Chapter 2

Aggregate Planning and Master Scheduling

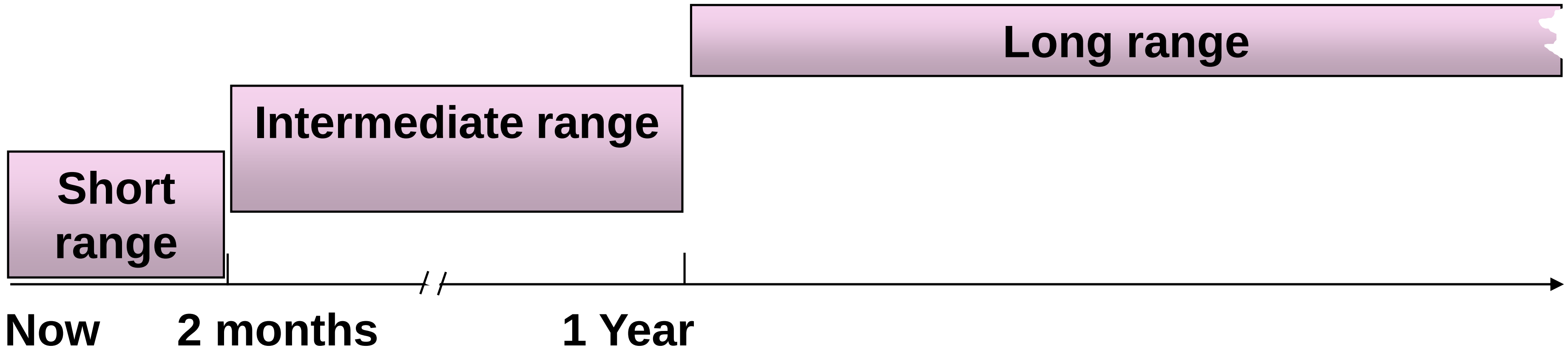
Introduction

Aggregate planning: is intermediate-range capacity planning that typically covers a time horizon of 2 to 12 months, although in some companies it may extend to as much as 18 months.

- ❖ It is particularly useful for organizations that experience seasonal or other fluctuations in demand or capacity.
- ❖ The goal of aggregate planning is to achieve a production plan that will effectively utilize the organization's resources to match expected demand.

Introduction

- Planners must make decisions on output rates, employment levels and changes, inventory levels and changes, back orders, and subcontracting in or out.
- A statement of a company's **production rates**, **workforce levels**, and **inventory** holding based on estimates of customer requirements and capacity limitations.



Introduction…

- Organizations make capacity decisions on three levels:
  - **Short-range plans** (Detailed plans)
    - ✓ Machine loading
    - ✓ Job assignments
  - **Intermediate plans** (General levels)
    - ✓ Employment
    - ✓ Output, and inventories
  - **Long-range plans**
    - Long term capacity
    - Location / layout

