Macro/Aggregate Production Planning

Production and operation analysis
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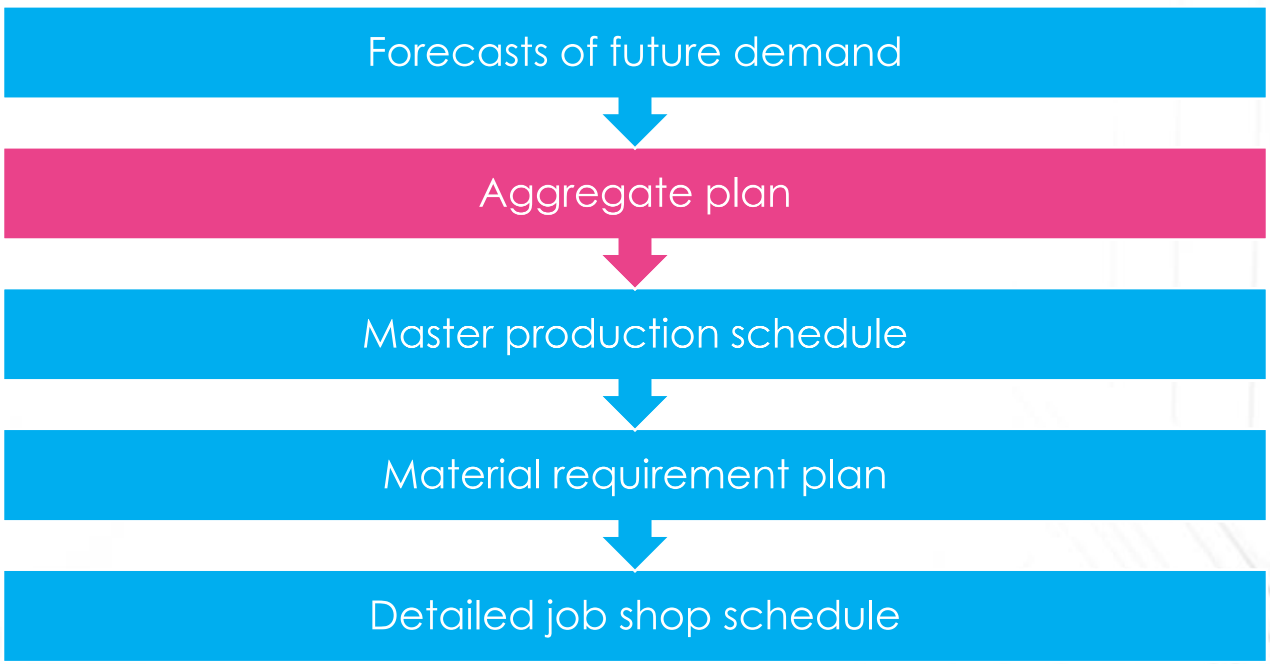
Aggregate planning

Objective

To plan gross work force level and set firm-wide production plans so that demand (forecasted) can be met in terms of aggregated units.

Hierarchy of production decisions



Aggregate planning

Trade-offs

Balancing the advantages of producing to meet the demand as closely as possible against the disruptions caused by changing levels of production and/or workforce level

Aggregate planning

Aggregate units

- Weight (tons of steel, kilos of gold...)
- Volume (liters of gasoline...)
- Amount of work required (man-year...)
- Dollar value (value of inventory in dollars)
- Fictitious quantity

Aggregate planning

Fictitious aggregate unit

One plant produces 6 models of washing machines:

Model	Man-hours	Selling Price	% Sales
A 5532	4.2	285	0.32
K 4242	4.9	345	0.21
L 9898	5.1	395	0.17
L 3800	5.2	425	0.14
M 2624	5.4	525	0.10
M 3880	5.8	725	0.06
Avg	5.1	450	

A -Avg. man-hour

B- Avg. Price

C- %Sales

D- Selling price/man-hour

E- %Sales * man-hour

F- %Sales * Selling price

What can be a reasonable aggregate unit here?

Aggregate planning

Fictitious aggregate unit

- Notice: Price is not necessarily proportional to worker hours (i.e., cost): why?
- One method for defining an aggregate unit:

$.32(4.2) + .21(4.9) + . . . + .06(5.8) = 4.856$ worker hours.

Forecasts of demand for aggregate units can be obtained by taking a weighted average (using the same weights) of individual item forecasts.

Aggregate planning

Overview

- 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) and production levels (P_t) to minimize total costs over the T period planning horizon.
- Demand is assumed to be known !

Primary issues

- **Smoothing**
  - Cost and disruptions caused by changing production/workforce level from a period to another.
    - How estimatable can the cost of firing a worker be?
    - In Sweden, is firing a worker really an option?
- **Bottleneck**
  - Refers to the inability of the system to respond to sudden changes in demand as a result of capacity restrictions.

