

ABC XYZ COOLERS

Family	Material Cost/ Unit (Rs.)	Revenue/ Unit (Rs.)	Setup Time/B atch (hour)	Average Batch Size	Production Time/ Unit (hour)	Net Production Time/Unit (hour)	Percentage Share of Units Sold
A	150	540	8	500	5.60	5.76	10
B	70	300	6	1500	3.00	3.04	25
C	90	390	8	1000	3.80	3.88	20
D	120	490	10	500	4.80	5.00	10
E	90	360	6	1000	3.60	3.66	20
F	130	480	5	750	4.30	4.37	15

Table 8-1

Module 4. Aggregate Planning Using Linear Programming

- STEP I: Identify set of decision variables
- STEP II: Define the Objective function
- STEP III: Specify Constraints (**then use EXCEL**)
- STEP IV: Use Average Inventory
- STEP V: Optimize the objective function
- STEP VI: Identify forecast errors

ABC XYZ COOLERS

Item	Cost
Material cost	Rs.100/unit
Inventory holding cost	Rs.20/unit/month
Marginal cost of stockout/backlog	Rs.50/unit/month
Hiring and training costs	Rs.3000/worker
Layoff cost	Rs.5000/worker
Labor hours required	4/unit
Regular time cost	Rs.40/hour
Overtime cost	Rs.60/hour
Cost of subcontracting	Rs.300/unit

Table 8-3

Decision Variables (SLIDE INSERT)

For $t = 1, \dots, 6$

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

ABC XYZ COOLERS: STEP II

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)

$$\begin{aligned} \text{Min} \sum_{t=1}^6 640W_t &+ \sum_{t=1}^6 6O_t + \sum_{t=1}^6 300H_t + \sum_{t=1}^6 500L_t \\ &+ \sum_{t=1}^6 2I_t + \sum_{t=1}^6 5S_t + \sum_{t=1}^6 10P_t + \sum_{t=1}^6 30C_t \end{aligned}$$

ABC XYZ COOLERS : STEP III: Constraints

All for $t = 1, \dots, 6$

1. Workforce, hiring, and layoff constraints

$$W_t = W_{t-1} + H_t - L_t$$

2. Capacity constraints

$$P_t \leq 40W_t + \frac{O_t}{4}$$

3. Inventory balance constraints

$$I_{t-1} + P_t + C_t = D_t + S_{t-1} + I_t - S_t$$

4. Overtime limit constraints

$$O_t \leq 10W_t$$

STEP IV: USE AVERAGE INVENTORY

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

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

ABC XYZ COOLERS

Total cost over planning horizon = Rs.422,275 Revenue
over planning horizon = $40 \times 16,000 = \text{Rs.}640,000$

Period, t	No. Hired, H_t	No. Laid Off, L_t	Workforce Size, W_t	Overtime, O_t	Inventory, I_t	Stock out, 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

ABC XYZ COOLERS

$$\text{Average seasonal inventory} = \frac{(I_0 + I_6) / 2 + \left(\sum_{t=1}^5 I_t \right)}{T} = \frac{5,367}{6} = 895$$

$$\text{Average flow time} = \frac{895}{2,667} = 0.34 = 0.34 \text{ months}$$

Step VI: 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

MOD5. Aggregate Planning In Excel

Step I = Build a table containing each decision variable.

Step II= Construct a table of constraints

Step III= Create a cell containing the Objective function

Step IV= Invoke the Solver application

- *With in the Solver parameters click on Options and then select ASSUME LINEAR MODEL (this will speed up the calculations as it uses faster algorithms) and then click on SOLVE.*

Step V= The optimal Solution should be returned

If it does not return the optimal solution, save this answer and then repeat this step, often a number of multiple repetitions or iterations is required, a built in limitation of EXCEL.

Aggregate Planning In Excel;

Create a table containing following decision variables

For $t = 1, \dots, 6$

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

Also note column J contains the actual demand. the demand information is required to calculate aggregate plan.

Figure 8-1

STEP II: Construct a table of constraints (WORKFORCE, CAPACITY, INVENTORY & OVERTIME) . COLUMN M CONTAINS.....

	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

Create a cell containing the Objective function, which is how each solution is judged / **checked**. the selected cell, C22 represents the total cost & contains the sum of cells from B15 to I 20.

	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

STEP IV:

Set target cell: C22

Equal to :select *Min*

By changing cells: B5 :I10

Subject to constraints

B5:I10 ≥ 0 { All decision variables are non negative}

F10 ≥ 500 { Inventory at end of Period 6 is at least 500}

G10=0{Stock out at end of Period 6 equals 0}

M5:M10=0{ $W_t - W_{t-1} - H_t + L_t = 0$ for $t = 0, 1, 2, 3, \dots, 6$ }

N5:M10 ≥ 0 { $40W_t + O_t/4 - P_t \geq 0$ for $t = 0, 1, 2, 3, \dots, 6$ }

O5:O10=0{ $I_{t-1} - S_{t-1} + P_t + C_t - D_t - I_t + S_t = 0$ for $t = 0, 1, 2, 3, \dots, 6$ }

P5:P10 ≥ 0 { $10W_t - O_t \geq 0$ for $t = 0, 1, 2, 3, \dots, 6$ }

Step IV= Invoke the Solver application

With in the Solver parameters click on Options and then select ASSUME LINEAR MODEL (this will speed up the calculations as it uses faster algorithms) and then click on SOLVE.

Figure 8-4

Step IV: Aggregate Planning In Excel

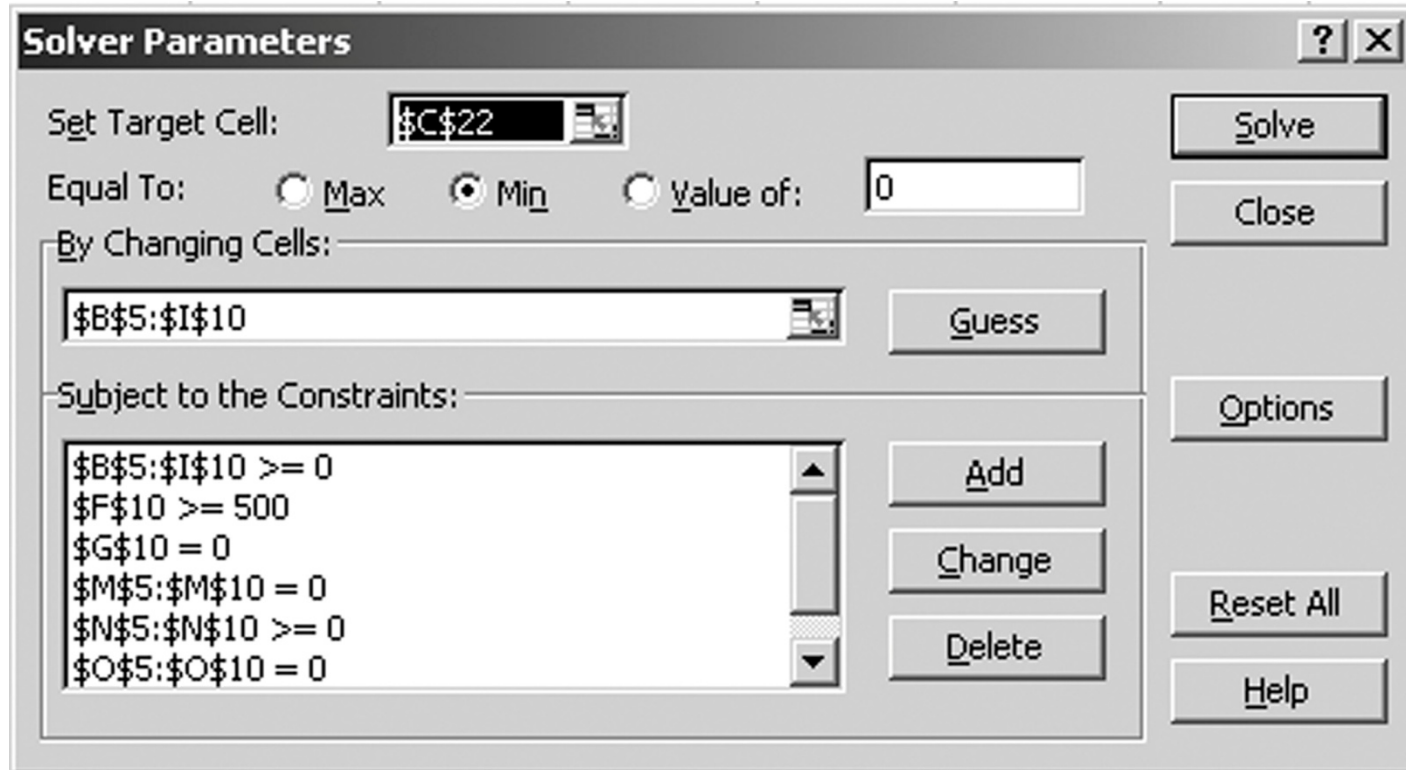


Figure 8-4

Step V

- The optimal Solution should be returned.
- If it does not return the optimal solution, save this answer and then repeat this step, often a number of multiple repetitions or iterations is required, a built in limitation of EXCEL.

Module 6: 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

Module 7: Implementing Aggregate Planning in Practice

1. Think beyond the enterprise to the entire supply chain
2. Make plans flexible because forecasts are always inaccurate
3. Re-run the aggregate plan as new data emerge
4. Use aggregate planning as capacity utilization increases

SIGNING OFF NOTE

- In words of James A Tompkins:
 - Supply chain excellence cannot be achieved without synthesized supply chain. **supply chain synthesis requires design, planning & execution.**

Learning Objectives

1. Manage supply to improve **synchronization (organization, harmonization, management, bringing together)** in a supply chain in the face of predictable variability.
2. Manage demand to improve synchronization in a supply chain in the face of predictable variability.
3. Use sales and operations planning to maximize profitability when faced with predictable variability in a supply chain.

