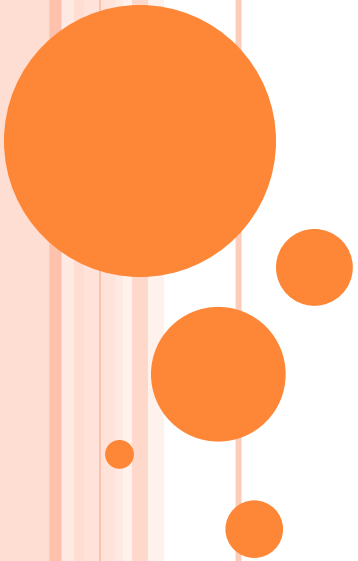
Aggregate Planning in a Supply Chain



Learning Objectives

- Identify the decisions that are best solved by aggregate planning.
- Understand the importance of aggregate planning as a supply chain activity.
- Describe the information needed to produce an aggregate plan.
- Explain the basic trade-offs to consider when creating an aggregate plan.
- Formulate and solve basic aggregate planning problems using Microsoft Excel.

Role of Aggregate Planning in a Supply Chain

- If manufacturing, transportation, warehousing, and even information capacity are all limitless and free and lead time is zero for any product then there is no use of aggregate planning.
- Real world is different. Capacity has its cost and lead times are never zero.
- So the company has to take decision based on anticipation of demand levels, production levels

Role of Aggregate Planning in a Supply Chain

- Aggregate planning: A Process by which a company determines ideal levels of capacity, production, subcontracting, inventory, stock outs, and even pricing over a specified time horizon.
- It solves problems involving aggregate decisions rather than stock-keeping unit (SKU)-level decisions.
- It is a useful tool for thinking about decisions with an intermediate time frame of between roughly 3 and 18 months

Role of Aggregate Planning in a Supply Chain

- It answers the question "How should a firm best utilize the facilities that it currently has?"
- It is an important supply chain issue and is focused within an enterprise.
- Collaborative forecasts are input for aggregate planning and are from both upstream and downstream
- Production plans for a firm define demand for suppliers and establish supply constraints for customers

Role of Aggregate Planning in a Supply Chain

Example: A premium paper supply chain

- Demand ripples up from customers to printers to distributors and finally to the manufacturers. It has demand peaks in summer and may have fall in other periods. Building a mill with capacity to meet demand in peak & fall on an as-needed basis is too costly, because of the high cost. Aggregate planning is used to determine production levels and inventory levels that should be built up for demand which may be at peak or fall.

Role of Aggregate Planning in a Supply Chain

Operational parameters needed to be identified:

- **Production Rate**: the number of units to be completed per unit time
- **Workforce**: the number of workers/units of capacity needed
- **Overtime**: the amount of overtime production planned

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Role of Aggregate Planning in a Supply Chain

- **Machine Capacity Level**: the number of units of machine capacity
- **Subcontracting**: the subcontracted capacity required over the planning horizon
- **Backlog**: demand not satisfied in the period in which it arises but carried over to future periods
- **Inventory on Hand**: the planned inventory carried over the various periods in the planning horizon

Role of Aggregate Planning in a Supply Chain

- Aggregate plan serves as a blueprint for establishing the parameters and allows the supply chain to alter capacity allocations and change supply contracts.
- All stages of the supply chain should work together. If each stage develops its own aggregate plan independently there will not be any coordination and it will create shortage/ oversupply.

The Aggregate Planning Problem

- "Given the demand forecast for each period in the planning horizon, determine the production level, inventory level, and capacity level (internal and outsourced) for each period that maximizes the firm's profit over the planning horizon."