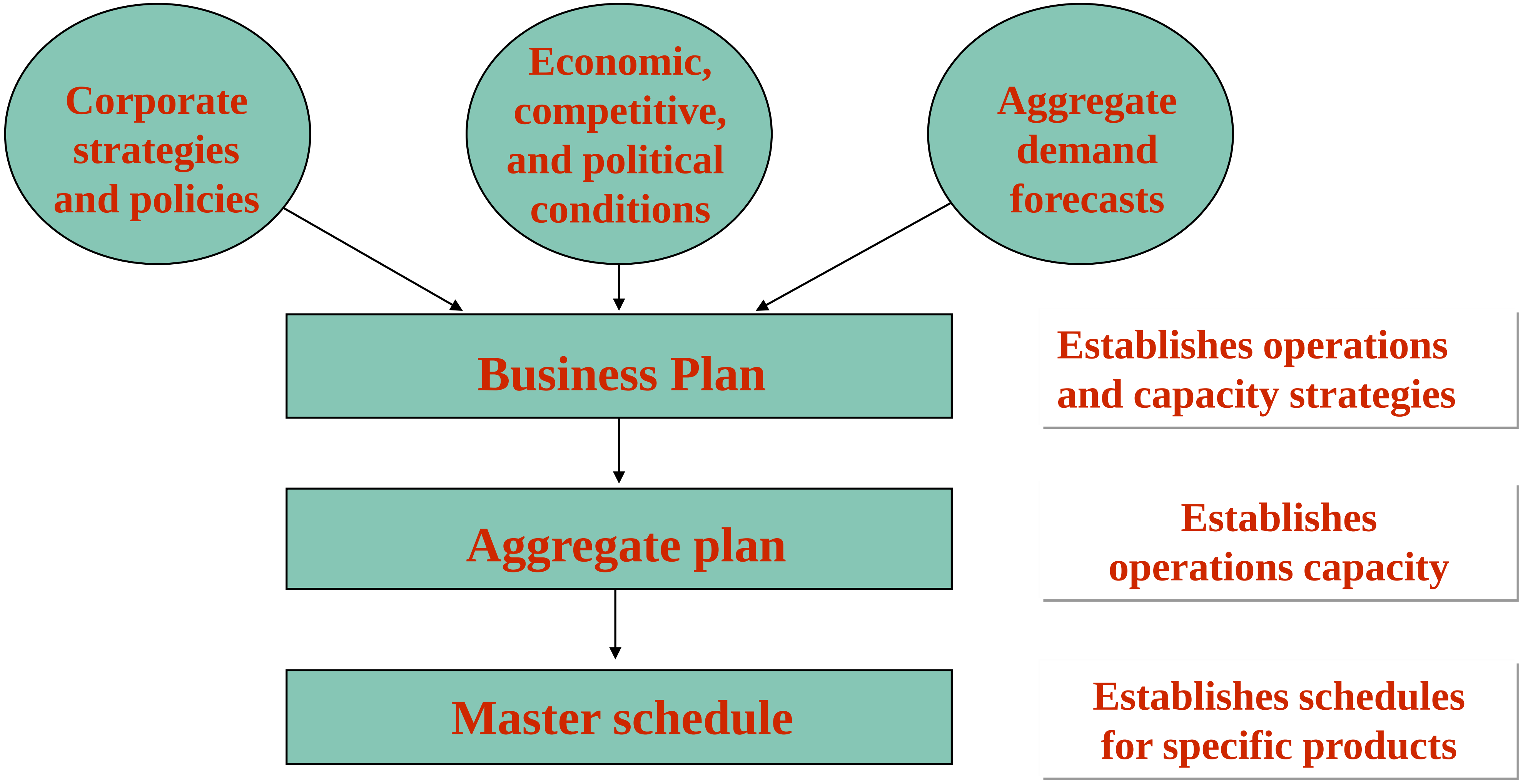
Characteristics of Aggregate Planning

- Aggregate planning begins with a forecast of aggregate demand for the intermediate range.
- Determines resource capacity to meet demand.
- For intermediate time horizon, 2-18 months.
- Not feasible to build new facility.
- May be feasible to hire/lay off workers, overtime, or subcontract
- Aggregate plans are updated periodically, often monthly, to take into account updated forecast and other changes.

Objectives of Aggregate planning

- Fully load facilities and minimizing overloading and under loading.
- Make sure enough capacity available to satisfy expected demand.
- Plan for the orderly and systematic change of production capacity to meet the picks and valleys of expected customer demand.
- Get the most output for the amount of resources available.

Planning Sequence



Overview of the aggregation problem

- Suppose that D_1, D_2, . . . , D_T are the forecasts of demand for aggregate units over the planning horizon (T periods).
- The problem is to determine both work force levels (W_t) , production levels (P_t) and Inventory level (I_t) to minimize total costs over the T period planning horizon.

Aggregate planning inputs

- Resources
  - ✓ Workforce
  - ✓ Facilities
- Demand forecast
- Policies
  - Subcontracting
  - Overtime
  - Inventory levels
  - Back orders
- Costs
  - Inventory carrying
  - Back orders
  - Hiring/firing
  - Overtime
  - Inventory changes
  - Subcontracting

Aggregate Planning Outputs

- Total cost of a plan
- Projected levels of inventory
  - Inventory
  - Output
  - Employment
  - Subcontracting
  - Backordering

Aggregate Units

- ❖ The method is (fundamentally) based on notion of aggregate units.

  They may be

  - ✓Actual units of production
  - ✓Weight (tons of steel)
  - ✓Volume (gallons of gasoline)
  - ✓Dollars (Value of sales)
  - ✓Fictitious aggregated units
    - they are a composite that estimates a tangible ‘input constant’

Aggregate Units cont…

- One plant produced 6 models of washing machines:

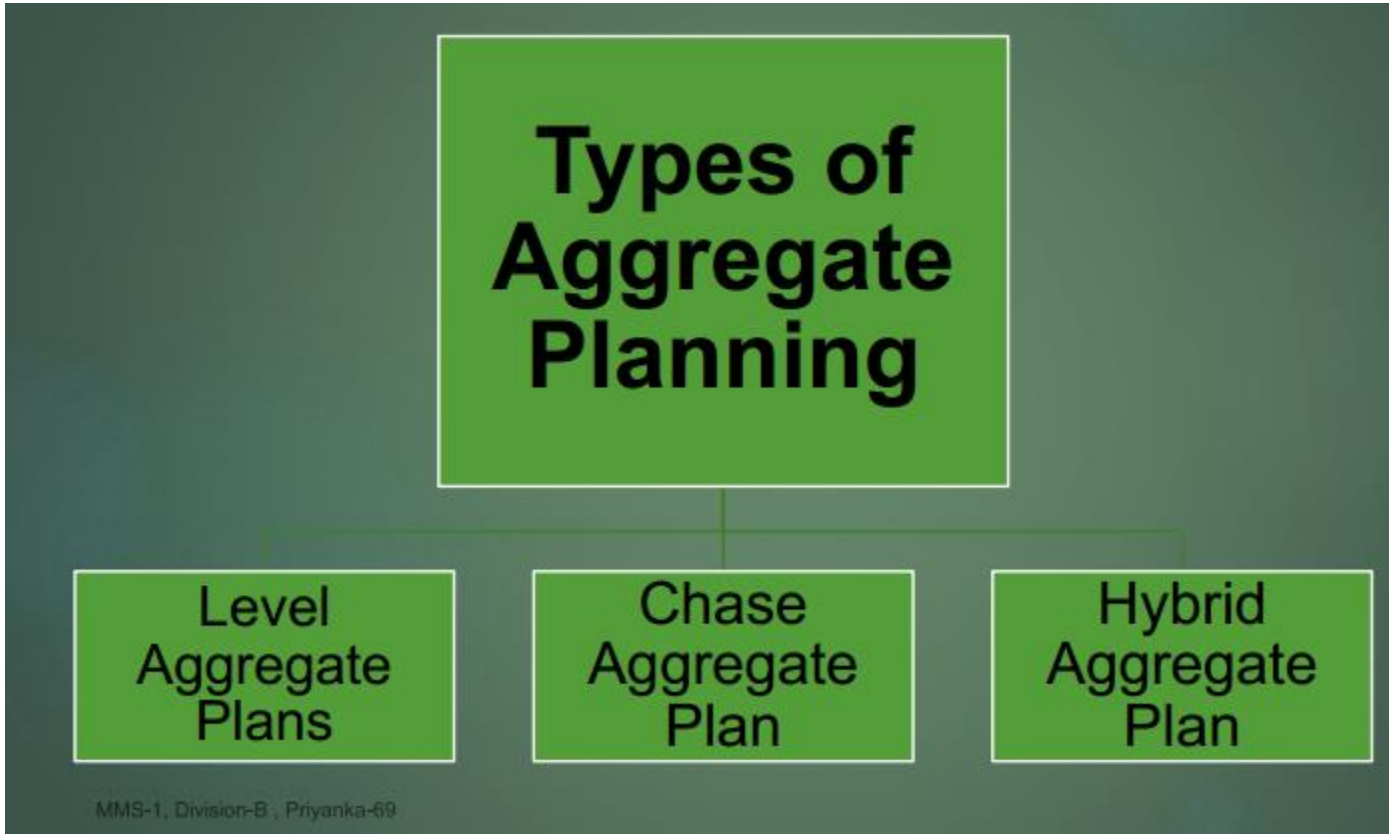
Model	# hrs.	Price	% sales
A 5532	4.2	285	32
K 4242	4.9	345	21
L 9898	5.1	395	17
L 3800	5.2	425	14
M 2624	5.4	525	10
M 3880	5.8	725	06

