CH. 17: PROJECT MGMT

Project: Unique, large, 1-time job requiring special activities to accomplish goal in ltd time frame
- Authorized, objectives/scope established, proj. mgr appointed, planned, est. resources, prepare budget
Program: Set of projects
Performance Goals: Achieved through projects – time / schedule, cost/budget, qual guidelines
Phases (life cycle): **1.** Project initiation (concept, feasibility, study/selection) **2.** Planning/scheduling **3.** Execution (purchase materials, perform tasks) **4.** Control (observe progress, changes) **5.** Closeout
Project Scope: Work accomplished to deliver g/s
Project Portfolio Selection: Which project to implement (budget, knowledge avail, financial benefit)
1. Establish project council (execs) **2.** Identify project categories (LT/ST, minor/major) and criteria (value, satisfaction, effectiveness) **3.** Collect project data **4.** Assess resources **5.** Prioritize projects within categ. **6.** Select project to fund **7.** Communicate results
- Determines how project is undertaken w/ **work breakdown structure**, resources needed, est. cost, scheduling, risk mgmt
Matrix Org: Temp group specialists from diff dept's
Project Mgr: Plans, schedules, execute, control project to meet reqt's within time, budget and standard
- Manages work, HR, comm., qual assurance, time, cost
- Strong leadership under high uncertainty

PROJECT PLANNING
Project Planning: Break down to activities, estimate resources, duration, scheduling

Risk Mgmt. Planning
- Delays, increased cost, failure to meet quality/perf
- Prob. of risk higher @ beg. of project, lower@ end
1. Identify potential risks early (brainstorming, ask Q's) **2.** Analyze (for prob. and consequences) **3.** Plan response to avoid/transfer/mitigate

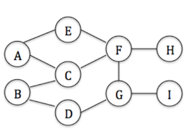
Work Breakdown Structure
WBS: Hierarchical listing of tasks in project
1. Identify major components **2.** Subcomponents **3.** Use sub-comp. for work packages **4.** List of activities

PROJECT SCHEDULING
1. Determine timing of activities **2.** Identify sequential dependencies **3.** Identify resources needed **4.** Estimate duration of activity (based on resource avail.)
5. Schedule developed by PERT/COM (1 pt estimate = deterministic, 3-pt = probabilistic)
Gantt Chart: Used to schedule/control simple projects
PERT: Program evaluation and review technique
CPM: Critical path method
- PERT/CPM used for large scale projects
- Visual of sequential relationship, estimate of time, indication of most critical/timely projects, leeway time to delay without holding up entire project

Precedence Network
PN: Activities in sequential relation. w/ nodes/arrows
- Either **activity-on-arrow** or **activity-on-node** (inc. "s")
- Finish-start relationship (before decessor begins)
Critical Path: Longest path, sum of duration = **length of path**
Path Slack Time: Allowable slippage (t of path – CP)

DETERMINISTIC ACTIVITY DURATIONS
- Activity duration determine based on:
Deterministic: Fairly certain duration
Probabilistic: Durations w/ variation
- Critical path has activities w/ 0 slack
- If 2 activities are on same path and have same slack, it is the total slack available to both – shared slack
- Allows estimate of prob. completed on time

Critical Paths Example (ES, EF, LS, LF):



Path	Compl. Time
AEFH	57
AEFGI	59*
ACFH	53
ACFGI	55
BCFH	55
BCFGI	57
BDGI	44

	Pred	Time	ES	EF (ES+t)	LS (ES+S)	LF (S+EF)	Slack
A	-	10	0	10	0	10	0
B	-	12	0	12	2	14	2
C	A, B	18	12	30	14	32	2
D	B	20	12	32	27	47	15
E	A	22	10	32	10	32	0
F	E, C	15	32	47	32	47	0
G	D, F	5	47	52	47	52	0
H	F	10	47	57	49	59	2
I	G	7	52	59	52	59	0

Slack = Longest path containing activity – length of CP is 0 for any critical activity
= LS – ES or LF – EF
ES = Time of longest predecessor. Take latest time ES of F is 32 (22+10))
EF = ES + t
LS = ES + Slack or (LF – t)
LF = Slack + EF or smallest LS

PROJECT CRASHING
Crash: Reduce length of project using added resources
- Time/cost tradeoff to determine cost reducing activities
- Only crash activities on CP 1 day at a time
- Crash activities w/ lowest crash cost first
- Look for activities that appear on more than 1 path
- Continue crashing until benefit > cost

