MSCI 432 Course Notes
Production and Service Operations Management

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1 OPERATIONS MANEGEMENT AND DEMAND FORECASTING (I)

1.1 Operations Management

1.1.1 Basic Premise of Supply and Demand

- As consumers, we decide how much we want to buy and how much we are willing to pay
- Consumers hold the cash and as such are the ultimate decision makers
- This underlies OM as it goes to the heart of the environment in which firms operate

1.1.2 Operations as an Aggregate Function

What is Operations Management?

- OM is the management of activities and resources that create goods and provide services
- Companies use OM to improve efficiency and effectiveness

Why Study Operations Management?

- A large percentage of a company's expenses occur in the OM area
- A large number of all jobs are in the OM area
- Activities in all other areas are interrelated with OM activities

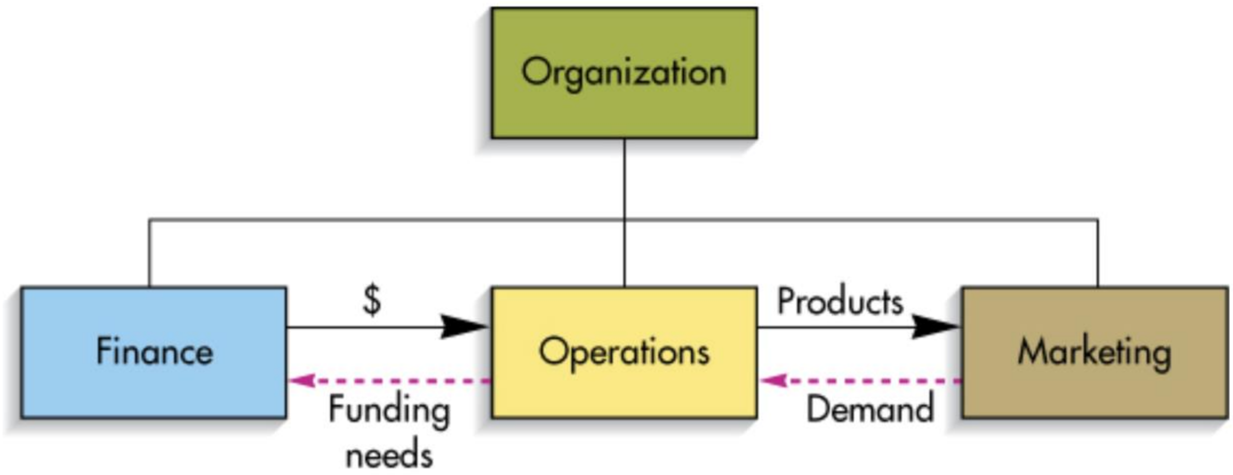
Three Basic Functions:

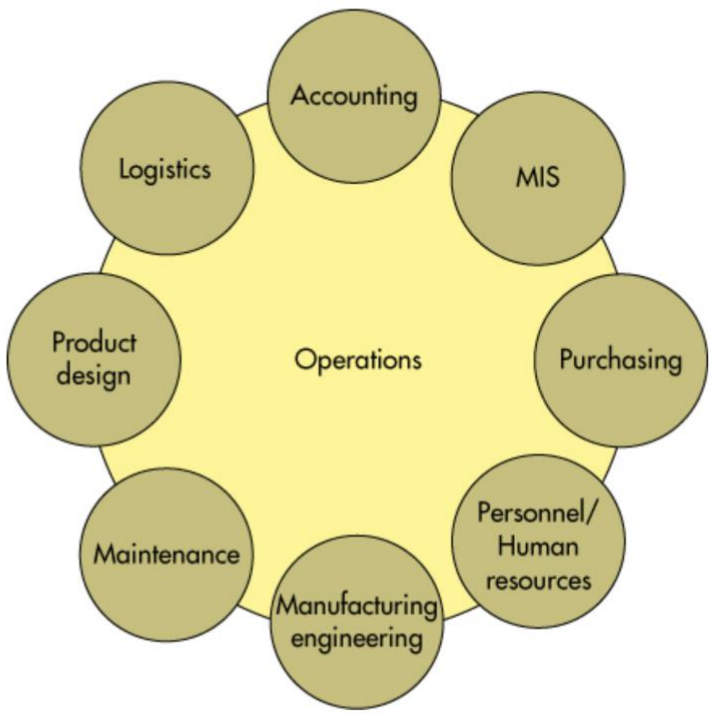
1. Operations: Create goods and services
2. Finance: Provide funds and the economic analysis of investment proposals
3. Marketing: Assess customer wants and needs and communicate them to others

Types of OM Decisions:

- Design (strategic) decisions that are medium to long term and deal with capital equipment and other physical assets (equipment needs, production capacity, etc.)
- Day-to-day operations involve the everyday decisions such as scheduling, packaging, quality control, and labour requirements

1.1.3 Operations as it Relates to the Firm





1.1.4 What Operations Managers Do

Defining the Role of the Operations Manager:

- Core (manufacturing)
- Support (maintenance, accounting, HR, purchasing)
- Managerial (general administration)

The Operations Manager's Job:

Management Process	Field of Responsibility
Planning	Capacity, location, make or buy
Organizing	Centralization, specialization, staffing
Controlling	Inventory, quality, motivation
Directing	Scheduling, incentive plans, work orders

Establishing Priorities:

- Pareto Phenomenon: A few factors account for a high percentage of the occurrence of some event(s)
- 80/20 Rule: 80% of problems are caused by 20% of the activities

1.1.5 The Importance of Collaboration

- A clear and comprehensive systems-based approach for issues is in demand
- Coordination between marketing and operations is essential for success
- For example, changing a package form needs to account for inventory costs and order quantities, existing packaging inventories, new equipment needs, plant layout, etc.

1.1.6 Concept of Value Added

- Difference between the cost of goods and the value of outputs
- For services, the cost of services and the value placed on those services by individuals
- Value of output is determined by the prices that consumers are willing to pay for goods

1.1.7 Stakeholder Management

- "Any group or individual who can affect or is affected by the achievement of an organization's objective" (Freeman, 1984)
- Stakeholders may include customers, employees, suppliers, financiers, etc.

1.2 Demand Forecasting

- Underlies strategic planning when it comes to plant or service design
- Essential for budgeting and determining capital requirements for both inputs and projects
- Dictates medium-term operations and affects short-term operations

1.2.1 Forecast Commonalities

1. Rely, to some extent, upon past demand and criteria identified as affecting that demand
2. Forecasts of aggregate demand for similar goods is more accurate than forecasts for individual items within a category
3. Increasing forecast horizons introduces greater uncertainty and reduced reliability

1.2.2 Requirements for a Useful Forecast

1. Forecast should be long enough to make it relevant
2. Limitations on accuracy must be clearly stated
3. Forecasting method should be reliable
4. Operations forecasts should be expressed in units

1.2.3 How it is Done

1. Determine why you are forecasting (who wants it and what will they use it for)
2. Assess and state the required levels of detail and accuracy
3. Establish a forecasting horizon
4. Gather historical data
5. Select a forecasting method
6. Complete the forecast
7. Monitor its accuracy

1.2.4 Judgemental Approaches

- Includes things such as hunches, personal opinions, non-quantitative observations
- Can be tainted by personal bias
- Developed as a non-quantitative analysis of historical data or analysis of subjective data

1.2.5 Quantitative Approaches

- Utilize hard data from the past (untainted from personal bias)
- Time series models (identifies patterns in data and projects these trends into the future)
- Associative models (describes demand in terms of independent causal variables)

1.2.6 Time Series Modeling

- A time-ordered sequence of observations taken at regular intervals over a period of time

- Assumes that future values of the series can be estimated from past values

Data Behaviour:

- Average (level): Horizontal pattern
- Trend: Persistent upward or downward pattern
- Seasonality: Regular wavelike pattern that corresponds with some repeatable event
- Cycles: Lasts more than one year and looks at longer-term patterns
- Irregular Variations: One-time events that tend to skew the data
- Random Variations: Multitude of minor events that combine to affect the data

Methods:

Naïve Method:

- Assumes that the value of the data for the last period will be the value of the next period
- Can be applied to average, trend, and seasonal data

Period	**Actual**	**Change**	**Naïve Forecast**
$t-1$	50		
t	53	$+3$	
$t+1$			$53+3=56$

Averaging Methods:

- Three types: moving average, weighted moving average, and exponential smoothing
- Requires stable data and can handle random variations but not irregular data points

Moving Average Method:

- Average of recent observations are used as the basis for the current forecast
- Choice of the number of data points used for the calculation will affect the sensitivity of the average to the most recent data point

Period	**Demand**
1	42
2	40
3	43
4	40
5	41

$$F_6 = \frac{43+40+41}{3} = 41.33$$

$$F_7 = \frac{40 + 41 + 39}{3} = 40.00$$

Weighted Moving Average Method:

- Assigns a heavier weight to more recent data points
- Sum of the weights must equal to one

$$F_6 = 0.40(41) + 0.30(40) + 0.20(43) + 0.10(40) = 41.0$$

$$F_7 = 0.40(39) + 0.30(41) + 0.20(40) + 0.10(43) = 40.2$$

Exponential Smoothing:

- Current forecast that is based upon the previous period plus a portion of the difference between the actual outcome in the period and the quantity forecast for that period
- Notation: $F_t = F_{t-1} + \alpha(A_{t-1} - F_{t-1}), where\ 0 < \alpha < 1$
- For example, if previous forecast was 42 units, previous actual demand was 40 units, and $\alpha = 0.10$, the new forecast would be:

$$F_t = 42 + 0.10(40 - 42) = 41.8$$

- Then, if the actual demand turned out to be 43, the next forecast would be:

$$F_{t+1} = 41.8 + 0.10(43 - 41.8) = 41.92$$

Associative Forecasting:

- If I want to predict ridership from a new train station, what data might I look at?

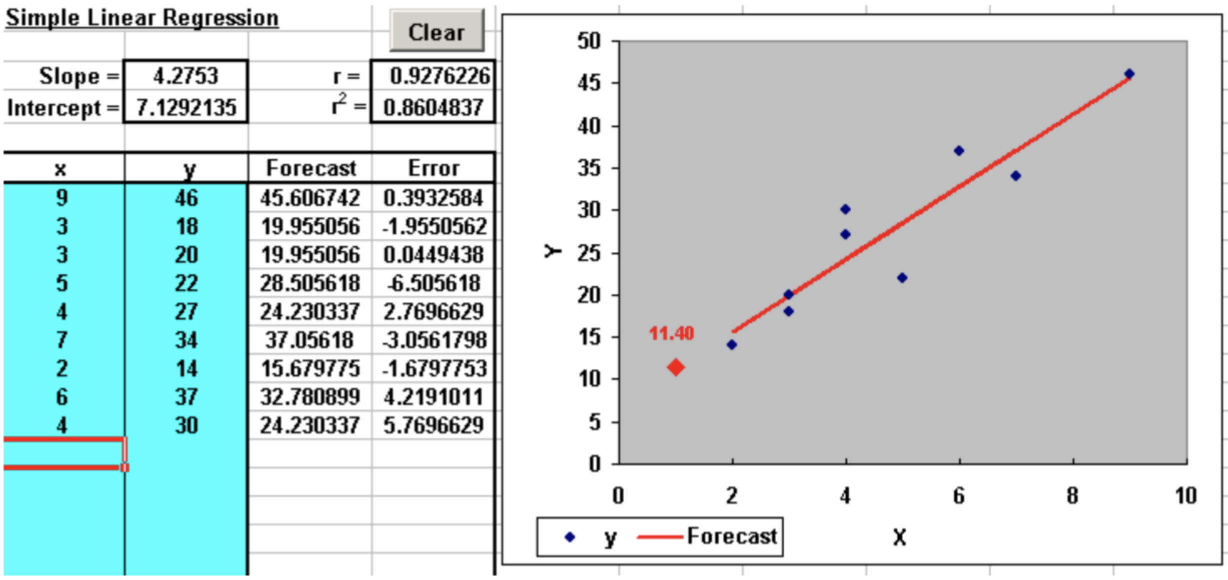
1. Find (predictor) variables associated with ridership at other stations
2. $Associated = correlated = as\ one\ moves\ the\ other\ moves$
3. Create a model that shows the relationship between the predictor variables and the predicted variable (ex. ridership)
4. Technique is regression analysis (ex. Simple linear regression with one variable, multiple regression that can be non-linear)
5. Test the model to see which variables are most useful in predicting ridership (r^2)
6. Use the model to predict ridership, given the values of the predictor variables