Primary issues

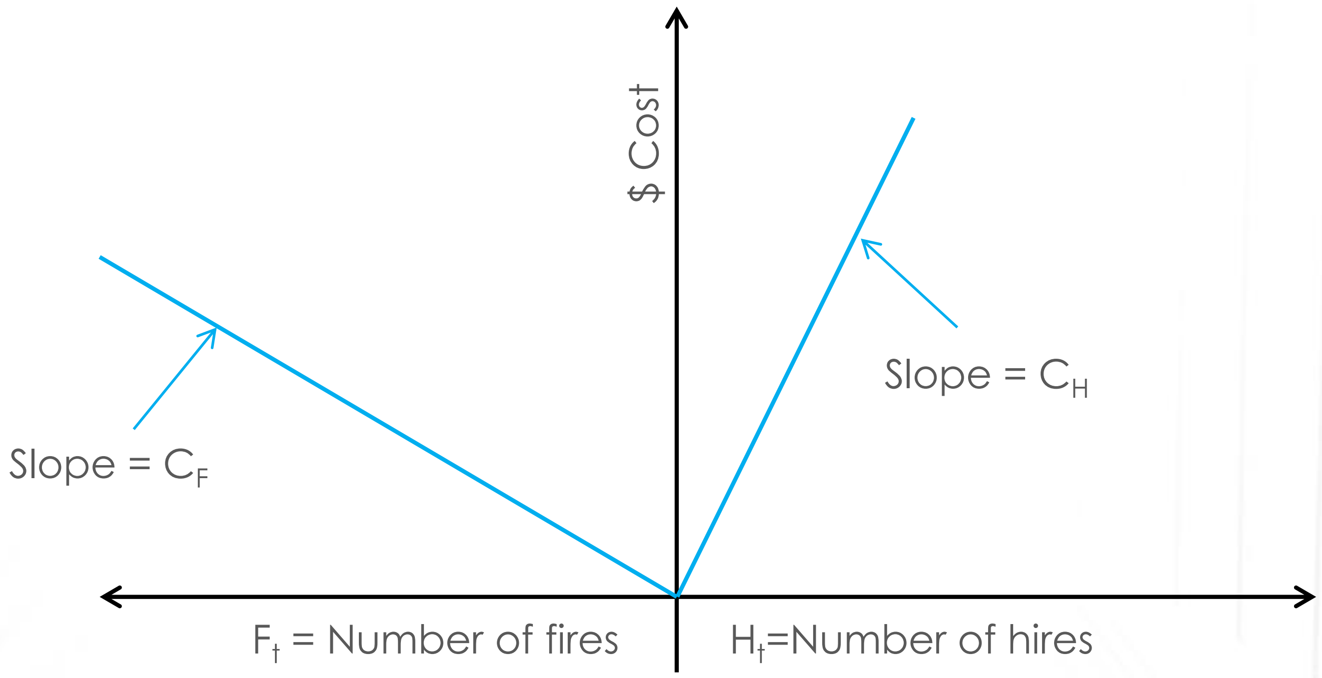
- **Planning horizon**
  - Refers to the number of periods of demand forecast used to generate the aggregate plan. If the horizon is too short, there may be insufficient time to build inventories to meet future demand surges and if it is too long the reliability of the demand forecasts is likely to be low.
  - End-of-horizan effect
  - Rolling schedules and frozen horizon
- **Treatment of demand**
  - Assume demand is known. Ignores uncertainty to focus on the predictable/systematic variations in demand, such as seasonality.

Relevant costs

- **Smoothing Costs**
  - changing size of the work force
  - changing number of units produced
- **Holding Costs**
  - Dollars per unit held per planning period
  - opportunity cost of investment
- **Shortage Costs**
  - Cost of demand exceeding stock on hand. Why should shortages be an issue if demand is known?
- **Other Costs:**
  - payroll, overtime, subcontracting.