The Aggregate Planning Problem

Parameters needed to create aggregate plan:

- **Planning horizon**: time period over which the aggregate plan is to produce a solution-usually between 3 and 18 months
- **Duration** of each period
- **Key information**: It is used to produce an aggregate plan and to make the decisions for which the aggregate plan will develop recommendations based on which recommendations are specified for a generic aggregate planning problem

The Aggregate Planning Problem

Information required by aggregate planner:

- **Demand forecast** F_t for each Period t in a planning horizon that extends over T periods
- **Production costs**
  - Labor costs, regular time ($/hr) and overtime
  - Subcontracting costs ($/hr or $/unit)
  - Cost of changing capacity – hiring or layoff ($/worker), adding or reducing machine capacity ($/machine)

The Aggregate Planning Problem

- Labor/machine hours required per unit
- Inventory holding cost ($/unit/period)
- Stockout or backlog cost ($/unit/period)

Constraints:

- Limits on overtime
- Limits on layoffs
- Limits on capital available
- Limits on stockouts and backlogs
- Constraints from suppliers to the enterprise

The Aggregate Planning Problem

Using previous information, following output are obtained:

- **Production Quantity from Regular time, Overtime, and Subcontracted Time:** used to determine number of workers and supplier purchase levels
- **Inventory Held:** used to determine the warehouse space and working capital required

Cont...

The Aggregate Planning Problem

- **Backlog/ Stockout Quantity:** used to determine customer service levels
- **Workforce Hired/Laid Off:** used to determine any labor issues likely to be encountered
- **Machine Capacity Increase/Decrease**: used to determine if new production equipment should be purchased or idled

Identifying Aggregate Units of Production

- Aggregate unit should be identified in a way that the resulting production schedule can be accomplished in practice
- Focus on the bottlenecks when selecting the aggregate unit and identifying capacity and production times
- Account for activities such as setups and maintenance

Red Tomato Tools

Family	Material Cost/ Unit ($)	Revenue/ Unit ($)	Setup Time/Batch (hour)	Average Batch Size	Production Time/ Unit (hour)	Net Production Time/Unit (hour)	Percentage Share of Units Sold
A	15	54	8	50	5.60	5.76	10
B	7	30	6	150	3.00	3.04	25
C	9	39	8	100	3.80	3.88	20
D	12	49	10	50	4.80	5.00	10
E	9	36	6	100	3.60	3.66	20
F	13	48	5	75	4.30	4.37	15

Table 8-1

Red Tomato Tools

- Weighted average approach

  Material cost per aggregate unit

  = 15 x 0.10 + 7 x 0.25 + 9 x 0.20 + 12 x 0.10 + 9 x 0.20 +

  13 x 0.15

  = $10

- Similarly

  Revenue per aggregate unit = $40

  Net production time per aggregate unit = 4.00 hours

Aggregate Planning Strategies

- Trade-offs among capacity, inventory, and backlog costs. Decreasing one cost increases other two costs. Most profitable combination is achieved.
- Varying demand makes one of the cost become a key lever for planner.

Aggregate Planning Strategies

- If the cost of varying capacity is low, there is no need to build inventory or carry backlogs. If the cost of varying capacity is high, it may be compensated by building inventory and carrying backlogs from peak demand periods to off-peak demand periods

Aggregate Planning Strategies

- Three distinct aggregate planning strategies for achieving balance between these costs. combination of these three and are referred to as *tailored strategies*

1.Chase strategy-using capacity as the lever

2.Time flexibility from workforce or capacity strategy-using utilization as the lever

3. Level strategy-using inventory as the lever:

Chase Strategy

- The production rate is synchronized with the demand rate
- Faces difficulty of varying capacity and workforce on short notice.
- High cost of varying machine or labor capacity over time makes it expensive and can cause negative impact on workforce
- Used when the cost of carrying inventory is very high and other costs are low

Time Flexibility Strategy

- Used if there is excess machine capacity. The workforce (capacity) is kept stable but the number of hours worked is varied over time
- Variable amounts of overtime or a flexible schedule can be used to synchronize production with demand.
- Results in results in low levels of inventory with lower average machine utilization
- Avoids the problem of changing the size of workforce.
- Used when inventory carrying costs are high and machine capacity is inexpensive

Level Strategy

- A stable machine capacity and workforce are maintained with a constant output rate. Shortages and surpluses fluctuate inventory levels. Production is not synchronized with demand
- Inventories are built up in anticipation of demand or backlogs are carried over from high- to low-demand periods

Cont...

Level Strategy

- Drawback: large inventories may accumulate and customer orders may be delayed.
- It keeps capacity and costs of changing capacity low
- Used when inventory carrying and backlog costs are relatively low.

