Aggregate Planning in a Supply Chain

Outline

- Definition of aggregate planning
- Pure aggregate planning strategies
- Aggregate planning example

Definition of Aggregate Planning

- Aggregate planning consists of efforts to plan a desired output over the longer range by adjusting the production rate, employment, inventory, and other controllable variables
- These controllable variables in effect constitute pure strategies by which fluctuations in demand and uncertainties in production activities can be accommodated
- The objective of aggregate planning is the productive utilization of both human and equipment resources

Pure Aggregate Planning Strategies

- **Vary work force size**
  - By hiring and firing in direct proportion to demand
  - Costs would consist of
    - Hiring and training costs
    - Severance costs
    - Unemployment insurance costs
    - Morale of the workforce
    - Image of the firm in the community

Pure Aggregate Planning Strategies

- **Stable work force but permit idle time when demand is slack and go overtime when demand is strong**
  - Idle time is obviously a waste and overtime and shift work usually command a premium

Pure Aggregate Planning Strategies

- **Constant work force and level production but carry sufficiently large amounts of inventory to absorb all demand fluctuations**
  - This could be an expensive proposition as it involves costs such as carrying costs, storage costs, taxes and obsolescence costs

Pure Aggregate Planning Strategies

- **Backorder Strategy**
  - It assumes that the customers are willing to wait for delivery and this effectively smoothes out production
  - Otherwise this strategy results in stock out costs because some customers will seek out other suppliers
  - In essence, this is the strategy of negative inventory

Pure Aggregate Planning Strategies

- **Subcontracting Strategy**
  - Permits level production pushing the fluctuations off into subcontracting
  - Subcontracting costs are higher than in-house production

Pure Aggregate Planning Strategies

- **Plant capacity**
  - This is not a short term project
  - Often requires major capital expenditure

Pure Aggregate Planning Strategies

- Pure strategies are often infeasible from a practical standpoint.
- Thus, a mixture of pure strategies is frequently used

Aggregate Planning Example

- It costs $100 to produce one unit of an item the forecast (in units) of which is given
- Perform the aggregate planning analysis to choose the best plan of the three plans given
- Assume that this is an ongoing concern and any amount of initial inventory can be made available at the beginning of January

Aggregate Planning Example

- **Plan 1**: Vary inventory.
  - Carrying cost is $20/unit-year and storage cost is $0.90/unit based on maximum inventory
- **Plan 2**: Produce at the rate of 10 units/day or 20 units/day.
  - Each changeover costs $3500
- **Plan 3**: Produce at a steady rate of 10 units per day and subcontract the rest
  - Subcontracted items cost $107/unit

Aggregate Planning Example

Month	Production Days	Demand Forecast
January	22	220
February	18	90
March	21	210
April	22	396
May	22	616
June	20	700
July	21	378
August	22	220
September	20	200
October	23	115
November	19	95
December	20	260
Totals	250	3500

Aggregate Planning Example

- **Analysis of Plan 1**
  - Calculate the average requirement per day
    - 3500/250 = 14 units/day

Aggregate Planning Example

Month	Production Days	Demand Forecast	Production @ 14/day	Inventory Change	Ending Balance with 0 on hand on Jan. 1	Ending Balance with 566 on hand on Jan. 1
January	22	220				
February	18	90				
March	21	210				
April	22	396				
May	22	616				
June	20	700				
July	21	378				
August	22	220				
September	20	200				
October	23	115				
November	19	95				
December	20	260				
Totals	250	3500				

Aggregate Planning Example

Month	Production Days	Demand Forecast	Production @ 14/day	Inventory Change	Ending Balance with 0 on hand on Jan. 1	Ending Balance with 566 on hand on Jan. 1
January	22	220	308			
February	18	90	252			
March	21	210	294			
April	22	396	308			
May	22	616	308			
June	20	700	280			
July	21	378	294			
August	22	220	308			
September	20	200	280			
October	23	115	322			
November	19	95	266			
December	20	260	280			
Totals	250	3500	3500			