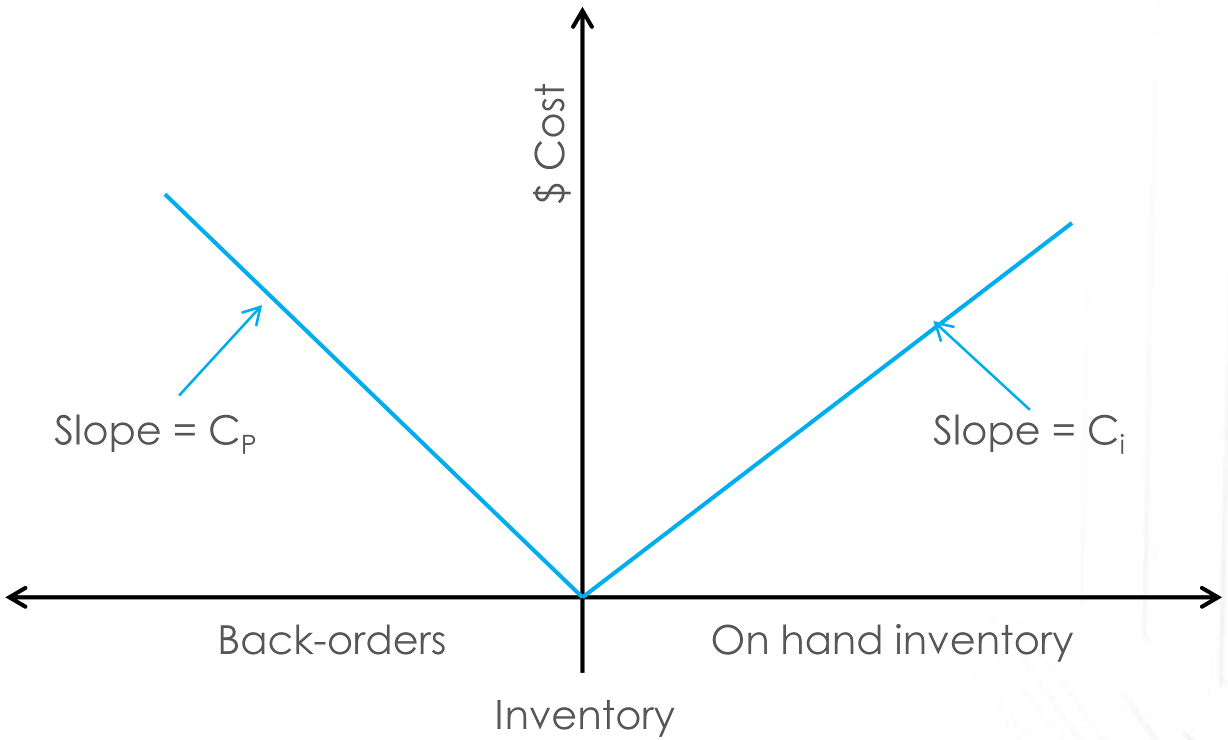
Smoothing cost for workforce

Smoothing cost is assumed to be linear!



Holding&backorder cost

Holding and shortage costs are assumed to be linear!



Aggregate planning example

- The washing machine plant is interested in determining work force and production levels for the next 8 months. Forecasted demands are;

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.
420	280	460	190	310	145	110	125

Starting inventory at the end of December is 200 and the firm would like to have 100 units on hand at the end of August.

What are the monthly production levels?

Inventory requirements

How to deal with specific inventory requirements

- Starting inventory is subtracted from first period's demand,
- Ending inventory requirement (for the end of the planning horizon) is added to the last period's demand,
- Buffer inventory requirement for all periods is added to first period only,
- Buffer inventory for some periods: add to the first period for the requirement, subtract from the period demand where it ends.

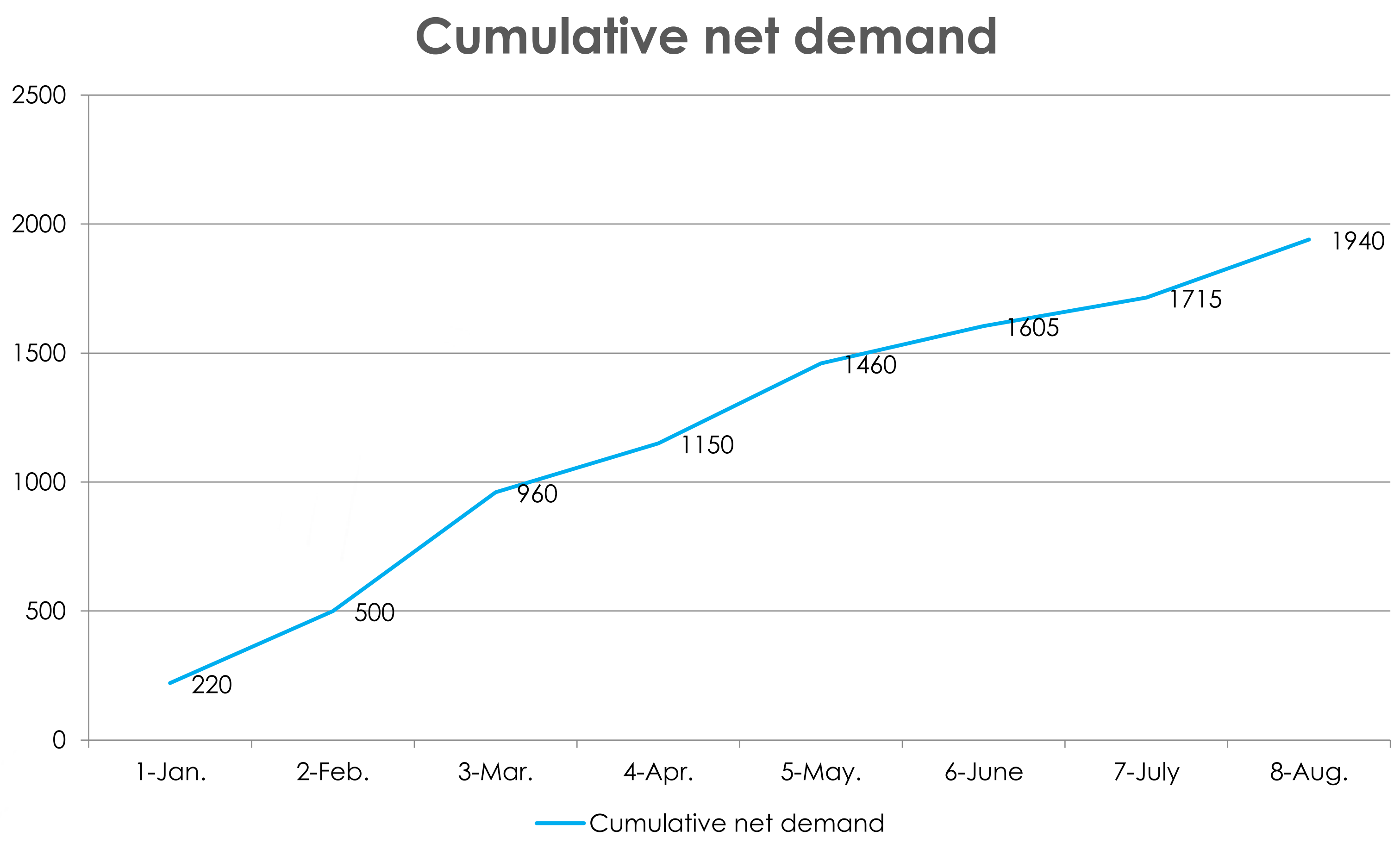
Net demand

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.
420	280	460	190	310	145	110	125
-200							+100
220	280	460	190	310	145	110	225

