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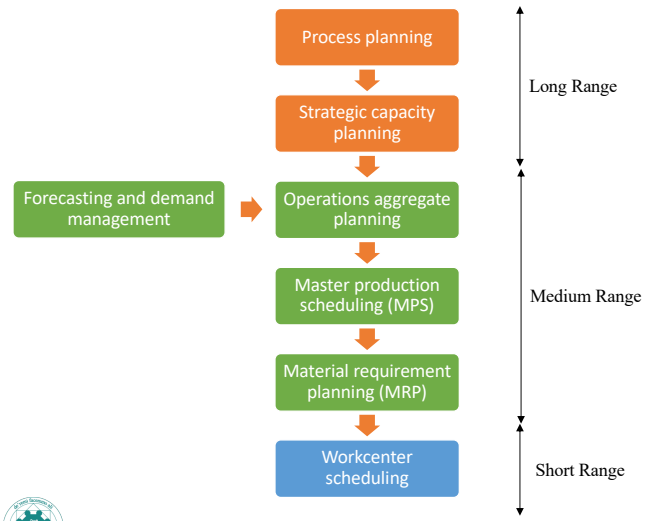
Operations Aggregate Planning

Production strategies

v1. Spring 2021

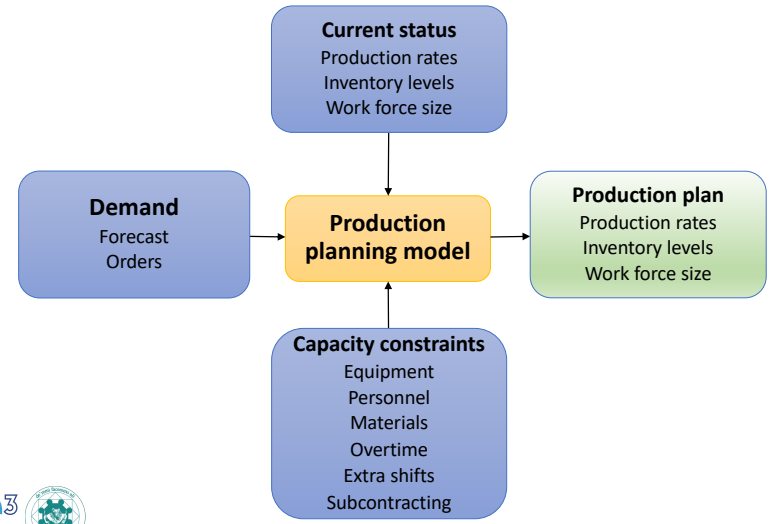
Operations Planning activities



Operation aggregate planning

- Defines the optimal combination of:
  - ***Production rate*** *(number of units completed per unit of time)*
  - ***Inventory on hand*** *(inventory from the previous period)*
  - ***Workforce level*** *(number of workers needed in a period)*
- The form of the aggregate plan varies from company to company
- Aggregation on the supply side is done by product families, and on the demand side it is done by groups of customers.
- This planning is generally developed for an intermediate term (3 to 18 months)

Production planning



Definition of the aggregate planning problem

Given the expected demand D_t for each period t in the planning horizon that extends over T period, $t = 1, 2, \ldots, T$, determine:

- Production rate P_t
- Inventory on hand I_t
- Workforce level W_t

that minimize the relevant costs over the planning horizon

Stages of the planning process

1. Identify the strategy
2. Define the time horizon and the time buckets
3. Develop the demand forecast system
4. Define an aggregation scheme
5. Determine a cost structure
6. Use a planning method

Production strategies

How to combine the available production capacity with the necessary one?