Aggregate Planning Using Linear Programming

- Certain constraints, such as the capacity of its facilities or a supplier's ability to deliver a component are faced while trying to meet customer demand
- *Linear programming* finds the solution that creates the highest profit while satisfying the constraints that the company faces.
- Linear programming is explained through the discussion of Red Tomato Tools, a small manufacturer of gardening equipments

Aggregate Planning Using Linear Programming

- A six-month time period i used for illustration

Month	Demand Forecast
January	1,600
February	3,000
March	3,200
April	3,800
May	2,200
June	2,200

Table 8-2

Red Tomato Tools

- The demand for Red Tomato's gardening tools from consumers is highly seasonal and aggregate planning used to overcome the obstacle of seasonal demand and maximize profits
- Options available are adding workers during the peak season, subcontracting out some of the work, building up inventory during the slow months, or building up a backlog of orders
- To select the best option, a attempt is made to build demand forecast

Red Tomato Tools

- The various costs are shown in Table 8-3.

Item	Cost
Material cost	$10/unit
Inventory holding cost	$2/unit/month
Marginal cost of stockout/backlog	$5/unit/month
Hiring and training costs	$300/worker
Layoff cost	$500/worker
Labor hours required	4/unit
Regular time cost	$4/hour
Overtime cost	$6/hour
Cost of subcontracting	$30/unit

Table 8-3

Red Tomato Tools

- Optimal aggregate plan is one that results in the highest profit over the six month planning horizon
- Red Tomato's desire for a very high level of customer service, assume all demand is to be met, although it can be met late
- The revenues earned over the planning horizon are fixed which results in minimizing cost over the planning horizon & it is the same as maximizing profit

Red Tomato Tools

- Decision variables

For $t = 1, \ldots, 6$

W_t = Workforce size for month t

H_t = Number of employees hired at the beginning of month t

L_t = Number of employees laid off at the beginning of month t

P_t = Production in month t

I_t = Inventory at the end of month t

S_t = Number of units stocked out at the end of month t

C_t = Number of units subcontracted for month t

O_t = Number of overtime hours worked in month t

Red Tomato Tools Objective Function

- The objective function is to minimize the total cost incurred during the planning horizon which are
- Regular-time labor cost
- Overtime labor cost
- Cost of hiring and layoffs
- Cost of holding inventory
- Cost of stocking out
- Cost of subcontracting
- Material cost

Red Tomato Tools Objective Function

1. ***Regular-time labor cost:***

- The workers are paid a regular-time wage of $640 ($4/hour X 8 hours/day X 20 days/month) per month

$$\text{Regular-time labor cost} = \sum_{t=1}^{6} 640 W_t$$

Red Tomato Tools Objective Function

2. *Overtime labor cost*:

As overtime labor cost is $6 per hour

$$\text{Overtime labor cost} = \sum_{t=1}^{6} 6O_t$$

Red Tomato Tools Objective Function

3. *Cost of hiring and layoffs*

- The cost of hiring a worker is $300 and the cost of laying off a worker is $500

$$\text{Cost of hiring and layoff} = \sum_{t=1}^{6} 300H_t + \sum_{t=1}^{6} 500L_t$$

Red Tomato Tools Objective Function

4. Cost of inventory and stockout.

The cost of carrying inventory is $2 per unit per month, and the cost of stocking out is $5 per unit per month

$$\text{Cost of holding inventory and stocking out} = \sum_{t=1}^{6} 2I_t + \sum_{t=1}^{6} 5S_t$$

Red Tomato Tools Objective Function

5. Cost of materials and subcontracting.

The material cost is $10 per unit and the subcontracting cost is $30/unit

$$\text{Cost of materials and subcontracting} = \sum_{t=1}^{6} 10P_t + \sum_{t=1}^{6} 30C_t$$

Red Tomato Tools Objective Function

- So we get the objective function as follows

$$Min \sum_{t=1}^{6} 640 W_t + \sum_{t=1}^{6} 6 O_t + \sum_{t=1}^{6} 300 H_t + \sum_{t=1}^{6} 500 L_t$$

$$+ \sum_{t=1}^{6} 2 I_t + \sum_{t=1}^{6} 5 S_t + \sum_{t=1}^{6} 10 P_t + \sum_{t=1}^{6} 30 C_t$$