Cumulative net demand

	Net predicted demand	Cumulative net demand	Working days
1-Jan.	220	220	22
2-Feb.	280	500	16
3-Mar.	460	960	23
4-Apr.	190	1150	20
5-May.	310	1460	21
6-June	145	1605	22
7-July	110	1715	21
8-Aug.	225	1940	22

Cum. Net demand



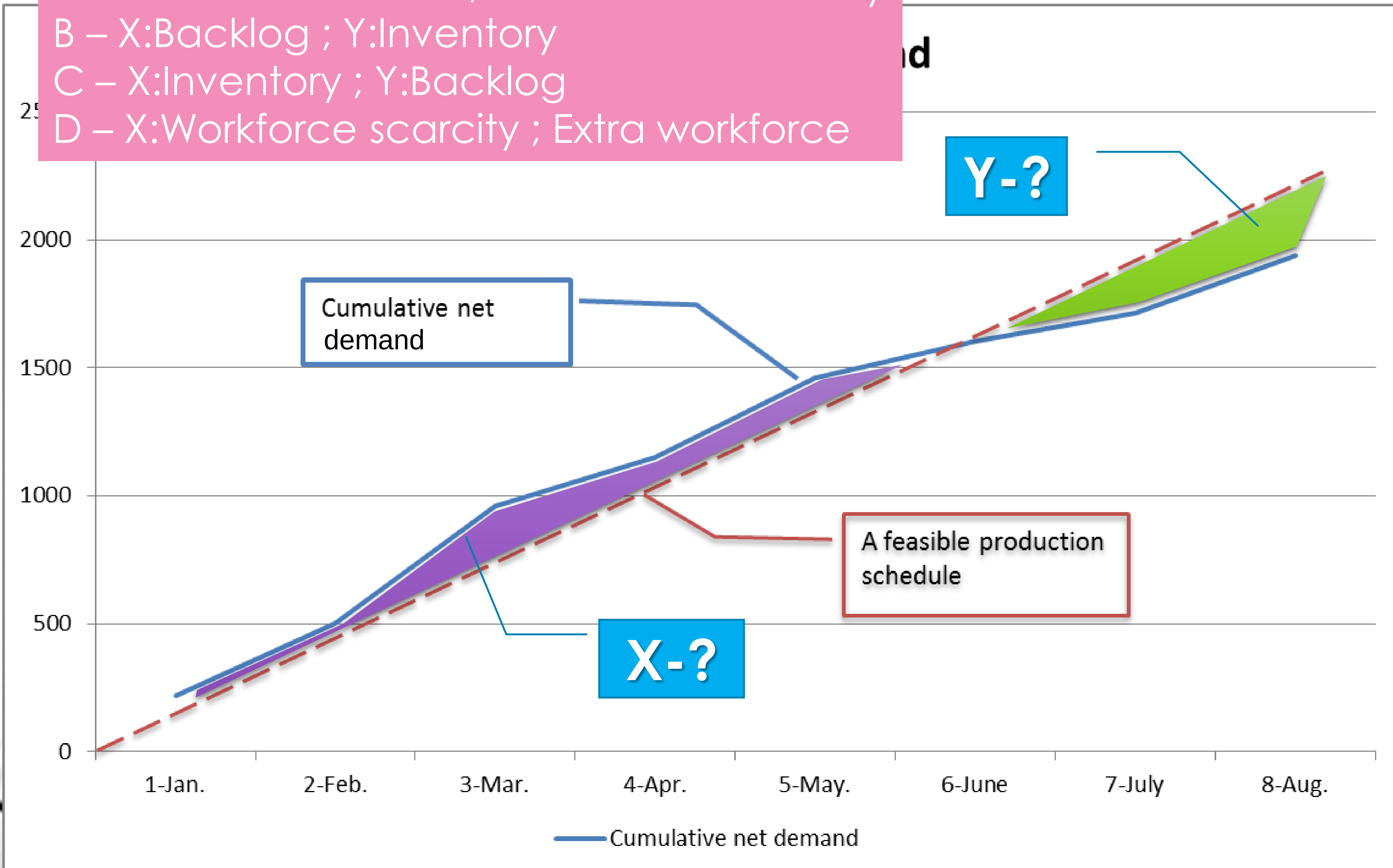
What are the areas X and Y representing?