- Modify the workforce level
- Use overtime
- Add work shifts
- Use inventory (anticipation stock, backorder)
- Use subcontracting
- Vary the product mix
- Stockout

Strategies involve trade-offs among the workforce size, work hours, inventory, and backlogs

Pure strategies

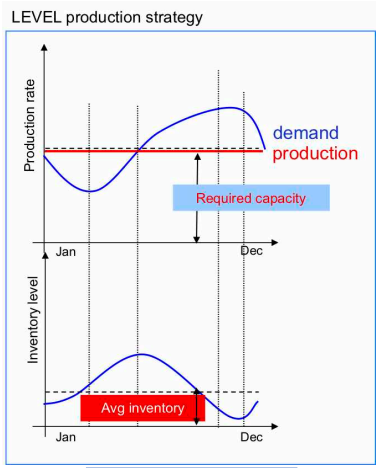
a. **LEVEL strategy**: maintain a stable workforce working at a constant output rate. Effect:
   - Fluctuating stock inventory
   - Order backlogs
   - Lost sales

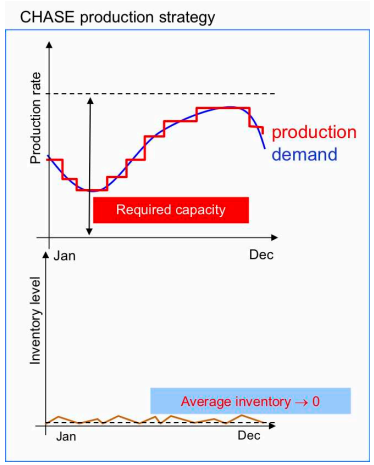
b. **STABLE workforce – VARIABLE work hours**
   The production rate varies by varying the number of hours worked through flexible work schedules or overtime. By varying the number of work hours, you can match production quantities to orders. (Up to what level?)

c. **CHASE strategy**: Match the production rate to the order rate by hiring and laying off employees as the order rate varies

d. **Subcontracting**: use the subcontracting of labour (TACTICAL BUY)

Pure strategies





Key issue
Inventory cost

Key issue
Capacity cost

Relevant costs

1. **Production costs** (direct and indirect labor cost and regular as well as overtime compensation)
2. **Cost associated with changes in the production rate** (Hiring, training and laying off personnel)
3. **Inventory holding costs** (storing, insurance, taxes, spoilage and obsolescence)
4. **Backordering costs** (costs of expediting, loss of customer goodwill, and loss and sales revenues resulting from backordering)

Aggregate planning techniques "Cut-and-try"

- Approach based on scenarios analysis, "what if"
- It involves costing out various production planning alternatives and selecting the one that is best
- *Spreadsheets* approach

Aggregate planning techniques: "Level Scheduling"

- Level scheduling has the target of a constant production rate over a defined period of time
- It is a combined of the strategies mentioned above
- In each period the workforce level is stable, the level of stock low and production is *pulled* by demand
- *It is the basis of JIT production*

Advantages of Level Scheduling

- Goal of the planning is to minimize inventory and WIP
- The products are always up to date, thanks to the low level of WIP
- The flow through the production system is stable
- Codes purchased from suppliers can be delivered when needed, often directly on the line

Level Scheduling requirements

1. Repetitive production (Assembly line)
2. The system must have excess capacity
3. The system output must be fixed for a defined period
4. There must be a linear flow between purchases, production and sales
5. High inventory costs
6. Low equipment costs
7. Flexible workforce

Operations Aggregate Planning

Industrial Cases and Examples

Spreadsheets – Example 1

A company must establish its aggregate production plan for the first half of next year

DEMAND FORECAST [unit/month]

January	February	March	April	May	June
10.000	15.000	30.000	27.000	30.000	16.000

- Safety Stock (SS) equal to 10% of the expected demand in each month
- No availability of goods in stock is expected at the beginning of January

Example 1

COSTS

Production cost	100 $/unit
Cost of subcontracting	104 $/unit
Inventory holding cost	2 $/[unit x month]
Cost of stock out	5 $/unit
Hourly workforce cost	8 $/[worker x hour]
Overtime cost	12 $/[worker x hour]
Cycle Time	4 hour/unit
Layoff cost	500 $/worker
Hiring and training cost	400 $/worker