Associative Models:

- Predictor Variables (x): Used to predict values of the variable of interest (y) – independent variables
- Linear Regression: Process of finding a straight line that best fits a set of points on a graph – least squares estimation

- Multiple Regression: Models with more than one predictor variables – computations complex, created with computer

Excel: Simple Linear Regression



Correlation and Excel:

- Correlation Coefficient (r): Measure of strength of the relationship between two variables
    - Ranges from -1 (moves in same direction) to $+1$ (moves in opposite direction)
- r^2 measures proportion of variation in the values of y that is "explained" by the predictor variables in the regression model
    - Ranges from 0 to 1 (higher values means more useful predictors)

Linear Regression Assumptions:

- Predictions are being made only within the range of observed values
- Variations around the line are random and normally distributed

1.2.7 Forecasting Accuracy

- Definition: A judgement or measurement of how accurate the forecast is to actual results from the demand being forecast (or predicted)
- Presence of random variables such as changes in tastes, preferences, and values of consumers make it almost impossible to create a perfect prediction of future demand

Forecasting Error:

$$E_t = A_t - F_t$$

- In words: The error E for period t is simply the difference between the actual demand A and the forecast demand F for the same period
- **Bias:** Sum of forecast errors, if positive then forecasts are underestimating demand, if negative then forecasts are overestimating demand

Three Methods for Measuring Accuracy:

1. **Mean Absolute Deviation:** $MAD = \frac{\sum|e|}{n}$
2. **Mean Squared Error:** $MSE = \frac{\sum(A_i - F_i)^2}{n}$
3. **Mean Absolute Percent Error:** $MAPE = \frac{\sum[\frac{|A_i - F_i|}{A_i} \times 100]}{n}$

- e is the value of individual forecast errors, n is the number of observations

Calculate MAD, MSE, and MAPE for the following data.

Period	Actual	Forecast	Forecast Error	$(A-F)$ |Error|	Forecast Error²	$\frac{\lvert\text{Error}\rvert}{\text{Actual}} \times 100$
1	217	215	2	2	4	.92%
2	213	216	−3	3	9	1.41
3	216	215	1	1	1	.46
4	210	214	−4	4	16	1.90
5	213	211	2	2	4	.94
6	219	214	5	5	25	2.28
7	216	217	−1	1	1	.46
8	212	216	−4	4	16	1.89
			−2	22	76	10.26%

d

SOLUTION

Using the numbers shown in the above table,

$$\text{MAD} = \frac{\sum |e|}{n} = \frac{22}{8} = 2.75$$

$$\text{MSE} = \frac{\sum e^2}{n} = \frac{76}{8} = 9.5$$

$$\text{MAPE} = \frac{\sum \left[\frac{|e|}{\text{Actual}} \times 100\right]}{n} = \frac{10.26\%}{8} = 1.28\%$$

1.2.8 Dealing with Control Charts

- Objective: Measure the accuracy of the forecasts within a set of prescribed boundaries
- Control limits "s" based upon the square root of the mean squared error: $s = \sqrt{MSE}$

Solution Process:

1. Setup the required data table and make the necessary calculations
2. Check average forecast error and comment on its proximity to zero
3. Calculate the square root of the forecast errors
4. Determine the 2s control limits
5. Compare forecast errors to the control limits

Monthly sales of leather jackets at a store for the past 24 months, and forecasts and forecast errors for those months, are shown below. Determine if the forecasting technique is satisfactory using a control chart with 2*s* limits. Use data from the first eight months to develop the control chart, then evaluate the remaining data with the control chart.

Month	*A* (Sales)	*F* (Forecast)	*A−F* (Error)
1	47	43	4
2	51	44	7
3	54	50	4
4	55	51	4
5	49	54	−5
6	46	48	−2
7	38	46	−8
8	32	44	−12
9	25	35	−10
10	24	26	−2
11	30	25	5
12	35	32	3
13	44	34	10
14	57	50	7
15	60	51	9
16	55	54	1
17	51	55	−4
18	48	51	−3
19	42	50	−8
20	30	43	−13
21	28	38	−10
22	25	27	−2
23	35	27	8
24	38	32	6
			−11

1. Make sure that the average forecast error is approximately zero:

$$\text{Average error} = \frac{\sum \text{errors}}{n} = \frac{-11}{24} - \; = -0.46 - 0$$

2. Compute the standard deviation of forecast errors using the first eight months:

$$s = \sqrt{\text{MSE}} = \sqrt{\frac{\sum e^2}{n}}$$

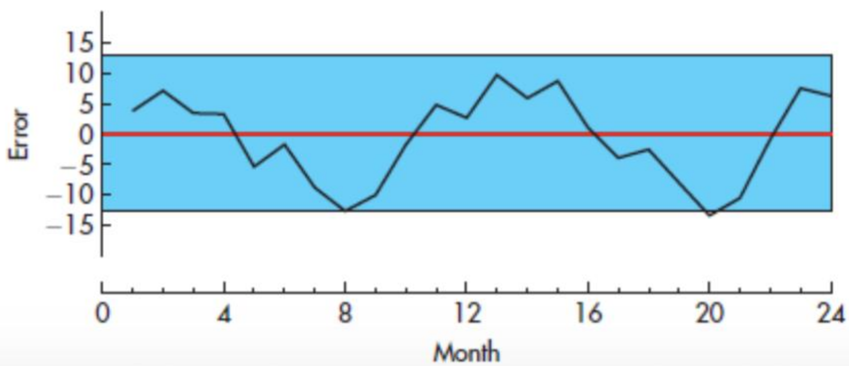
$$= \sqrt{\frac{\sum 4^2 + 7^2 + 4^2 + 4^2 + (-5)^2 + (-2)^2 + (-8)^2 + (-12)^2}{8}} = 6.46$$

3. Determine $2s$ control limits:

$$0 \pm 2s = 0 \pm 2(6.46) = -12.92 \text{ to } +12.92$$

   i. Check that all forecast errors are within the control limits. Month 20's forecast error (–13) is just below the lower control limit (–12.92).

   ii. Check for nonrandom patterns. Note the runs of positive and negative errors in the following plot. This suggests nonrandomness (and that a better forecasting technique is possible). (We present more on control charts in Chapter 10.)



2 DEMAND FORECASTING (II) AND PRODUCT DESIGN

2.1 Demand Forecasting

2.1.1 Trend Adjusted Forecasts (TAF)

- Slightly more complicated version of exponential smoothing:

$$S_t = TAF_t + \alpha(A_t - TAF_t)$$

$$T_t = T_{t-1} + \beta(S_t - S_{t-1} - T_{t-1})$$

$$TAF_{t+1} = S_t + T_t$$

- S_t: Smoothed series at the end of period t
- T_t: Smoothed trend at the end of period t

- α and β are arbitrary smoothing constants
- A_t is the actual data from period t

Example 4

Cellphone sales of a company over the last 10 weeks are shown below. The data appear to have a linear trend. Determine the equation of the linear trend and predict the sales of cellphones for weeks 11 and 12. Plot the data and trend line.

Week	Unit Sales
1	700
2	724
3	720
4	728
5	740
6	742
7	758
8	750
9	770
10	775

Using the cellphone data from Example 4 (where it was concluded that the data exhibited a linear trend), use trend-adjusted exponential smoothing to prepare forecasts for periods 5 through 11, with α = .4 and β = .3. Use the first four weeks to estimate starting smoothed series and smoothed trend.

SOLUTION

Table 3-1 displays the data again in the Actual column. We will use the average of the first four weeks as the starting smoothed series:

$$S_4 = (700 + 724 + 720 + 728)/4 = 718.$$

t (Week)	A_t (Actual)			
1	700			
2	724	Starting values:		
3	720	$S_4 = (700+724+720+728)/4 = 718$, $T_4 = (728-700)/3 = 9.33$		
4	728	$TAF_5 = 718 + 9.33 = 727.33$		
		$TAF_t + \alpha(A_t - TAF_t) = S_t$	$T_{t-1} + \beta(S_t - S_{t-1} - T_{t-1}) = T_t$	$TAF_{t+1} = S_t + T_t$
5	740	727.33 + .4(740 − 727.33) = 732.40	9.33 + .3(732.40 − 718 − 9.33) = 10.85	743.25
6	742	743.25 + .4(742 − 743.25) = 742.75	10.85 + .3(742.75 − 732.40 − 10.85) = 10.70	753.45
7	758	753.45 + .4(758 − 753.45) = 755.27	10.70 + .3(755.27 − 742.75 − 10.70) = 11.25	766.52
8	750	766.52 + .4(750 − 766.52) = 759.91	11.25 + .3(759.91 − 755.27 − 11.25) = 9.27	769.18
9	770	769.18 + .4(770 − 769.18) = 769.51	9.27 + .3(769.51 − 759.91 − 9.27) = 9.37	778.88
10	775	778.88 + .4(775 − 778.88) = 777.33	9.37 + .3(777.33 − 769.51 − 9.37) = 8.90	786.23

2.1.2 Review of Seasonality

- Seasonal data is defined as data that exhibits a repeating pattern that is tied to some regularly occurring event (summer ice cream sales, winter natural gas sales, etc.)
- Expressed as the amount of deviation from the period average, by using the average over the length of the repeating pattern to calculate an adjustment factor
- Seasonality is measured relative to the trend

Computing Seasonal Relatives:

- Need to identify the trend in the data in order to compare seasonal values to some average
- Decompose data into smaller segments through use of a centered moving average (CMA)
- Number of periods in CMA is equal to the number of "seasons" portrayed in the data
- Example: Quarterly data, use a 4-period CMA

Period	Historical Value	CMA	Seasonal Relative
1	79		$79/76.67 = 1.03$
2	86	76.67	$86/76.67 = 1.12$
3	65		$65/76.67 = 0.85$

Steps in Dealing with Seasonal Data:

1. Write out the given data in table form
2. Calculate the appropriate Centered Moving Average (CMA)
3. Use CMA to calculate seasonal relatives
4. Average and adjust the seasonal relatives to the relevant seasonal data
5. Use the "adjusted" averaged seasonal relatives to de-seasonalize the original data
6. Describe the data (does it exhibits a linear trend, upward or downward)
7. Using calculated (GIVEN) Linear Trend Equation, calculate the forecasts for the periods
8. Re-seasonalize forecast using the average seasonal relatives calculated in Step 4

Below are quarterly data for production of ice cream in Canada from quarter 1 of 2006 to quarter 3 of 2009.[2]

a. Calculate the quarterly relatives using the centred moving average method.

b. Deseasonalize the data, fit an appropriate model, project it four quarters ahead, and reseasonalize to obtain forecasts for ice cream demand for the 4th quarter of 2009 and Q1 to Q3 of 2010.

a.

Quarter		Production (million litres)	CMA$_4$	CMA$_2$	Production/CMA$_2$
2006	1	66			
	2	96			
			79.75		
	3	91		78.875	91/78.876 = 1.154
			78		
	4	66		77.375	66/77.375 = 0.853
			76.75		
2007	1	59		75.875	0.778
			75		
	2	91		74.250	1.226
			73.5		
	3	84		73.000	1.151
			72.5		
	4	60		71.375	0.841
			70.25		
2008	1	55		69.500	0.791
			68.75		
	2	82		66.875	1.226
			65		
	3	78		63.875	1.221
			62.75		
	4	45		59.750	0.753
			56.75		
2009	1	46		54.875	0.838
			53		
	2	58			
	3	63			

	QUARTER				
Year	1	2	3	4	Total
2006			1.154	0.853	
2007	0.778	1.226	1.151	0.841	
2008	0.791	1.226	1.221	0.753	
2009	0.838				
Average	0.802	1.226	1.175	0.816	4.019
Adjusted	.802(4/4.019)=0.798	1.226(4/4.019)=1.220	1.170	0.812	4.000

b.

Quarter	Production (million litres)	Seasonal Relatives	Deseasonalized Production
2006 1	66	0.798	66/.798=82.707
2	96	1.220	96/1.220=78.689
3	91	1.170	77.778
4	66	0.812	81.281
2007 1	59	0.798	73.935
2	91	1.220	74.590
3	84	1.170	71.795
4	60	0.812	73.892
2008 1	55	0.798	68.922
2	82	1.220	67.213
3	78	1.170	66.667
4	45	0.812	55.419
2009 1	46	0.798	57.644
2	58	1.220	47.541
3	63	1.170	53.846

The deseasonalized data has a (decreasing) linear trend. Therefore, a linear trend is fitted to the deseasonalized data using regression, and its equation is displayed at the top of the chart above.