A – X:Extra workforce ; Y:Workforce scarcity

B – X:Backlog ; Y:Inventory

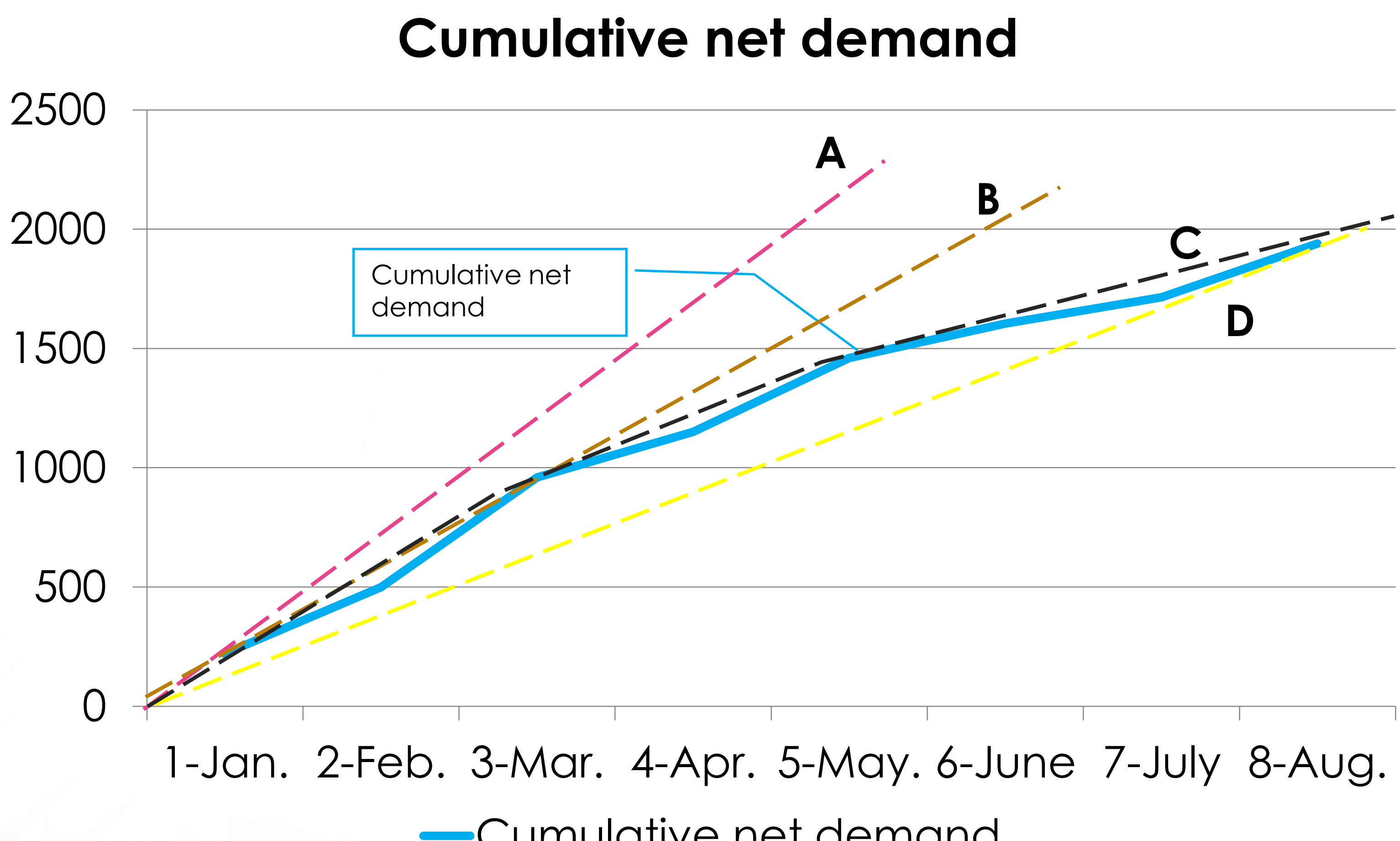
C – X:Inventory ; Y:Backlog

D – X:Workforce scarcity ; Extra workforce



Cumulative net demand

- Find the line that is over cumulative demand all the time during the planning horizon but with as little inventory as possible by keeping production level constant.



Aggregate planning

Conflicting objectives

- ***Objective 1 :*** React quickly to anticipated changes in demand
  - Called "chase" strategy
  - Involves frequent and large changes in the size of the labor force
  - May not be the best strategy in the long-run
  - Cost of firing and hiring is substantial
- ***Objective 2 :*** Retaining a stable workforce
  - Leads in to inventory build-ups during low demand periods or to idle time increases.

