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

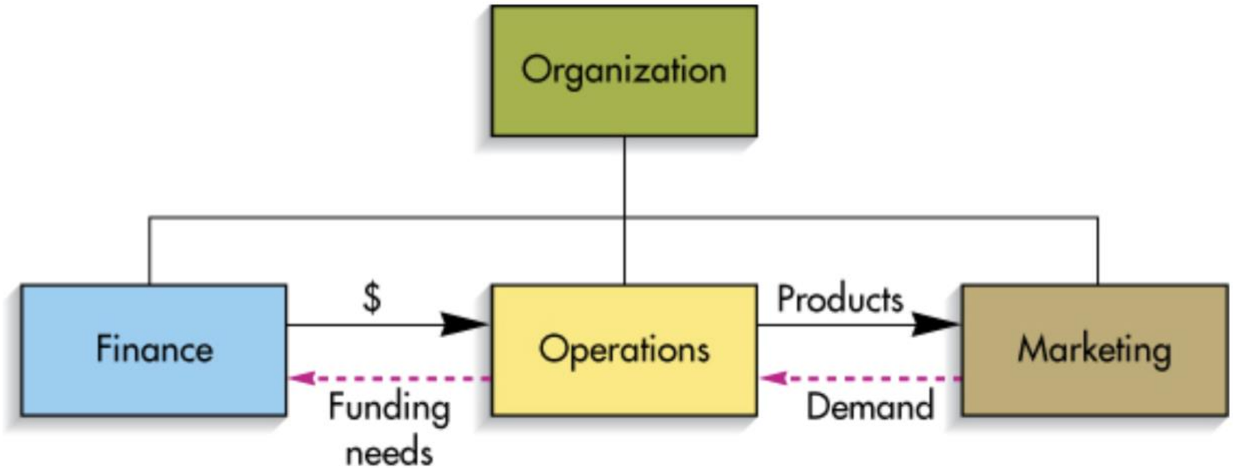
Three Basic Functions:

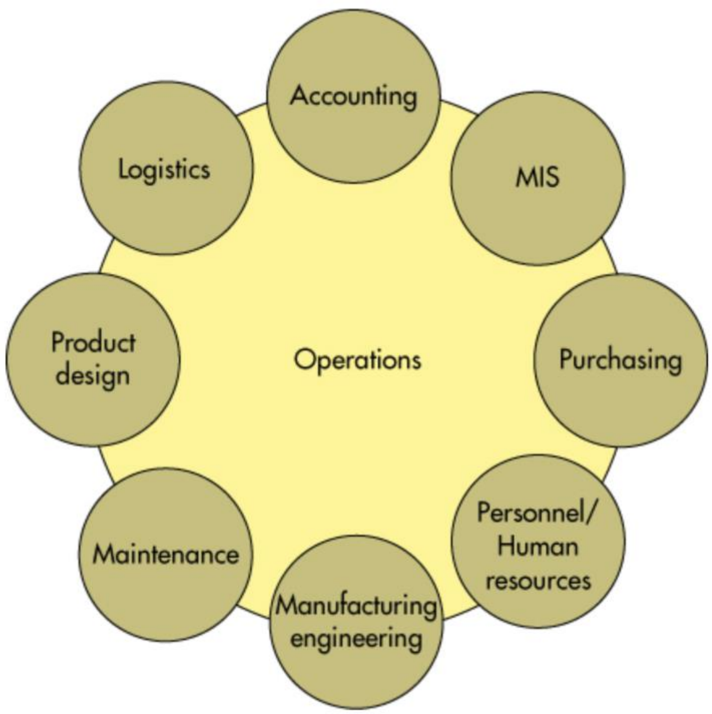
1. Operations: Create goods and services
2. Finance: Provide funds and the economic analysis of investment proposals
3. Marketing: Assess customer wants and needs and communicate them to others

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?

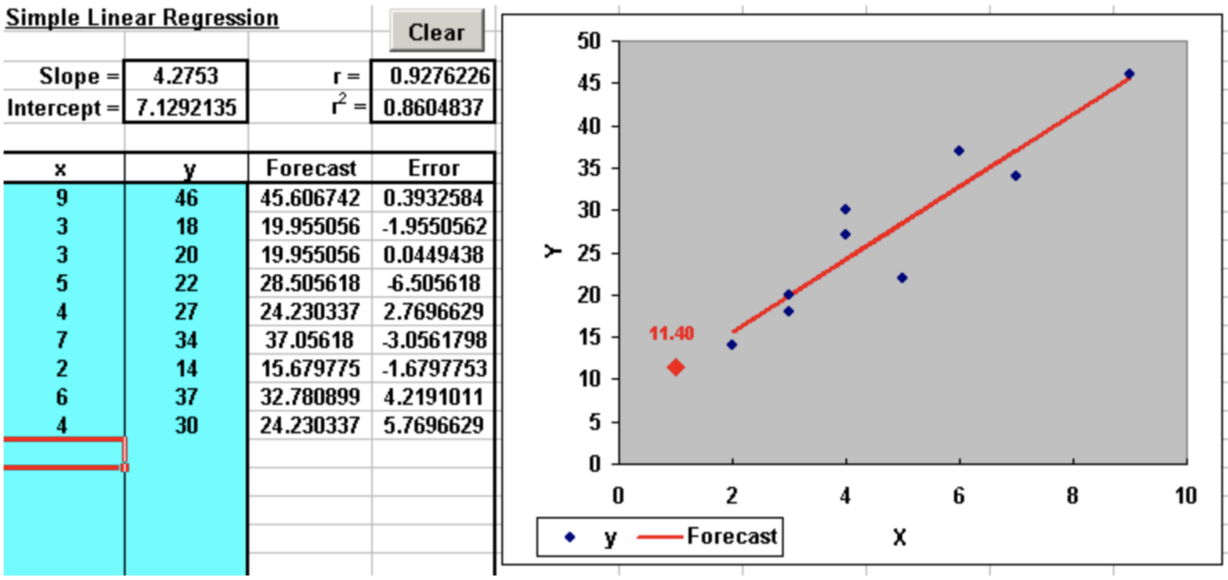
1. Find (predictor) variables associated with ridership at other stations
2. $Associated = correlated = as\ one\ moves\ the\ other\ moves$
3. Create a model that shows the relationship between the predictor variables and the predicted variable (ex. ridership)
4. Technique is regression analysis (ex. 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