Aggregate Planning Example

Month	Production Days	Demand Forecast	Production @ 14/day	Inventory Change	Ending Balance with 0 on hand on Jan. 1	Ending Balance with 566 on hand on Jan. 1
January	22	220	308	88		
February	18	90	252	162		
March	21	210	294	84		
April	22	396	308	-88		
May	22	616	308	-308		
June	20	700	280	-420		
July	21	378	294	-84		
August	22	220	308	88		
September	20	200	280	80		
October	23	115	322	207		
November	19	95	266	171		
December	20	260	280	20		
Totals	250	3500	3500			

Aggregate Planning Example

Month	Production Days	Demand Forecast	Production @ 14/day	Inventory Change	Ending Balance with 0 on hand on Jan. 1	Ending Balance with 566 on hand on Jan. 1
January	22	220	308	88	88	
February	18	90	252	162	250	
March	21	210	294	84	334	
April	22	396	308	-88	246	
May	22	616	308	-308	-62	
June	20	700	280	-420	-482	
July	21	378	294	-84	**-566**	
August	22	220	308	88	-478	
September	20	200	280	80	-398	
October	23	115	322	207	-191	
November	19	95	266	171	-20	
December	20	260	280	20	0	
Totals	250	3500	3500			

Aggregate Planning Example

Month	Production Days	Demand Forecast	Production @ 14/day	Inventory Change	Ending Balance with 0 on hand on Jan. 1	Ending Balance with 566 on hand on Jan. 1
January	22	220	308	88	88	654
February	18	90	252	162	250	816
March	21	210	294	84	334	900
April	22	396	308	-88	246	812
May	22	616	308	-308	-62	504
June	20	700	280	-420	-482	84
July	21	378	294	-84	**-566**	0
August	22	220	308	88	-478	88
September	20	200	280	80	-398	168
October	23	115	322	207	-191	375
November	19	95	266	171	-20	546
December	20	260	280	20	0	566
Totals	250	3500	3500			5513

Aggregate Planning Example

- **Cost calculations for Plan 1**
  - Maximum inventory requiring storage = 900 units
  - Average inventory balance

$$= \frac{654 + 816 + ... + 566}{12} = \frac{5513}{12}$$

$$\approx 460 \text{ units}$$

  - **Inventory cost** = carrying cost + storage cost

= 20 * 460 + 0.90 * 900

= $10,010

Aggregate Planning Example

- **Analysis of Plan 2**
  - In plan 2, production is either 10 units/day or 20 units/day. First, we need to calculate the number of days with 10/day production and number of days with 20/day production
  - Since the total number of days is 250, if we produce 20 units/day for 100 days and 10 units/day for 150 days, we would have produced a total of 3500 units (the annual requirement)
  - Next we need to decide when to change the number of shifts
  - Let us decide to change it on March 1

Aggregate Planning Example

Month	Production Days	Demand Forecast	Production Rate/day	Total Production	Inventory Change	Ending Balance with 0 on hand on Jan. 1	Ending Balance with 150 on hand on Jan. 1
January	22	220					
February	18	90					
March	21	210					
April	22	396					
May	22	616					
June	20	700					
July	21	378					
August	22	220					
September	20	200					
October	23	115					
November	19	95					
December	20	260					
Totals	250	3500					

Aggregate Planning Example

Month	Production Days	Demand Forecast	Production Rate/day	Total Production	Inventory Change	Ending Balance with 0 on hand on Jan. 1	Ending Balance with 150 on hand on Jan. 1
January	22	220	10				
February	18	90	10				
March	21	210	20				
April	22	396	20				
May	22	616	20				
June	20	700	20				
July	21	378	20(15d)+10(6d)				
August	22	220	10				
September	20	200	10				
October	23	115	10				
November	19	95	10				
December	20	260	10				
Totals	250	3500					