Crashing Example:

Activity	Pred	Regular Time	Crash Time	Regular Cost	Crash Cost	Max Possible Crashing	Crash Cost Per Day
A	-	10	8	40	50	2	5
B	-	7	5	20	40	2	10
C	B	5	4	98	100	1	2
D	A,C	8	5	29	50	3	7
E	B	12	10	8	20	2	6
Total Normal Cost				195			

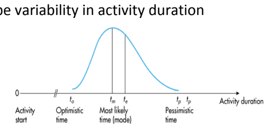
Crash Cost Per Day = $\frac{\text{Crash Cost – Regular Cost}}{\text{Regular Time – Crash Time}}$
Max Possible Crash = Regular Time – Crash Time

Paths	Path Length at Step 0	Step 1 Crash C	Ste Crash B	Step 3 Crash (D,E)	Step 4 Crash (D,E)	Step 5 Crash (A,B)
A-D	18	18	18	17	16	15
B-C-D	20	19	18	17	16	15
B-E	19	19	18	17	16	15

If multiple critical paths exist (2,3), group options so crashing an activity will affect all paths listed:
1. Crash from 20 to 19 (B-C-D)
Options B($10), C($**2**), D($7) – crash C, C @ max
2. Crash from 19 to 18 (B-C-D or B-E)
Options B($**10**), D,E ($7+6=13) – crash B
3. Crash from 18-17 (A-D, B-C-D, or B-E) – crash D,E
Options: A,B ($15), D,E ($**13**), or D,B ($17) – crash D,E
4. Crash D,E – E @ max
5. Crash A,B – B @ max

Activity	Crash	Cost
1	C	2
2	B	10
3	D, E	13
4	D, E	13
5	A, B	15
Total Crashing Cost		53
Total Normal Cost		195
Total Project Cost After Crashing (TC + TM)		248

PROBABILISTIC ACTIVITY DURATION
3-pt Estimates: Optimistic (t under best conditions, t_o), Pessimistic (t under worst conditions, t_p), Most Likely (most probable (t_m)
Beta Distribution: Continuous +'ve dist. used to describe variability in activity duration



Expected Duration: $t_e = \frac{t_o + 4t_m + t_p}{6}$

Path Mean: $\Sigma (t_e)$

SD: $\sigma^2 = \left[\frac{(t_p - t_o)}{6}\right]^2$ or $\sigma_{path} = \sqrt{\sum(\text{Variances of activities on path})}$

Prob. Activity Example:

Activity	Pred	Time Estimates t_o	t_m	t_p	Exp. Time t_e	Activity Variance σ^2
START	-		0			
A	ST	2	3	10	4	1.778
B	ST	2	5	8	5	1
C	ST	1	4	10	4.5	2.5
D	A	3	3	15	5	4
E	B	4	8	18	9	5.44
F	D,E	3	5	10	5.5	1.361
G	C,E	3	6	18	7.5	6.25
END	F,G					

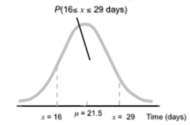
Path	Path Length	Path Slack
A-D-F-END	4+5+5.5 = 14.5	21.5-14.5 = 7
B-E-F-END	5+9+5.5 = 19.5	21.5-19.5 = 2
B-E-G-END (Crit. P)	5+9+7.5= 21.5	21.5-21.5 =0
C-G-END	4.5+5.5 =10	21.5 – 10 = 11.5

Project Completion:
= Length of Longest Path = t_e = 21.5
Variance on Critical Path:
= Sum of Variances (σ^2)
(of activities on a Critical Path (B, E, and G))
= 1+5.44+6.25 = 12.69 (σ = 3.56)

Path Probability
$z = \frac{t - t_e}{\sigma_{path}}$
- How many SDs specified time is beyond expected (-'ve = early completion)
- Includes prob of *all* paths including CP
- Multiply prob of each completion for total value (assuming ind. path durations/activities on 1 path)

PERT Example (Con't from Previous):

What is the prob. that the project completion time is between 16 and 29 days?