Using the regression equation, the trend forecasts for periods 16 to 19 (Q4 of 2009 and Q1 to Q3 of 2010) are:

$$Y_{16} = -2.2575(16) + 86.85 = 50.730$$
$$Y_{17} = -2.2575(17) + 86.85 = 48.473$$
$$Y_{18} = -2.2575(18) + 86.85 = 46.215$$
$$Y_{19} = -2.2575(19) + 86.85 = 43.958$$

d

The reseasonalized forecasts for the fourth quarter of 2009 and Q1 to Q3 of 2010 are:

$$F_{16} = 50.730(0.812) = 41.193$$
$$F_{17} = 48.473(0.798) = 38.681$$
$$F_{18} = 46.215(1.220) = 56.382$$
$$F_{19} = 43.958(1.170) = 51.431$$

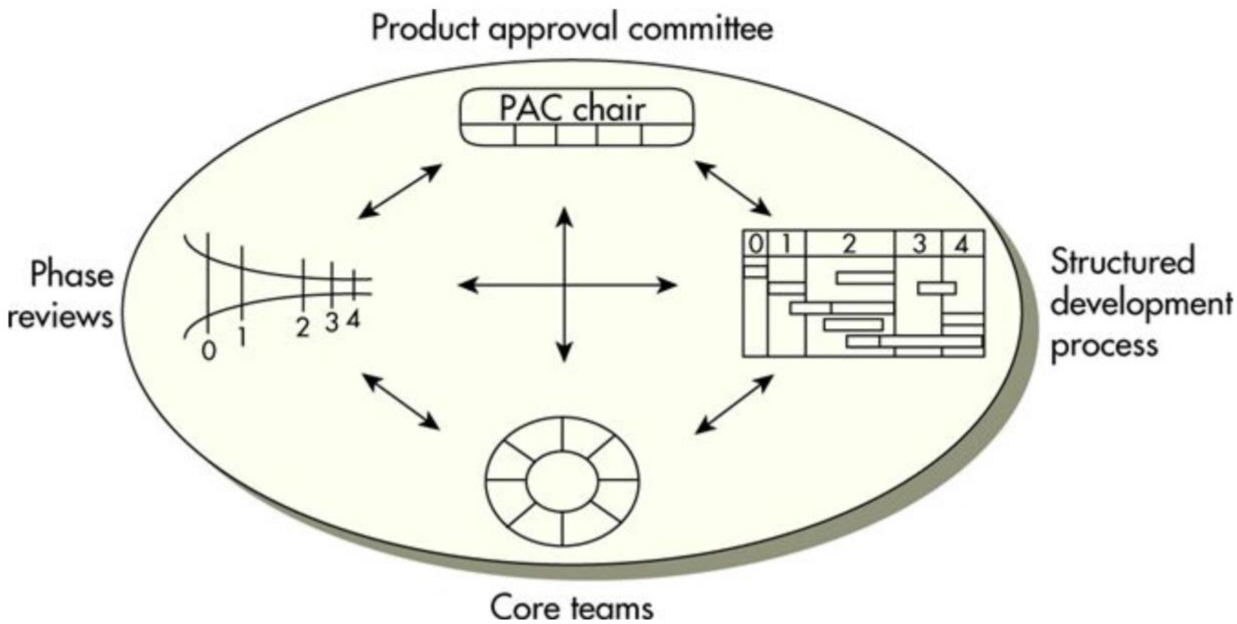
2.2 Product Design

Product Design:

- Determines the form and function

- Is expensive and time consuming
- Governs the level of product quality and hence the level of customer satisfaction
- Contributes to competitive advantage

2.2.1 Product Design Process



- Product Approval Committee: Management team
- Core Teams: Members from all aspects of the organization
- Phase Reviews: Milestones
- Structural Development: Structured and explicit project management technique

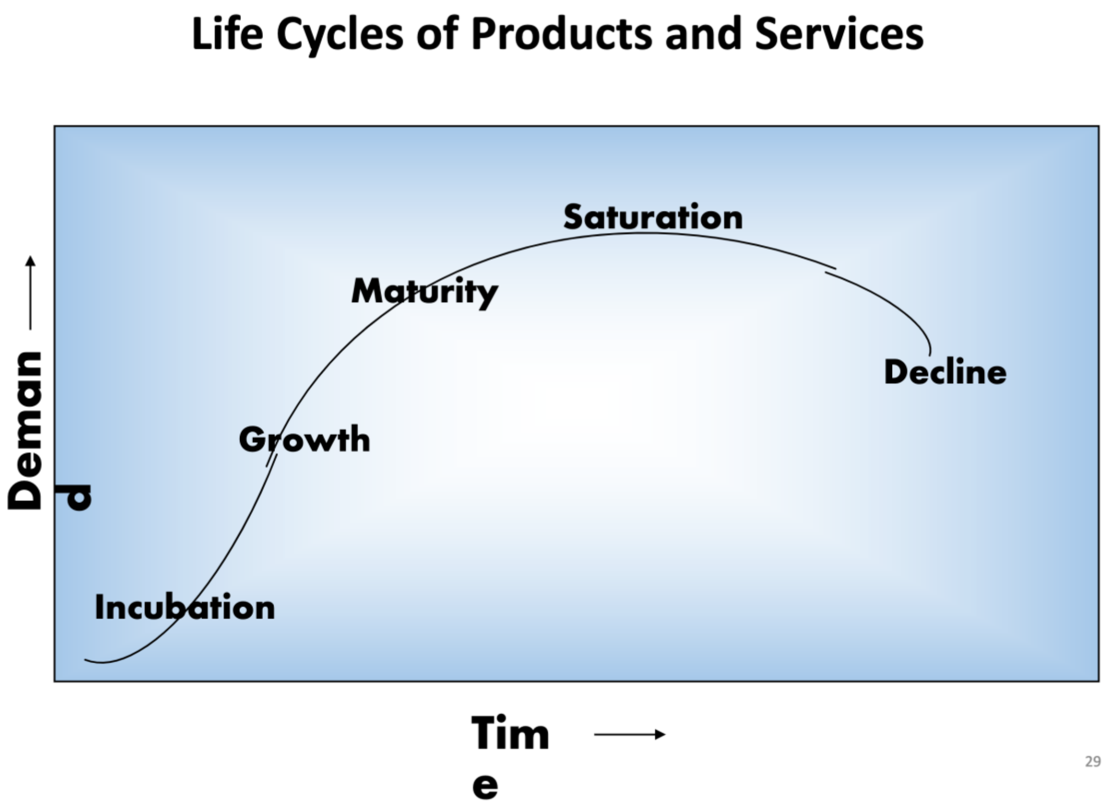
2.2.2 Sequential Steps in New Product Developments

1. Idea Generation
2. Build a Business Case: Market and Competitive Analysis
3. Development: Product attributes we need to meet or exceed customer expectations?
4. Testing and Validation
5. Launch

2.2.3 Sources of New Product Ideas

- Customers, front-line production workers, suppliers, competitive products, R&D

2.2.4 Key Issues in Product Design



Standardization

- Every consumer receives the same product
- High volumes of the same product reduce costs through economies of scale
- Can reduce the level of variety in product offerings
- May breed a climate of resistance of product improvements and modifications

Design for Mass Customization: Attempts to reach a compromise between the benefits of standardization for the producer and the desire of consumers for variety and customization

Reliability: Ability of a product (or part) to perform for its intended use under normal conditions

Robust Design: Products that can stand up under a wide range of operational environments

Legal and Ethical Issues: Product liability (injuries), ethical issues (sub-standard products)

Design for the Environment: Energy efficient, minimization of waste/packaging, etc.

Concurrent Engineering: Bringing design engineering staff into direct work with others

Computer Assisted Design (CAD): Computerizes design to avoid hand-drawn designs

Design for Manufacturing and Assembly: Ease can be incorporated into the design

Component Commonality: Occurs when a component can be used in multiple products

3 CAPACITY PLANNING AND PROCESS DESIGN/FACILITY LAYOUT

3.1 Strategic Capacity Planning

3.1.1 Overview

- **Capacity:** Upper workload limit that a production unit can accommodate
- **Production Rate:** Measured in terms of the units of production per unit of time
- **Capacity Time Frames:** Long-term (1-5 years), medium-term (next 12 months), short-term (up to 12 weeks)
- **Strategic Capacity Planning:** Systematic determination of facility and equipment needs

Importance of Long-Term Capacity

1. Capacity directly impacts the ability of the company to meet future demand
2. Effective capacity planning optimizes operating costs
3. Capacity decisions have a direct impact on initial capital costs
4. Capacity involves long-term commitment of resources
5. Capacity can directly affect competitiveness

Measuring Capacity

- Design Capacity: Max amount of output that can be produced under ideal conditions
- Effective Capacity: Amount of output that can realistically be made given delays, etc.

1. Efficiency: Ratio of actual output to effective capacity:

$$Efficiency = \frac{Actual\ Output}{Effective\ Capacity}$$

2. Utilization: Ratio of actual output to design capacity:

$$Utilization = \frac{Actual\ Output\ (or\ Uptime)}{Design\ Capacity\ (or\ Available\ Time)}$$

Minco produces silica and magnesia (http://www.mincoitc.com). To process silica, eight furnaces are used. Each furnace has 2,200 pounds/hour capacity. Minco works 24 hours a day, 5 days a week. During a typical week, total preventive maintenance is 65 hours and total other downtime is 39 hours. Effective capacity is 1,700,000 pounds and actual production is 1,600,000 pounds per week. Calculate the design capacity, utilization, and efficiency of silica furnaces.

SOLUTION

Available hours per week = 8(24)(5) = 960

Design capacity per week = 2,200(960) = 2,112,000 pounds

Productive hours per week = 960 – 65 – 39 = 856

Utilization = uptime hours/available hours = 856/960 = 0.89 or 89%

Efficiency = actual output rate/effective capacity = 1,600,000/1,700,000 = 0.94 or 94%

Note: Effective capacity = 1,700,000 < utilization × design capacity = .89(2,112,000) = 1,879,680

Factors Influencing Capacity

Facilities and equipment, products, workers, planning and operations, external factors

3.1.2 Effective Capacity Planning

1. Forecast demand for a period of 5 years or more
2. Calculate the capacity required to meet that demand
3. Measure existing in-house capacity and if necessary, begin discussing how additional capacity can be achieved

3.1.3 Focusing on Long-Term Demand

1. Identify the trend as expressed over time (growth, decline, cyclical, stable)
2. Consider forecasting technique (regression, judgemental)

3.1.4 Basic Capacity Requirement Question

1. Have a reasonably accurate forecast of annual demand
2. Know standard run times for each product on its respective machine
3. Know the number of hours worked per day
4. Know the number of workdays per year

A department works one eight-hour shift, 250 days a year. Three new products with the following annual demands are to be produced in the department. There is no excess capacity, so the department needs to buy new machines. Fortunately, there is a type of machine that can produce all three products. The expected processing times per unit are also given below. How many machines are needed?

Product	Annual Demand	Standard Processing Time per Unit (Hr)	Processing Time Needed (Hr)
#1	400	5.0	2,000
#2	300	8.0	2,400
#3	700	2.0	1,400
			5,800

d

SOLUTION

Working one eight-hour shift, 250 days a year provides an annual capacity of 8 × 250 = 2,000 hours per year for each machine. We can see that three of these machines would be needed to handle the required volume:

$$\frac{5{,}800}{2{,}000 \text{ hours/machine}} = 2.90 \text{ machines (round up to 3)}$$

The size of the facility can be determined by summing the area required for machines, inventory, handling material, and the offices required. 15

3.1.5 Major Concerns When Assessing Various Capacity Alternatives

- Design flexibility into system
- Differentiate between new and mature products
- Look at the organization in its entirety
- Prepare to deal with large (chunkier) increases in capacity
- Attempt to smooth out capacity requirements as dictated by consumer demand
- Use of capacity cushions
- Identify the optimal operating level

The first product created by toy company Spin Master, now the third largest toy manufacturer in North America, was Earth Buddy, a grass head.[1] Spin Master was hoping to produce and sell 8,000 Earth Buddies for Mother's Day and had one week to produce them. The Earth Buddy assembly consisted of the following operations: A: fill grass seeds and sawdust in a nylon stocking (average time 90 seconds), B: form ears and nose using elastic bands (average time 48 seconds), C: stick on the eyeglass and eyes (average time 24 seconds; eyeglasses were formed off line), and D: paint the mouth (average time 15 seconds). Finally, Earth Buddies are left to dry overnight and then packed. There are 6 workers doing A, 3 doing B, 2 doing C, and 1 doing D. There is enough space for inventory between operations so that they can work fairly independently. Determine the bottleneck operation and capacity of the "line" for a 40-hour week. Is the line balanced? Can Spin Master meet its production goal?