- Question: How do we define an aggregate unit here?

Aggregate units…

- Thus, Agg. Demand = .32*(D_{A5532}) + .21(D_{K4242}) + … + .06(D_{M3880}).
- This method for defining an aggregate unit points to an aggregate labor requirement (/Agg. Unit) of:

  .32(4.2) + .21(4.9) + . . . + .06(5.8) = 4.8644 worker hours .


Types of Aggregate Planning
Level Aggregate Plans
Chase Aggregate Plan
Hybrid Aggregate Plan
MMS-1, Division-B , Priyanka-69

Level Aggregate Plan

Advantage:

- ❑Maintain the constant workforce
- ❑ Sets capacity to accommodate average demand
- ❑ Often used for make-to-stock product
- ❑ stable output rates and workforce

Disadvantage

- ✓builds inventory and/or uses back orders
- ✓ greater inventory costs
- ✓ increased overtime and idle time
- ✓ resource utilization vary over time

Chase Aggregate Plan

Advantages:

- ❖Produces exactly what is needed in each period
- ❖Sets labor/equipment what is needed in each period
- ❖Minimize finished good inventories by trying to keep pace with demand fluctuations
- ❖Matches demand varying either work force level or output rate
- ❖ Investment in inventory is low
- ❖High labor utilization

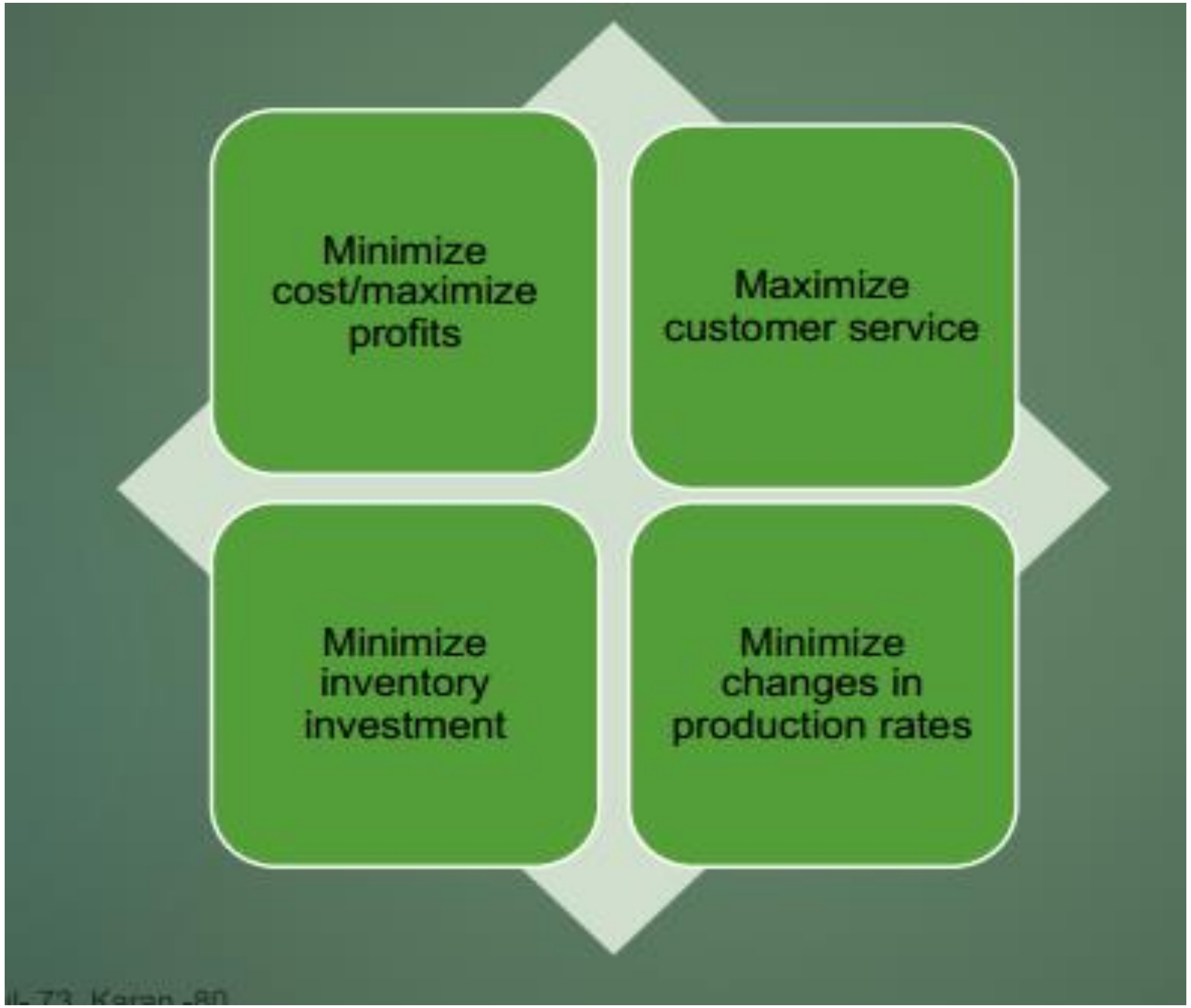
Disadvantage

- ✓constantly changing short term capacity
- ✓ cost of adjusting output rates and/or workforce levels