Simple Linear Regression

Slope =	4.2753	r =	0.9276226
Intercept =	7.1292135	r^2 =	0.8604837

x	y	Forecast	Error
9	46	45.606742	0.3932584
3	18	19.955056	-1.9550562
3	20	19.955056	0.0449438
5	22	28.505618	-6.505618
4	27	24.230337	2.7696629
7	34	37.05618	-3.0561798
2	14	15.679775	-1.6797753
6	37	32.780899	4.2191011
4	30	24.230337	5.7696629

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 Error^2	$\frac{\|Error\|}{Actual} \times 100$
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,

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

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

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

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:

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

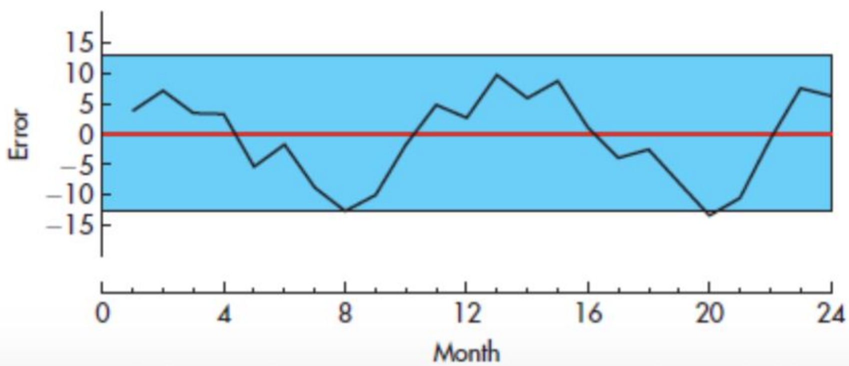
$$= \sqrt{\frac{\sum 4^2 + 7^2 + 4^2 + 4^2 + (-5)^2 + (-2)^2 + (-8)^2 + (-12)^2}{8}} = 6.46$$

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:

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

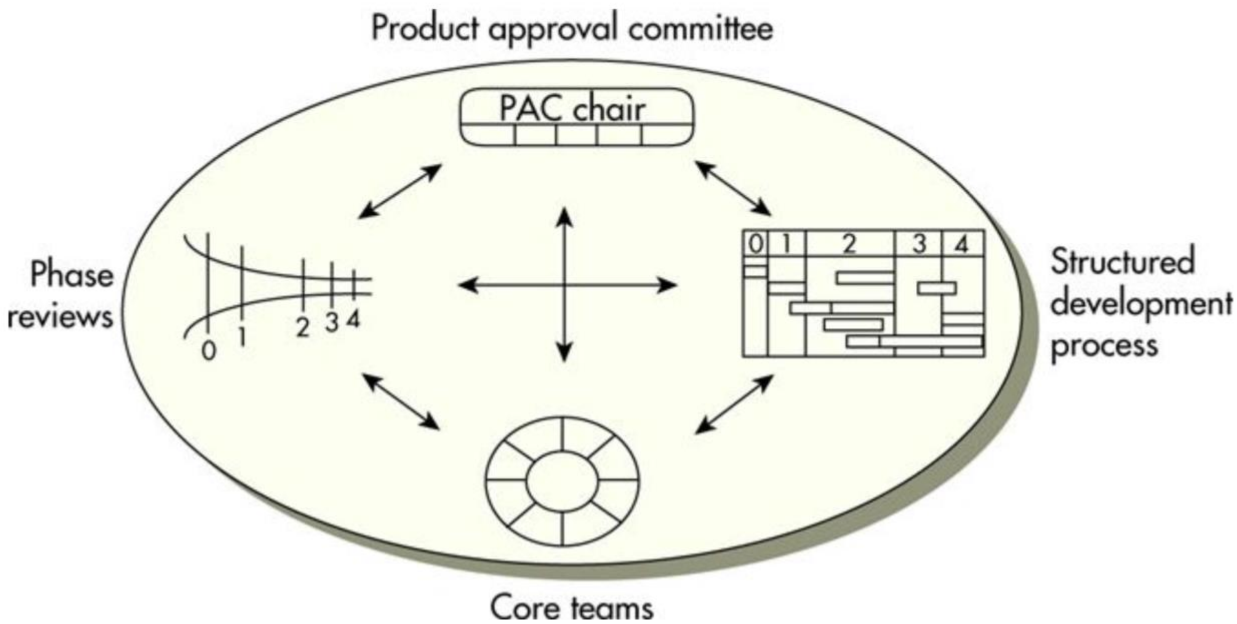
2.2 Product Design

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