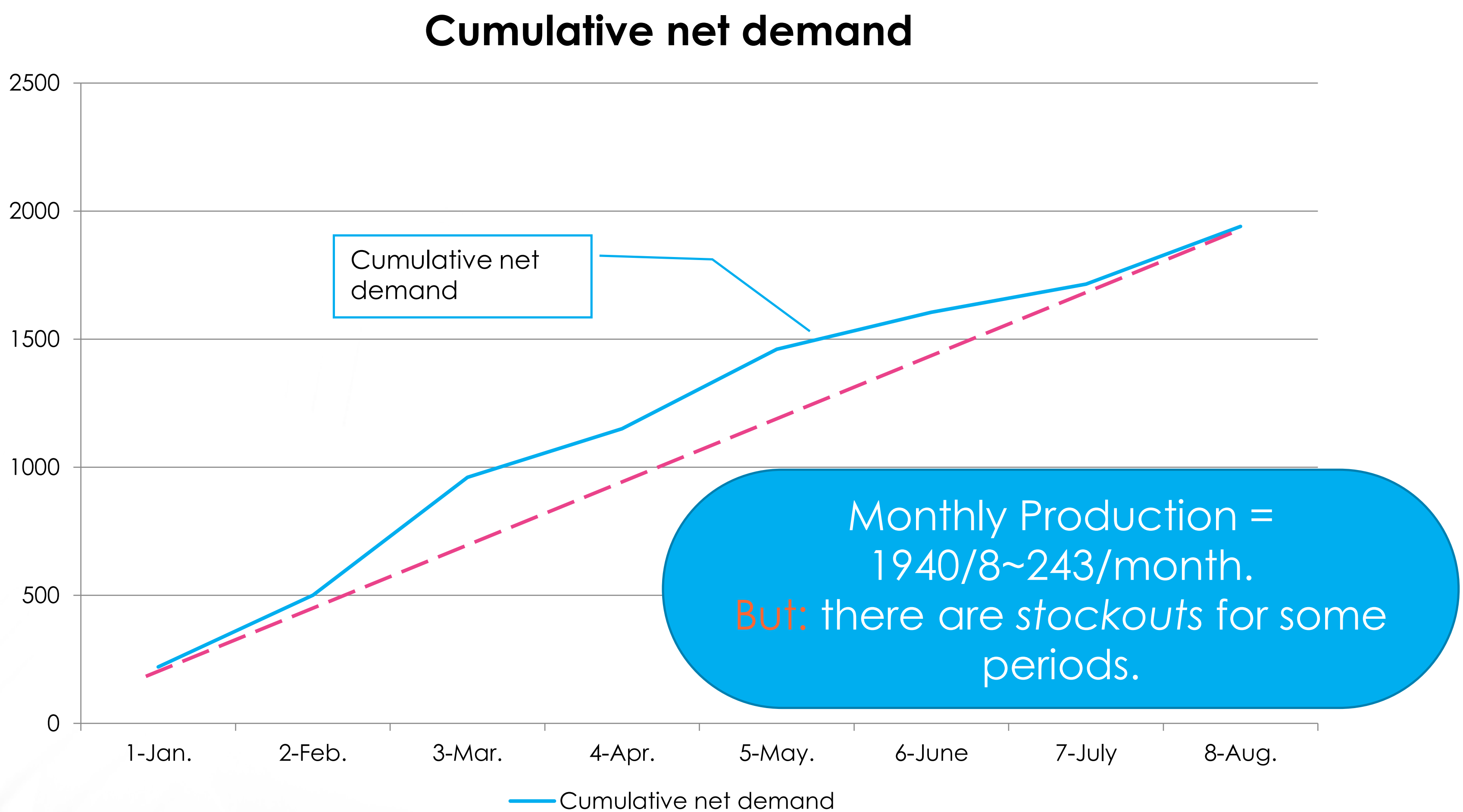
Constant workforce plan

- Suppose that we are interested in determining a production plan that doesn't change the size of the workforce over the planning horizon. How would we do that?

- One method: In previous picture, draw a straight line from origin to 1940 units in month 8: The slope of the line is the number of units to produce each month.

