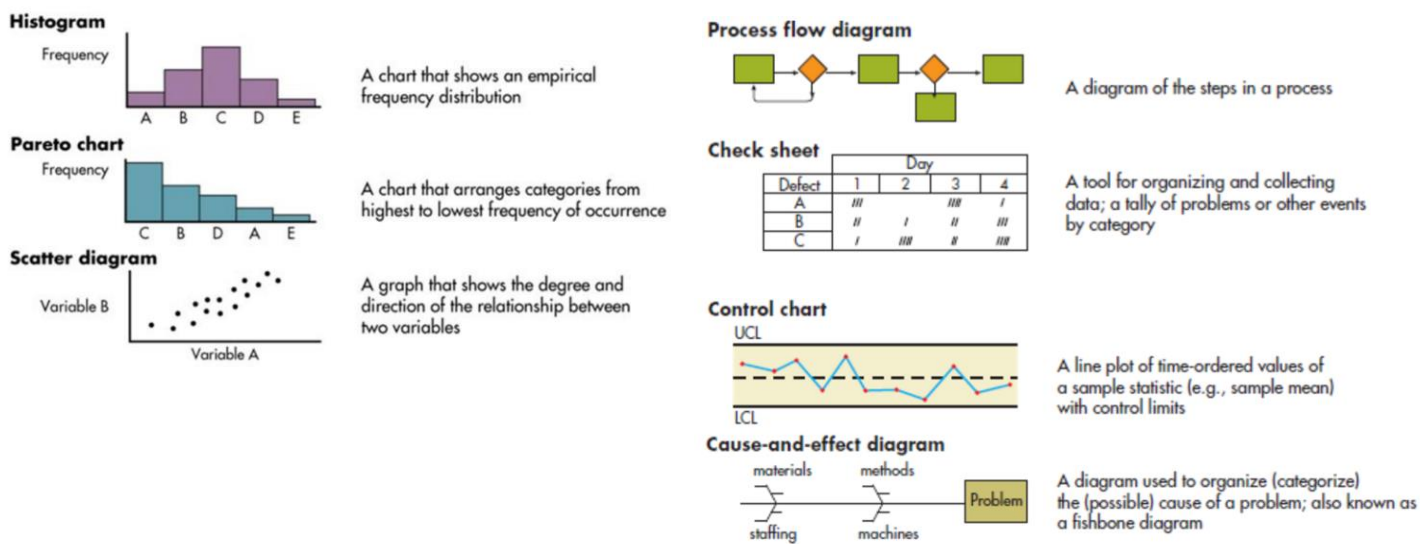
plan-do-study-act (PDSA) cycle: the problem-solving and quality improvement methodology used in continuous improvement

– LO5 –

Six Sigma

- Statistically
  - → having no more than 3.4 defects per million
- Conceptually
  - → program designed to reduce defects
  - → requires the use of certain tools and techniques
- DMAIC
  - → Define, Measure, Analyze, Improve, Control

basic quality tools



Methods for generating ideas

brainstorming: technique for generating a free flow of ideas in a group of people
quality circles: groups of workers who meet to discuss ways of improving products or processes
interviewing: technique for identifying problems and collecting information
benchmarking: process of measuring performance against the best in the same or another industry
5W2H approach: a method of asking questions about a process/problem that include who, what, where, when, why, how, and how much

Reaching consensus

1. List reduction
   - → applied to a list of possible solutions, purpose is to clarify items and in the process reduce the list by posing questions about affordability, feasibility, etc.
2. Balance sheet
   - → lists the pros and cons of each item and focuses discussion on important issues
3. Paired comparisons
   - → process by which item on a list is compared with every other item, two at a time. For each pair, team members select the preferred item. It works best when the list of items is small—i.e five or fewer

Chapter 10: Statistical Quality Control

– LO1 –

statistical quality control: use of statistical techniques and sampling in monitoring and testing quality of goods and services

> **acceptance sampling:** relies primarily on inspection of previously produced items, determines to accept or reject a produce, the least progressive
>
> **statistical process control:** determines if process is operating within acceptable limits, more progressive than acceptance sampling

inspection: the appraisal of goods/services against standards

<u>Statistical process control planning process</u>

1. Define the quality characteristics important the customers, and how each is measured
2. For each characteristic,
    a. Determine a quality control point
    b. Plan how inspection is to be done, how much to inspect, and whether centralized or on site
    c. Plan the corrective action