Aggregate Planning Example

Month	Production Days	Demand Forecast	Production Rate/day	Total Production	Inventory Change	Ending Balance with 0 on hand on Jan. 1	Ending Balance with 150 on hand on Jan. 1
January	22	220	10	220			
February	18	90	10	180			
March	21	210	20	420			
April	22	396	20	440			
May	22	616	20	440			
June	20	700	20	400			
July	21	378	20(15d)+10(6d)	360			
August	22	220	10	220			
September	20	200	10	200			
October	23	115	10	230			
November	19	95	10	190			
December	20	260	10	200			
Totals	250	3500		3500			

Aggregate Planning Example

Month	Production Days	Demand Forecast	Production Rate/day	Total Production	Inventory Change	Ending Balance with 0 on hand on Jan. 1	Ending Balance with 150 on hand on Jan. 1
January	22	220	10	220	0		
February	18	90	10	180	90		
March	21	210	20	420	210		
April	22	396	20	440	44		
May	22	616	20	440	-176		
June	20	700	20	400	-300		
July	21	378	20(15d)+10(6d)	360	-18		
August	22	220	10	220	0		
September	20	200	10	200	0		
October	23	115	10	230	115		
November	19	95	10	190	95		
December	20	260	10	200	-60		
Totals	250	3500		3500			

Aggregate Planning Example

Month	Production Days	Demand Forecast	Production Rate/day	Total Production	Inventory Change	Ending Balance with 0 on hand on Jan. 1	Ending Balance with 150 on hand on Jan. 1
January	22	220	10	220	0	0	
February	18	90	10	180	90	90	
March	21	210	20	420	210	300	
April	22	396	20	440	44	344	
May	22	616	20	440	-176	168	
June	20	700	20	400	-300	-132	
July	21	378	20(15d)+10(6d)	360	-18	**-150**	
August	22	220	10	220	0	-150	
September	20	200	10	200	0	-150	
October	23	115	10	230	115	-35	
November	19	95	10	190	95	60	
December	20	260	10	200	-60	0	
Totals	250	3500		3500			

Aggregate Planning Example

Month	Production Days	Demand Forecast	Production Rate/day	Total Production	Inventory Change	Ending Balance with 0 on hand on Jan. 1	Ending Balance with 150 on hand on Jan. 1
January	22	220	10	220	0	0	150
February	18	90	10	180	90	90	240
March	21	210	20	420	210	300	450
April	22	396	20	440	44	344	494
May	22	616	20	440	-176	168	318
June	20	700	20	400	-300	-132	18
July	21	378	20(15d)+10(6d)	360	-18	**-150**	0
August	22	220	10	220	0	-150	0
September	20	200	10	200	0	-150	0
October	23	115	10	230	115	-35	115
November	19	95	10	190	95	60	210
December	20	260	10	200	-60	0	150
Totals	250	3500		3500			2145

Aggregate Planning Example

- **Cost calculations for Plan 2**
  - Maximum inventory requiring storage = 494 units
  - Average inventory balance

$$= \frac{150 + 240 + ... + 150}{12} = \frac{2145}{12}$$

$$\approx 179 \text{ units}$$

  - **Inventory cost** = carrying cost + storage cost
    = 20 * 179 + 0.90 * 494 = $4,025
  - **Shift change cost** = 3500 * 2 = $7,000
  - **Total costs** = 4025 + 7000 = $11,025

Aggregate Planning Example

- **Analysis of Plan 3**
  - In plan 3, the production rate is 10 units/day.
  - Since the total number of days is 250, we will end up producing a total of 2500 units. It means that we will be 1000 units short and those will have to be subcontracted

Aggregate Planning Example

Month	Production Days	Demand Forecast	Production @ 10/day	Inventory Change	Ending Balance with 0 on hand on Jan. 1	Ending Balance with 150 on hand on Jan. 1
January	22	220				
February	18	90				
March	21	210				
April	22	396				
May	22	616				
June	20	700				
July	21	378				
August	22	220				
September	20	200				
October	23	115				
November	19	95				
December	20	260				
Totals	250	3500				