Question:

- Discuss how a firm can respond to predictable variability of demand in the supply chain?

Discuss how a firm can respond to predictable variability of demand in the supply chain.

- Faced with predictable variability, a company's goal is to respond in a manner that maximizes profitability. A firm must choose how to handle predictable variability by utilizing techniques in two broad categories:
 - **1. Manage supply using capacity, inventory, subcontracting, and backlogs.**
 - **2. Manage demand using short-term price discounts and trade promotions.**

Discuss how a firm can respond to predictable variability of demand in the supply chain.

- 1. One way to meet seasonal demand requires carrying enough manufacturing capacity to meet demand in any period.

Discuss how a firm can respond to predictable variability of demand in the supply chain.

- 2. Another approach to meeting demand would be to build up inventory during the off season to keep production stable year round.
- 3. A third approach would be for a firm to work with their retail partners in the supply chain to offer a price promotion during periods of low demand.

Discuss how a firm can respond to predictable variability of demand in the supply chain.

- Therefore, maximizing profitability depends on these decisions being made in a coordinated fashion and requires supply chain partners to work together across enterprises.

QUESTION

Discuss the approaches that can be used to manage capacity to meet predictable variability of demand?

Answer: Capacity

- 1. Time flexibility from workforce*
- 2. Use of seasonal workforce*
- 3. Use of subcontracting*
- 4. Use of dual facilities—dedicated and flexible:*
- 5. Designing product flexibility into the production processes*

Discuss the approaches that can be used to manage capacity to meet predictable variability of demand

- The capacity on each line can be varied by moving the workforce from one line to the other.

Responding to Predictable Variability in a Supply Chain

- Predictable variability is change in demand that can be forecasted.
- Can cause increased costs and decreased responsiveness in the supply chain.
- Two broad approaches:
 1. Manage supply using capacity, inventory, subcontracting, and backlogs.
 2. Manage demand using short-term price discounts and trade promotions.

Managing Supply

- Managing capacity
 - Time flexibility from workforce
 - Use of seasonal workforce
 - Use of subcontracting
 - Use of dual facilities – specialized and flexible
 - Designing product flexibility into production processes
- Managing inventory
 - Using common components across multiple products
 - Build inventory of high demand or predictable demand products

- Discuss the approaches a firm can use to manage inventory to meet predictable variability of demand.
- Discuss the importance of collaboration within a supply chain when performing aggregate planning.
- Promotion on Supply within a Supply Chain.
- Discuss the impact of promotion on demand within a supply chain.

Info 1: Inventory/Capacity Trade-off

- Leveling capacity, **forces** inventory to build up in anticipation of seasonal variation in demand.
- **Carrying low levels of inventory requires capacity to vary with seasonal variation in demand or enough capacity to cover peak demand during season.**

Question

- Discuss **the approaches** a firm can use to manage inventory to meet predictable variability of demand.

Inventory

- 1. Using common components across multiple products.*
- 2. Build inventory of high demand or predictable demand products.*

Inventory

- As more is known about demand closer to the selling season, production of more uncertain items should take place.
- This strategy helps the supply chain better synchronize supply and demand.

Question

- Discuss the importance of **collaboration** within a supply chain when performing aggregate planning.

Collaboration Means

1. Relationship
2. Partnership
3. Teamwork
4. Group Effort
5. Association
6. Alliance
7. Cooperation

Organizational Relationships

- Types of Relationships (COLLABORATION)
- Vertical relationships: These refer to the traditional linkages between firms in the supply chain such as retailers, distributors, manufacturers, and parts and materials suppliers.
- Horizontal relationships: Includes those business agreements between firms that have “parallel” or cooperating positions in the logistics process.

Collaboration

- The retailer sets the price and runs promotions to generate demand. This is regularly done without taking into account the impact on the rest of the supply chain.
- Therefore, the combination of pricing and aggregate planning (both demand and supply management) can be used to maximize supply chain profitability.

Managing Demand @ ABCXYZ Water Coolers. FICTIOUS CASE

- Promotion at ABCXYZ Coolers

Item	Cost
Material cost	Rs100/unit
Inventory holding cost	Rs20/unit/month
Marginal cost of stockout/backlog	Rs50/unit/month
Hiring and training costs	Rs300/worker
Layoff cost	Rs500/worker
Labor hours required	4/unit
Regular time cost	Rs4/hour
Overtime cost	Rs6/hour
Cost of subcontracting	Rs30/unit

Managing Demand

- Promotion at Red Tomato and Green Thumb

Item	Cost
Material cost	Rs10/unit
Inventory holding cost	Rs2/unit/month
Marginal cost of stockout/backlog	Rs5/unit/month
Hiring and training costs	Rs300/worker
Layoff cost	Rs500/worker
Labor hours required	4/unit
Regular time cost	Rs4/hour
Overtime cost	Rs6/hour
Cost of subcontracting	Rs30/unit

Managing Demand

	A	B	C	D	E	F	G	H	I	J	K
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	Price
4	0	0	0	80	0	1,000	0	0			
5	1	0	15	65	0	1,983	0	0	2,583	1,600	40
6	2	0	0	65	0	1,567	0	0	2,583	3,000	40
7	3	0	0	65	0	950	0	0	2,583	3,200	40
8	4	0	0	65	0	0	267	0	2,583	3,800	40
9	5	0	0	65	0	117	0	0	2,583	2,200	40
10	6	0	0	65	0	500	0	0	2,583	2,200	40
22	Total Cost =		\$422,275								
23						Base Price		\$ 40			
24	Total Revenue =	\$640,000		Promote? (0/1)		0	Consumption		0.10		
25	Profit =	\$217,725		Month (1/4)		1	Forward buy		0.20		

Managing Demand

Total cost over planning horizon = Rs. 422,275

Revenue over planning horizon = Rs. 640,000

Profit over planning horizon = Rs. 217,725

$$\text{Average seasonal inventory} = \frac{(I_0 + I_6) / 2 + \left(\sum_{t=1}^5 I_t \right)}{T} = \frac{5,367}{6} = 895$$

$$\text{Average flow time} = \frac{\text{average inventory}}{\text{average sales}} = \frac{895}{2,667} = 0.34 \text{ months}$$

The Timing of a Promotion

- Impact of the promotion on demand
- Cost of holding inventory
- Cost of changing the level of capacity
- Product margins
- Increase in demand from
 - Market growth
 - Stealing share
 - Forward buying

When to Promote

- Is it more effective to promote during the peak period of off-peak?
- Analyze the impact of a promotion on demand and the resulting optimal aggregate plan.

Promotion in January

Total cost over planning horizon = Rs. 421,915

Revenue over planning horizon = Rs. 643,400

Profit over planning horizon = Rs. 221,485

- Lower seasonal inventory
- A somewhat lower total cost
- A higher total profit

Promotion in April

Total cost over planning horizon = Rs. 438,857

Revenue over planning horizon = Rs. 650,140

Profit over planning horizon = Rs. 211,283

- Higher seasonal inventory
- A somewhat higher total cost
- A slightly smaller total profit

QUESTION

- Discuss the impact of promotion on demand within a supply chain.

PROMOTION

- Companies want to explore if and when to potentially offer a promotion. **Four** key factors influence the timing of a trade promotion:
 1. Impact of the promotion on demand
 2. **Product margins**
 3. Cost of holding inventory
 4. **Cost of changing capacity**

PROMOTION

- 1. *Market growth*: An increase in consumption of the product, either from new or existing customers.
- 2. *Stealing share*: Customers substituting the firm's product for a competitor's product.
- 3. *Forward buying*: Customers move up future purchases to the present.

PROMOTION

- In general, as the fraction of increased demand coming from forward buying grows, offering the promotion during the peak demand period becomes less attractive.
- Offering a promotion during a peak period that has significant forward buying creates even more variable demand than before the promotion.
- Product that was once demanded in the slow period is now demanded in the peak period, making this demand pattern even more costly to serve.
- Average inventory increases if a promotion is run during the peak period and decreases if the promotion is run during the off-peak period.

- When faced with seasonal demand, a firm should use a combination of pricing (to manage demand) and production and inventory (to manage supply) to improve profitability.
- The precise use of each lever varies with the situation. This makes it crucial that enterprises in a supply chain coordinate both their forecasting and planning efforts. Only then are profits maximized.

Conclusions on Promotion

1. Average inventory increases if a promotion is run during the peak period and decreases if the promotion is run during the off-peak period .
2. Promoting during a peak-demand month may decrease overall profitability if there is a small increase in consumption and a significant fraction of the demand increase results from a forward buy.

Implementing Sales and Operations Planning in Practice

1. Coordinate planning across enterprises in the supply chain.
2. Take predictable variability into account when making strategic decisions.
3. Design Sales & Operations Planning to understand and manage the drivers of demand usage.
4. Ensure that the Sales & Operations Planning process modifies plans as the reality or forecasts change.