$Z1 = \frac{X1 - \mu}{\sigma} = \frac{16 - 21.5}{3.56} = -1.54$

$Z2 = \quad = \frac{29 - 21.5}{3.56} = 2.11$

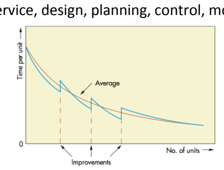
Thus $P(16 \le X \le 29)$
$= P(-1.54 \le Z \le 2.11)$
$= 0.9824 - 0.0612 = 0.921$

PROJECT EXECUTION & CONTROL
PE: Performance of activities as planned
Critical Chain: Students syndrome (delay start of assignment until last possible time) & Parkinson's law (work expands to fill time available to completion)
- Safety/buffer time added at end of critical chain and at end of feeder chains
Project Control: Assessing progress vs. plans for corrective action to bring on track
Scope Creep: Uncontrolled changes to project scope
Earned Value Analysis: Progress measured by budgeted cost of work performed (EV)
Scheduled Time Overrun (Variance) = PV – EV
- PV – Budgeted cost of work scheduled

CH. 7S: LEARNING CURVES

Learning Curve: Time to perform dec. w/ inc. in repetition (subject to complexity of task)
- Quantifies expected future improvements
- LC's differ b/w orgs, where all projections are appx.
- Do not apply to mass production

Improvement Curve
- Time per unit dec. as # units inc.
- Rate of dec. in unit time is constant, # units prod. doubles (80% L/C & 20% dec in unit t when units x2)
- Factors – dexterity, reduced work, tooling, equip, training, effort, prod. design, method change, layout, support service, design, planning, control, motivation



Unit times
1. $t_n = t_1 X n^b$ $b = \frac{\ln ®}{\ln(2)}$ (r = learning rate)
2. $r = 2^b$ (Learning % = 100 x 2^b)
3. $t_n = t_1$ x unit time factor
4. $\Sigma t_n = t_1$ x total time factor (from chart)

For a given Learning Rate:
t for 2^{nd} unit = Learning Rate x t 1^{st} unit
t for 4^{th} unit = learning rate x t for 2^{nd} unit
t for 8^{th} unit = Learning rate x t for the 4^{th} unit

Application of L/C
- Labour planning/scheduling, negotiated selling/purchasing, assessing labour training needs/perf
- Compare expected learning rate to results

Min Number of Repetitions to Achieve Standard
ln (T_n) = ln (T_1) + b ln (n)
n = e ^ [ln(T_n) – ln(T_1)]/b

Calculating LR w/ Regression
Ln (t_n) = Ln (a) +b Ln(n) where:
Intercept = Ln(a) → $t_1 = e^{Ln(a)}$ or $e^{(\text{intercept if given})}$
Slope = b → r = 2^b

Disadvantages of Learning Curves
- Learning % changes b/w orgs and type of work
- Projections of L/C are pprox.. of actual time
- Be sure to validate estimate for first unit – can be subject to time compression, design changes, equip
- L/C n/a to mass production (short cycle time)
- Carryover effects from experience: $T_n = T_1 X (n + n_p)^b$

Learning Curve Examples:
Finding time:

Time for 5^{th} unit = 28 min. Learning rate = 90%		
Time of 1^{st} unit	**Time of 25^{th} unit**	**Time of 10^{th} unit**
1. $b = \frac{\ln(0.9)}{\ln(2)} = -0.152$ 2. $28 = t_1 (5)^{-0.152}$ $t_1 = 35.76$	$\frac{t_{25}}{t_5} = \frac{t_5}{t_1}$ $\frac{t_{25}}{28} = \frac{28}{35.92}$ $t_{25} = 21.92$	$t_{2n} = t_n$ x r $t_{10} = t_5$ x r t_{10} = 29 x 0.9 = 25.98

Finding the Learning Rate:

Time for 1^{st} unit = 25 min. Time for 10^{th} = 15 min.	
Find R	**Time of 90^{th} Unit**
$15 = 25 (10)^b$ $0.6 = 10^b$ $\frac{\ln(0.6)}{\ln(10)} = -0.2218$	1. $t_{90} = 25 (5)^{-0.2218}$ $t_{90} = 9.21$ $r = 2^b$ 2. $= 2^{-0.2218}$ = 0.8575

Finding R using $r = 2^b$:

Find 4 if t_1 = 50 and t_8 = 25	
t_1	= 40
t_2	= r (40)
t_4	= (r)(r)(40)
t_8	= (r)(r)(r)(40) 25 = r^3 (40) r = 0.85

Estimating R:

Cake No	Time (min)	Rate
1	20	
2	15	15/20 = 0.750
3	15	
4	13	13/15 = 0.867
5	12	
6	11	11/15 = 0.733
7	10	
8	10	10/13 = 0.769
Average / Learning Rate Est.		0.780

CH. 8: LOCATION PLANNING

- Adding new location due to growth in demand, depletion, economies of scale
1. LT commitment **2.** Impact investment reqt's, op. cost, revenue **3.** Bad choice = labour/supply shortages
Steps: **1.** Identify search parameters/factors (raw mater) **2.** Gather info on sites **3.** Narrow 3-4 sites **4.** Eval/select

FACTORS AFFECTING LOCATION DEC'N

Manufacturing Location Decn's
1. Location of raw materials
- Necessity (mining, fishing, forestry)
- Perishability (food canning/freezing)
- Transportation costs (bulk processing)
2. Location of Markets
- Common for retailers/services for convenience
3. Labour
- Avail of workers, wage rate, productivity, unions
4. Utilities, taxes, real estate cost
5. Foreign Locations
- Exploit nat. resource, cheap labour, gov't corrupt
6. Labour climate 7. Supplier/parent proximity

Community/Site-related Factors
1. Proximity to customers 2. Trans. 3. Markets 4. Close to competitors 5. Site specifics (for mark.shr, profit)

CALCULATING LOCATIONS

Weighted Scores Method
1. Identify factors effecting location
2. Rate imp of factors (high imp. = high weight, total = 1)
3. Identify potential locations
4. Score locations by factor (highest score = preference, total factors = 100)
5. Calc weight 6. Add weights 7. Select highest total weight factor

Factors	Weight	Kitchener Score	Kitchener W/S	Toronto Score	Toronto W/S	Ottawa Score	Ottawa W/S
Population	0.2	10	2	50	10	40	8
Suppliers	0.25	15	3.75	60	15	25	6.25
Demographics	0.15	10	1.5	50	7.5	40	6
Infrastructure	0.15	50	7.5	30	4.5	20	3
Real Estate	0.1	40	4	20	2	40	4
Climate	0.1	30	3	30	3	40	4
Transportation	0.05	20	1	50	2.5	30	1.5
			22.75		44.5		32.75

- Scoring based on qual/quant

Centre of Gravity Method
- Determines location of distr. that min distr. cost
1. Identify potential market area
2. Plot locations on map (x/y axis)
3. Estimate customers (load)
4. Calc load-weight on each axis for market
WL_x = load x value of x-axis
5. Calc total load
6. Calc centre of gravity

x = $\frac{\text{Total Weighted Load on X}}{\text{Total Load}}$

Locations	X	Y	Load	Weighted Load X	Weighted Load Y
Etobicoke	1	4	6,000	6000	24000
Waterloo	4	5	4,000	16000	20000
Burlington	6	2	1,000	6000	2000
			11,000	28000	46000
Centre of Gravity				2.55	4.18

Centre of Gravity: (X,Y) = (2.55, 4.8)
- Choose physical location closest to CG

Purpose:
- Min travel time/distance of all cx in location
- Implicitly assumes cx have same travel time/distance

B/E Analysis
- Lowest fixed/variable cost location choice based on quantity to produce

Site	Fixed Cost (F)	Variable Cost (v)	Best at interval	Break- Even Equation	Break-Even Quantity
Cambridge	3500	2.5	0 to Q1	3500 +2.5Q1 =5000 + Q1	Q1 = 1000
Waterloo	5000	1.0	Q1 to Q2	5000 +Q2 =7000 + 0.5Q2	Q2 = 4000
Milton	5500	1.2	Dominated by Waterloo*		
Guelph	7000	0.5	Over Q2		4000

Location Analysis
Geographic Info System (GIS): Collecting, storing, retrieving location-dept demog. Data on maps

Sources	Destinations: Warehouse 1	Warehouse 2	Warehouse 3	Dummy	Capacity
Phoenix	5 200	6	5.4 200	0	400
Atlanta	7	4.6 400	6.6 100	0	500
Dummy	0	0	0	0	0
					900
Requirements	200	400	300	0	900
Costs	$1,000	$1,840	$1,740	$0	
Total Cost					$4,580

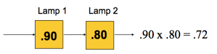
CH. 4S: RELIABILITY

Reliability: Ability of product, part or system to perform intended function under set of conditions