Hybrid Aggregate Plan

- ❖ Uses combination of options
- ❖ Option should be limited to facilitate execution
- ❖ May use a level workforce with overtime
- ❖ May use short term sourcing

Role of Aggregate Planning



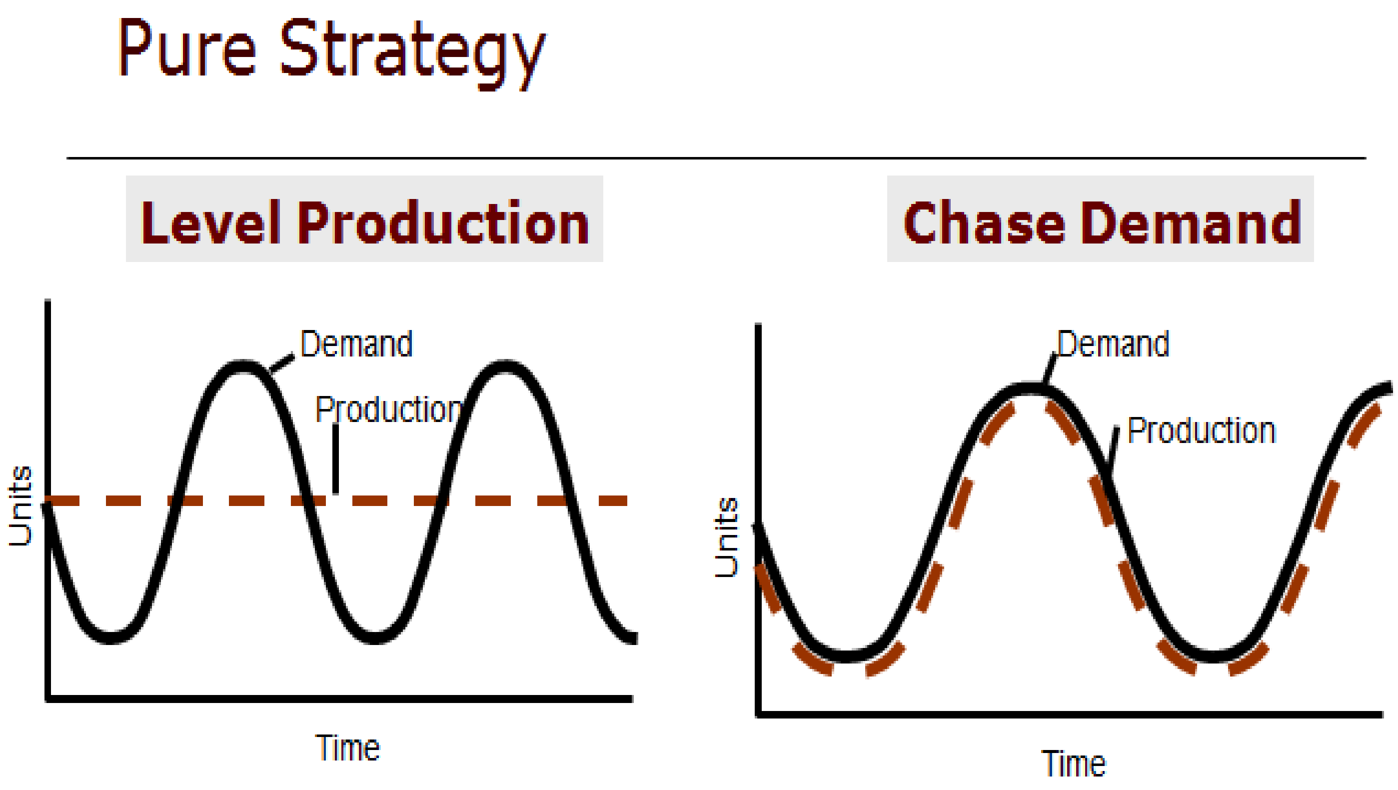
Aggregate Planning (AP) Strategies

- Proactive
  - Involve demand options: Attempt to alter demand to match capacity
- Reactive
  - Involve capacity options: attempt to alter capacity to match demand
- Mixed
  - Sum of each

Basic AP Strategies

- Level capacity strategy:
  - Maintaining a steady rate of regular-time output while meeting variations in demand by a combination of options such as: inventories, overtime, part-time workers, subcontracting and back orders.
- Chase demand strategy:
  - Matching capacity to demand; the planned output for a period is set at the expected demand for that period.

AP strategies cont…



Chase Strategy

- **Advantages**
  - Investment in inventory is low
  - Labor utilization is high
- **Disadvantages**
  - The cost of adjusting output rates and/or workforce levels

Level strategy

- **Advantages**
  - Stable output rates and workforce levels
- **Disadvantages**
  - Greater inventory costs
  - Increased overtime and idle time
  - Resource utilizations vary over time

Capacity Options

- Hire and layoff workers
- Overtime
- Part-time workers
- Inventories
- Subcontracting (in- out)

AP strategies cont…

Strategy	Possible Alternatives during Slack Season	Possible Alternatives during Peak Season
1. Chase #1: *vary workforce level to match demand*	Layoffs	Hiring
2. Chase #2: *vary output rate to match demand*	Layoffs, undertime, vacations	Hiring, overtime, subcontracting
3. Level #1: *constant workforce level*	No layoffs, building anticipation inventory, undertime, vacations	No hiring, depleting anticipation inventory, overtime, subcontracting, backorders, stockouts
4. Level #2: *constant output rate*	Layoffs, building antici-pation inventory, undertime, vacations	Hiring, depleting antici-pation inventory, over-time, subcontracting, backorders, stockouts

A general procedure for Aggregate Planning

1. Determine demand for each period
2. Determine capacities for each period
3. Identify policies that are pertinent
4. Determine unit costs
5. Develop alternative plans and costs
6. Select the best plan that satisfies objectives.
7. Otherwise return to step 5.