- 1. Coordinate planning across enterprises in the supply chain.*
- 2. Take predictable variability into account when making strategic decisions.*
- 3. Preempt, do not just react to, predictable variability.*

Modules Basis

- ◆ **1. Supply chain coordination requires all stages to take actions that maximize total supply chain profits.**

Objectives

- ◆ Module 1: Describes supply chain coordination, the bullwhip effect, and their impact on performance
- ◆ Module 2: Identifies obstacles to coordination in a supply chain
- ◆ Module 3: Discusses managerial levers that help achieve coordination in a supply chain
- ◆ Module 4: Explains actions that facilitate the building of strategic partnerships and trust within a supply chain
- ◆ Module 5: Understands the different forms of collaborative planning, forecasting and replenishment possible in a supply chain

Bullwhip Effect

- ◆ Fluctuations in orders increase as they move up the supply chain from retailers to wholesalers to manufacturers to suppliers
- ◆ Distorts demand information within the supply chain, where different stages have very different estimates of what demand looks like
- ◆ Results in a loss of supply chain coordination

The Effect on Performance

- Supply chain lacks coordination if each stage optimizes only its local objective
- Reduces total profits
- Performance measures include
 - Manufacturing cost
 - Inventory cost
 - Replenishment lead time
 - Transportation cost
 - Labor cost for shipping and receiving
 - Level of product availability
 - Relationships across the supply chain

Causes and Counter-measures of the Bullwhip Effect

Table 1 The Causes and Counter-Measures of the Bullwhip Effect

Causes	Contributing factors	Counter-measures	State of practice
Demand signaling	• No visibility of end demand • Multiple forecasts • Long lead-time	• Access sell-thru or POS data • Single control of replenishment • Lead-time reduction	• Sell-thru data in contracts (e.g., HP, Apple, IBM) • VMI (P&G and WalMart) • Quick Response mfg strategy
Order batching	• High order cost • FTL economics • Random or correlated ordering	• EDI & CAO • Discount on assorted truckload, consolidation by 3rd party logistics • Regular delivery appointment	• McKesson, Nabisco • 3rd party logistics in Europe, emerging in the US • P&G
Fluctuating prices	• High-low pricing • Delivery & purchase asynchronized	• EDLP • Special purchase contract	• P&G (resisted by some retailers) • Under study
Shortage game	• Proportional rationing scheme • Ignorance of supply conditions • Unrestricted orders & free return policy	• Allocate based on past sales • Shared capacity & supply information • Flexibility limited over time, capacity reservation	• Saturn, HP • Scheduling sharing (HP, Motorola) • HP, Sun, Seagate

Obstacles to Coordination in a Supply Chain

- 1. Incentive Obstacles**
- 2. Information Processing Obstacles**
- 3. Operational Obstacles**
- 4. Pricing Obstacles**
- 5. Behavioral Obstacles**

2.Information Processing Obstacles

- ◆ When demand information is distorted as it moves between different stages of the supply chain, leading to increased variability in orders within the supply chain
- ◆ Forecasting based on orders, not customer demand
 - Forecasting demand based on orders magnifies demand fluctuations moving up the supply chain from retailer to manufacturer (e.g. beer game)
- ◆ Lack of information sharing
 - Mis-interpretation of fluctuations in demand

3.Operational Obstacles

- ◆ Rationing and shortage gaming (common in the computer industry because of periodic cycles of component shortages and surpluses).

Managerial Levers to Achieve Coordination

- ◆ 1. Aligning Goals and Incentives
- ◆ 2. Improving Information Accuracy
- ◆ 3. Improving Operational Performance
- ◆ 4. Designing Pricing Strategies to Stabilize Orders
- ◆ 5. Building Strategic Partnerships and Trust

2.Improving Information Accuracy

- ◆ Sharing point of sale data, inventory info, etc.
- ◆ Collaborative forecasting and planning
 - e.g. manufacturer need to know retailer's promotion plans
- ◆ Single stage control of replenishment
 - Continuous replenishment programs (CRP)
 - Vendor managed inventory (VMI)

-
- ◆ Module 4: Explains actions that facilitate the building of strategic partnerships and trust within a supply chain
 - ◆ Module 5 : Understands the different forms of collaborative planning, forecasting and replenishment possible in a supply chain
 - ◆ Module 6: Future trends
 - ◆ Module 7 : False Failure Rates

Building Strategic Partnerships and Trust in a Supply Chain

Each party is interested in the others' welfare and will not act without considering impact on others.

Cooperation and trust improve SC performance because:

- ◆ 1. Alignment of incentives and goals.
- ◆ 2. Actions to achieve coordination

IA.Building Trust into a Supply Chain Relationship

How to initiate and sustain a trust relationship?

- ◆ 1.Deterrence-based view
- ◆ 2. Process-based view

IIA. Building Trust into a Supply Chain Relationship

- ◆ 1. Trust improves by:
 - Information sharing
 - Aligning incentives
 - Operational improvements
 - Stabilisation of prices

How to initiate and sustain a trust relationship?

Managing Supply Chain Relationships for Cooperation and Trust

- ◆ Effective management of a relationship is important for its success

Continuous Replenishment and Vendor-Managed Inventories

- ◆ A single point of replenishment
 - Ensures visibility
 - One common forecast drives orders across the supply chain

MODULE 5 :UNDERSTANDS THE DIFFERENT FORMS OF COLLABORATIVE PLANNING, FORECASTING AND REPLENISHMENT POSSIBLE IN A SUPPLY CHAIN

Collaborative Planning, Forecasting, and Replenishment (CPFR)

- ◆ Sellers and buyers in a supply chain may collaborate along any or all of the following:
 - Strategy and planning
 - Demand and supply management
 - Execution (production, shipping, receiving, stocking)
 - Analysis (identifying exceptions, performance metrics, trends)

Common CPFR Scenarios

CPFR Scenario	Where Applied in Supply Chain	Industries Where Applied
Retail event collaboration	Highly promoted channels or categories	All industries other than those that practice EDLP
DC replenishment collaboration	Retail DC or distributor DC	Drugstores, hardware, grocery
Store replenishment collaboration	Direct store delivery or retail DC-to-store delivery	Mass merchants, club stores
Collaborative assortment planning	Apparel and seasonal goods	Department stores, specialty retail

Table 10-2

Collaborative Planning, Forecasting, and Replenishment (CPFR)

- ◆ 1. Retail Event Collaboration
- ◆ 2. DC Replenishment Collaboration
- ◆ 3. Store replenishment collaboration
- ◆ 4. Collaborative assortment planning (for seasonal goods)

The Role of IT in Coordination

- ◆ Enablement of coordination the ultimate goal
- ◆ IT's role:
 - Information availability
 - Use of information available to make decisions
 - Facilitate sharing of forecasts and historical information, and enable revisions
 - Enterprise systems that record all the supply-chain transactions
- ◆ Pitfalls/Challenges:
 - Systems integration
 - Co-ordinating operational procedures
 - trust

Achieving Coordination in Practice

- ◆ 1. Quantify the bullwhip effect
- ◆ 2. Get top management commitment for coordination
- ◆ 3. Devote resources to coordination
- ◆ 4. Focus on communication with other stages
- ◆ 5. Try to achieve coordination in the entire supply chain network
- ◆ 6. Use technology to improve connectivity in the supply chain
- ◆ 7. Share the benefits of coordination equitably

Future Trends

FALSE FAILURE RETURNS

◆ **False failure returns are products that are returned by consumers to retailers with no functional or cosmetic defect.**

Learning Objectives

- 1. Fundamentals of Cycle Inventory**
- 2. Balance the appropriate costs to choose the optimal lot size and cycle inventory in a supply chain.**

Objective

- The models help illustrate how buyers or sellers react to various inventory situations leading to the buildup of cycle and safety inventory.

- **Cost comparisons can be performed between ordering and delivering lots independently for each product, joint ordering and delivering, and joint ordering and delivering of a subset of products.**

- The concept of quantity discounts can be introduced by discussing lot size based discounts (all unit and marginal unit discounts), volume based discounts, and short-term discounts (trade promotions).

- Cycle inventory exists because producing or purchasing in large lots allows a stage of the supply chain to exploit economies of scale and thus lower cost.

FUNDAMENTALS

- 1. Inventory costs are of great concern to the management.
- 2. The inventory requires investments and hence excess inventories will tend to lower the profit margins.
- 3. The inventory shortage will close down the enterprise factory or lead to lose of market and customers.

PERFORMANCE MEASUREMENT AND CONTROLS

- The supply chain performance metrics are developed on various parameters. The key parameters amongst them are:
 - 1. Cycle Time
 - 2. Fill Rates

CYCLE TIME

- 1. Order Fulfilment cycle
- 2. Inventory replenishment cycle time
- 3. Manufacturing Cycle time
- 4. Cash to Cash Cycle time

CYCLE TIME

- 1. Order Fulfillment cycle: It is the time period required to supply the product after it is ordered. Customer will pick up the product from retail shelf if it is available there. For other products, it is the time till the product is in customers hand after he places an order.

CYCLE TIME

- 2. Inventory replenishment cycle time: It is the time taken to replenish the product at retail store or dealer showroom after it is delivered to the customer.
- The replenishment is done from the company's depot or regional distribution center or from manufacturing plant depending on the physical distance between source and the place of delivery.

CYCLE TIME

- 3. Manufacturing Cycle time: It is measured from the time firm planned order until the final production is done. It is time taken for converting raw material and components into finished product in usable form.

CYCLE TIME

- 4. Cash to Cash Cycle time: It is the time required for getting the raw material and components after it is ordered to the vendors. For imported material the procurement cycle time is longer.

CYCLE TIME

- 5.Cash-to-Cash cycle time: The number of days between paying for raw materials and getting paid for the product. It is calculated by inventory days of supply plus days of sales outstanding minus average payment period for material.