NUMBER OF WORKING DAYS

January	February	March	April	May	June
22	19	21	21	22	20

Example 1

Three alternative production strategy are available:

1. **CHASE** – produce the exact monthly customer demand using a regular eight-hour day by varying workforce size. Do not use overtime and subcontracting. At the beginning of January the workforce is equal to 250
2. **LEVEL** – produce to meet expected average demand over the next six months by maintaining a constant workforce (518 workers). Inventory is allowed to meet demand through withdrawals. Do not use subcontracting
3. **LEVEL AND SUBCONTRACTING** - produce to meet the expected demand using a constant workforce (500 workers) on regular time. Subcontract and inventory is allowed to meet demand through withdrawals. Stock out is forbidden

Example 1

Production plan for each month

(1+4-2) of the previous period

	Jan	Feb	Mar	Apr	May	Jun
1. Beginning inventory	0	1.000	1.500	3.000	2.700	3.000
2. Demand forecast	10.000	15.000	30.000	27.000	30.000	16.000
3. Safety stock	1.000	1.500	3.000	2.700	3.000	1.600
4. Actual requirement (2+3-1)	**11.000**	**15.500**	**31.500**	**26.700**	**30.300**	**14.600**

Example 1

Plan 1 – Chase strategy

	1 Production Requirement	2 Production hours required	3 Working days per month	4 Hours per month per worker	5 Workers required	6 New workers hired	7 Workers laid off	8 Hiring cost	9 Layoff cost
	[unit]	[hr]	[days]	[hr/wrk]	[wrk]	[wrk]	[wrk]	[$]	[$]
		(col.1)*4		(col.3)*8	(col.2)/(col.4)			(col.6)*400	(col.7)*500
Jan	11.000	44.000	22	176	250	0	0	0	0
Feb	15.500	62.000	19	152	408	158	0	63.200	0
Mar	31.500	126.000	21	168	750	342	0	136.800	0
Apr	26.700	106.800	21	168	636	0	114	0	57.000
May	30.300	121.200	22	176	689	53	0	21.200	0
Jun	14.600	58.400	20	160	365	0	324	0	162.000
								221.200	**219.000**

EXTRA COSTS

Example 1

Plan 2 – Level strategy (518 workers)

	1 Production Requirement [unit]	2 Working days per month [days]	3 Production hours available [hours]	4 Actual Production [unit]	5 Ending Inventory [unit]	6 Inventory cost [$]	7 Shortage cost [$]
			(col.2)*8*518	(col.3)/4		(col.5)*2	(col.5)*5
Jan	11.000	22	91.168	22.792	11.792	23.584	0
Feb	15.500	19	78.736	19.684	15.976	31.952	0
Mar	31.500	21	87.024	21.756	6.232	12.464	0
Apr	26.700	21	87.024	21.756	1.288	2.576	0
May	30.300	22	91.168	22.792	-6.220	0	31.100
Jun	14.600	20	82.880	20.720	-100	0	500
						70.576	**31.600**

EXTRA COSTS

Example 1

Plan 3 – Level and subcontracting strategy (500 workers)

	1 Production Requirement [unit]	2 Working days per month [days]	3 Production hours available [hours]	4 Actual Production [unit]	5 Ending Inventory [unit]	6 Sub contracting [unit]	8 Inventory cost [$]	9 Sub contracting cost [$]
			(col.2)*8*500	(col.3)/4			(col.5)*2	(col.6)*4
Jan	11.000	22	88.000	22.000	11.000	0	22.000	0
Feb	15.500	19	76.000	19.000	14.500	0	29.000	0
Mar	31.500	21	84.000	21.000	4.000	0	8.000	0
Apr	26.700	21	84.000	21.000	0	1.700	0	6.800
May	30.300	22	88.000	22.000	0	8.300	0	33.200
Jun	14.600	20	80.000	20.000	5.400	0	10.800	0
							69.800	**40.000**