Average inventory

- In practice, we may use either ending inventory criteria or average inventory level criteria.

$$\text{Average inventory} = \frac{\text{Beginning Inventory} + \text{Ending Inventory}}{2}$$

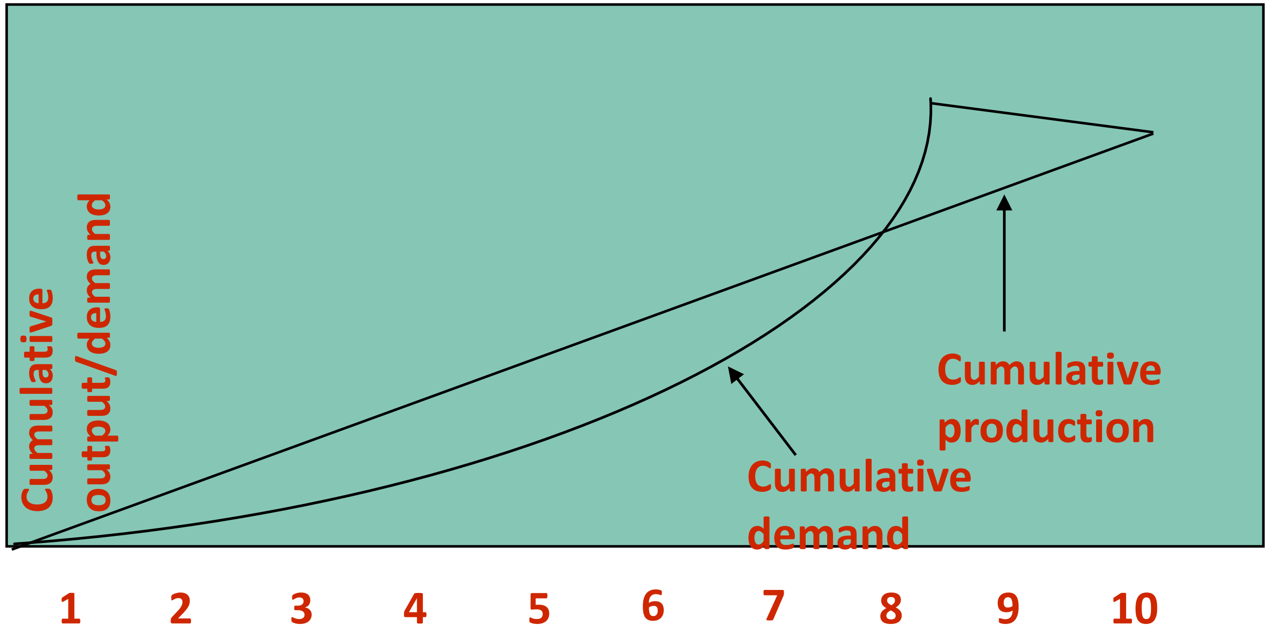
AP strategies cont…

Number of workers in a period = Number of workers at end of the previous period + Number of new workers at start of the period - Number of laid-off workers at start of the period

Cost for a period = Output cost (Reg. + OT +Subcontract) + Hire/Lay off cost + Inventory Cost + Back-order cost

Aggregate planning Techniques

- **Graphical/charting technique :**
  - Trial and error method
  - Easy to understand
  - Solution not necessarily optimal



Graphical method cont…

Example 1

Suppose we have the following unit demand and cost information:

Demand/mo	Jan	Feb	Mar	Apr	May	Jun	Total
	200	200	300	400	500	200	1,800

Cost
- Output
  - Regular time: $2 per unit
  - Over time: $3 per unit
  - Subcontract: $6 per unit
- Inventory $1 per unit per month
- Back orders: $5 per unit per period

Suppose the initial inventory is 0. Assuming a level of output rate of 300 units per month with regular time, what is the total cost?

Graphical method cont…

Period	Jan	Feb	Mar	Apr	May	Jun	Total
Demand	200	200	300	400	500	200	1,800
Output							
Regular	300	300	300	300	300	300	1,800
Overtime	-	-	-	-	-	-	-
subcontract	-	-	-	-	-	-	-
Output-demand	100	100	0	-100	-200	100	0
Inventory							
Beginning	0	100	200	200	100	0	
Ending	100	200	200	100	0	0	
Average	50	150	200	150	50	0	
Backorder	0	0	0	0	100	0	
Cost	650	750	800	750	1,150	600	$4,700

Example 2

- For the previous example, the company just learned that one person is going to retire. Rather than replace that person, the company would like to stay with the smaller workforce and use overtime to make up for the lost output. The reduced regular time output is 280 units per month. The maximum amount of overtime output per period is 40 units.

Develop a plan and compare it to the previous one.

Graphical method cont…

Period	Jan	Feb	Mar	Apr	May	Jun	Total
Demand	200	200	300	400	500	200	1,800
Output							
Regular	280	280	280	280	280	280	1,680
Overtime	0	0	40	40	40	0	120
subcontract	-	-	-	-	-	-	
Output-demand	80	80	20	-80	-180	80	0
Inventory							
Beginning	0	80	160	180	100	0	
Ending	80	160	180	100	0	0	
Average	40	120	170	140	50	0	
Backorder	0	0	0	0	80	0	80
Cost	600	680	850	820	1,130	560	$4,640

- **Chase strategy example**

The forecasted demands (in thousand)

Month	1	2	3	4	5	6
Demand	12	11	13	11	12	15

Summary information

Current workforce	12 employees
Production capacity	1,000 boxes/employee/month
Payroll cost	$1,730/person/month
Hiring cost	$200
Layoff cost	$300

- Compute the total cost .