SOLUTION

	Fill	Form	Eyes	Paint
Time per unit per worker (sec)	90	48	24	15
No. of units per minute per worker	60/90 = 2/3	60/48 = 1.25	60/24 = 2.5	60/15 = 4
Number of workers	6	3	2	1
Capacity per minute	6(2/3) = 4	3(1.25) = 3.75	2(2.5) = 5	4(1) = 4
Capacity per hour	4(60) = 240	3.75(60) = 225 Bottleneck	5(60) = 300	4(60) = 240

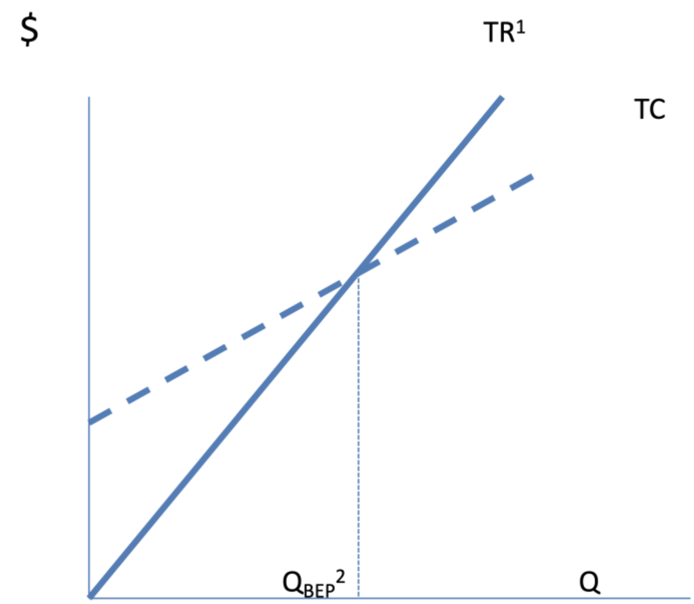
d

Line capacity = 225 units per hour. Yes, the line is fairly balanced because capacity per hour for the operations are all close.

Productive hours required to make 8,000 units = 8,000/225 = 35.6 hours.

Yes, Spin Master should be able to meet its target production goal of 8,000 units provided employees work[17] approximately 36 hours (excluding breaks).

3.1.6 Relationship Between Total Costs and Total Revenues



1 TR = R x Q where R is revenue per unit

2 $Q_{BEP} = FC/(R-V)$

3.1.7 Break-Even Analysis

- Focuses on the relationship between costs, revenues, and volumes
- Goal is to determine the quantity at which the alternative capacity arrangement being considered will provide an economic advantage profit

Costs

- Fixed Costs (FC) are independent of volume produced
- Variable Costs (VC) are entirely dependent upon how much is produced
- Assume that variable costs (v) remains constant per unit of output (Q) regardless of the volume produced

$$Total\ Cost\ (TC) = FC + VC$$

$$Variable\ Costs\ (VC) = Q \cdot v$$

$$Total\ Revenue\ (TR) = Q \cdot R$$

$$Profit\ (P) = TR - TC = (Q \cdot R) - (FC + VC) = (Q \cdot R) - FC - Q \cdot v$$

$$P = Q(R - v) - FC$$

$$Q = \frac{P + FC}{R - v} \Rightarrow Q_{BEP} = \frac{FC}{R - v}$$

The management of a large bakery is contemplating making pies, which will require leasing a new equipment for a monthly cost of \$6,000. Variable cost will be \$2.00 per pie and retail price will be \$7.00 each.

a. How many pies must be sold per month in order to break even?
b. What would the profit (loss) be if 1,000 pies are made and sold in a month?
c. How many pies must be sold to realize a profit of \$4,000 per month?
d. If demand is expected to be 1,500 pies per month, is this a good investment?

SOLUTION

$FC = \$6{,}000$ per month, $v = \$2$ per pie, $R = \$7$ per pie
d

a. $Q_{BEP} = \dfrac{FC}{R - v} = \dfrac{\$6{,}000}{\$7 - \$2} = 1{,}200$ pies/month
b. For $Q = 1{,}000$, $P = Q(R - v) - FC = 1{,}000(\$7 - \$2) - \$6{,}000 = -\$1{,}000$ (i.e., loss of \$1,000)
c. $P = \$4{,}000$; solve for Q using formula 5-7:

$$Q = \frac{\$4{,}000 + \$6{,}000}{\$7 - \$2} = 2{,}000 \text{ pies}$$

d. Because $1{,}500 > 1{,}200 = Q_{BEP}$, this is a good investment.

3.2 Process Design and Facility Layout

3.2.1 General Overview

Process Design and **Plant Layout** have long-term consequences for a company affecting:

- Long-term feasibility of the company
- Ability of the firm to meet its mission statement
- Morale of the workforce who actually operate the equipment and effectively run the plant
- The ability of the firm to meet its long-term strategic goals

3.2.2 Process Types

Job Shop

- Low volume of highly variable customized goods or services
- Process is intermittent
- Employs skilled workers
- Uses highly flexible equipment that can be used on a wide variety of applications

Batch Processing

- This describes a firm that produces a moderate quantity of a good or service
- Process is intermittent (i.e., by batch scheduled)
- Equipment is not as flexible as it is in a job shop
- Workers are skilled but not as skilled as those in a job shop

Repetitive Process

- Marked by higher volumes of more standardized goods
- Lower skilled workforce – this is changing
- Equipment is not very flexible

Continuous

- High volumes of highly standardized output
- Production is continuous and there is not typically counted
- Low skilled workforce

3.2.3 Process Considerations – Matching Process to Product Type and Volume

- **Focused Factory Concept:** High volume shops that specialize in a particular output

- **Hybridization:** Some organizations have been able to combine volume and specialization in their product offerings

3.2.4 Automation

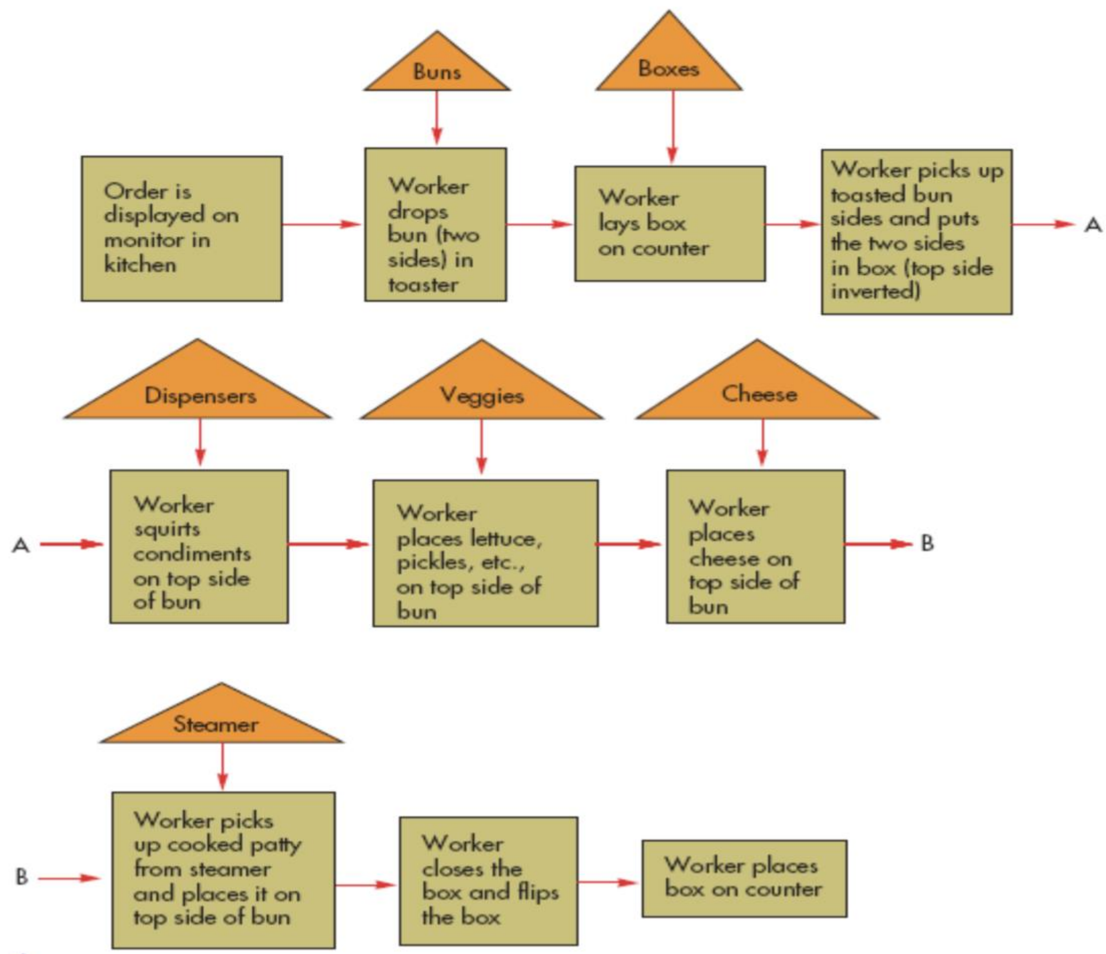
- Using machinery with sensing and control devices that enable it to operate automatically
- Advantages: Low variability, contrasts to labour, strategy necessary for competitiveness
- Disadvantages: Costly, inflexible, can adversely affect worker morale
- Types: Fixed automation, programmable automation, flexible automation

3.2.5 Process Design

- Determines the form and function of how the production of goods and services take place
- Involves the allocation of resources, the sequencing of activities and control mechanisms

Process: Determine state of inputs, outline objectives (speed, type, cost, quality, dates, etc.)

Conceptualize: $inputs \rightarrow outputs$, assess alternatives, incremental/hierarchical, flow diagram



Select: Establish design of choice, build a prototype (computer model) of the process and test it

Create: Specify machinery, determine labour requirements, design placement and work centers

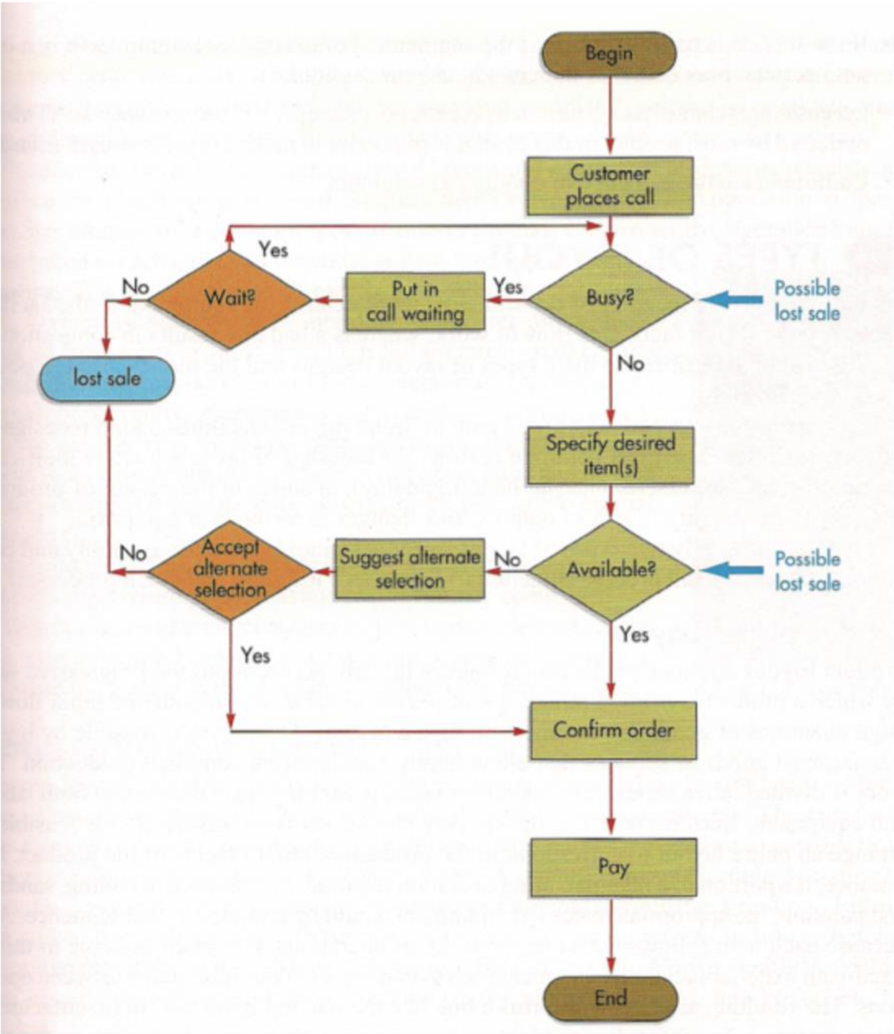
Implement: Buy equipment, hire and train workers, initiate trial runs

3.2.6 Fail-Safe Service Process

- Customer presence infers that quality and delivery problems are going to have immediate consequences
- This suggests that the service provider has a great incentive to ensure that the process is fail-safe, i.e., not prone to failure or on the positive side, to manage process design

3.2.7 Service Process Design

Service process design involves the direct or indirect involvement of the customer or of something belonging to the customer.