R AT AN INSTANT IN TIME
(2+ Independent Systems):

$R = R_1 \times R_2 \times R_3 .. R_N$

- R of system is < R of the least reliable machine in series



Independent Events Example:

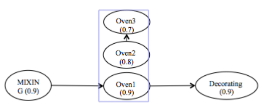
Stage	Mixing	Baking	Decorating	
No. of Trials	1000	900	810	
Reliability	0.9	0.9	0.9	
Successes	900	810	729	729
Failures	100	90	81	271
Reliability = **0.9x0.9x0.9** = 0.729 OR Successes/Trials = 729/1000 OR 1 – Failures/Trials = 1 – 271/1000 = 0.729				

Parallel System/Backup:

$R = 1 - (1-R_1)(1-R_2)(1-R_3)$

- R of system (w/ backup) is > R of most reliable machine

Example 1:



System Reliability = 0.9 x [1-(1-0.9) (1-0.8) (1-0.7)] x 0.7
= 0.9 x 0.994 x 0.7
= 0.80514
(where R of the oven system is 0.994)

Example 2. Backup with Cost:
System has R = 0.98, where failure costs $20,000. Should a backup with R = 0.98 be added if it costs $100?

System with no backup		
	Does NOT Fail	If it Fails
Prob	R = 0.98	1 - R = 1 - 0.98 = 0.02
Cost	0	$20,000
Expected Failure Cost	**(0) x R + 20,000 x (1 – R) = 0 (0.98) + 20000(1-0.98) = $400**	

System with backup		
	Does NOT Fail	If it Fails
Prob	R = 0.9996	1 – R = 1 - 0.9996 = 0.0004
Cost	0	$20,000
Expected Failure Cost	**(0) x R+ 20,000 x (1 – R) = 0 (0.9996) + 20,000(1-0.9996) = $8**	
Total Cost for System with backup = Initial Cost of backup system + expected Failure Cost = 100 + 8 = 108 → better with backup		

R OVER SPECIFIC LENGTH OF TIME:

Failure Rate/h = # failures / Total operating hours

Availability:
Availability = MTTF / (MTTF + MTTR) *make sure units are same (min/hr)*

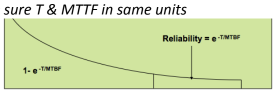
MTTF (Mean Time To Failure) = 1 / Failure Rate
MTTR (Mean Time To Repair)

Example:
Choice to a) Inc. MTTF by 5% for $450 or b) Reduce MTTR by 10% for $200. MTTF = 100 h, MTR = 4 h

Option 1: Increase MTTF by 5% from 100 to 105
Availability = 105/(105+4) = 0.963
Cost: 450

Option 2: Reduce MTTR by 10% from 4hrs to 3.6
Availability: 100/(100+3.6) = 0.968
Cost: 200

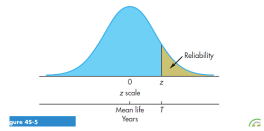
R w/ Exponential Distribution:
R = P (NO Failure before T) = $e^{-T/MTTF}$
P (Failure before T) = $1 - e^{-T/MTTF}$
- MTTF is exponentially distributed
- *Make sure T & MTTF in same units*



Example: Mean = 4 yrs
a) P (no failure in T=4 yrs) = $e^{-T/MTTF} = e^{-4/4}$ = 0.3679
b) P (fails in T =4 yrs)
= 1 – P (no failure in T = 4 yrs) = $1-e^{-T/MTTF}$
= $1-e^{-4/4}$ = 0.6321
c) P (no failure in T = 6 yrs) = $e^{-T/MTTF} = e^{-6/4}$ = 0.2231
d) P (no failure in T = 6 yrs) = $1 - e^{-T/MTTF}$ = 1 – 0.2231
= 0.7769
e) P (failure in 4 to 6 yrs)
= P (fails in 6 yrs) – P (fails in 4 yrs)
= 0.7769-0.6321 = 0.1448
f) P (fails in 6 yrs given it has already lasted 4 yrs)
= P (fails in 2 yrs from the 4^{th} yr after lasting 4 yrs)
= P (fails in T = 2 yrs)
= $1 - e^{-T/MTTF} = 1-e^{-2/4}$ = 0.3935

R w/ Normal Distribution:

Z = (T – mean of wear-out time) / (Stand. Dev. Of Wear-out Time) = $\frac{x - \mu}{\sigma}$