Red Tomato Tools Constraints

All for $t = 1, \ldots, 6$

- Workforce, hiring, and layoff constraints

$$W_t = W_{t-1} + H_t - L_t$$

- Capacity constraints

$$P_t \leq 40W_t + \frac{O_t}{4}$$

- Inventory balance constraints

$$I_{t-1} + P_t + C_t = D_t + S_{t-1} + I_t - S_t$$

- Overtime limit constraints

$$O_t \leq 10W_t$$

Red Tomato Tools Constraints

- Observe that one can easily add constraints that limit the amount ·purchased from subcontractors each month or the maximum number of employees to be hired or laid off. Any other constraints limiting backlogs or inventories can also be accommodated.

Red Tomato Tools

- If we assume the average inventory in Period *t* *to be the average of the starting and* ending inventories, that is, *(I_{t-1} +I_t)/2, the average inventory over the planning horizon* is given by

$$\text{Average inventory} = \frac{(I_0 + I_T)/2 + \left(\sum_{t=1}^{T-1} I_t\right)}{T}$$

Red Tomato Tools

- The average time that units spend in inventory over the planning horizon is obtained using Little's law (average flow time = average inventory/throughput).

Average time in inventory is given as

$$\text{Average time in inventory} = \left[\frac{(I_0 + I_T)/2 + \left(\sum_{t=1}^{T-1} I_t\right)}{T}\right] \Big/ \left[\frac{\left(\sum_{t=1}^{T-1} D_t\right)}{T}\right]$$

Red Tomato Tools

Period, t	No. Hired, H_t	No. Laid Off, L_t	Workforce Size, W_t	Overtime, O_t	Inventory, I_t	Stockout, S_t	Subcontract, C_t	Total Production, P_t
0	0	0	80	0	1,000	0	0	
1	0	15	65	0	1,983	0	0	2,583
2	0	0	65	0	1,567	0	0	2,583
3	0	0	65	0	950	0	0	2,583
4	0	0	65	0	0	267	0	2,583
5	0	0	65	0	117	0	0	2,583
6	0	0	65	0	500	0	0	2,583

Aggregate plan is obtained as shown

Total cost over planning horizon = $422,275

Revenue over planning horizon

= 40 x 16,000 = $640,000

Red Tomato Tools

Average seasonal inventory

$$= \frac{(I_0 + I_6)/2 + \left(\sum_{t=1}^{5} I_t\right)}{T} = \frac{5{,}367}{6} = 895$$

$$\text{Average flow time} = \frac{895}{2{,}667} = 0.34 = 0.34 \text{ months}$$

Red Tomato Tools

- If the seasonal fluctuation of demand grows, synchronization of supply and demand becomes more difficult

Red Tomato Tools

- *Example 8-1* All the data are exactly the same as in previous discussion of Red Tomato, except for the demand forecast. Assume that the same overall demand (16,000 units) is distributed over the six months in such a way that the seasonal fluctuation of demand is higher, as shown in Table 8-4. Obtain the optimal aggregate plan in this case.

Red Tomato Tools

Month	Demand Forecast
January	1,000
February	3,000
March	3,800
April	4,800
May	2,000
June	1,400

Table 8-5

$$\text{Average seasonal inventory} = \frac{(I_0 + I_T)/2 + \left(\sum_{t=1}^{T-1} I_t\right)}{T} = \frac{6,450}{6} = 1,075$$

Red Tomato Tools

Table 8-6

Period, t	No. Hired, H_t	No. Laid Off, L_t	Workforce Size, W_t	Overtime, O_t	Inventory, I_t	Stockout, S_t	Subcontract, C_t	Total Production, P_t
0	0	0	80	0	1,000	0	0	
1	0	15	65	0	2,583	0	0	2,583
2	0	0	65	0	2,167	0	0	2,583
3	0	0	65	0	950	0	0	2,583
4	0	0	65	0	0	1,267	0	2,583
5	0	0	65	0	0	683	0	2,583
6	0	0	65	0	500	0	0	2,583