Graphical method cont..

- **Solution:**

Month	Demand (in 1000)	Employee Rqrd.	Employee Hired	Employee Layoffs
1	12	12		
2	11	11		1
3	13	13	2	
4	11	11		2
5	12	12	1	
6	15	15	3	
		74	6	3

Total cost = 74 (1730) + 6(200) + 3(300) = $130,120

Graphical method cont..

- **Level strategy example**:

The forecasted demands (in thousand)

Month	1	2	3	4	5	6
Demand	12	11	13	11	12	15

Summary information

Current workforce	12 employees
Production capacity	1,000 units/employee/month
Payroll cost	$1,730/person/month
Inventory holding cost	$0.17/unit/month
Initial inventory	2,000 units

- Compute the total cost.

Graphical method cont..

- Solution:

Month	Demand (in 1000)	Employee Level	Inventory (in 1000) Beginning	Ending
1	12	12	2	2
2	11	12	2	3
3	13	12	3	2
4	11	12	2	3
5	12	12	3	3
6	15	12	3	0
		72	15	13

Ending Inv. = Beginning Inv. + Production - Demand

Total cost = 72 (1730) + 14,000(0.17) = $126,940

Mathematical Technique

Linear programming method:

- Linear programming models are methods for obtaining optimal solutions to problems involving the allocation of scarce resources in terms of cost minimization or profit maximization.
- With aggregate planning, the goal is usually to minimize the sum of costs related to regular labor time, overtime, subcontracting, carrying inventory, and cost associated with changing the size of the workforce. Constraints involve the capacities of the workforce, inventories, and subcontracting.
- The aggregate planning problem can be formulated as a transportation problem (special case of linear programming.

Mathematical method cont…

- LP MODEL:
- *Let*
  - W_t = workforce size for period t
  - P_t =units produced in period t
  - I_t =units in inventory at the end of period t
  - F_t =number of workers fired for period t
  - H_t = number of workers hired for period t

Mathematical method cont…

- **Transportation Method:**

➢ A method of LP

➢ Gather all cost info into one matrix

➢ Try to obtain the lowest cost alternative

Alternatives		Quarter 1	Quarter 2	Quarter 3	Quarter 4	Unused Capacity	Total Capacity
Quarter	Beginning inventory	0	h	$2h$	$3h$	$4h$	I_0
1	Regular time	r	$r+h$	$r+2h$	$r+3h$	u	R_1
	Overtime	c	$c+h$	$c+2h$	$c+3h$	0	O_1
	Subcontract	s	$s+h$	$s+2h$	$s+3h$	0	S_1
2	Regular time	$r+b$	r	$r+h$	$r+2h$	u	R_2
	Overtime	$c+b$	c	$c+h$	$c+2h$	0	O_2
	Subcontract	$s+b$	s	$s+h$	$s+2h$	0	S_2
3	Regular time	$r+2b$	$r+b$	r	$r+h$	u	R_3
	Overtime	$c+2b$	$c+b$	c	$c+h$	0	O_3
	Subcontract	$s+2b$	$s+b$	s	$s+h$	0	S_3
4	Regular time	$r+3b$	$r+2b$	$r+b$	r	u	R_4
	Overtime	$c+3b$	$c+2b$	$c+b$	c	0	O_4
	Subcontract	$s+3b$	$s+2b$	$s+b$	s	0	S_4
Requirements		D_1	D_2	D_3	$D_4 + I_4$	U	

Mathematical method cont…

Notations :

I_t = inventory at the end of period t (I_0 = beginning inventory)

h = holding cost per unit per period,

r = regular production cost per unit,

o = overtime cost per unit,

u = under time cost per unit

s = subcontracting cost per unit,

b = backordering cost per unit per period

R_t = regular-time capacity in period t

O_t = overtime capacity in period t

S_t = subcontracting capacity in period t

D_t = forecasted demand for period t

U = total unused capacities

Mathematical method cont…

- Example :
- Given the following information set up the problem in a transportation table and solve for the minimum cost plan.

	period		
	1	2	3
demand	550	700	750
Capacity			
Regular	500	500	500
Overtime	50	50	50
subcontract	120	120	100
Beginning inventory	100		
Costs			
Regular time	$60 per unit		
Overtime	80 per unit		
Subcontract	90 per unit		
Inventory carrying cost	$1 per unit per month		
Back order cost	$3 per unit per month		

Mathematical method cont…

- **Solution**:

- Inventory carrying cost, h = $1 per unit per period. Hence, units produced in one period and carried over to a later period will incur a holding cost that is a linear function of the length of time held.
- Linear programming models of this type require that supply (capacity) and demand be equal. A dummy column has been added (nonexistent capacity) to satisfy that requirement. Since it does not "cost" anything extra to not use capacity in this case, cell costs of $0 have been assigned.
- No backlogs were needed in this example
- The quantities (e.g., 100, 450 in column 1) are the amounts of output or inventory that will be used to meet demand requirements. Thus, the demand of 550 units in period 1 will be met using 100 units from inventory and 450 obtained from regular time output.