FILL RATES

- 1.Line Fill Rate: This means amount of order lines shipped on the initial shipment versus the amount of lines ordered. This measure may or may not take into consideration as per the requested delivery date.

FILL RATES

- A customer orders 5 products one each from 5 product lines. The manufacturer dispatches 4 products from 4 product lines. In this case, the line fill rate is 80 percent.

FILL RATES

- 2.SKU Fill rate: This represents the number of SKU(Stock Keeping Units) ordered and shipped as against the ordered.

FILL RATES

- 3. Case Fill rate: This represents the amount of cases shipped on the initial shipment versus the amount ordered.

Role of Cycle Inventory in a Supply Chain

- The primary role of cycle inventory is to allow different stages in the supply chain to purchase product in lot sizes that minimize the sum of the material, ordering, and holding cost.

Role of Cycle Inventory in a Supply Chain

- Ideally, cycle inventory decisions should be made considering the total cost across the entire supply chain.

Role of Cycle Inventory in a Supply Chain

- Ideally, cycle inventory decisions should be made considering the total cost across the entire supply chain.

Role of Cycle Inventory in a Supply Chain

- **1. A fixed cost is incurred each time an order is placed or produced.**
- **2. The supplier offers price discounts based on the quantity purchased per lot.**
- **3. The supplier offers short-term discounts or holds trade promotions.**

Role of Cycle Inventory in a Supply Chain

- ***Lot or batch size*** is the quantity that a stage of a supply chain either produces or purchases at a time.

Role of Cycle Inventory in a Supply Chain

- ***Cycle inventory*** is the average inventory in a supply chain due to either production or purchases in lot sizes that are larger than those demanded by the customer.

**Q: Quantity in a lot or batch
size**

D: Demand per unit time

Inventory Profile

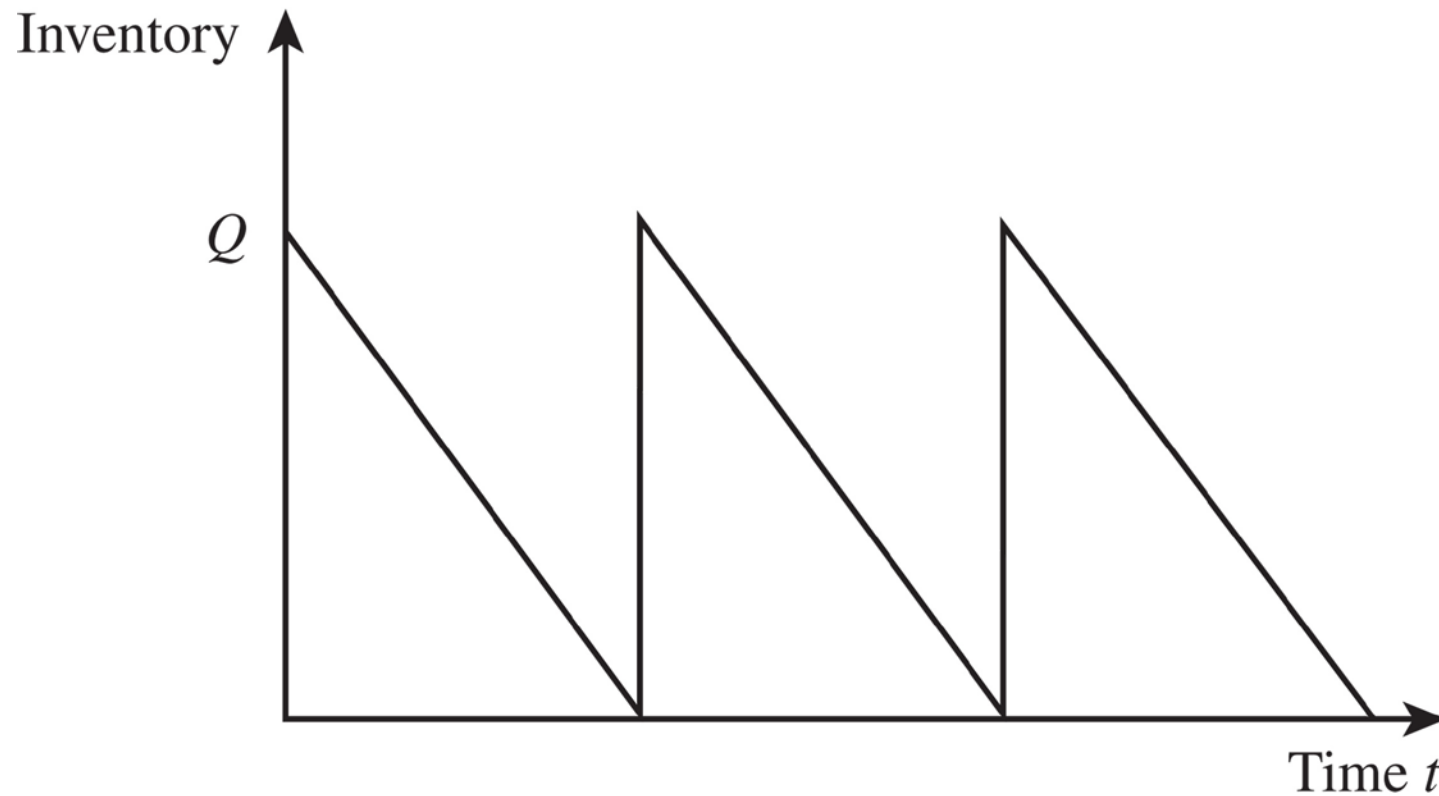


Figure 11-1

Role of Cycle Inventory in a Supply Chain

$$\text{Cycle inventory} = \frac{\text{lot size}}{2} = \frac{Q}{2}$$

$$\text{Average flow time} = \frac{\text{average inventory}}{\text{average flow rate}}$$

$$\text{Average flow time resulting from cycle inventory} = \frac{\text{cycle inventory}}{\text{demand}} = \frac{Q}{2D}$$

Role of Cycle Inventory in a Supply Chain

- *Average price paid per unit purchased* is a key cost in the lot-sizing decision.

Material cost = C

Role of Cycle Inventory in a Supply Chain

- ***Holding cost “H” is the cost of carrying one unit in inventory for a specified period of time.***

$$\text{Holding cost} = H = hC$$

Role of Cycle Inventory in a Supply Chain

- **Primary role of cycle inventory is to allow different stages to purchase product in lot sizes that minimize the sum of material, ordering, and holding costs.**

Estimating Cycle Inventory Related Costs in Practice

- **Inventory Holding Cost**
 - **Cost of capital**

$$WACC = \frac{E}{D + E} (R_f + \beta \times MRP) + \frac{D}{D + E} R_b (1 - t)$$

where

E = amount of equity

D = amount of debt

R_f = risk-free rate of return

β = the firm's beta

MRP = market risk premium

R_b = rate at which the firm can borrow money

t = tax rate

Estimating Cycle Inventory Related Costs in Practice

- **Inventory Holding Cost**
 - **Obsolescence cost**
 - **Handling cost**
 - **Occupancy cost**
 - **Miscellaneous costs**
 - **Theft, security, damage, tax, insurance**

Estimating Cycle Inventory Related Costs in Practice

- **Ordering Cost**
 - **Buyer time**
 - **Transportation costs**
 - **Receiving costs**
 - **Other costs**

- A few of the key goals (from the manufacturer's perspective) of a trade promotion are as follows:
- 1. Induce retailers to use price discounts, displays, or advertising to spur sales.

- **2. Shift inventory from the manufacturer to the retailer and the customer.**
- **3. Defend a brand against competition.**

Economies of Scale to Exploit Fixed Costs

- **Lot sizing for a single product (EOQ)**

D = Annual demand of the product

S = Fixed cost incurred per order

C = Cost per unit

H = Holding cost per year as a fraction of product cost

Economies of Scale to Exploit Fixed Costs

- **Basic assumptions:**
 - Demand is steady at D units per unit time
 - No shortages are allowed
 - Replenishment lead time is fixed

Economies of Scale to Exploit Fixed Costs

- Minimize:
 - Annual material cost
 - Annual ordering cost
 - Annual holding cost

Lot Sizing for a Single Product

$$\text{Annual material cost} = CD$$

$$\text{Number of orders per year} = \frac{D}{Q}$$

$$\text{Annual ordering cost} = \left(\frac{D}{Q}\right)s$$

$$\text{Annual holding cost} = \left(\frac{Q}{2}\right)H = \left(\frac{Q}{2}\right)hC$$

$$\text{Total annual cost, } TC = CD + \left(\frac{D}{Q}\right)s + \left(\frac{Q}{2}\right)hC$$