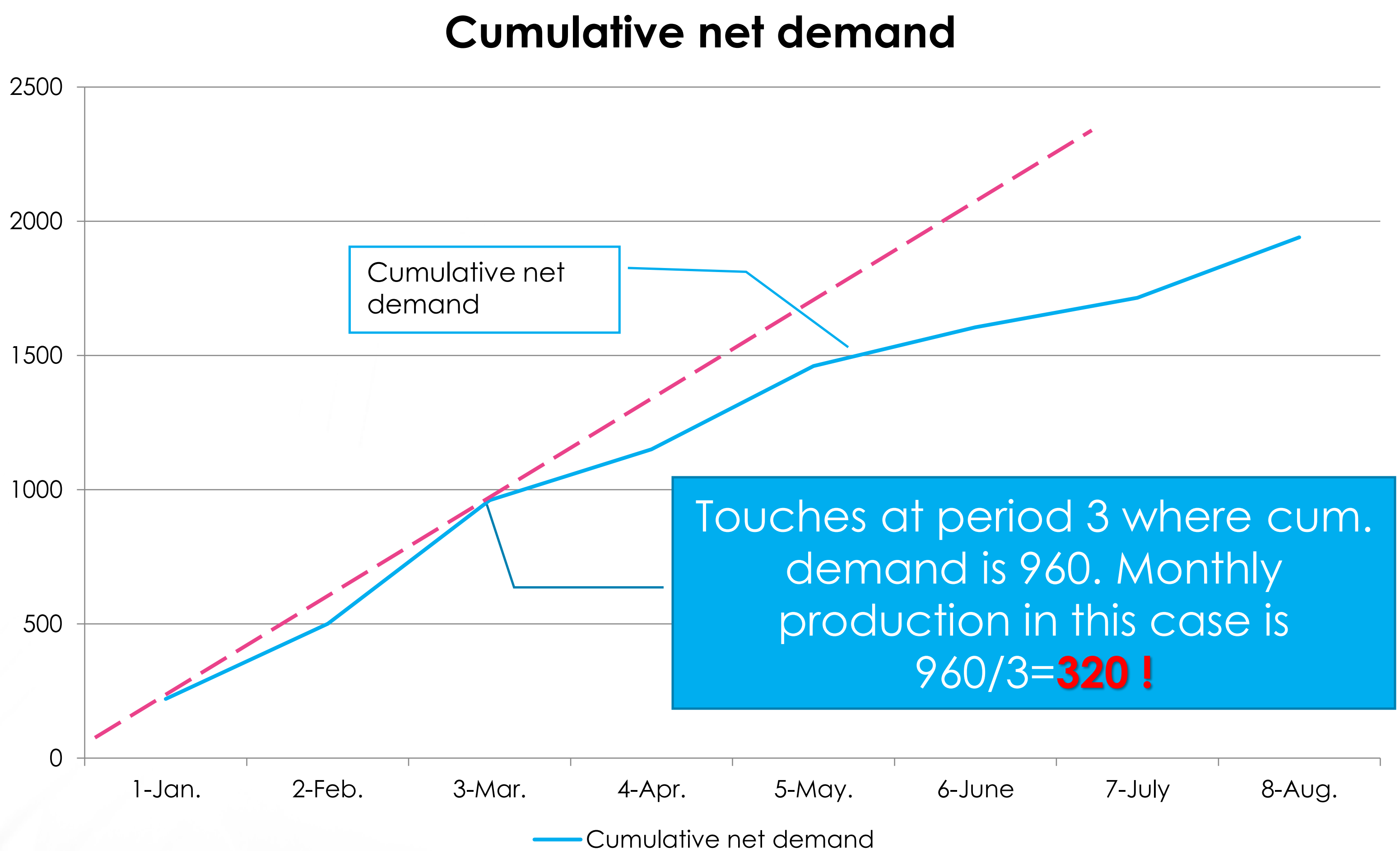
Constant workforce plan

Zero ending inventory



Constant workforce plan

No stockouts



Ending inventory for no stockout production

	Cumulative net demand	Cumulative production	Ending inventory
1-Jan.	220	320	100
2-Feb.	500	640	140
3-Mar.	960	960	0
4-Apr.	1150	1280	130
5-May.	1460	1600	140
6-June	1605	1920	315
7-July	1715	2240	525
8-Aug.	1940	2560	620

Is this a realistic plan?

May not be realistic for several reasons

- It may not be possible to achieve the production level of 320 unit/month with an integer number of workers

- Since all months do not have the same number of workdays, a constant production level may not translate to the same number of workers each month.

To overcome these shortcomings

- Number of workdays per month is known.
- K factor is known (or computed) where

K = # of aggregate units produced
by one worker
in one day
= unit/worker/day

Finding K

- Suppose that we are told that over a period of 40 days, the plant had 38 workers who produced 520 units. It follows that:
- K= 520/(38*40) = **0.3421**

= average number of units produced by one worker in one day.

Constant workforce plan

Assume we are given the following # of working days per month:

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.
22	16	23	20	21	22	21	22

March is the critical month. Why?

Why march is critical

Number of workdays*K = unit/worker in that specific month

Max. # workers is required at March for no stockout constant workforce plan

	Cumulative net demand	Number of units produced per worker	Cumulative number of units produced per worker	Ratio
1-Jan.	220	7,5262	7,5262	30
2-Feb.	500	5,4736	12,9998	38
3-Mar.	960	7,8683	20,8681	46
4-Apr.	1150	6,842	27,7101	42
5-May.	1460	7,1841	34,8942	42
6-June	1605	7,5262	42,4204	38
7-July	1715	7,1841	49,6045	35
8-Aug.	1940	7,5262	57,1307	34

Constant workforce plan

=K*Workers*Days

With 46 workers

	# of working days	Production level	Cumulative production	Cumulative net demand	Ending inventory
1-Jan.	22	346	346	220	126
2-Feb.	16	252	598	500	98
3-Mar.	23	362	960	960	0
4-Apr.	20	315	1275	1150	125
5-May.	21	330	1605	1460	145
6-June	22	346	1951	1605	346
7-July	21	330	2281	1715	566
8-Aug.	22	346	2627	1940	687
				Total:	**2093**

Costs

Suppose the costs are

- Holding Cost (per unit per month): $8.50
- Hiring Cost per worker: $800
- Firing Cost per worker: $1,250
- Payroll Cost: $75/worker/day
- Shortage Cost: $50 unit short/month

Cost Evaluation of Constant Work Force Plan

- Assume that the work force at the end of Dec. was 40.
- Need to have 46 workers. Cost to hire 6 workers: 6*800 = $4800
- Inventory Cost:

  accumulate ending inventory: (126+98+0+. . .+687) = 2093.

  Add in 100 units (netted out in Aug) = 2193.

  Hence Inv. Cost = 2193*8.5 = $18,640.50
- Payroll cost:

  ($75/worker/day)(46 workers)(167days) = $576,150
- Cost of plan: $576,150 + $18,640.50 + $4800 = **$599,590.50**

Zero inventory plan

Chase strategy

- Here the idea is to change the workforce each month in order to reduce ending inventory to nearly zero by matching the workforce with monthly demand as closely as possible. This is accomplished by computing the # units produced by one worker each month (by multiplying K by #days per month) and then taking net demand each month and dividing by this quantity. The resulting ratio is rounded up and possibly adjusted downward.