Mathematical method cont…

- **Solution :**

		Period 1	Period 2	Period 3	Unused capacity	capacity
Period	Beginning inventory	100 / 0	1	2	0	100
1	Regular	450 / 60	50 / 61	62	0	500
	Overtime	80	50 / 81	82	0	50
	subcontract	90	30 / 91	92	90 / 0	120
2	Regular	63	500 / 60	61	0	500
	Overtime	83	50 / 80	81	0	50
	subcontract	93	20 / 90	100 / 91	0	120
3	Regular	66	63	500 / 60	0	500
	Overtime	86	83	50 / 80	0	50
	subcontract	96	93	100 / 90	0	100
demand		550	700	750	90	2090

Total cost is

$124730

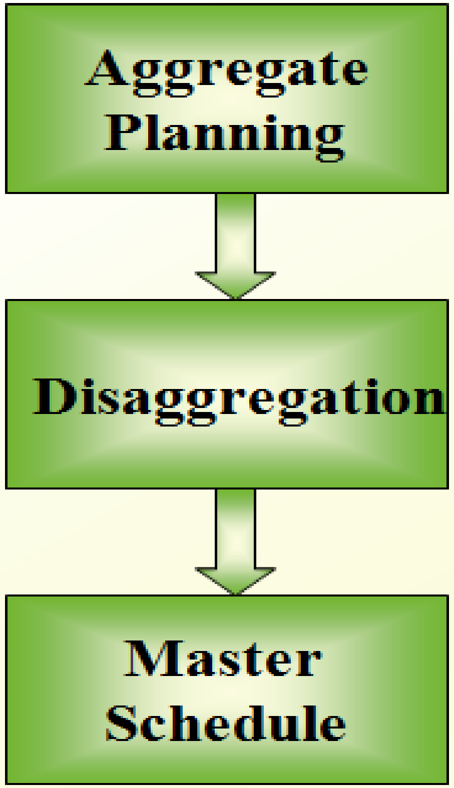
Master scheduling

- For the production plan to be translated into meaningful terms of production, it is necessary to disaggregate the aggregate plan.
- This means breaking down the aggregate plan into specific product requirements in order to determine labor requirements (skills, size of workforce), materials, and inventory requirements.
- To put the aggregate production plan into operation, one must convert, or decompose, those aggregate units into units of actual product or services that are to be produced or offered.
- For example, televisions manufacturer may have an aggregate plan that calls for 200 television in January, 300 in February, and 400 in March. This company produce 21, 26, and 29 inch TVs, therefore the 200, 300, and 400 aggregate TVs that are to be produced during those three months must be translated into specific numbers of TVs of each type prior to actually purchasing the appropriate materials and parts, scheduling operations, and planning inventory requirements.

Master scheduling cont…

- The result of disaggregating the aggregate plan is a master schedule showing the quantity and timing of specific end items for a scheduled horizon, which often covers about six to eight weeks ahead.
- The master schedule shows the planned output for individual products rather than an entire product group, along with the timing of production.
- It should be noted that whereas the aggregate plan covers an interval of, say, 12 months, the master schedule covers only a portion of this. In other words, the aggregate plan is disaggregated in stages , or phases, that may cover a few weeks to two or three months.
- The master schedule contains important information for marketing as well as for production. It reveals when orders are scheduled for production and when completed orders are to be shipped.

Master scheduling cont…



Aggregate plan

Jan	Feb	Mar.
200	300	400

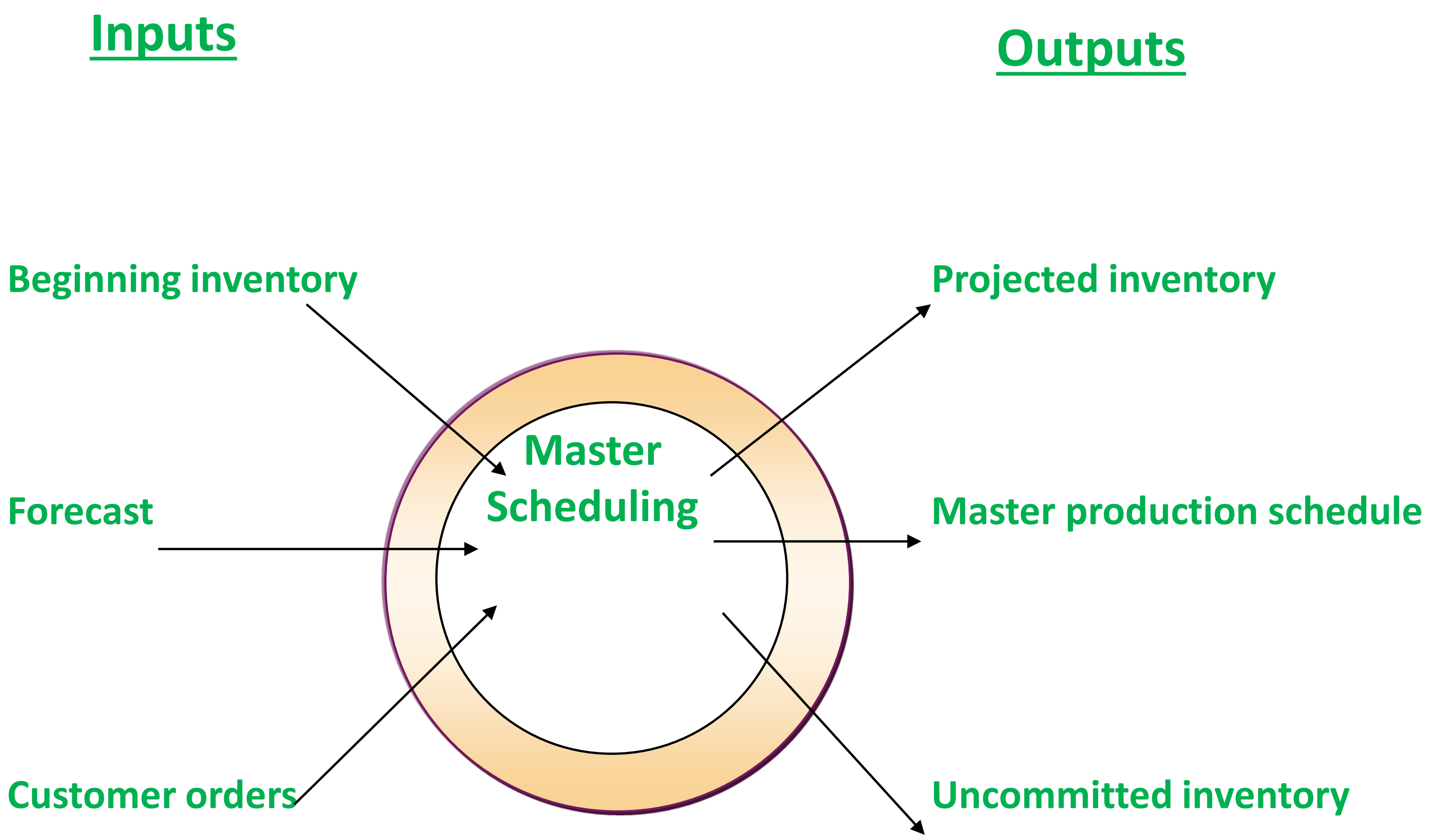
Master schedule

Type	Jan.	Feb.	Mar
21 inch	100	100	100
26 inch	75	150	200
29 inch	25	50	100
total	200	300	400