Lot Sizing for a Single Product

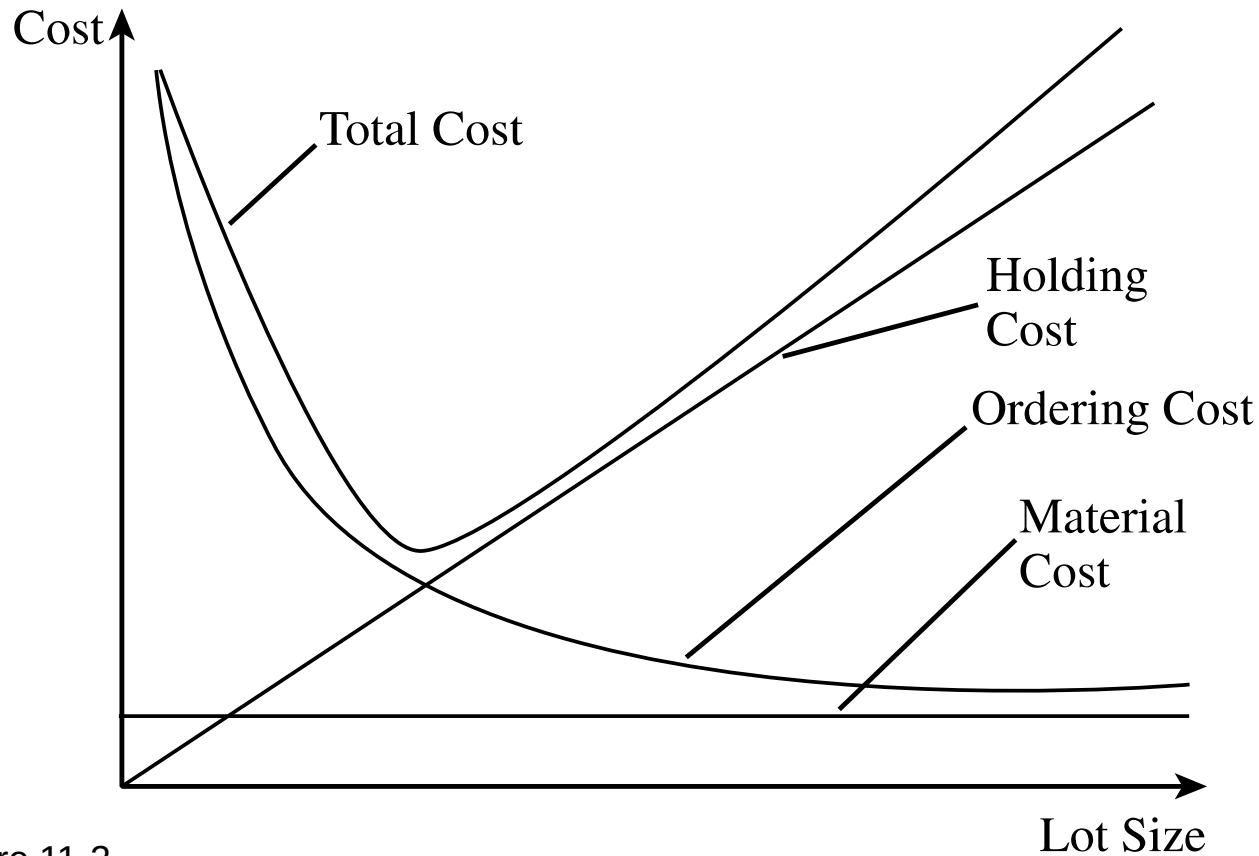


Figure 11-2

Lot Sizing for a Single Product

- The *economic order quantity (EOQ)*

$$\text{Optimal lot size, } Q^* = \sqrt{\frac{2DS}{hC}}$$

- The optimal ordering frequency

$$n^* = \frac{D}{Q^*} = \sqrt{\frac{DhC}{2S}}$$

Learning Objectives

- 1. Aggregate Multiple orders, Lots ordered and delivered jointly**
- 2. Understand the impact of quantity discounts on lot size and cycle inventory.**
- 3. Lessons learnt from discounting schemes for a supply chain.**
- 4. Understand the impact of trade promotions on lot size and cycle inventory.**
- 5. Managing Multi-Echelon Cycle Inventory.**

Lot Sizing with Multiple Products or Customers

- **Lot sizes and ordering policy that minimize total cost**

D_i : Annual demand for product i

S : Order cost incurred each time an order is placed, independent of the variety of products in the order

s_i : Additional order cost incurred if product i is included in the order

Lot Sizing with Multiple Products or Customers

- **Three approaches:**
 - 1. Each product manager orders his or her model independently.**
 - 2. The product managers jointly order every product in each lot.**

Lots Ordered and Delivered Jointly for a Selected Subset

Step 1: Identify the most frequently ordered product assuming each product is ordered independently, **n_i is the ordering frequency**

$$\bar{n}_i = \sqrt{\frac{hC_i D_i}{2(S + s_i)}}$$

Step 2: For all products $i \neq i^*$, evaluate the ordering frequency

$$n_i = \sqrt{\frac{hC_i D_i}{2s_i}}$$

Lots Ordered and Delivered Jointly for a Selected Subset

Step 3: For all $i \neq i^*$, evaluate the frequency of product i relative to the most frequently ordered product i^* to be m_i

$$m_i = \left| \frac{\bar{n}}{n / n_i} \right|$$

Step 4: Recalculate the ordering frequency of the most frequently ordered product i^* to be n

$$n = \sqrt{\frac{\sum_{i=1}^l hC_i m_i D}{2 \left(S + \sum_{i=1}^l s_i / m_i \right)}}$$

Lots Ordered and Delivered Jointly for a Selected Subset

Step 5: Evaluate an order frequency of $n_i = n/m_i$ and the total cost of such an ordering policy

$$TC = nS + \sum_{i=1}^l n_i s_i + \sum_{i=1}^l \left(\frac{D_i}{2n_i} \right) hC_1$$

Tailored aggregation – higher-demand products ordered more frequently and lower-demand products ordered less frequently.

QUANTITY DISCOUNTS

Economies of Scale to Exploit Quantity Discounts

- *Lot size-based discount* – Discounts based on quantity ordered in a single lot.
- *Volume based discount* – Discount is based on total quantity purchased over a given period.
- Two common schemes:
 - All-unit quantity discounts
 - Marginal unit quantity discount or multi-block tariffs

Quantity Discounts

- Two basic questions
 1. What is the optimal purchasing decision for a buyer seeking to maximize profits? How does this decision affect the supply chain in terms of lot sizes, cycle inventories, and flow times?
 2. Under what conditions should a supplier offer quantity discounts? What are appropriate pricing schedules that a supplier seeking to maximize profits should offer?

All-Unit Quantity Discounts

- Objective is to decide on a lot size that will minimize the sum of material, order, and holding costs.

All-Unit Quantity Discounts

Step 1: Evaluate the optimal lot size for each price $C_i, 0 \leq i \leq r$ as follows

$$Q_i = \sqrt{\frac{2DS}{hC_i}}$$

All-Unit Quantity Discounts

Step 2: We next select the order quantity Q_i^* for each price C_i

1. $q_i \leq Q_i < q_{i+1}$
2. $Q_i < q_i$
3. $Q_i \geq q_{i+1}$

- Case 3 can be ignored as it is considered for Q_{i+1}
- For Case 1 if $q_i \leq Q_i < q_{i+1}$, then set $Q_i^* = Q_i$
- If $Q_i < q_i$, then a discount is not possible
- Set $Q_i^* = q_i$ to qualify for the discounted price of C_i

All-Unit Quantity Discounts

Step 3: Calculate the total annual cost of ordering Q_i^* units

$$\text{Total annual cost, } TC_i = \left(\frac{D}{Q_i^*} \right) S + \left(\frac{Q_i^*}{2} \right) hC_i + DC_i$$

All-Unit Quantity Discounts

Step 4: Select Q_i^* with the lowest total cost TC_i

- Cutoff price

$$C^* = \frac{1}{D} \left(DC_r + \frac{DS}{q_r} + \frac{h}{2} q_r C_r - \sqrt{2hDSC_r} \right)$$

Marginal Unit Quantity Discounts

- *Multi-block tariffs* – the *marginal cost* of a unit that decreases at a breakpoint.

For each value of i , $0 \leq i \leq r$, let V_i be the cost of ordering q_i units

$$V_i = C_0(q_1 - q_0) + C_1(q_2 - q_1) + \dots + C_{i-1}(q_i - q_{i-1})$$

Why Quantity Discounts?

- 1. Improved coordination
to increase total
supply chain profits**
- 2. Extraction of surplus
through price
discrimination**

Two-Part Tariff

- Manufacturer charges its entire profit as an up-front franchise fee ff
- Sells to the retailer at cost
- Retail pricing decision is based on maximizing its profits
- Effectively maximizes the coordinated supply chain profit

Volume-Based Quantity Discounts

- Design a volume-based discount scheme that gets the retailer to purchase and sell the quantity sold when the two stages coordinate their actions.

DISCOUNTING SCHEMES

Lessons from Discounting Schemes

- Quantity discounts play a role in supply chain coordination and improved supply chain profits.
- Discount schemes that are optimal are volume based and not lot size based unless the manufacturer has large fixed costs associated with each lot.
- Even in the presence of large fixed costs for the manufacturer, a two-part tariff or volume-based discount, with the manufacturer passing on some of the fixed cost to the retailer, optimally coordinates the supply chain and maximizes profits.

Lessons from Discounting Schemes

- Lot size–based discounts tend to raise the cycle inventory in the supply chain.
- Volume-based discounts are compatible with small lots that reduce cycle inventory.
- Retailers will tend to increase the size of the lot toward the end of the evaluation period, the *hockey stick phenomenon*.
- With multiple retailers with different demand curves optimal discount continues to be volume based with the average price charged to the retailers decreasing as the rate of purchase increases.

Price Discrimination to Maximize Supplier Profits

- Firm charges differential prices to maximize profits.
- Setting a fixed price for all units does not maximize profits for the manufacturer.
- Manufacturer can obtain maximum profits by pricing each unit differently based on customers' marginal evaluation at each quantity.
- Quantity discounts are one mechanism for price discrimination because customers pay different prices based on the quantity purchased.

TRADE PROMOTIONS

Short-Term Discounting: Trade Promotions

- Trade promotions are price discounts for a limited period of time
- Key goals:
 1. Induce retailers to use price discounts, displays, or advertising to spur sales.
 2. Shift inventory from the manufacturer to the retailer and the customer.
 3. Defend a brand against competition.