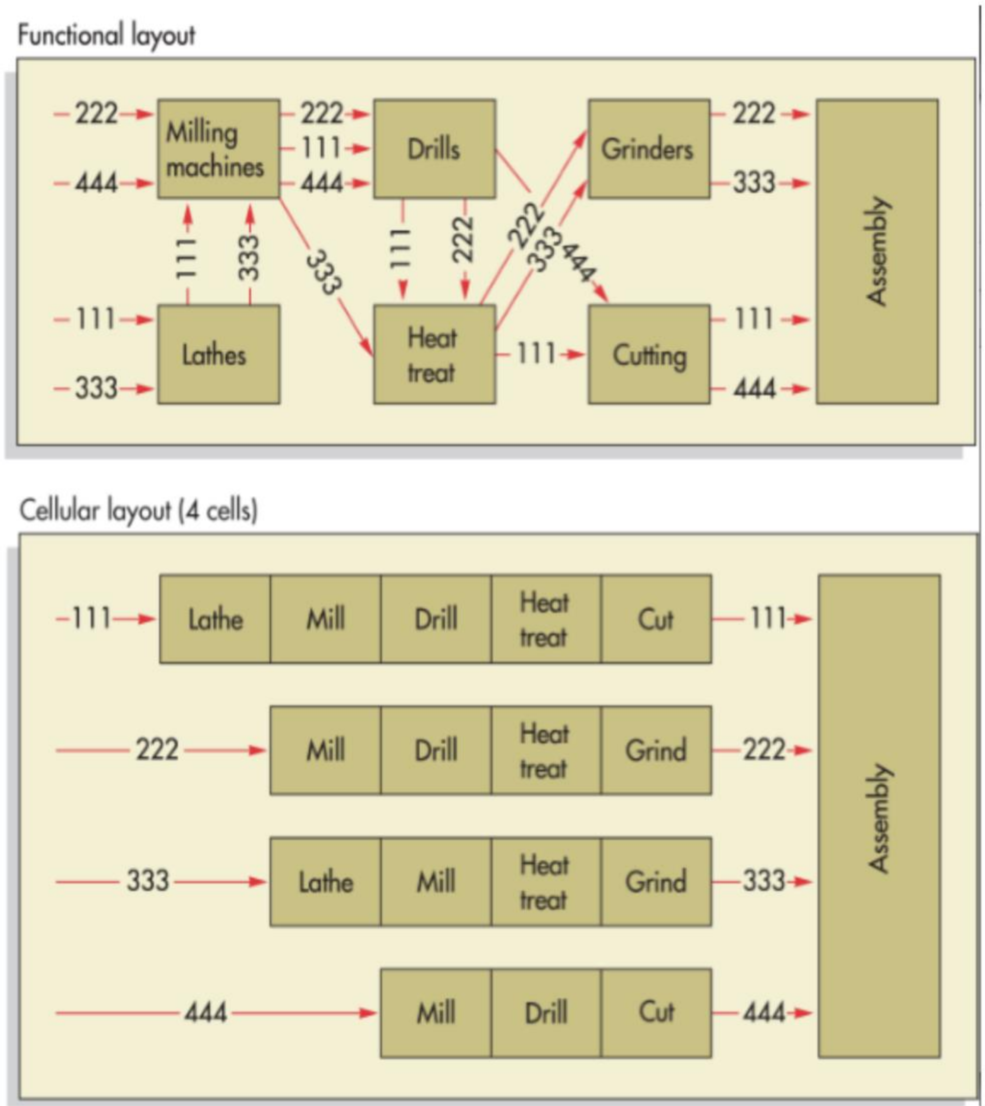


3.2.8 Basic Layout Types

Product (Line): Arranges the process (plant layout) linearly according to the progressive steps by which a product is made.

Process (Functional): Arranges production resources together according to the similarity of function.

Cellular: Layout in which different machines are arranged in a cell that can process items that have similar processing requirements.



3.2.9 Assembly Line Balancing

- Assigning tasks to workstations such that the workstations have approximately equal time requirements

- Cycle time is determined by the desired output rate:

$$Cycle\ Time = \frac{Operating\ Time\ Per\ Day}{Desired\ Output\ Rate}$$

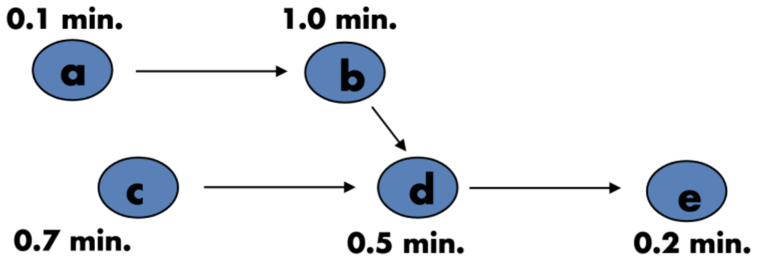
- Number of workstations is determined by the cycle time, the sum of task times, and the ability to bundle activities into appropriately sized workstations:

$$Theoretical\ Number\ of\ Workstations = \frac{Sum\ of\ Task\ Times}{Cycle\ Time}$$

- **Precedence Network:** A diagram that shows the task and their precedence requirements
- **Balancing Rules:** Assign the tasks with the longest time, assign the task with the most followers

A must be done before B, B and C must be done before D, and D must be done before E

Question: Calculate the number of work stations required and the activities done at each work station. Assume a cycle time 0f 1.0 minutes. 'Assign task with the most followers'



Workstation	Time Remaining	Eligible	Assign Task	Revised Time Remaining	Station Idle Time
1	1.0	a, c	a	0.9	
	0.9	c	c	0.2	
	0.2	$none$	–		0.2
2	1.0	b	b	0.0	0.0
3	1.0	d	d	0.5	
	0.5	e	e	0.3	0.3
	0.3	–	–		<u>0.5</u>

Two measures of facility layout effectiveness:

$$Percentage\ Idle\ Time = \left\{\frac{Sum\ of\ Idle\ Times}{Actual\ Number\ of\ Workstations \times Cycle\ Time}\right\} \times 100$$

$$Efficiency\ of\ the\ Line = 100 - Percentage\ Idle\ Time$$

In this example:

$$\%\ idle\ time = \frac{0.5}{3 \times 1.0} \times 100 = 16.7\%$$

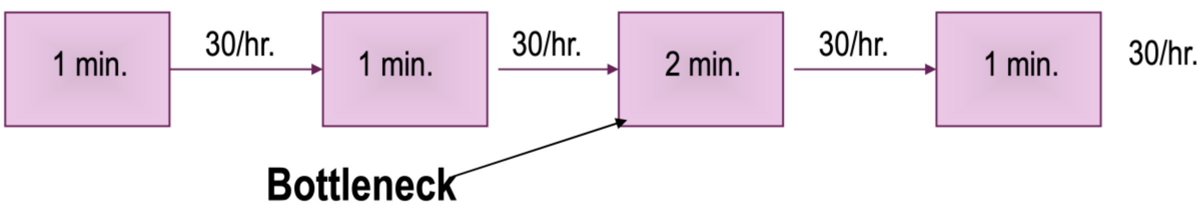
$$efficiency = 100\% - 16.7\% = 83.3\%$$

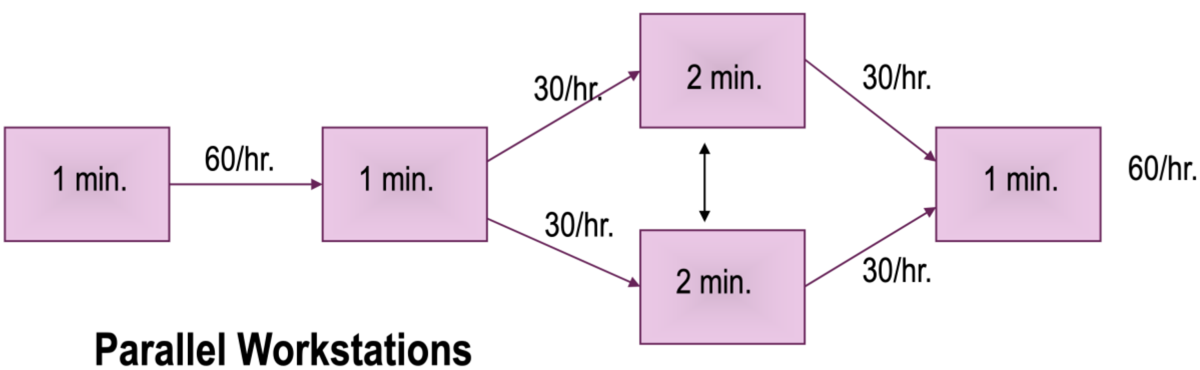
Dealing with Variable Task Times

- Task times vary due to worker fatigue, boredom, mechanical failures, shortages, etc.
- Solutions: Reduce variability in the task time themselves, allow for use of buffer inventories, build some idle time into the process itself, cross training workers

Resolving Bottlenecks

- The task time of the slowest workstation will determine the cycle time for the entire line
- Solutions: Parallelize workstations to decrease process time in half, cross train workers



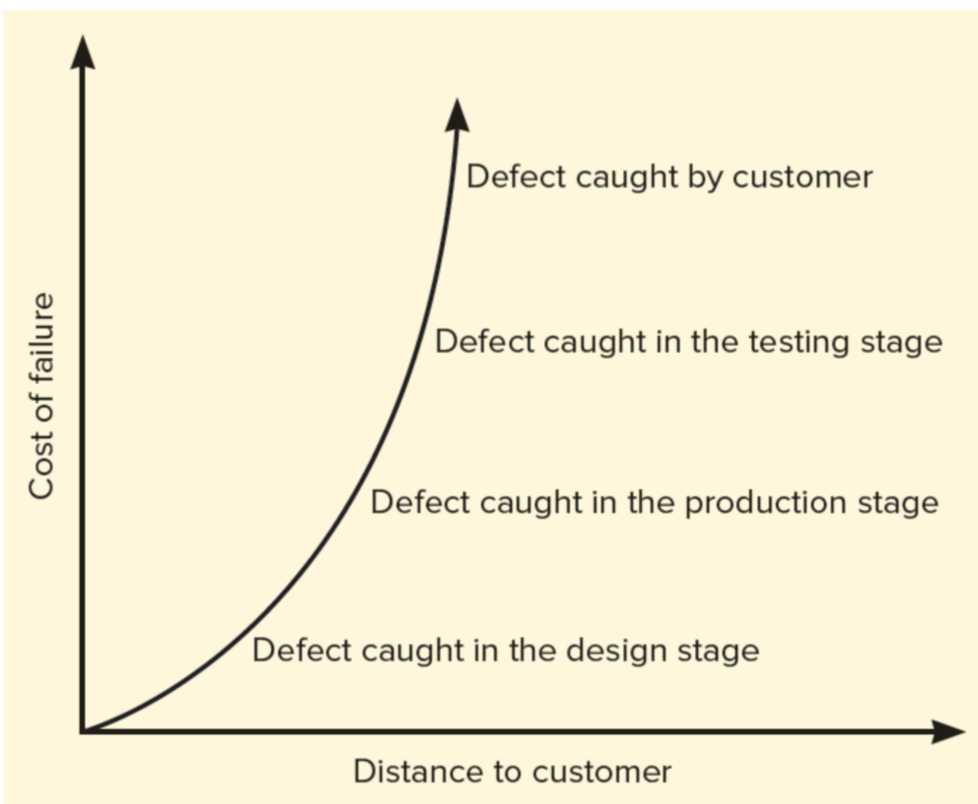


4 QUALITY MANAGEMENT AND STATISTICAL PROCESS CONTROL

4.1 Quality Management

4.1.1 Quality Overview

- **Quality:** The ability of a product or service to consistently meet or exceed customer expectations
- Evolution: craftsmanship (pre-industrial revolution), division of labour (industrial revolution), quality assurance (1950s), quality management systems (1970s), TQM/continuous improvement (1980s), Six Sigma/statistical tools (today)
- Dimensions: Performance, aesthetics, special features, conformance, reliability, durability, serviceability (example: quality of car)
- Service: Tangibles, convenience, reliability/consistency, responsiveness, time, assurance, courtesy (example: service of car repair)
- Determinants: Product design, process design, production
- Benefits: Improved quality, better reputation, increased market share, higher profitability
- Costs: Failure (defective), appraisal (inspection, testing), prevention (training, planning)