Example: Mean = 6 yrs, SD = 2 yrs

a) P (t < 7.5)
= P (Z < (7.5-6)/2) = P (Z <0.75)
= 0.5 + 0.2734 = 0.7734
b) P of wearing out after 7.5 yrs
= 1 – P (t < 7.5) = 1- 0.7734 = 0.2266
c) P of wearing out b/w 4 and 7 yrs
= P (t < 7) – P (t < 4)
= P (Z < (7 – 6)/2) – P (Z < (4-6)/2)
= (0.5 + 0.1915) - [1- (0.5+0.3413)]
= 0.6915 - 0.1587
= 0.5328
d) P (t < 4.5)
= P (Z < (4.5-6)/2) = P (Z < -0.75)
= Prob (Z > 0.75) = 1 – Prob (Z< .75)
= 1 – (0.5+0.2734) = 0.2266
e) Service life w/ wear-out P of 20%.
= z score of 0.2 = - z score (1 – 0.2)
= 0.5 + x = 0.8 = - 0.85
z = -0.85 = (t-6)/2 → t = 4.3

CHAPTER 10S: ACCEPTANCE SAMPLING

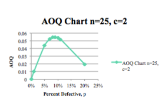
c = max defect # p = defect rate
P_a = prob of accepting lot (use binomial chart)
- Find the Pa lot for different values of incoming lot defect rate P

Average Outgoing Quality (AOQ): Defect rate of lot post acceptance sampling process
- If p = 0, Pa = 1 (perfect lot) ; if p = 1, Pa = 0 (bad lot)

Avg Outgoing Qual Limit: Worst AOQ level for a given acceptance plan (n, c)
- If incoming lot perfect, P = 0 & if income lot bad, P = 1
- Using n, c, p → use binomial table
- If incoming lot has low defect rate, plan is accepting more than it rejects

Acceptance Plan: n= 25, c=2

Incoming Lot Defective p	P_a	AOQ = pP_a
0%	1.00	0.00
1%	0.9980	.00998
5%	0.8729	.04364
7%	0.7466	.05226
8%	0.6768	.05415
9%	0.6063	.05457
10%	0.5371	.05371
11%	0.4709	.05180
20%	0.0982	0.01965
90%	0.0	0



For the Acceptance Sampling Plan
n=25; c=2

AOQL = 5.457%
This is achieved when the defect rate of incoming lot is 9%

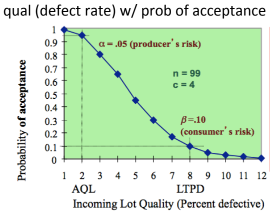
Acceptable Quality Level (AQL): Max acceptable % of defects defined by producer
- 95% CI accepted lot has qual > AQL

Example of Producer Risk:
- If defective rate of income lot p = 0.02 (2%) & prob. of **accepting** lot using sampling plan is 95%:
1) AQL = 2% prob of rejecting a good lot
2) a = 5% : **producer's risk** (Type 1 E), the producer is REJECTING an othewise good lot due to lack of info

Lot Tolerance Percent Defective (LTPD): Qual level consumer will reject % of the time (e.g. 90%)
- 90% confidence qual of rejected lot is < LTPD
- % of defects (consumer's rejection point)

Example of Consumer Risk:
- If defective rate of incoming lot p = 0.08 (8%) & the prob of **rejecting** lot using sampling plan is 90%:
1) LTPD = 8% : prob of accepting bad lot
2) B = 10% : **consumer's risk** (Type 2 E), manu is ACCEPTING an otherwise bad lot

Operating Characterisitics Curve: Relates incoming lot qual (defect rate) w/ prob of acceptance



OC Curve is unique for an Acceptance Plan
AQL, 1-α
and
LTPD, β
are two points on the OC curve

- Smaller AQL = smaller defect rate
- Higher LTPD = smaller defect rate/better for cx

Example 1:
Example: Double Sampling Plan

Sample 1, sample size = n_1	Sample 2, sample size = n_2
First Acceptance No = c_1	Second Acceptance No = c_2
First Rejection No = r_1	Second Rejection No = $r_2 = c_2+1$