Short-Term Discounting: Trade Promotions

- Impact on the behavior of the retailer and supply chain performance.
- Retailer has two primary options:
 1. Pass through some or all of the promotion to customers to spur sales.
 2. Pass through very little of the promotion to customers but purchase in greater quantity during the promotion period to exploit the temporary reduction in price (*forward buy*).

Forward Buying Inventory Profile

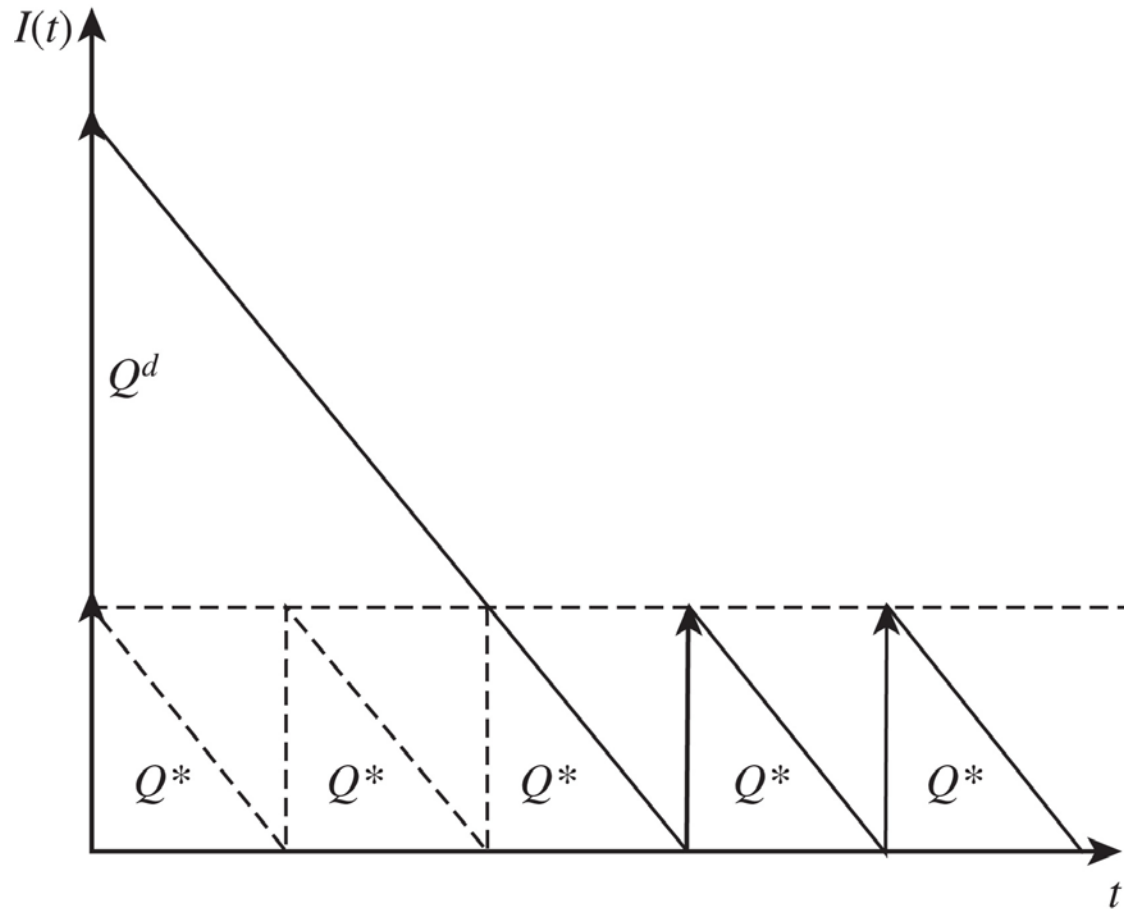


Figure 11-5

Forward Buy

- Costs to be considered – material cost, holding cost, and order cost
- Three assumptions
 1. The discount is offered once, with no future discounts
 2. The retailer takes no action to influence customer demand
 3. Analyze a period over which the demand is an integer multiple of Q^*

Trade Promotions

- **Trade promotions generally increase cycle inventory in a supply chain and hurt performance.**

Trade Promotions

- Counter measures:
 - EDLP (every day low pricing)
 - **Discount applies to items sold to customers (sell-through) not the quantity purchased by the retailer (sell-in)**
 - Scan based promotions

MANAGING MULTI-ECHELON INVENTORY

QUESTION

- Discuss the characteristics of a successful multi-echelon supply chain.
- ***Answer:*** For such a multi-echelon distribution supply chain, a good replenishment policy has the following characteristics:

QUESTION

- 1 All parties within a stage are divided into groups such that all parties within a group order simultaneously from the same supplier.
- 2. When a party receives a replenishment order, the receipt should be synchronized with the shipment of a replenishment order to at least one of its customers.

QUESTION

- 3. In other words, a portion of any replenishment order at a stage should be cross-docked onto the next stage.
- 4 If a customer replenishes less frequently than its supplier, the supplier replenishment frequency should be an integer multiple of the customer replenishment frequency and replenishment at both stages should be synchronized to facilitate cross-docking.

QUESTION

- 5. In other words, a supplier should cross-dock all orders from customers who reorder less frequently than the supplier himself.
- 6. If a customer replenishes more frequently than its supplier, the customer's replenishment frequency should be an integer multiple of the supplier's replenishment frequency and replenishment at both stages should be synchronized to facilitate cross-docking.

QUESTION

- 7. In other words, a supplier should cross-dock one out of every k shipments to a customer who orders more frequently than himself, where k is an integer.

QUESTION

- 8. The relative frequency of reordering will depend upon the setup cost, holding cost, and demand at different parties.

QUESTION

- 9. Replenishment orders in multi-echelon supply chains should be synchronized to keep cycle inventory and order costs low. In general, each stage should attempt to coordinate orders from customers who order less frequently and cross-dock all such orders.

QUESTION

- 10. Some of the orders from customers that order more frequently should also be cross-docked.

Managing Multiechelon Cycle Inventory

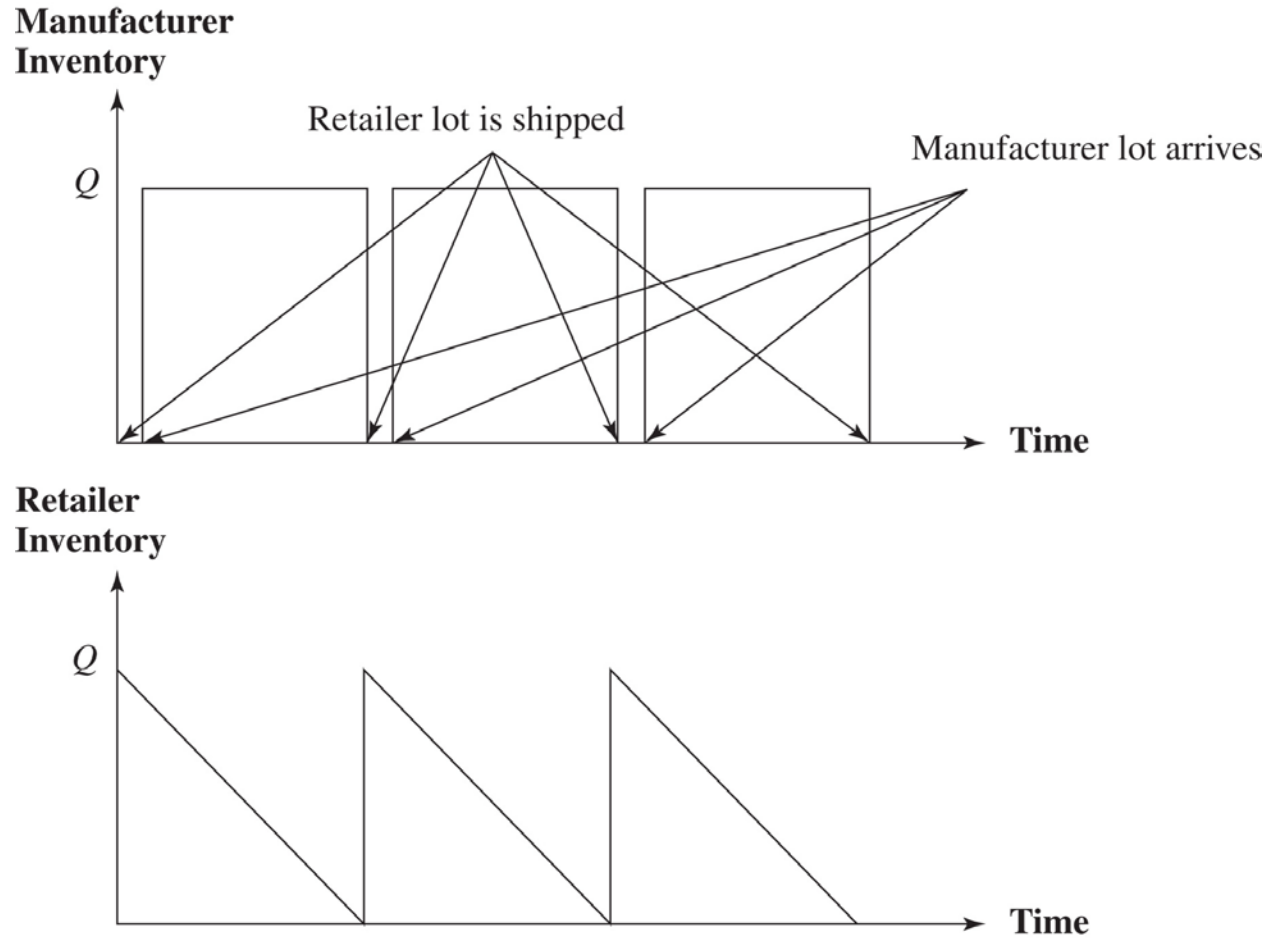


Figure 11-6

Integer Replenishment Policy

- **For customers with a longer reorder interval than the supplier, make the customer's reorder interval an integer multiple of the supplier's interval and synchronize replenishment at the two stages to facilitate cross-docking.**