<u>on-site inspection</u>

- → immovable product (i.e ship)
- → simple or handheld measuring equipment
- → automated inspection

<u>in lab inspection</u>

- → specialized equipment
- → skilled quality control inspectors
- → more favourable test environment

– LO2 –

random variation: natural variation in the output of a process, created by countless minor factors

- → i.e older machines have a higher degree of random variation than newer machines, partly because of worn down parts and new machines may have design improvements that lessen the variability in their output

assignable variation: non-random variability in process output; a variation whose cause can be identified

- → i.e excessive tool wear, equipment that needs adjustment, defective materials, and human error

central limit theorem: the distribution of sample averages tends to be normal regardless of the shape of the process

control chart: a time-ordered plot of a sample statistic, with limits

- → purpose is to monitor process output to distinguish between random and assignable variation
- → upper and lower control limits define the range of acceptable variation

control limits: the dividing lines between random and assignable deviations from the mean of the distribution

Type I error: concluding that a process has shifted (i.e an assignable variation is present) when it has not (i.e only random variation is present)

Type II error: concluding that a process has not shifted when it has

	In control	Out of control
In control	No error	Type I error (producers risk)
Out of control	Type II error (consumers risk)	No error

Designing control charts:

1. Determine a sample size *n* (usually between 2 and 20). The larger *n* is, the smaller the probability of a type II error.
2. Obtain 20 to 25 samples of size *n*.
3. Establish and graph preliminary control limits
4. Plot sample statistic values on control chart
5. Are any points outside control limits?
   a. No – assume no assignable cause
   b. Yes – investigate and correct

sample mean control ($\bar{x}$) chart: the control chart for sample mean, used to monitor the process mean
The first approach to calculate the control limits is to use the standard deviation of the process.

$$\text{Upper Control Limit } (UCL_{\bar{x}}) = \bar{\bar{x}} + z\sigma_{\bar{x}}$$

$$\text{Lower Control Limit } (LCL_{\bar{x}}) = \bar{\bar{x}} - z\sigma_{\bar{x}}$$

where

$\sigma_{\bar{x}}$ = Standard deviation of the sampling distribution of the sample mean = $\sigma/\sqrt{n}$

σ = Process standard deviation

n = Sample size

z = Standard Normal deviate (usually z = 3)

$\bar{\bar{x}}$ = Average of sample means = grand mean

A second approach to is to use the sample range (maximum value – minimum value in the sample) as a measure of process variability (instead of the standard deviation).

$$UCL_{\bar{x}} = \bar{\bar{x}} + A_2\bar{R}$$

$$LCL_{\bar{x}} = \bar{\bar{x}} - A_2\bar{R}$$

where

A_2 can be obtained from Table 10-3

$\bar{R}$ = Average of sample ranges of a few samples

Example: Control chart using sample range

Twenty sample of *n* = 8 have been taken of the weight of a part. The average of sample ranges for the 20 sample is 0.016kg, and the average of sample means is 3kg. Determine three sigma control limits for sample mean of this process.

Solution:

$\bar{\bar{x}}$ = 3, $\bar{R}$ = 0.016, A_2 = 0.36 (for n = 8, from Table)

$$UCL_{\bar{x}} = \bar{\bar{x}} + A_2\bar{R} = 3 + .37(.016) = 3.006kg$$

$$LCL_{\bar{x}} = \bar{\bar{x}} - A_2\bar{R} = 3 - .37(.016) = 2.994kg$$

sample range (R) control chart: the control chart for sample range, used to monitor process dispersion or spread

$$UCL_R = D_4\bar{R}$$

$$LCL_R = D_3\bar{R}$$

where values of D_3 and D_4 are obtained from Table 10-3.

individual unit (X) control chart: control chart for individual unit, used to monitor single observations

$$UCL_x = \bar{X} + z\sigma$$

$$LCL_x = \bar{X} - z\sigma$$

$\bar{X}$ is the mean of a few individual observations (that estimates the process mean)

moving range (MR) control chart: control chart for moving range, i.e the difference between consecutive observations, used to monitor the dispersion or spread when n = 1

$$UCL_{MR} = 3.27\bar{R}$$

$$LCL_{MR} = 0\bar{R} = 0$$

where $\bar{R}$ is the average of the moving ranges (the absolute value of the difference between two consecutive observations)

Example: Control chart using moving range control chart

a. Determine the Three Sigma control limits for the *X*-chart and the moving range control chart. Is the process in control?
b. If the 11th observation is 38.7, using the control charts in part a, is the process still in control?