Double Sampling Process

Take Sample 1. Let d_1 = no of defects in Sample 1
If $d_1 <= c_1$ Accept Lot
If $d_1 >= r_1$ Reject Lot
If $c_1 < d_1 < r_1$ Take a second sample, Sample 2
Let d_2 = no. of defects in the second sample, Sample 2
If $d_1 + d_2 <= c_2$ Accept Lot
If $d_1 + d_2 >= r_2$ (that is, $d_1 + d_2 > c_2$) Reject Lot

Example 2:

Supplier	Selling P	D/R (P)	Sampling Plan	Pa	AOQ = pPa
A	$51	5%	n=20, c=1	0.736	0.036
B	$53	0%	N=15, c=2	1.0	0.0

1) Find the effective selling prices per unit (given defectives are discarded)
ESP = Actual Selling Price / % Of good items (1-AOQ)
Supplier A: = 51/(1-0.036)
= $52.95
Supplier B: = 53
2) Thus, cheaper to purchase from A and discard 3.6% vs. pay B

Example 3:
NDP ships to FCF
- NDB ACCEPTABLE qual = 1.5% defective rate → P for producer's risk, alpha
- FGF wants 1% prob. of REJECTING
- Will REJECT lot with 8% → P for consumer's risk, beta

Risk	n=20, c=2 Pa (use chart)	n=30, c=2 Pa (use chart)	Party effected
Producer's Risk a P = 1.5% (P of rejecting lot w/ defects < 1.5%?)	= 1 – Pa = 1 – 0.9868 = 0.0032	= 1 – Pa = 1 – 0.9258 = 0.0742	NDP
Consumer's Risk B P = 8% (P of accepting lot w/ defects > 8%?)	= Pa = 0.7879	= Pa = 0.5654	FGF

- Both plans satisfy FGF's 1% objective (0.32% & 0.7% < 1%)
- Plan 1 rejection rate of lot w/ 8% defects = 21.21% (1-Pa = 1-0.7879)
- Plan 2 rejection rate of lot w/ 8% defects = 43.46% (1-0.5654)
- Rejection rate of bad lots has increased in plan 2 → should change to plan 2

CHAPTER 10: STATISTICAL PROCESS CONTROL

CONTROL CHARTS:

Variable Control Charts: (weight, length, volume)
- Calc UCL & LCL, plot grand mean and individual means OR plot mean range and individual ranges

1) X-bar Chart: Monitor shifts in process mean (large n

$UCL_{\bar{x}} = \bar{\bar{X}} + z\sigma_{\bar{x}}$ $LCL_{\bar{x}} = \bar{\bar{X}} - z\sigma_{\bar{x}}$ $O_X = O/\sqrt{n}$

Example with Large Data:

Sample	Obs1	Obs2	Obs3	Obs4	Obs5	Mean $\bar{X}$	Range R
1	0.995	0.996	1.004	1.015	0.998	1.001	0.020
2	1.005	1.011	0.987	1.001	1.004	1.002	0.024
3	1.004	0.993	1.019	1.004	0.999	1.004	0.025
15	0.983	0.995	0.991	1.010	0.999	0.996	0.027
						$\bar{\bar{X}}$	$\bar{R}$
					Mean	1.000	0.021
	σ		0.008		$\sigma_{\bar{x}}$	0.0037	

$\bar{X} - Chart$
$UCL_{\bar{X}} = 1.0 + 3(0.0037) = 1.011$
$LCL_{\bar{X}} = 1.0 - 3(0.0037) = 0.989$

- If SD is not known and n is small use X-bar Chart
- A_2 is from given table, R-bar = avg of sample bars
- Always use **N value of OBSERVATIONS** within the sample size (chart will be for stated sample size of n)

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

A_2 = from table; Rbar = avg of sample ranges (max-min)

Example Cont'd from Above: (A is from chart)
$\bar{X} - Chart$
$UCL_{\bar{X}} = 1.0 + 0.58(0.021) = 1.012$
$LCL_{\bar{X}} = 1.0 - 0.58(0.021) = 0.988$

2) R-Range Chart: Monitor process variability (sample range control chart) and shifts / increases in variability
- When using R chart use **N (# of occurrences)**

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

Process/Attribute Control Charts
If type of measurement is discrete (not continuous)

1) C-Chart: # of defects per unit
- single obsv. n =1, **# occurrences an be counted**
(X ± z σ) (c: # defects)

$UCL_c = \bar{c} + 3\sqrt{\bar{c}}$
$LCL_c = \bar{c} - 3\sqrt{\bar{c}}$

2) P-Chart: Proportion of defects in process **(%)**
- 2 types of results possible (pass/fail, good/bad)
- p = proportion of defects
- Data has multiple samples of several observations ea.
- Calc UCL & LCL, plot p-bar and individual p values