Integer Replenishment Policy

- **For customers with a shorter reorder interval than the supplier, make the supplier's reorder interval an integer multiple of the customer's interval and synchronize replenishment at the two stages to facilitate cross-docking.**

Integer Replenishment Policy

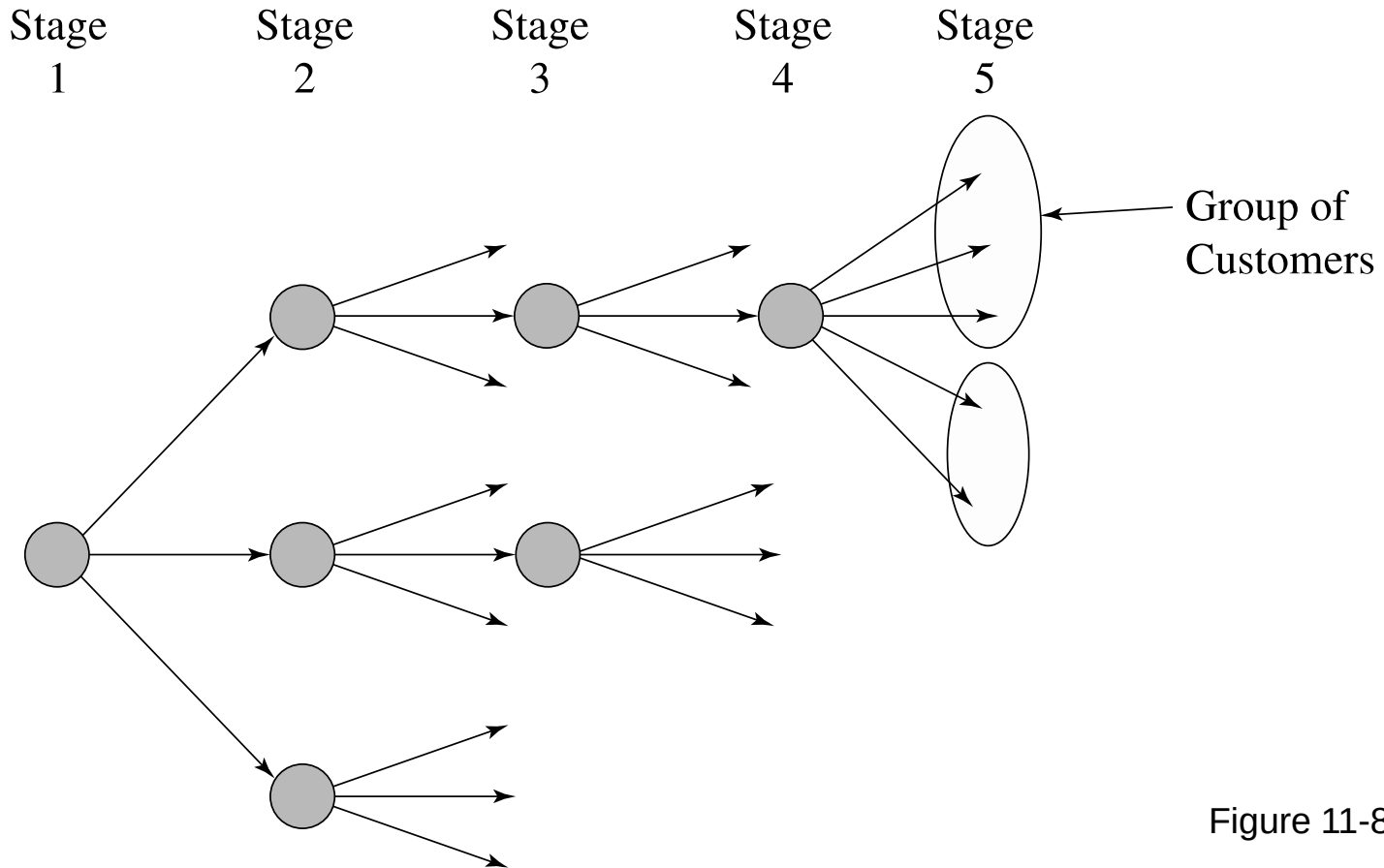
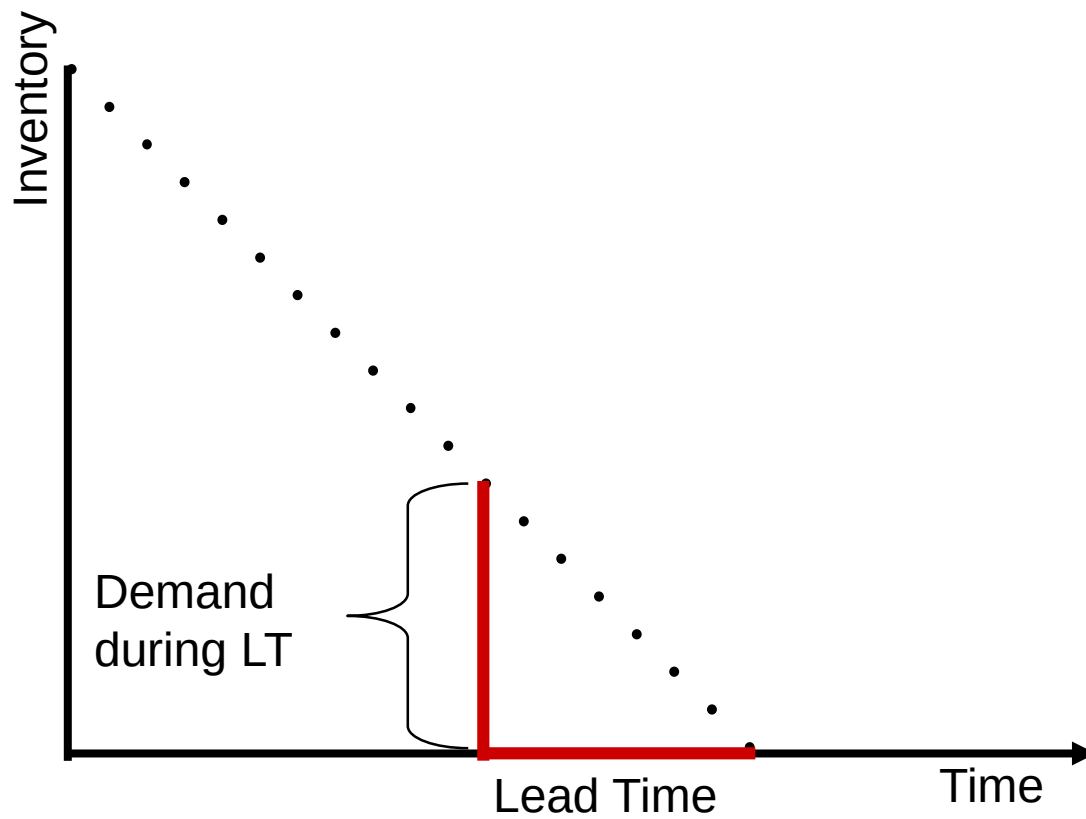
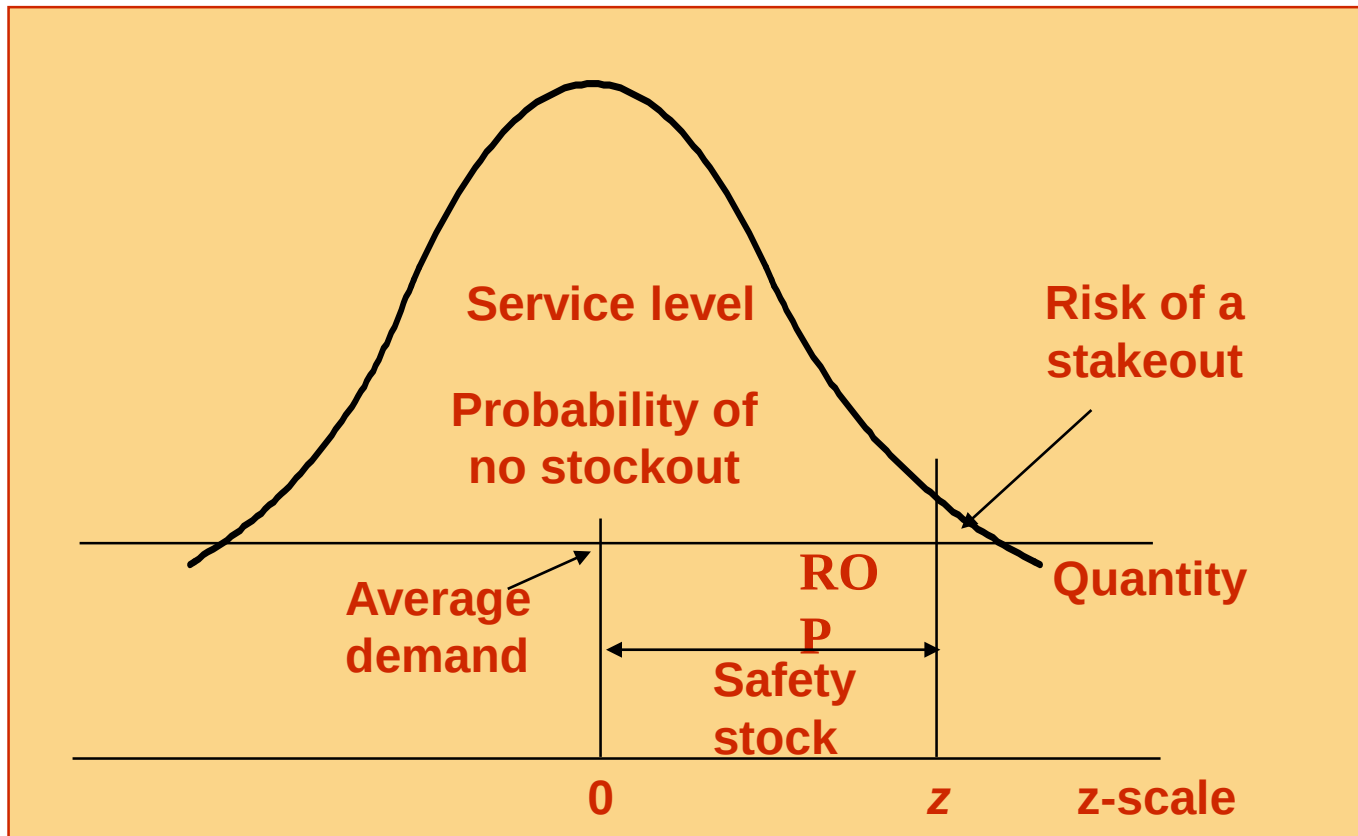