EXTRA COSTS

Example 1

	Plan 1 Exact production, vary workforce ($)	**Plan 2** Constant workforce, vary inventory, stock out ($)	**Plan 3** Constant low workforce, vary inventory, subcontracting ($)
Hiring	221.200	0	0
Layoff	219.000	0	0
Excess inventory	0	70.576	69.800
Shortage	0	31.600	0
Subcontract	0	0	40.000
	440.200	**102.176**	**109.800**

Spreadsheets – Example 2

A company updates every month its production plan for the 12 next months

DEMAND FORECAST [10^3 unit/month]

1	2	3	4	5	6	7	8	9	10	11	12
10	15	30	27	30	16	12	10	18	26	30	15

- Demand must be completely satisfy each month
- Demand fluctuation can be satisfied by varying:
  - Inventory
  - Overtime
  - Subcontracting

Example 2

CAPACITY CONSTRAINTS AND COSTS

Max straight time production	19.000 unit/month
Max overtime production	4.000 unit/month
Regular time production cost	30 $/unit
Overtime production cost	35 $/unit
Subcontracting production cost	37 $/unit
Inventory cost	1 $/unit*month

- Beginning inventory is equal to zero
- Ending inventory in the last period must be equal to zero

Define the optimal production plan!

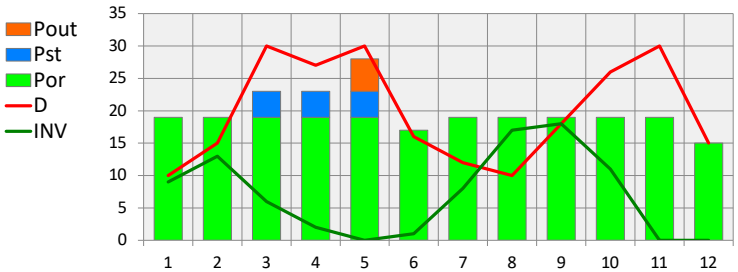
Example 2

			Strategic variable			
Month	***Production Requirement***	***Beginning Inventory***	***Straight time Production***	***Overtime production***	***Subcontracting production***	***Ending Inventory***
1	10	0	10 (1), 7 (3), 2 (4)			9
2	15	9	15 (2), 4 (3)			13
3	30	13	19 (3)	2 (4), 2 (5)		6
4	27	6	19 (4)	4 (4)		2
5	30	2	19 (5)	4 (5)	5 (5)	0
6	16	0	16 (6), 1 (11)			1
7	12	1	12 (7), 7 (11)			8
8	10	8	10 (8), 6 (10), 3 (11)			17
9	18	17	18 (9), 1 (10)			18
10	26	18	19 (10)			11
11	30	11	19 (11)			0
12	15	0	15 (12)			0

Example 2

PRODUCTION PLAN [10^3 unit]

	1	2	3	4	5	6	7	8	9	10	11	12
Straight time production	19	19	19	19	19	17	19	19	19	19	19	15
Overtime production			4	4	4							
Subcontracting production					5							
	19	19	23	23	28	17	19	19	19	19	19	15



Linear Programming – Example 3

- A company with a fixed workforce size, can use inventory, overtime and subcontracting in order to satisfy demand fluctuation
- Demand must be completely satisfy each month

Month	Forecast demand	Straight time Production capacity	Overtime production capacity	Subcontracting production capacity
	[unit]	[unit]	[unit]	[unit]
1	1.000	600	180	200
2	500	500	150	200
3	700	600	180	200
4	800	650	200	200
5	900	600	180	200
6	900	600	180	200
	4.800	3.550	1.070	1.200

Example 3

COSTS

Straight time production cost	100 $/unit
Overtime production cost	125 $/unit
Subcontracting production cost	130 $/unit
Inventory cost	2 $/unit*month

- Beginning inventory is 200 units
- Ending inventory in the last period must be equal to 100 units

