Chapter 8

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

- Capacity has a cost and lead times are often long
- Aggregate planning:
  - process by which a company determines levels of capacity, production, subcontracting, inventory, stockouts, and pricing over a specified time horizon
  - goal is to maximize profit
  - decisions made at a product family (not SKU) level
  - time frame of3 to 18 months
  - how can a firm best use the facilities it has?

Role of Aggregate Planning in a Supply Chain

- Specify operational parameters over the time horizon
  - Production rate: Subcontracting
  - Workforce: Backlog
  - Overtime: Inventory on hand
  - Machine capacity level

- All supply chain stages should work together on an aggregate plan that will optimize supply chain performance

The Aggregate Planning Problem

- Given the demand forecast for each period in the planning horizon, determine the production level, inventory level, and the capacity level for each period that maximizes the firm's (supply chain's) profit over the planning horizon
- Specify the planning horizon (typically 3-18 months)
- Specify the duration of each period
- Specify key information required to develop an aggregate plan

Information Needed for an Aggregate Plan

- Aggregate demand forecast F_t for each Period t over T periods
- Production costs
  - Labor costs, regular time ($/hr) and overtime ($/hr)
  - Subcontracting costs ($/hr or $/unit)
  - Cost of changing capacity – hiring or layoff ($/worker), adding or reducing machine capacity ($/machine)
- Labor/machine hours required per unit
- Inventory holding cost ($/unit/period)
- Stockout or backlog cost ($/unit/period)
- Constraints – overtime, layoffs, capital available, stockouts, backlogs, from suppliers

Outputs of Aggregate Plan

- Production quantity from regular time, overtime, and subcontracted time
- Inventory held
- Backlog/stockout quantity
- Machine capacity increase/decrease
- A poor aggregate plan can result in lost sales, lost profits, excess inventory, or excess capacity

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-off between capacity, inventory, backlog/lost sales
- Chase strategy – using capacity as the lever
- Time flexibility from workforce or capacity strategy – using utilization as the lever
- Level strategy – using inventory as the lever
- Tailored or hybrid strategy – a combination of strategies

Chase Strategy

- Vary machine capacity or hire and lay off workers as demand varies
- Often difficult to vary capacity and workforce on short notice
- Expensive if cost of varying capacity is high
- Negative effect on workforce morale
- Results in low levels of inventory
- Used when inventory holding costs are high and costs of changing capacity are low

Time Flexibility Strategy

- Use excess machine capacity
- Workforce stable, number of hours worked varies
- Use overtime or a flexible work schedule
- Flexible workforce, avoids morale problems
- Low levels of inventory, lower utilization
- Used when inventory holding costs are high and capacity is relatively inexpensive

Level Strategy

- Stable machine capacity and workforce levels, constant output rate
- Inventory levels fluctuate over time
- Inventories carried over from high to low demand periods
- Better for worker morale
- Large inventories and backlogs may accumulate
- Used when inventory holding and backlog costs are relatively low

Aggregate Planning Using Linear Programming

- Red Tomato Tools
  - Highly seasonal demand
  - Develop a forecast

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

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 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

- Minimize
  - (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)

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

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

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

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

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

Red Tomato Tools

Total cost over planning horizon = $422,275

Revenue over planning horizon = 40 x 16,000 = $640,000

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

Table 8-4

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

- Higher demand variability

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

Total cost over planning horizon = $432,858

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

Table 8-6

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

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

- Forecast errors must be considered
- Safety inventory
- Safety capacity
  - 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

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

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

Figure 8-2

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

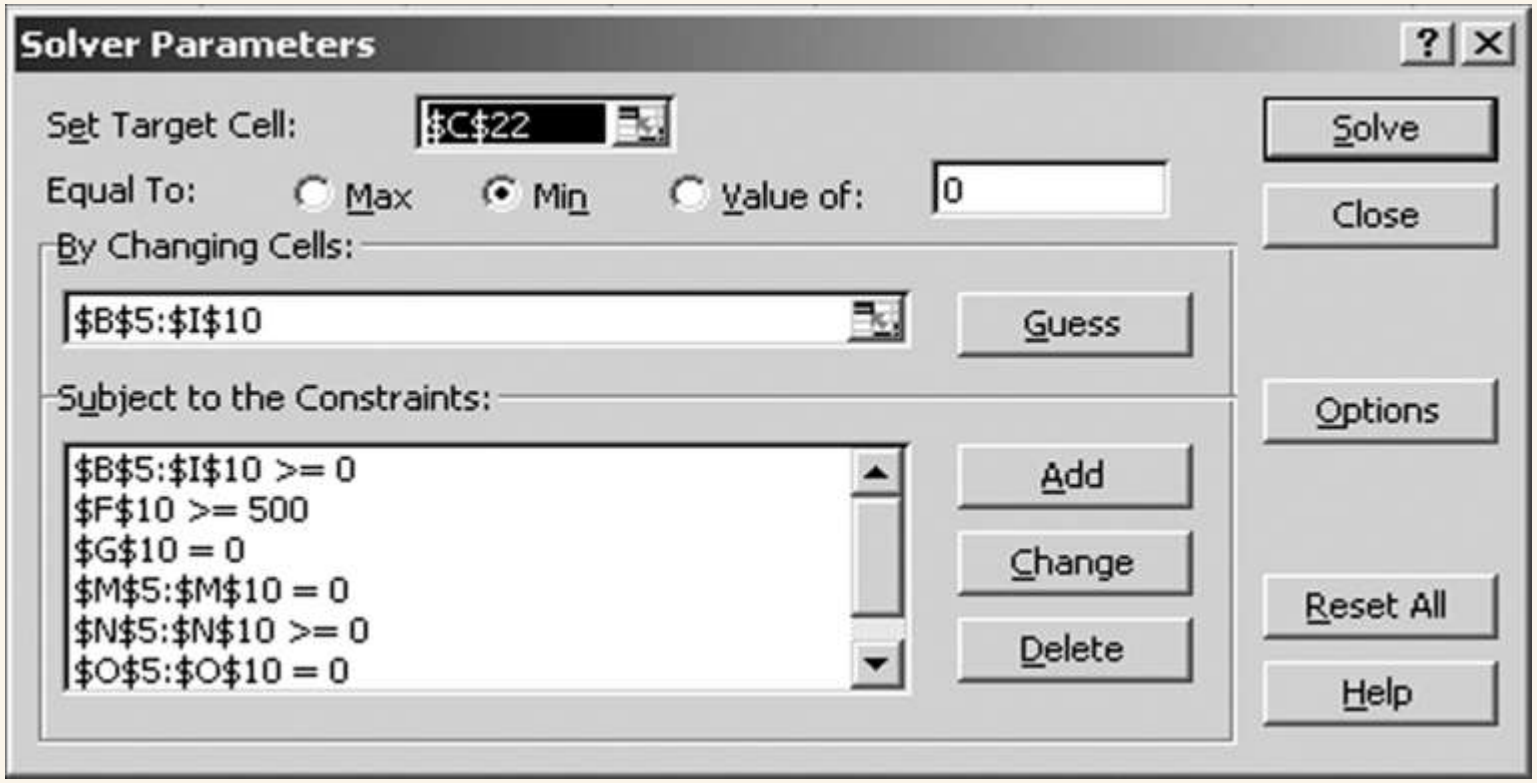

Figure 8-4

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

- 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

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

- Think beyond the enterprise to the entire supply chain
- Make plans flexible because forecasts are always inaccurate
- Rerun the aggregate plan as new data emerge
- Use aggregate planning as capacity utilization increases

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