Aggregate Planning Example

Month	Production Days	Demand Forecast	Production @ 10/day	Inventory Change	Ending Balance with 0 on hand on Jan. 1	Ending Balance with 150 on hand on Jan. 1
January	22	220	220			
February	18	90	180			
March	21	210	210			
April	22	396	220			
May	22	616	220			
June	20	700	200			
July	21	378	210			
August	22	220	220			
September	20	200	200			
October	23	115	230			
November	19	95	190			
December	20	260	200			
Totals	250	3500	2500			

Aggregate Planning Example

Month	Production Days	Demand Forecast	Production @ 10/day	Inventory Change	Ending Balance with 0 on hand on Jan. 1	Ending Balance with 150 on hand on Jan. 1
January	22	220	220	0		
February	18	90	180	90		
March	21	210	210	0		
April	22	396	220	-176		
May	22	616	220	-396		
June	20	700	200	-500		
July	21	378	210	-168		
August	22	220	220	0		
September	20	200	200	0		
October	23	115	230	115		
November	19	95	190	95		
December	20	260	200	-60		
Totals	250	3500	2500			

Aggregate Planning Example

Month	Production Days	Demand Forecast	Production @ 10/day	Inventory Change	Ending Balance with 0 on hand on Jan. 1	Ending Balance with 150 on hand on Jan. 1
January	22	220	220	0	0	
February	18	90	180	90	90	
March	21	210	210	0	90	
April	22	396	220	-176	0	
May	22	616	220	-396	0	
June	20	700	200	-500	0	
July	21	378	210	-168	0	
August	22	220	220	0	0	
September	20	200	200	0	0	
October	23	115	230	115	115	
November	19	95	190	95	210	
December	20	260	200	-60	150	
Totals	250	3500	2500			

Aggregate Planning Example

Month	Production Days	Demand Forecast	Production @ 10/day	Inventory Change	Ending Balance with 0 on hand on Jan. 1	Ending Balance with 150 on hand on Jan. 1
January	22	220	220	0	0	150
February	18	90	180	90	90	240
March	21	210	210	0	90	240
April	22	396	220	-176	0	64
May	22	616	220	-396	0	0
June	20	700	200	-500	0	0
July	21	378	210	-168	0	0
August	22	220	220	0	0	0
September	20	200	200	0	0	0
October	23	115	230	115	115	115
November	19	95	190	95	210	210
December	20	260	200	-60	150	150
Totals	250	3500	2500			1169

Aggregate Planning Example

- **Cost calculations for Plan 3**
  - Maximum inventory requiring storage = 240 units
  - Average inventory balance

$$= \frac{150 + 240 + \ldots\ldots + 150}{12} = \frac{1169}{12}$$

$$= 97.42 \text{ units}$$

  - **Inventory cost** = carrying cost + storage cost
    = 20 * 97.42 + 0.90 * 240 = $2,164
  - **Subcontracting cost** = 1000 * 7 = $7,000
  - **Total costs** = 2164 + 7000 = **$9,164**

Aggregate Planning Example

- **Cost comparison of the three plans**
  - Cost of Plan 1 = $10,010
  - Cost of Plan 2 = $11,025
  - Cost of Plan 3 = **$9,164**

  - **Choose Plan 3** since it gives the minimum cost

Using Transportation Algorithm to Solve an Aggregate Planning Problem

Example

Period	Regular time capacity	Overtime capacity	Demand
1	2	5	4
2	1	3	9
3	9	2	2

- **Given**
  - Initial Inventory = 4
  - Final Inventory required = 3
  - Regular time production cost = \$10/unit
  - Overtime production cost = \$12/unit
  - Carrying cost = \$3/unit-period
  - Backordering cost = \$4/unit-period