Zero inventory plan

	# of working days	Number of units produced per worker	Forecast net demand	Min. # of workers required
1-Jan.	22	7,5262	220	30
2-Feb.	16	5,4736	280	52
3-Mar.	23	7,8683	460	59
4-Apr.	20	6,842	190	28
5-May.	21	7,1841	310	44
6-June	22	7,5262	145	20
7-July	21	7,1841	110	16
8-Aug.	22	7,5262	225	30

Zero inventory plan

	Min. # of workers required	Hired	Fired	Number of units produced per worker	Number of units produced	Cum. production	Cum. net demand	Ending inventory
1-Jan.	30		10	7,5262	226	226	220	6
2-Feb.	52	22		5,4736	285	511	500	11
3-Mar.	59	7		7,8683	465	976	960	16
4-Apr.	28		31	6,842	192	1168	1150	18
5-May.	44	16		7,1841	317	1485	1460	25
6-June	20		24	7,5262	151	1636	1605	31
7-July	16		4	7,1841	115	1751	1715	36
8-Aug.	30	14		7,5262	226	1977	1940	37
TOTAL		**59**	**69**					**180**

Cost evaluation of zero inventory plan

Hiring cost: 59*$800 = 47200

Firing cost: 69*$1250 = 86250

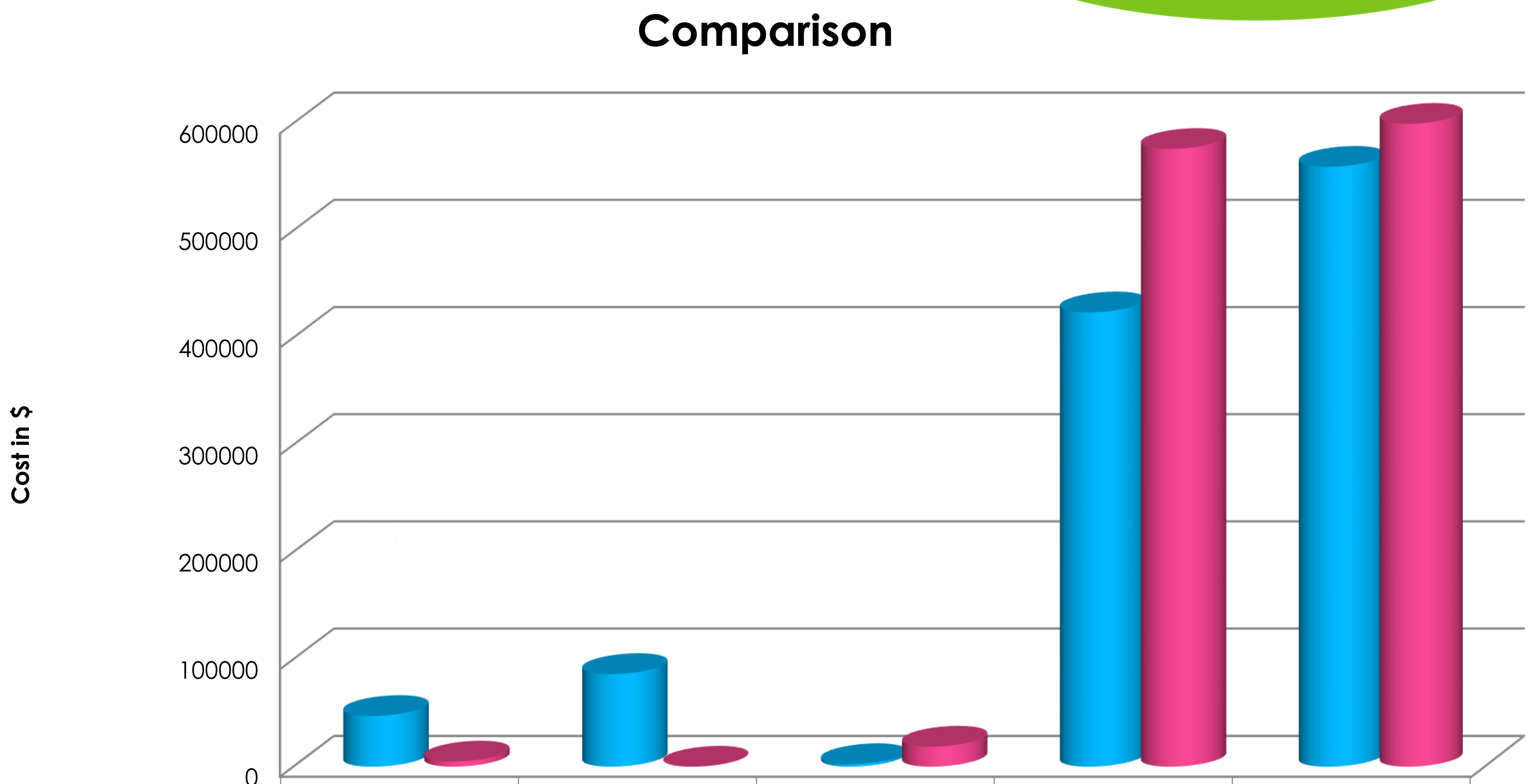
Inventory cost: 180 + 100 units (netted out in Aug) = 280*$8,5=2380

Payroll cost: 5769*$75= 432675

Total = **$568 505**

Comparison

What are we missing ?



	Hiring	Firing	Inventory holding	Payroll	TOTAL
Zero Inventory	47200	86250	2380	423675	559505
Constant workforce	4800	0	18641	576150	599591

What are we missing?

3rd alternative: Cost reduction with changing production rate

- In the original cum net demand curve, consider making changes in the production rate one or more times over the planning horizon to decrease inventory costs.