Master scheduling cont…

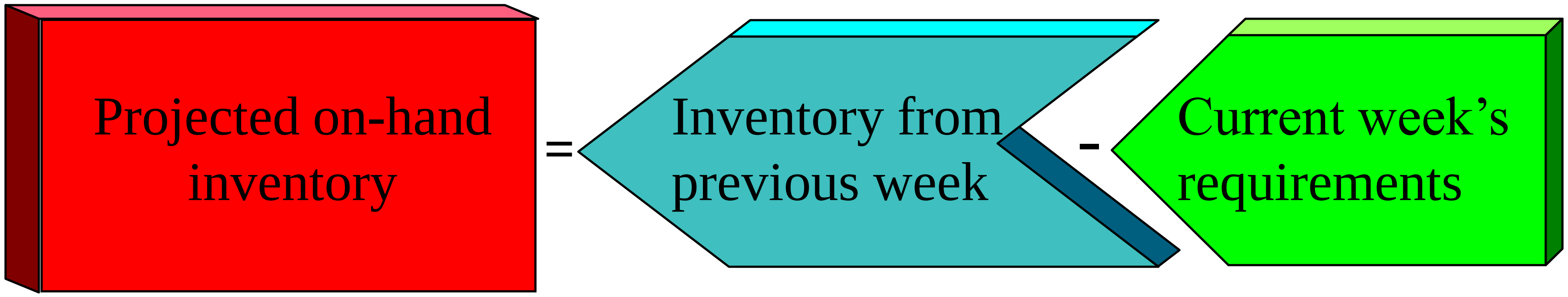
- Master schedule
  - Determines quantities needed to meet demand
  - Interfaces with
    - Marketing: it enables marketing to make valid delivery commitments to warehouse and final customers.
    - Capacity planning: it enables production to evaluate capacity requirements
    - Production planning
    - Distribution planning

Master scheduling cont…



Master scheduling cont…

- *Master production schedule (MPS):* indicates the quantity and timing of planned production, taking into account desired delivery quantity and timing as well as on-hand inventory. The MPS is one of the primary outputs of the master scheduling process.



Master scheduling cont…

- **Example:**

A company that makes industrial pumps wants to prepare a master production schedule for June and July. Marketing has forecasted demand of 120 pumps for June and 160 pumps for July. These have been evenly distributed over the four weeks in each month: 30 per week in June and 40 per week in July.

Now suppose that there are currently 64 pumps in inventory (i.e., beginning inventory is 64 pumps), and that there are customer orders that have been committed for the first five weeks (booked) and must be filled which are 33, 20, 10, 4, and 2 respectively. The following figure (see next slide) shows the three primary inputs to the master scheduling process: beginning inventory, the forecast, and the customer orders that have been committed. This information is necessary to determine three quantities: the projected on-hand inventory, the master production schedule (MPS) and the uncommitted (ATP) inventory. Suppose a production lot size of 70 pumps is used.

Prepare the master Schedule

Master scheduling cont…

- **Solution :**

The master schedule before MPS

Beginning Inventory

	JUNE				JULY			
64	1	2	3	4	5	6	7	8
Forecast	30	30	30	30	40	40	40	40
Customer Orders (committed)	33	20	10	4	2			
Projected on-hand inventory	31	1	-29					

Forecast is larger than Customer orders in week 3

Customer orders are larger than forecast in week 1

Forecast is larger than Customer orders in week 2

Master scheduling cont…

- The first step you have to calculate the on hand inventory

Week	Inventory from previous week	Requirements	Net inventory before MPS	MPS	Projected inventory
1	64	33	31		31
2	31	30	1		1
3	1	30	-29	70	41
4	41	30	11		11
5	11	40	-29	70	41
6	41	40	1		1
7	1	40	-39	70	31
8	31	40	-9	70	61

Master scheduling cont…

- The projected on-hand inventory and MPS are added to the master schedule

Initial inventory	June				July			
64	1	2	3	4	5	6	7	8
Forecast	30	30	30	30	40	40	40	40
Customer orders (committed)	33	20	10	4	2			
Projected on hand inventory	31	1	41	11	41	1	31	61
MPS			70		70		70	70
Available to promise inventory (uncommitted)	11		56		68		70	70

Master scheduling cont…

- **Notes:**
  - ➢ The requirements equals the maximum of the forecast and the customer orders
  - ➢ The net inventory before MPS equals the inventory from previous week minus the requirements.
  - ➢ The MPS = run size, will be added when the net inventory before MPS is negative (weeks 3, 5, 7, and 8).
  - ➢ The projected inventory equals the net inventory before MPS plus the MPS (70).

Master scheduling cont…

- The amount of inventory that is uncommitted, and, hence, available to promise is calculated as follows:

Sum booked customer orders week by week until (but not including) a week in which there is an MPS amount. For example, in the first week, this procedure results in summing customer orders of 33 (week 1) and 20 (week 2) to obtain 53. in the first week, this amount is subtracted from the beginning inventory of 64 pumps plus the MPS (zero in this case) to obtain the amount that is available to promise [(64 + 0 – (33 + 20)] = 11