Using Transportation Algorithm to Solve an Aggregate Planning Problem

	Per.1	Per.2	Per.3	Final Inv.	Slack	Capacity
Initial Inv.	0	3	6	9	0	4
Per.1 RT	10	13	16	19	0	2
Per 1 OT	12	15	18	21	0	5
Per 2 RT	14	10	13	16	0	1
Per 2 OT	16	12	15	18	0	3
Per 3 RT	18	14	10	13	0	9
Per 3 OT	20	16	12	15	0	2
Demand	4	9	2	3	8	26 26

Using Transportation Algorithm to Solve an Aggregate Planning Problem

u_i \ v_j		0	3	6	9	-4	
		Per. 1	Per. 2	Per. 3	Final Inv.	Slack	Capacity
0	Initial Inv.	4 [0]	0 [3]	△0 [6]	△0 [9]	△4 [0]	~~4~~
10	Per. 1 RT	△0 [10]	2 [13]	△0 [16]	△0 [19]	△-6 [0]	~~2~~
12	Per 1 OT	△0 [12]	5 [15]	△0 [18]	△0 [21]	△-8 [0]	~~5~~
7	Per 2 RT	△7 [14]	1 [10]	△0 [13]	△0 [16]	△-3 [0]	~~1~~
9	Per 2 OT	△7 [16]	1 [12]	2 [15]	0 [18]	△-5 [0]	~~3~~ ~~2~~
4	Per 3 RT	△14 [18]	△7 [14]	△0 [10]	3 [13]	6 [0]	~~9~~ ~~6~~
4	Per 3 OT	△16 [20]	△9 [16]	△2 [12]	△2 [15]	2 [0]	~~2~~
	Demand	~~4~~	~~9~~ ~~7~~ ~~2~~ ~~1~~	~~2~~	~~3~~	~~8~~ ~~2~~	26 / 26

No. of filled cells = # of rows + # of columns − 1
= 7 + 5 − 1 = 11

For filled cells
$c_{ij} - u_i - v_j = 0$

For empty cells
$\triangle e_{ij} = c_{ij} - u_i - v_j$

Using Transportation Algorithm to Solve an Aggregate Planning Problem

	Per. 1	Per. 2	Per. 3	Final Inv.	Slack	Capacity
Initial Inv.	4 [0]	0 [3]	[6]	[9]	[0]	4
Per. 1 RT	[10]	2 [13]	[16]	[19]	[0]	2
Per 1 OT	[12]	5 [15]	[18]	[21]	0 [0]	5
Per 2 RT	[14]	1 [10]	[13]	[16]	[0]	1
Per 2 OT	[16]	1 [12]	2 [15]	[18]	[0]	3
Per 3 RT	[18]	[14]	[10]	3 [13]	6 [0]	9
Per 3 OT	[20]	[16]	[12]	[15]	2 [0]	2
Demand	4	9	2	3	8	26 / 26

Continue this till you get the optimal solution.

Using Transportation Algorithm to Solve an Aggregate Planning Problem

Optimal Solution

	Per.1	Per.2	Per.3	Final Inv.	Slack	Capacity
Initial Inv.	4 [0]	[3]	[6]	[9]	[0]	4
Per.1 RT	[10]	2 [13]	[16]	[19]	[0]	2
Per 1 OT	[12]	[15]	[18]	[21]	5 [0]	5
Per2 RT	[14]	1 [10]	[13]	[16]	[0]	1
Per2 OT	[16]	3 [12]	[15]	[18]	[0]	3
Per3 RT	[18]	3 [14]	2 [10]	3 [13]	1 [0]	9
Per3 OT	[20]	[16]	[12]	[15]	2 [0]	2
Demand	4	9	2	3	8	26 / 26

Total cost = $173

Summary of Learning Objectives

- What types of decisions are best solved by aggregate planning?
- What is the importance of aggregate planning as a supply chain activity?
- What kinds of information are needed to produce an aggregate plan?
- What are the basic trade-offs a manager makes to produce an aggregate plan?
- How are aggregate planning problems formulated and solved using Transportation Algorithm?