Total cost over planning horizon = $432,858

$$\text{Average flow time} = \frac{1{,}075}{2{,}667} = 0.40 \text{ months}$$

Red Tomato Tools

- Lower hiring and layoff costs

Total cost over planning horizon = $412,688

$$\text{Average seasonal inventory} = \frac{(I_0 + I_T)/2 + \left(\sum_{t=1}^{T-1} I_t\right)}{T} = \frac{2{,}500}{6} = 417$$

$$\text{Average flow time} = \frac{417}{2{,}667} = 0.16 \text{ months}$$

Red Tomato Tools

Period, t	No. Hired, H_t	No. Laid Off, L_t	Workforce Size, W_t	Overtime, O_t	Inventory, I_t	Stockout, S_t	Subcontract, C_t	Total Production, P_t
0	0	0	80	0	1,000	0	0	
1	0	35	45	0	1,200	0	0	2,267
2	0	0	45	0	0	0	0	2,267
3	42	0	87	0	300	0	0	2,267
4	0	0	87	0	0	1,267	0	2,267
5	0	26	61	0	250	683	0	2,267
6	0	0	61	0	500	0	0	2,267

Table 8-7

Forecast Error in Aggregate Plans

- There is always an error in forecast which is needed to be considered to improve quality of forecast.
- Forecasting errors are dealt with using 2 parameters

1. ***Safety inventory***, defined as inventory held to satisfy demand that is higher than forecasted (discussed
2. ***Safety capacity***, *defined as capacity used to satisfy* demand that is higher than forecasted.

Forecast Error in Aggregate Plans

There are several ways to create buffer for forecast error.

- Use overtime as a form of safety capacity.
- Carry extra workforce permanently as a form of safety capacity.
- Use subcontractors as a form of safety capacity.
- Build and carry extra inventories as a form of safety inventory.
- Purchase capacity or product from an open or spot market as a form of safety capacity.

Aggregate Planning In Excel

- Create a table containing the following decision variables:

For $t = 1, \ldots, 6$

W_t = Workforce size for Month t

H_t = Number of employees hired at the beginning of Month t

L_t = Number of employees laid off at the beginning of Month t

P_t = Production in Month t

I_t = Inventory at the end of Month t

S_t = Number of units stocked out at the end of Month t

C_t = Number of units subcontracted for Month t

O_t = Number of overtime hours worked in Month t

Aggregate Planning In Excel

	A	B	C	D	E	F	G	H	I	J
1	*Aggregate Plan Decision Variables*									
2		H_t	L_t	W_t	O_t	I_t	S_t	C_t	P_t	
3	*Period*	*# Hired*	*# Laid off*	*# Workforce*	*Overtime*	*Inventory*	*Stockout*	*Subcontract*	*Production*	*Demand*
4	0	0	0	80	0	1,000	0	0		
5	1	0	0	0	0	0	0	0	0	1,600
6	2	0	0	0	0	0	0	0	0	3,000
7	3	0	0	0	0	0	0	0	0	3,200
8	4	0	0	0	0	0	0	0	0	3,800
9	5	0	0	0	0	0	0	0	0	2,200
10	6	0	0	0	0	0	0	0	0	2,200

Figure 8-1

Aggregate Planning In Excel

	M	N	O	P
1	***Constraints***			
2				
3	***Workforce***	***Capacity***	***Inventory***	***Overtime***
4				
5	-80	0	-600	0
6	0	0	-3000	0
7	0	0	-3200	0
8	0	0	-3800	0
9	0	0	-2200	0
10	0	0	-2200	0

Figure 8-2

Cell	Cell Formula	Equation	Copied to
M5	=D5 - D4 - B5 + C5	8.2	M6:M10
N5	=40*D5 + E5/4 -I5	8.3	N6:N10
O5	=F4-G4+I5+H5-J5-F5+G5	8.4	O6:O10
P5	=-E5 + 10*D5	8.5	P6:P10

Aggregate Planning In Excel

	A	B	C	D	E	F	G	H	I
12	***Aggregate Plan Costs***								
14	***Period***	***Hiring***	***Layoff***	***Regular time***	***Overtime***	***Inventory***	***Stockout***	***Subcontract***	***Material***
15	1	0	0	0	0	0	0	0	0
16	2	0	0	0	0	0	0	0	0
17	3	0	0	0	0	0	0	0	0
18	4	0	0	0	0	0	0	0	0
19	5	0	0	0	0	0	0	0	0
20	6	0	0	0	0	0	0	0	0
22	***Total Cost =***		$ -						