Deming's 14 Steps to Quality:

1. Create constancy of purpose toward improvement
2. Management must adopt the TQM philosophy
3. Cease dependence on inspection
4. Minimize total cost
5. Improve constantly and forever
6. Institute training
7. Institute leadership to act on quality issues
8. Drive out fear
9. Work as a team
10. Eliminate exhortations, and fix the system
11. Eliminate work standards and MBO
12. Remove barriers to pride of workmanship
13. Institute education and self-improvement
14. The transformation is everybody's job

4.1.2 Quality Certifications

- ISO 9001: Set of international standards on quality management and quality assurance, critical to international business
- ISO 14000: Family of standards related to environmental management

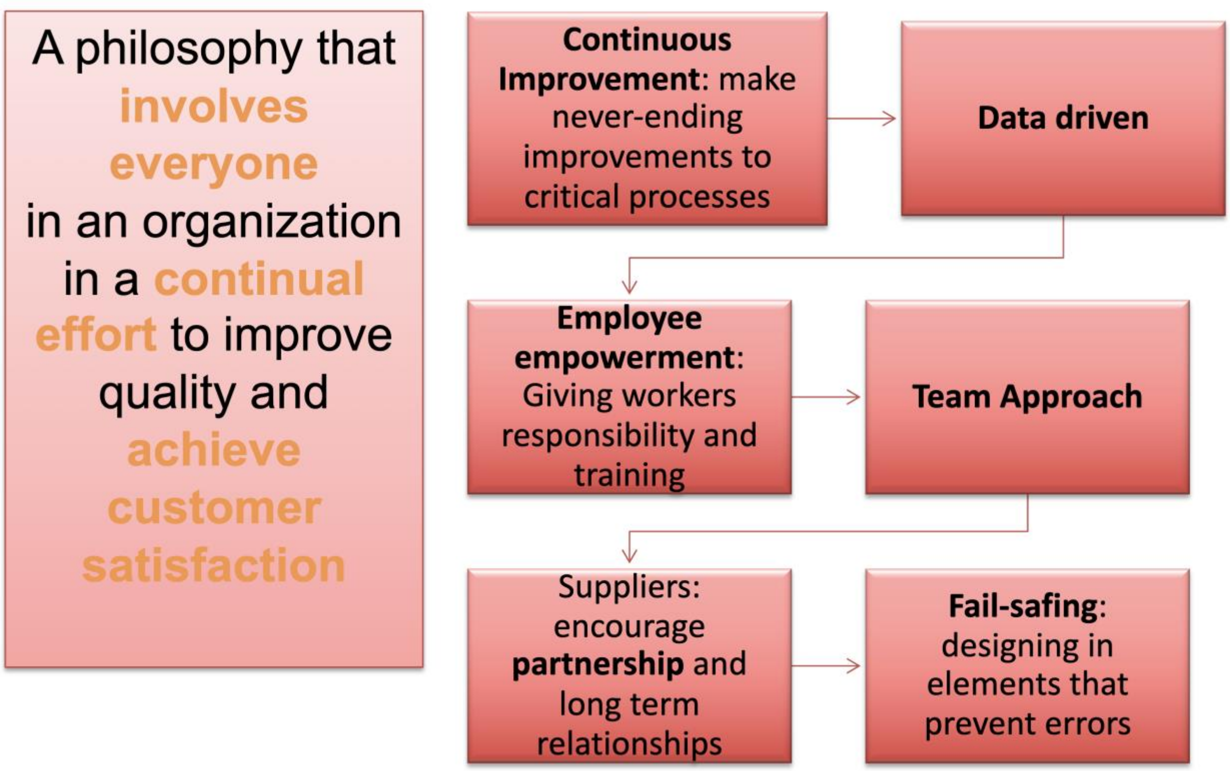
4.1.3 Hazard Analysis Critical Control Point (HACCP)

- A quality control system, similar to ISO 9001, designed for food processors
- Main steps: Hazard analysis, determination of the critical control points, creation of the HACCP plan

4.1.4 National Quality Institute (NQI) and Total Quality Management TQM

NQI:

TQM:



TQM Approach:

1. Find out what the customer wants

2. Design a product or service that meets or exceeds customer wants
3. Design processes that facilitate doing the job right the first time
4. Keep track of results
5. Extend these concepts to suppliers

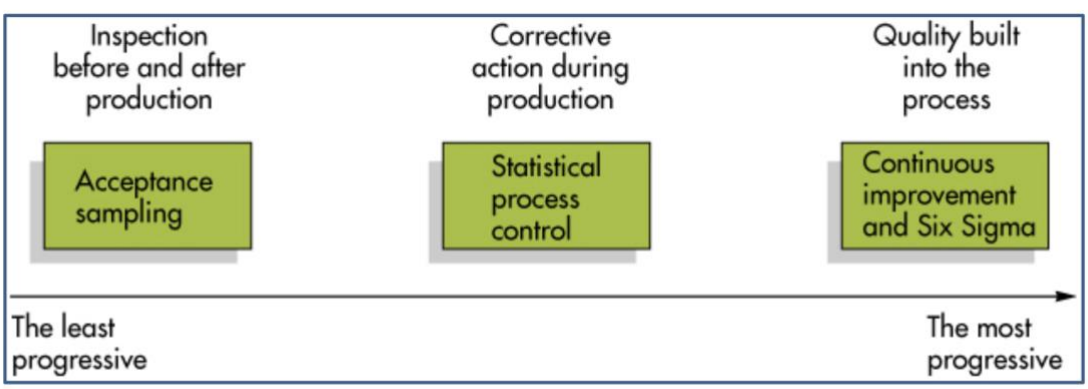
4.1.5 Problem Solving, Process Improvement, and Quality Tools

- Problem solving: Define problem, collect data, analyze problem, generate potential solutions, choose a solution, implement solution, monitor solution
- PDSA cycle: Plan, do, study, act
- Six Sigma: A business process for improving quality, reducing costs, and increasing customer satisfaction ($\leq 3.4\ defects\ per\ million$)
- Quality tools: Flowcharts, check sheets, histograms, Pareto charts, scatter diagrams, control charts, cause-and-effect diagrams, run charts
- Methods for generating ideas: Brainstorming, quality circles, interviewing, etc.

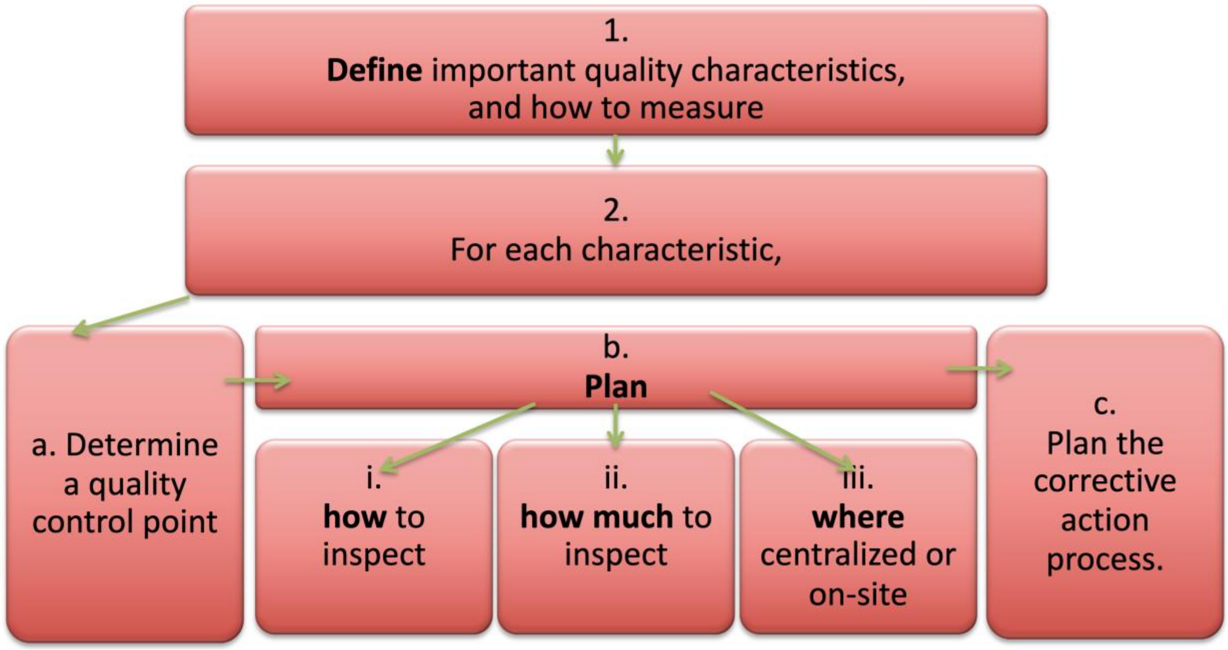
4.2 Statistical Quality Control

- **Statistical Quality Control:** Uses statistical techniques and sampling to monitor and test the quality of goods and services (acceptance sampling – accept or reject, statistical process control – if process is operating within acceptable limits)
- Inspection: The appraisal of goods/services against standards

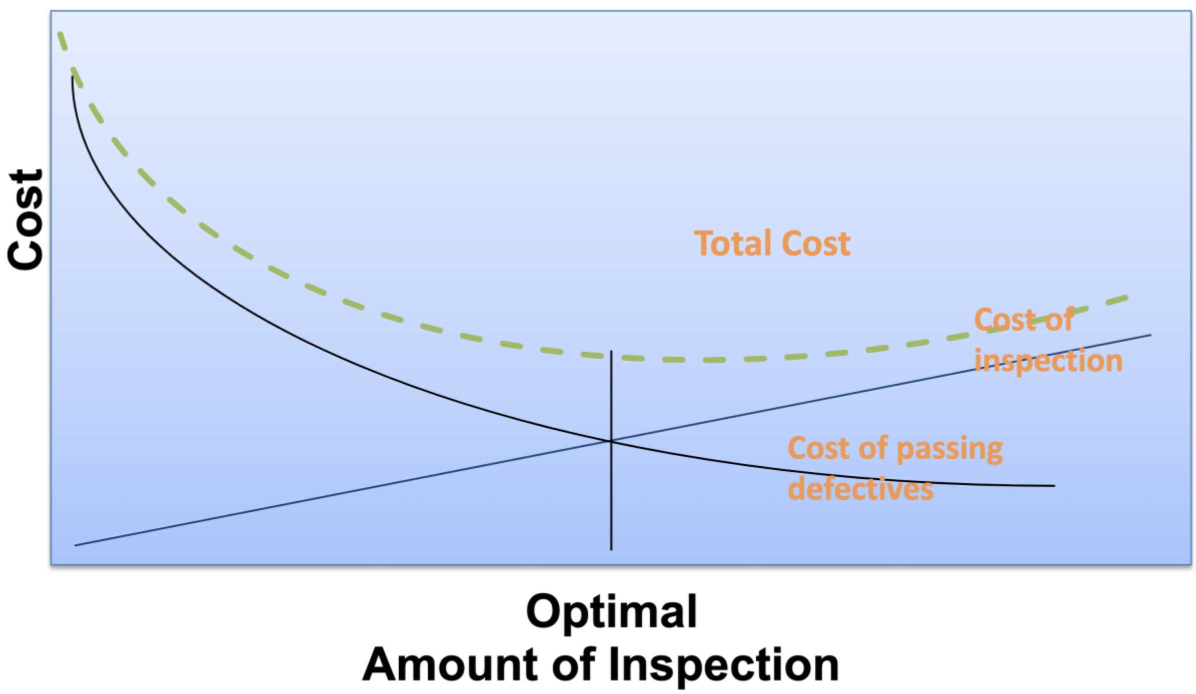
Phases of Quality Control



4.2.1 Elements of Statistical Process Control (SPC) Process



Inspection Costs:

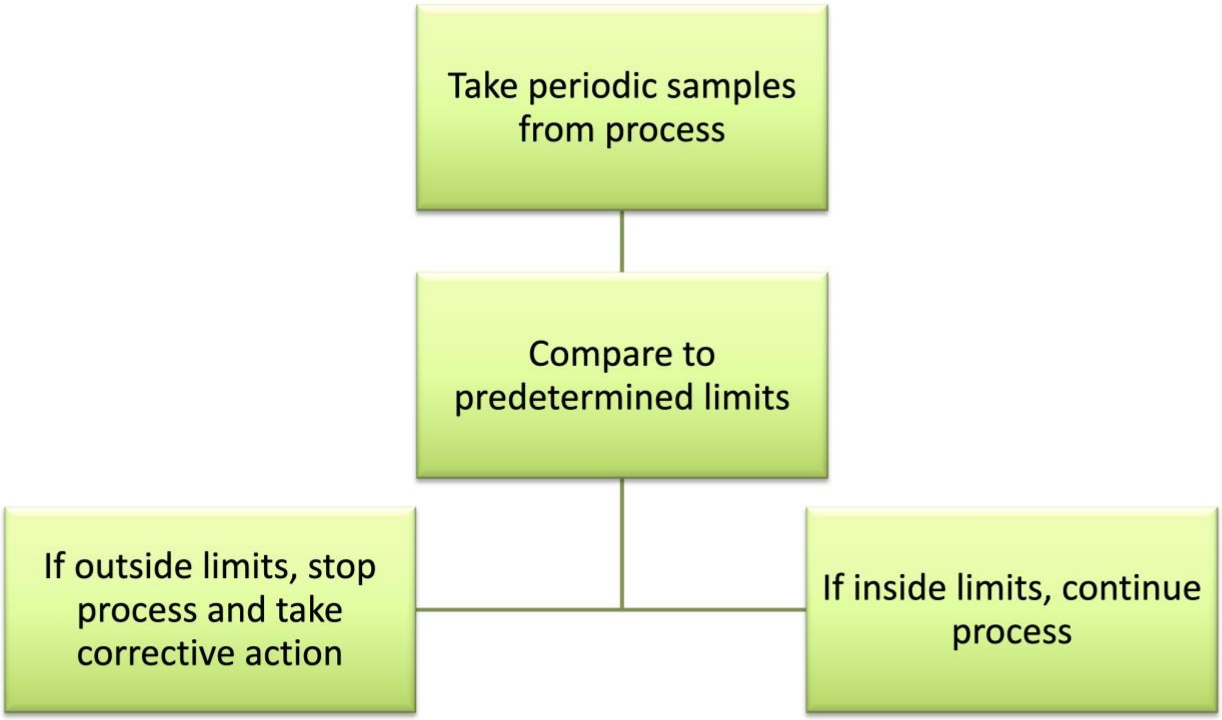


Statistical Process Control:

1. The quality control steps
2. Type of variations
3. Control charts

4. Designing control charts
5. Individual unit and moving range charts
6. Control charts for attributes
7. Using control charts

Steps:

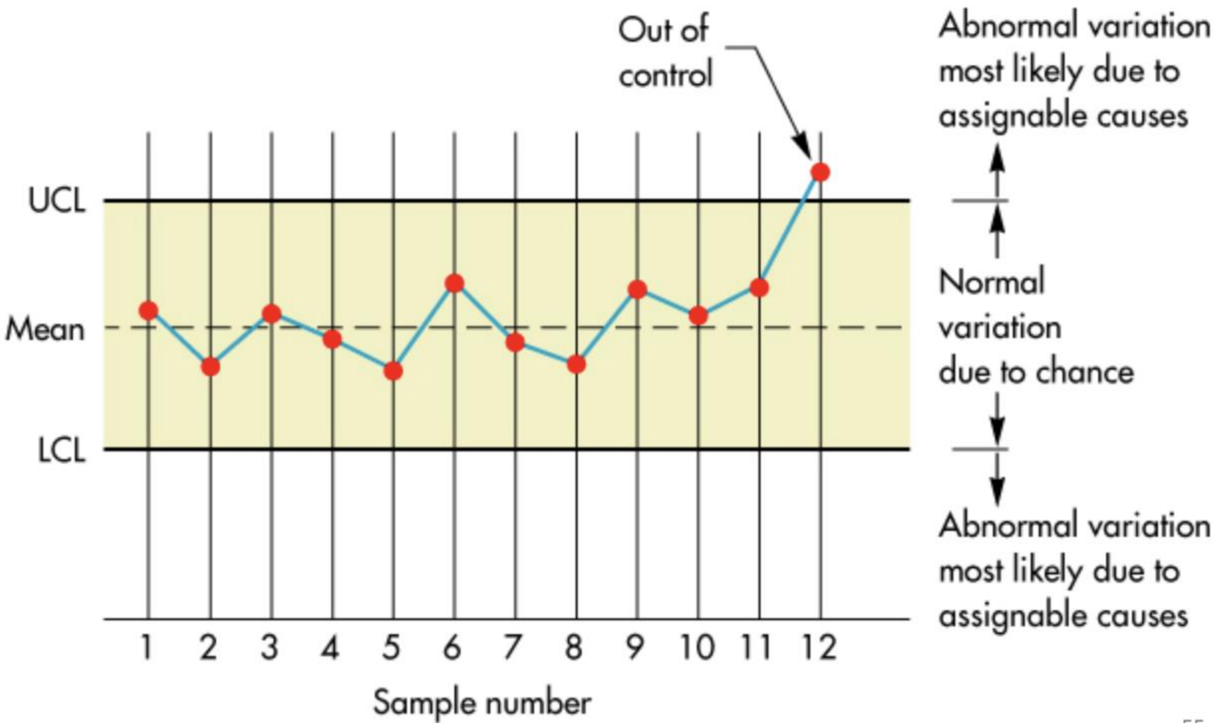


Types of Variations: Random variation (natural), assignable variation (source can be identified)

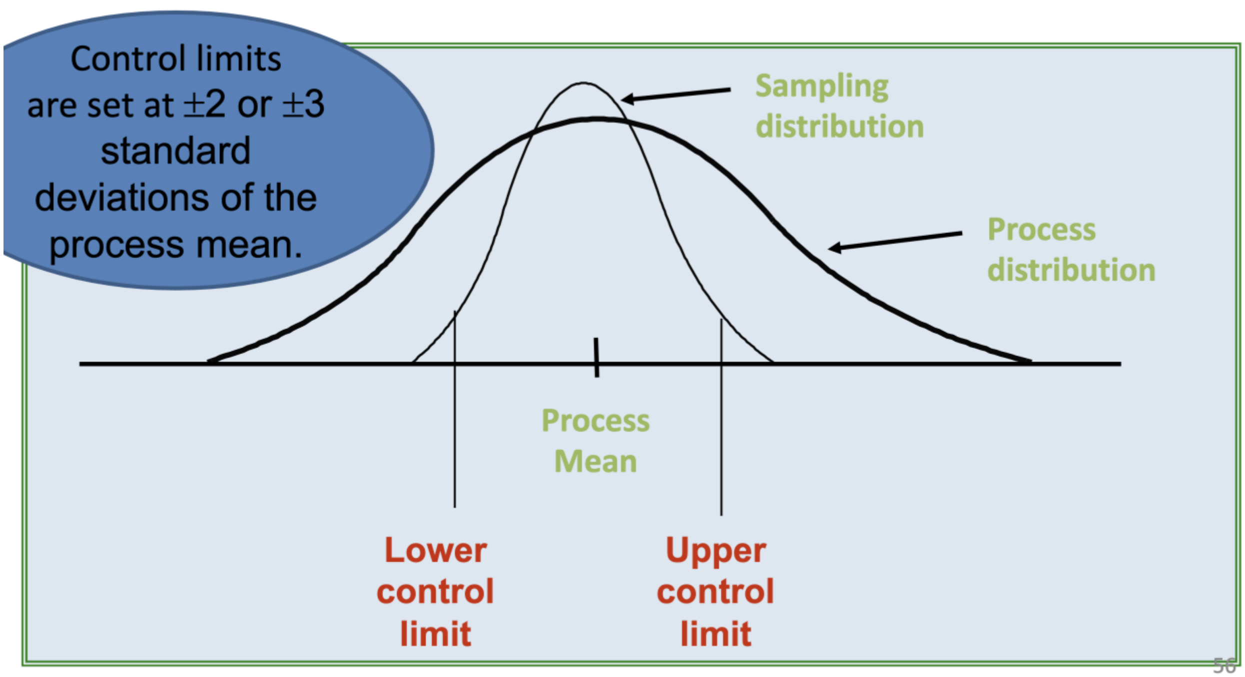
4.2.2 Control Charts

Purpose: To monitor process output to distinguish between random and assignable variation

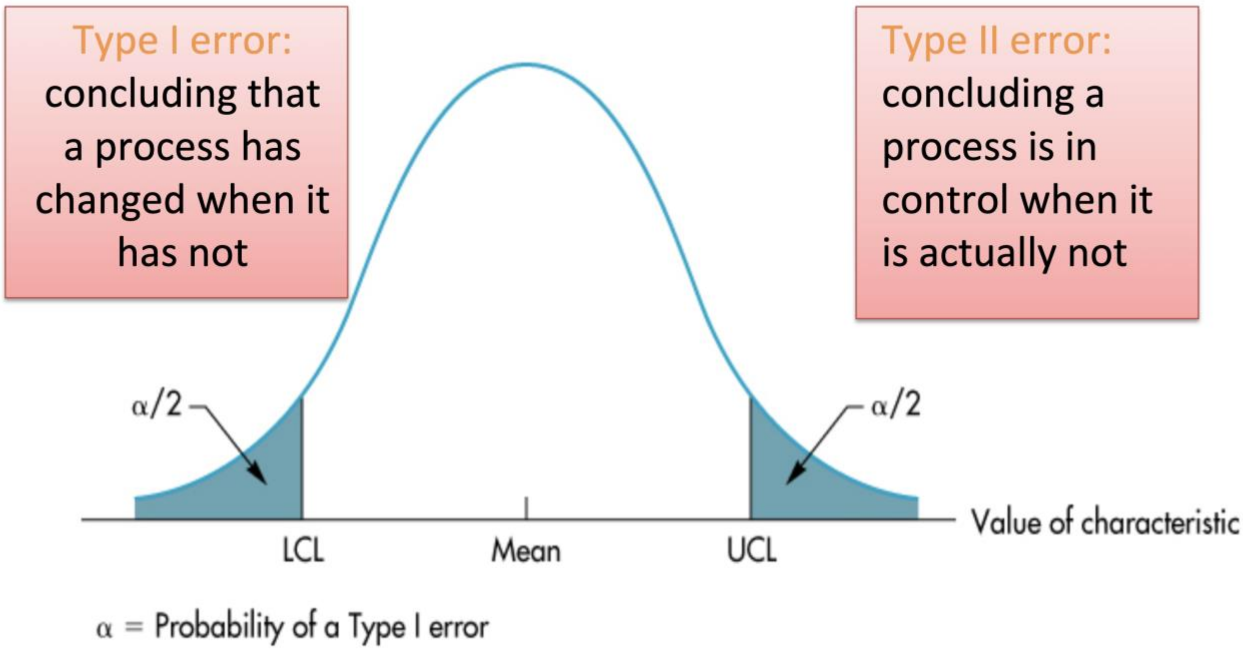
Example:



Control Limits: The dividing lines between random and non-random deviations from the process mean



Type I and Type II Errors:



Conclusion

Actually

	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
2. Obtain 20 to 25 samples
3. Establish and graph preliminary control limits
4. Plot sample statistic values on control chart
5. Are any points outside control limits (CL)?
    a. NO: Assume no assignable cause
    b. YES: Investigate and correct

Control Charts for Variables: Variables generate data that are <u>measured</u>, sample mean/range

Upper and Lower Control Limits for Sample Mean Chart:

$$UCL_{\bar{x}} = \bar{\bar{X}} + z\sigma_{\bar{x}}$$

$$LCL_{\bar{x}} = \bar{\bar{X}} - z\sigma_{\bar{x}}$$

Where:

$$\sigma_x = Standard\ deviation\ of\ sampling\ distribution\ of\ sample\ means = \frac{\sigma}{\sqrt{n}}$$

$$\sigma = Process\ standard\ deviation$$

$$n = Sample\ size$$

$$z = Standard\ normal\ deviate\ (usually\ z = 3)$$

$$\bar{\bar{X}} = Average\ of\ sample\ means\ (grand\ mean)$$

Example:

A quality inspector took five samples, each with four observations, of the length of a part (in cm). She computed the mean of each sample (see table below).

a. Use the following data to obtain Three Sigma (i.e., $z = 3$) control limits for sample mean. Is the process in control?

b. If a new sample has values 12.10, 12.19, 12.12, and 12.14, using the sample mean control chart in part *a*, has the process mean changed (i.e., is there an assignable variation)?