Sample Number	Hardness
1	36.3
2	28.6
3	32.5
4	38.7
5	35.4
6	27.3
7	37.2
8	36.4
9	38.3
10	30.5

Solution:

a. We have to compute the average and standard deviation of the individual observations (estimate of process standard deviation). Also, we need to calculate the difference of consecutive observations (absolute value) to obtain the moving ranges, and then average these to get $\overline{R}$. These are displayed below:

Sample Number	Hardness	Moving Range
1	36.3	—
2	28.6	7.7
3	32.5	3.9
4	38.7	6.2
5	35.4	3.3
6	27.3	8.1
7	37.2	9.9
8	36.4	0.8
9	38.3	1.9
10	30.5	7.8
Average =	34.12	5.51
Std dev =	4.11	

The control limits for *X*-chart are:

$$UCL_x = \overline{X} + z\sigma = 34.12 + 3(4.11) = 46.45$$

$$LCL_x = \overline{X} - z\sigma = 34.12 - 3(4.11) = 21.79$$

The control limits for moving range control chart are:

$$UCL_{MR} = 3.27(5.51) = 18.02$$

$$LCL_{MR} = 0$$

All 10 hardness values fall within the *X*-chart control limits and all nine moving range values fall within the moving range control limits. Therefore, the process in in control.

b. 21.79 < 38.7 < 46.45, therefore the 11th observation is within its control limits. The new moving range is 38.7 – 30.5 = 8.2. Because 0 < 8.2 < 18.02, the new moving range is also within its control limits. Therefore, the process is still in control.

p-chart: used when observations can be placed into one of *two* categories, similar to binomial

→ examples include items that can be classified as good or bad, pass or fail, operate or don't operate
→ Use when the data consists of multiple samples of *n* observations each (i.e 15 samples of *n* = 20 observations each)

$$\sigma_p = \sqrt{\frac{p(1-p)}{n}}$$

$$UCL_p = p + z\sigma_p$$

$$LCL_p = p - z\sigma_p$$

p is unknown, use

$$\overline{p} = \frac{\text{Total number of defectives}}{\text{Total number of observations}}$$

c-chart: used to monitor the number of defects per unit product, similar to Poisson distribution

→ only number of occurrences *per unit,* non-occurrences cannot be counted
→ i.e scratches per item, bacteria per unit of volume, calls per unit of time

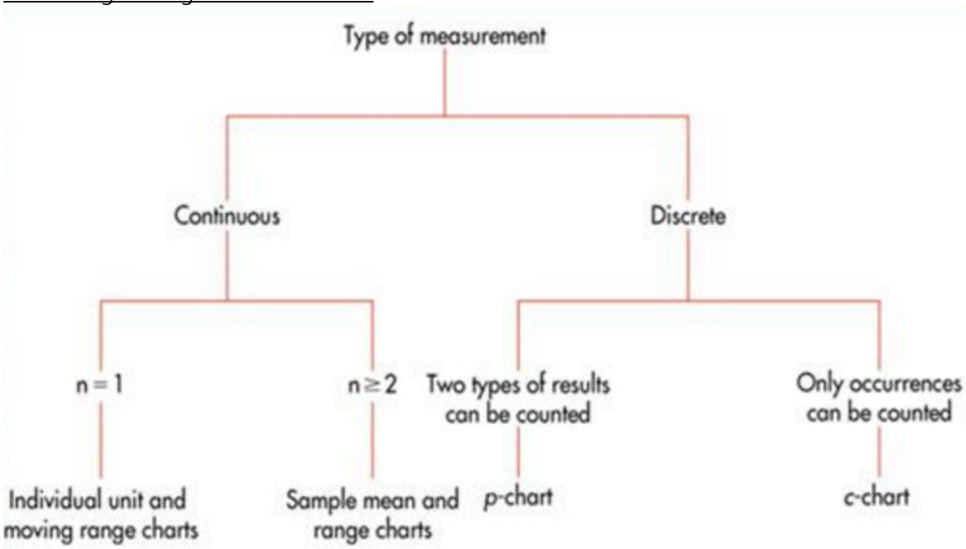
standard deviation is $\sqrt{c}$.