Figure 8-3

Aggregate Planning In Excel

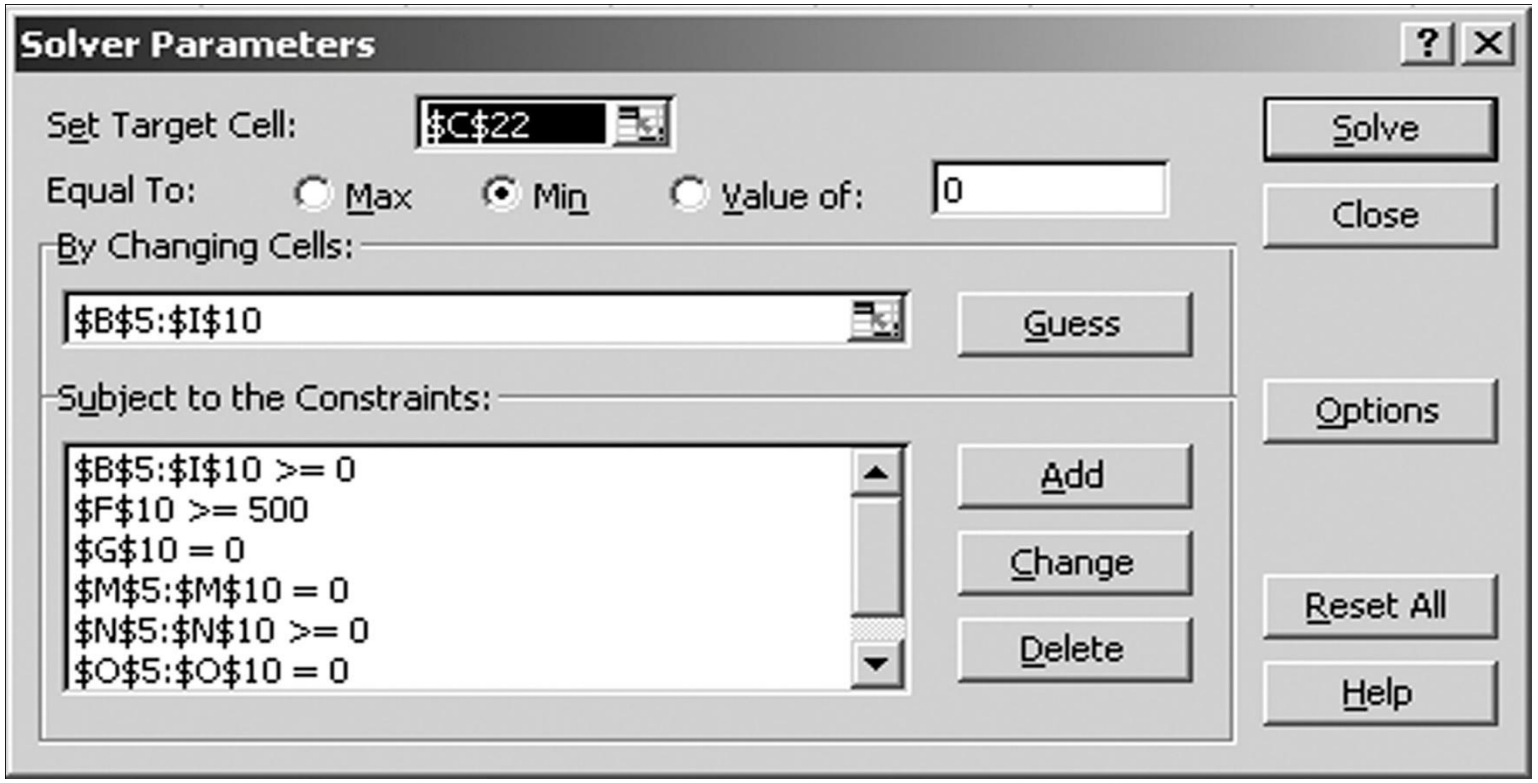

Figure 8-4

Building a Rough Master Production Schedule

- Disaggregate an aggregate plan

Family	Setup Time/Batch (hour)	Average Batch Size	Production Time/Unit (hour)	Production Quantity	Number of Setups	Setup Time (hours)	Production Time (hours)
A	8	50	5.60	258	5	40	1,445
B	6	150	3.00	646	4	24	1,938
C	8	100	3.80	517	5	40	1,965
D	10	50	4.80	258	5	50	1,238
E	6	100	3.60	517	5	30	1,861
F	5	75	4.30	387	5	25	1,664