It is known from previous experience that the standard deviation of the process is .02 cm.

		Sample				
		1	**2**	**3**	**4**	**5**
Observation	**1**	12.11	12.15	12.09	12.12	12.09
	2	12.10	12.12	12.09	12.10	12.14
	3	12.11	12.10	12.11	12.08	12.13
	4	12.08	12.11	12.15	12.10	12.12
	$\bar{x}$	12.10	12.12	12.11	12.10	12.12

a. $\bar{\bar{X}} = \frac{12.10+12.12+12.11+12.10+12.12}{5} = 12.11\ cm$

$$UCL_{\bar{x}} = 12.11 + 3\left(\frac{0.02}{\sqrt{4}}\right) = 12.14$$

$$LCL_{\bar{x}} = 12.11 - 3\left(\frac{0.02}{\sqrt{4}}\right) = 12.08$$

All 5 sample means fall between the control limits; the process is in control.

b. $\overline{x_6} = \frac{12.10+12.19+12.12+12.14}{4} = 12.1375\ cm$

Because $12.08 < 12.1375 < 12.14$, the process mean has not changed.

Upper and Lower Control Limits Alternate Method:

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

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

Where:

A_2 *can be obtained from table below*

$\bar{R}$ = *Average of sample ranges*

Sample range = *Maximum value* − *minimum value in the sample*

$\bar{\bar{X}}$ = *Average of sample means (grand mean)*

Range Table

Number of Observations in Sample, n	Factor for $\bar{x}$ Charts, A_2	Factors for R-Charts: Lower Control Limit, D_3	Factors for R-Charts: Upper Control Limit, D_4
2	1.88	0	3.27
3	1.02	0	2.57
4	0.73	0	2.28
5	0.58	0	2.11
6	0.48	0	2.00
7	0.42	0.08	1.92
8	0.37	0.14	1.86
9	0.34	0.18	1.82
10	0.31	0.22	1.78
11	0.29	0.26	1.74
12	0.27	0.28	1.72
13	0.25	0.31	1.69
14	0.24	0.33	1.67
15	0.22	0.35	1.65
16	0.21	0.36	1.64
17	0.20	0.38	1.62
18	0.19	0.39	1.61
19	0.19	0.40	1.60
20	0.18	0.41	1.59

Example:

- Twenty samples of *n* = 8 have been taken of the weight of a part. The average of sample ranges for the 20 samples is .016kg, and the average of sample means is 3kg. Determine three sigma control limits for sample mean of this process.

$$\bar{\bar{X}} = 3, \bar{R} = 0.016, A_2 = 0.37\ (for\ n = 8\ from\ table)$$

$$UCL_{\bar{x}} = \bar{\bar{X}} + A_2\bar{R} = 3 + 0.37(0.016) = 3.006\ kg$$

$$LCL_{\bar{x}} = \bar{\bar{X}} - A_2\bar{R} = 3 - 0.37(0.016) = 2.994\ kg$$

Upper and Lower Control Limits for Sample Range Control Chart:

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

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

Example:

- Twenty-five samples of *n*=10 observations have been taken from a milling process. The average of sample ranges is .01 centimetre. Determine upper and lower control limits for sample range.

$$\bar{R} = 0.01\ cm, D_3 = 0.22, D_4 = 1.78\ (for\ n = 10, from\ table)$$

$$UCL_R = D_4\bar{R} = 1.78(0.01) = 0.0178\ cm$$

$$LCL_R = D_3\bar{R} = 0.22(0.01) = 0.0022\ cm$$

Example:

	Observation				
Sample	1	2	3	4	5
1	10.68	10.69	10.78	10.80	10.71
2	10.79	10.86	10.60	10.75	10.78
3	10.78	10.67	10.84	10.79	10.72
4	10.59	10.73	10.81	10.78	10.73
5	10.69	10.71	10.79	10.76	10.67
6	10.75	10.71	10.74	10.72	10.61
7	10.79	10.71	10.69	10.88	10.60
8	10.74	10.78	10.11	10.74	10.75
9	10.77	10.77	10.64	10.64	10.73
10	10.72	10.67	10.71	10.85	10.71
11	10.79	10.82	10.76	10.66	10.71
12	10.62	10.80	10.82	10.87	10.73
13	10.66	10.82	10.89	10.54	10.75
14	10.81	10.75	10.86	10.80	10.70
15	10.66	10.68	10.64	10.75	10.73

Calculate sample means, sample ranges, grand mean, and average of sample ranges:

	Observations						
Sample	1	2	3	4	5	Mean	Range
1	10.68	10.69	10.78	10.80	10.71	10.73	0.12
2	10.79	10.86	10.60	10.75	10.78	10.75	0.26
3	10.78	10.67	10.84	10.79	10.72	10.76	0.17
4	10.59	10.73	10.81	10.78	10.73	10.73	0.22
5	10.69	10.71	10.79	10.76	10.67	10.72	0.12
6	10.75	10.71	10.74	10.72	10.61	10.71	0.14
7	10.79	10.71	10.69	10.88	10.60	10.73	0.27
8	10.74	10.78	10.11	10.74	10.75	10.62	0.67
9	10.77	10.77	10.64	10.64	10.73	10.71	0.13
10	10.72	10.67	10.71	10.85	10.71	10.73	0.18
11	10.79	10.82	10.76	10.66	10.71	10.75	0.16
12	10.62	10.80	10.82	10.87	10.73	10.77	0.25
13	10.66	10.82	10.89	10.54	10.75	10.73	0.35
14	10.81	10.75	10.86	10.80	10.70	10.78	0.16
15	10.66	10.68	10.64	10.75	10.73	10.69	0.10
				Averages		**10.73**	**0.22**

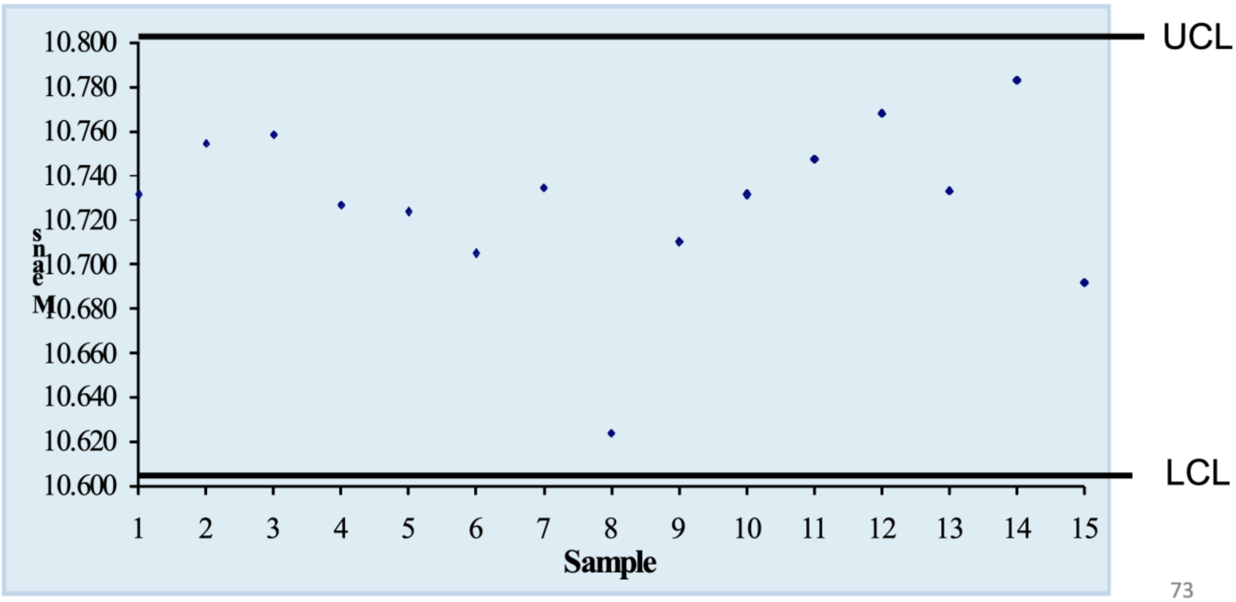
Determine control limits:

$$From\ table, with\ n = 5 \rightarrow A_2 = 0.58$$

$$UCL_{\bar{x}} = \bar{\bar{X}} + A_2\bar{R} = 10.728 + 0.58(0.2204) = 10.856$$

$$LCL_{\bar{x}} = \bar{\bar{X}} - A_2\bar{R} = 10.728 - 0.58(0.2204) = 10.601$$

Create sample mean chart and plot values:



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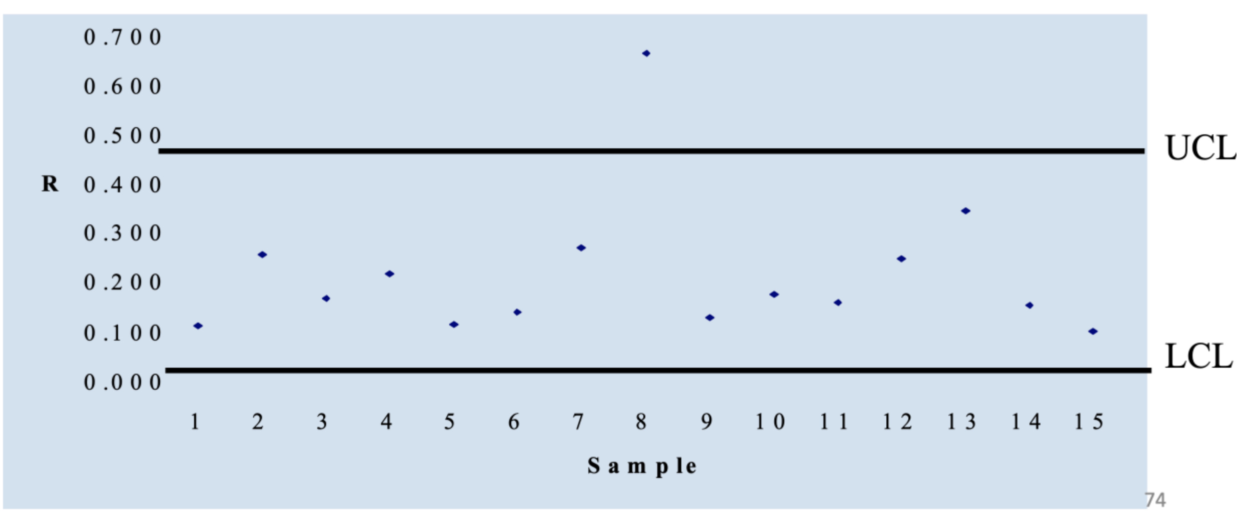
Create sample range chart and plot values:

$$From\ table, with\ n = 5 \rightarrow D_3 = 0, D_4 = 2.11$$

$$UCL_R = D_4\bar{R} = (2.11)(0.2204) = 0.46504$$

$$LCL_R = D_3\bar{R} = (0)(0.2204) = 0$$



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