$\sigma_p = \sqrt{\frac{\bar{p}(1-\bar{p})}{n}}$ $UCL_p = \bar{p} + z\sigma_{\bar{p}}$ $LCL_p = \bar{p} - z\sigma_{\bar{p}}$

- n = number of observations in each sample (NOT number of samples)

Example 1: P-Chart

Sample	n	Defectives	Proportion
1	100	4	0.04
2	100	2	0.02
15	100	3	0.03
			p
Total	1500	55	0.550
		p-bar	0.037

$\sigma_p = \sqrt{\bar{p}(1-\bar{p})/n}$
$\sigma_p = \sqrt{0.037(1-0.037)/100} = 0.019$

$p - Chart$
$UCL_p = \bar{p} + 3\sigma_p = 0.037 + 3(0.019) = 0.094$
$LCL_p = \bar{p} - 3\sigma_p = 0.037 - 3(0.019) = -0.02 = 0.0$

Example 2: Constructing a P-Chart:

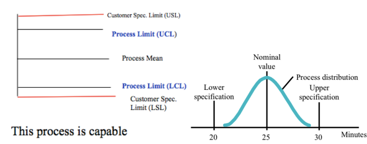
Sample N = 100	Error	Proportion Error
1	4	0.04
2	3	0.03
3	5	0.05
4	0	0
5	2	0.02
6	8	0.08
7	1	0.01
8	3	0.03
9	4	0.04
10	2	0.02
11	7	0.07
12	2	0.02
13	1	0.01
14	3	0.03
15	1	0.01
	46	
P-bar		0.0302
Sigma		0.017

P-bar = Total Defects / N x n
= 46 / (100 x 15)
= 0.0307

1) 5% error or randomness:
Tails = alpha/2
= 0.05/2
= 0.025
2) z-score (0.025 alpha) = 1.96
3) UCL = 0.03 + 1.96(0.17)
LCL = 0.03 – 1.96 (0.17)
4) Plot individual error proportions around p-bar
5) 2 points are outside the CLs. Variations can be due to common or assignable causes. Need to investigate for exact type of cause. Also dependent on alpha (% error)

PROCESS CAPABILITY

- You will have control limits (stable process, predictable or consistent results)
Design Specs: Range of acceptable values/req (customer's specs) – USL & LSL
Process Variability: Natural/actual variability in process
Process Capability: If control limits are within cx specs
- USL > UCL & LSL < LCL



Calc Capability Ratio to prove process capability:

If the process is centered use Cp
Cp = (Upper specification – lower specification) / 6σ
If the process is not centered use Cpk
Smaller of:
(Process mean – Lower specification) / 3σ and (Upper specification – Process mean) / 3σ

- Use C_{PK} if centre of process control DOES NOT coincide w/ centre of design/customer spec limits
- Process Capable when **$C_P \geq 1$**
- Six Sigma Qual: $C_{PK} = 2$

Example:
C_{pk} for Customers
Process: $\bar{\bar{x}} = 1.00$ and $\sigma_{\bar{x}} = 0.0037$

	Customer Specification Limits		Process Capability			
Customer	Lower Spec Limit (LS)	Upper Spec Limit (US)	C_{pk} (LSL) = (X-Bar -LSL)/3Sigma	C_{pk} (USL) = (USL-X-bar)/3Sigma	C_{pk} = Smaller of C_{pk} (LSL) and C_{pk} (LSL)	C_p
1	0.982	1.019	1.62	1.71	**1.62**	1.67
2	0.991	1.015	0.811	1.35	0.811	1.08
3	0.982	1.007	1.622	0.631	0.631	1.13
4	0.985	1.013	1.351	1.171	**1.171**	1.26

- If the questions asks you to compare machines vs. one set of customer specifications, use the following:

Customer Design Specs: X = 0.0970, LCL = 0.082, USL = 0.112

			Process Capability			
Machine	X	SD (sigma)	C_{pk} (LSL)	C_{pk} (USL)	C_{pk}	C_p
1	0.0995	0.004	1.46	1.04	1.04	1.25
2	0.1002	0.009	0.67	0.44	0.44	0.56
3	0.095	0.005	0.87	1.13	0.87	1