$$UCL_c = c + z\sqrt{c}$$

$$LCL_c = c - z\sqrt{c}$$

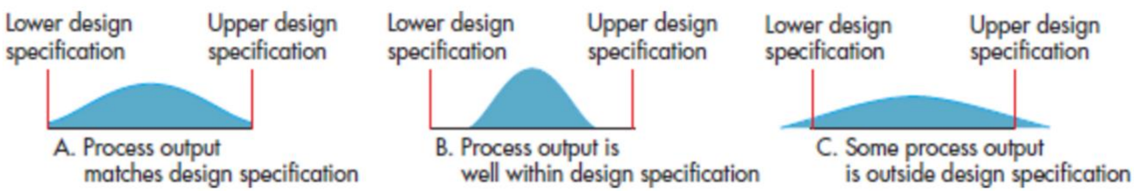
$\overline{c}$ = total number of defects ÷ total number of samples

<u>Choosing the right control chart</u>



– LO3 –

design specification: a range of acceptable values established by engineering design or customer requirements
process variability: actual variability process for a product
process capability: the ability of a process to meet the design specification



process capability ratio C_p

$$\text{Process capability ratio, } C_p = \frac{\text{Design specification width}}{\text{Process width}} = \frac{\text{Upper design specification} - \text{Lower design specification}}{6\sigma}$$

used to express the capability of a machine or process

ratio must be at least 1.00 to be capable

C_{pk}

→ used if a process is not centered between design specification limits, or if there is no design specification limit on one side
→ C_{pk} is the *smaller* between the two:

$$\frac{\text{Upper design specification} - \text{Process mean}}{3\sigma} \quad \text{or} \quad \frac{\text{Process mean} - \text{Lower design specification}}{3\sigma}$$

Example: Using C_{pk} and C_p

A process's output has a mean of 9.20 kg and a standard deviation of 0.30 kg. The lower design specification is 8.00 kg and the upper design specification is 10.00 kg. Calculate the C_{pk}.

Solution:

1. Calculate the ratio for the lower design specification:

$$\frac{\text{Process mean} - \text{Lower design specification}}{3\sigma} = \frac{9.20 - 8.00}{3(.30)} = \frac{1.20}{.90} = 1.33$$

2. Calculate the ratio for the upper design specification:

$$\frac{\text{Upper design specification} - \text{Process mean}}{3\sigma} = \frac{10.00 - 9.20}{3(.30)} = \frac{.80}{.90} = .89$$

The smaller of the two ratios is .89, so this is the C_{pk}. Because the C_{pk} is less than 1.00, the process is *not* capable. Note that if C_p had been used, it would have given the false impression that the process was capable:

$$C_p = \frac{\text{Upper design Specification} - \text{Lower design specification}}{6\sigma} = \frac{10.00 - 8.00}{6(.30)} = \frac{2.00}{1.80} = 1.11 > 1.00$$

– LO4 –

Six Sigma quality: a more advanced version of problem solving/continuous improvement, also refers to the goal of achieving process variability so small that the half-width of design specification equals six standard deviations of the process

Define	Determine the customers and critical-to-quality procedures
Measure	Identify and measure the quality problem, determine the baseline Sigi identify possible influencing factors
Analyze	Test the influencing factors and identify the vital few
Improve	Select the solution method, prove its effectiveness, and implement it
Control	Develop a process control plan

Improving process capability

1. Simplify
2. Standardize
3. Mistake-proof
4. Upgrade equipment
5. Automate

design of experiments: performing experiments by changing levels of factors to measure their influence on output and identifying best levels for each factor

- → Taguchi suggested a more concise set of experiments by changing the level of more than one factor at a time
    - → identify controllable factors that could influence variation
    - → set each factor to 2 or more levels
    - → measure the variation in the process