Table 8-8

The Role of IT in Aggregate Planning

- Information technology is used to widely in aggregate planning
- Earlier aggregate planning module :factory, production, or manufacturing planning which tried to obtain a feasible production plan subject to constraints
- Later modules: provided tools that chose an optimal solution among the feasible production plans, based on objectives.

The Role of IT in Aggregate Planning

- Basically linear programming is used to get a production schedule of products. Nonlinear optimization is also carried out when constraints/objectives are not linear.
- Supply chain planning modules combine both production planning and inventory planning. The supply chain planning module uses the output of the forecasting module as a constraint in setting up the production schedule and inventory levels.

The Role of IT in Aggregate Planning

Dimensions along which IT can add value in the aggregate planning realm:

- The ability to handle large problems
- The ability to handle complex problems (through either nonlinear optimization or linear approximations)
- The ability to interact with other core IT systems such as inventory management and sourcing

The Role of IT in Aggregate Planning

- Major softwares in this area include the ERP software firms (SAP and Oracle) and the best softwares such as i2 Technologies and Manugistics
- Some firms also specialize their planning software by industry verticals.
- Example,: the production planning problems for an oil company are structured differently than those for an aircraft manufacturer. These differences allow IT firms to enhance the value of their product by focusing on particular industries.

Inventory Planning and Economic Theory-Aberrations

- Available evidence indicates that Indian industries, by and large do not show any serious concern for inventory ordering and carrying costs. What are the main reasons for their indifference to scientific inventory management techniques?

- What adaptations of Just In Time (JIT) practices do you visualize emerging in the Indian environment in the near future?

Implementing Aggregate Planning in Practice

1. *Think beyond the enterprise to the entire supply chain*

- Most aggregate plans consider only enterprise at the centre but other factors are ignored
- Work downstream partners to produce forecasts, with upstream partners to determine constraints, and with any other supply chain entities that can improve the quality of the inputs in the aggregate plan.
- communicate the aggregate plan to all supply chain partners who will be affected by it.

Implementing Aggregate Planning in Practice

2. Make plans flexible, because forecasts are always wrong

- By building flexibility into the plan, when future demand changes, or other changes occur such as increases in costs, the plan can adjust appropriately to handle the new situation

Cont...

Implementing Aggregate Planning in Practice

- A manager perform sensitivity analysis on the inputs into an aggregate plan to create flexibility
- Using sensitivity analysis on the inputs into the aggregate plan enables a planner to choose the best solution for the range of possibilities that could occur.

Implementing Aggregate Planning in Practice

3. *Rerun the aggregate plan as new data emerge*.

- Aggregate plans are provided for generally 3 to 18 months.
- As inputs such as demand forecasts change, managers should use the latest values of these inputs and rerun the aggregate plan
- By using the latest inputs, the plan will avoid sub optimization based on old data and will produce a better solution

Implementing Aggregate Planning in Practice

4. *Use aggregate planning as capacity utilization increases.*

- Sometimes companies do not use aggregate plans and rely on orders which are driven by actual demand /inventory management algorithms.

Cont...

Implementing Aggregate Planning in Practice

- When utilization becomes high and capacity is an issue, relying on orders to set the production schedule can lead to capacity problems
- Planning needs to be done to best utilize the capacity to meet the forecasted demand. Therefore, as capacity utilization increases, it becomes more important to perform aggregate planning.

Summary of Learning Objectives

- Identify the decisions that are best solved by aggregate planning
- Understand the importance of aggregate planning as a supply chain activity
- Describe the information needed to produce an aggregate plan
- Explain the basic trade-offs to consider when creating an aggregate plan
- Formulate and solve aggregate planning problems using Microsoft Excel