Define the production plan able to satisfy the demand with the minimum cost

Linear Programming Problem

x_{ijk} **product units** (decision variables)

i = production mode

i = 0 beginning inventory

i = 1 straight time production

i = 2 overtime production

i = 3 subcontracting production

j = production period

k = using period

Objective Function: Total Cost Min C $=\sum_i \sum_j \sum_k c_{ijk} x_{ijk}$

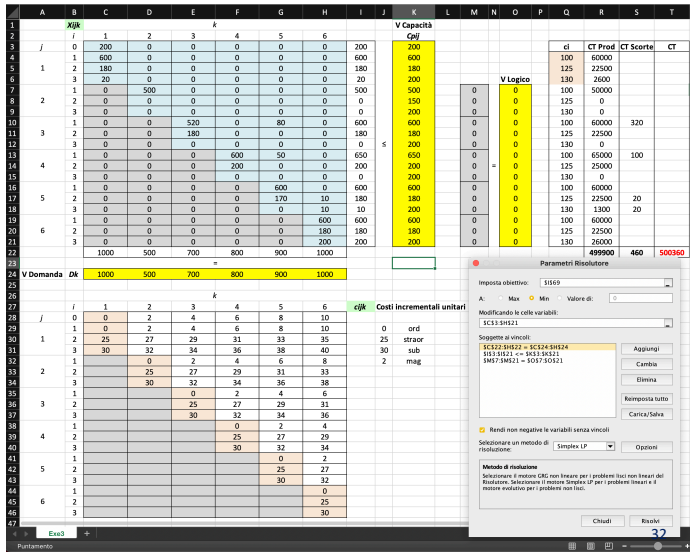
Demand constraints $\sum_i \sum_j x_{ijk} = D_k$, for each period k

Production constraints $\sum_k x_{ijk} \leq Cp_{ij}$, for each production mode i,j

Example 3

Production period		Demand period 1	2	3	4	5	6	Available capacity
	Beginning Inventory	X_{011}	X_{012}	X_{013}	X_{014}	X_{015}	X_{016}	200
1	Straight time Prod.	X_{111}	X_{112}	X_{113}	X_{114}	X_{115}	X_{116}	600
	Overtime Prod.	X_{211}	X_{212}	X_{213}	X_{214}	X_{215}	X_{216}	180
	Subcontracting Prod.	X_{311}	X_{312}	X_{313}	X_{314}	X_{315}	X_{316}	200
2	Straight time Prod.		X_{122}	X_{123}	X_{124}	X_{125}	X_{126}	500
	Overtime Prod.		X_{222}	X_{223}	X_{224}	X_{225}	X_{226}	150
	Subcontracting Prod.		X_{322}	X_{323}	X_{324}	X_{325}	X_{326}	200
3	Straight time Prod.			X_{133}	X_{134}	X_{135}	X_{136}	600
	Overtime Prod.			X_{233}	X_{234}	X_{235}	X_{236}	180
	Subcontracting Prod.			X_{333}	X_{334}	X_{335}	X_{336}	200
4	Straight time Prod.				X_{144}	X_{145}	X_{146}	650
	Overtime Prod.				X_{244}	X_{245}	X_{246}	200
	Subcontracting Prod.				X_{344}	X_{345}	X_{346}	200
5	Straight time Prod.					X_{155}	X_{156}	600
	Overtime Prod.					X_{255}	X_{256}	180
	Subcontracting Prod.					X_{355}	X_{356}	200
6	Straight time Prod.						X_{166}	600
	Overtime Prod.						X_{266}	180
	Subcontracting Prod.						X_{366}	200
	Demand	1000	500	700	800	900	~~900~~ 1000	

Ms Excel Solver ™



Example 3

PRODUCTION PLAN

Month	Straight time Production capacity [unit]	Overtime production capacity [unit]	Subcontracting production capacity [unit]	Total production cost* [$]
1	600	180	20	85.100
2	500	0	0	50.000
3	600	180	0	82.500
4	650	200	0	90.000
5	600	180	10	83.800
6	600	180	200	108.500
	3.550	920	230	499.900

* Inventory cost excluded