Figure 11-8

Learning Objectives

- 1. Understand the role of safety inventory in a supply chain.
- 2. Identify factors that influence the required level of safety inventory.
- 3. Describe different measures of product availability.
- 4. Determine the appropriate level of safety inventory.



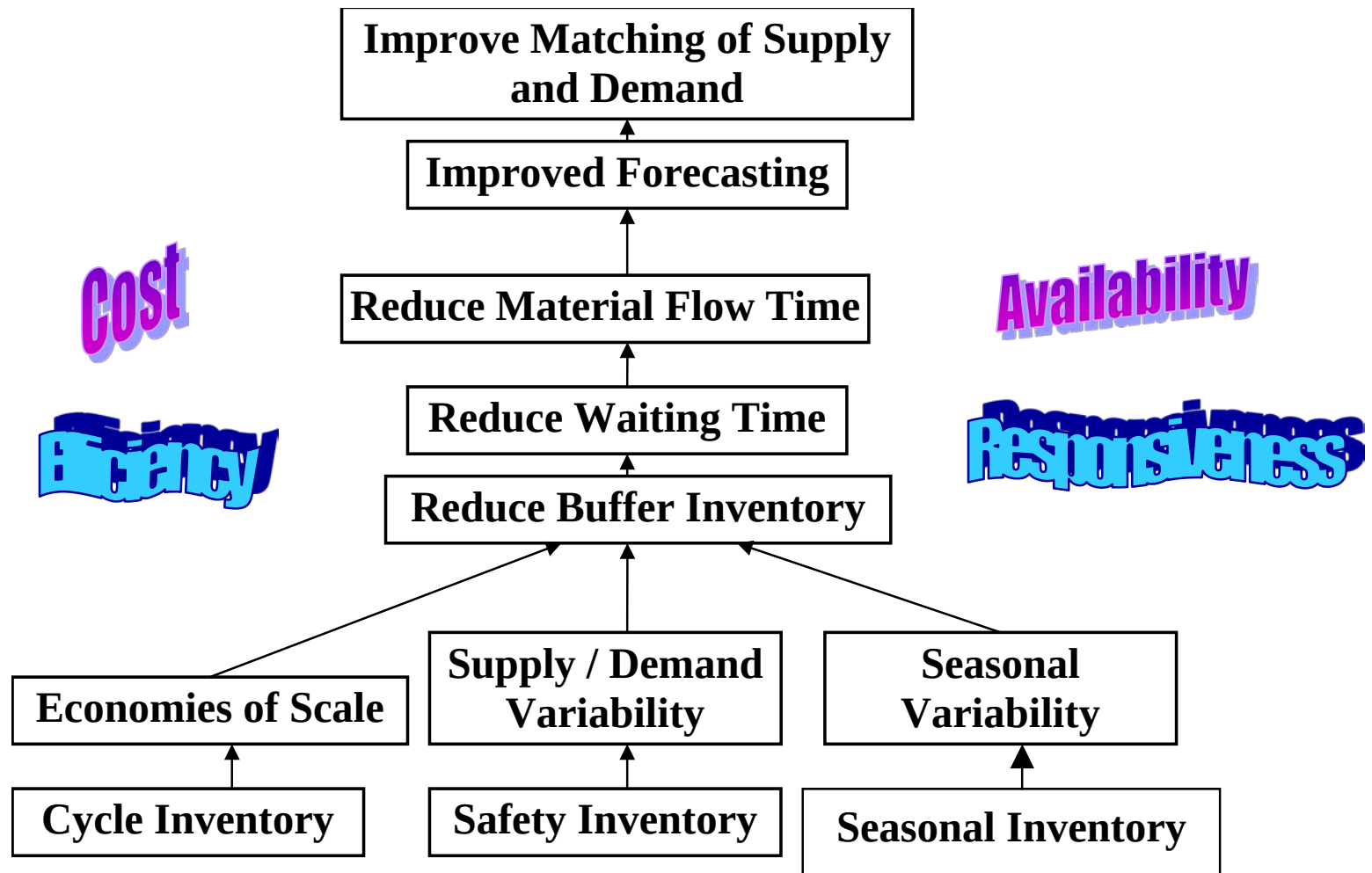


LTD = Lead Time Demand

ROP = Average LTD + z (Standard Deviation of LTD)

ROP = LTD + zσ_{LTD} → ROP = LTD + I_{safety}

Role of Inventory in the Supply Chain



The Role of Safety Inventory in a Supply Chain

◆ **Safety inventory:**
**Inventory carried for the
purpose of satisfying demand
that exceeds the amount
forecasted in a given period.**

The Role of Safety Inventory in a Supply Chain

◆ Safety inventory:

The average inventory remaining when the replenishment lot arrives.

The Role of Safety Inventory in a Supply Chain

◆ Safety inventory:

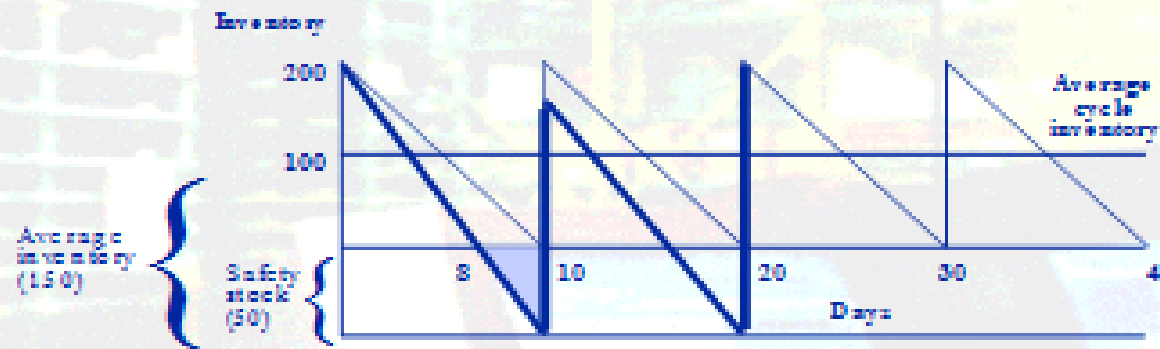
◆ To manage :

- Demand uncertainty
- Supply uncertainty

Raising the level of safety inventory

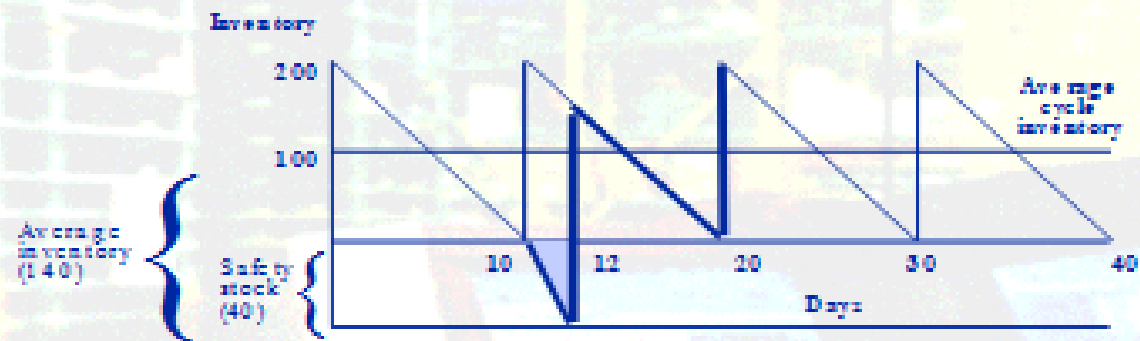
- ◆—Increases :
 - Product availability
 - Inventory holding costs

(A) With variable demand



- The average inventory would be 100 units when demand (20/d) and lead time (10 day) were constant
- If demand was actually 25/d, inventory would be depleted by 8 (200/25). And there would be a stockout of 50 units.
- A safety stock of 50 units would prevent a stockout due to variation in demand

(B) With variable lead time

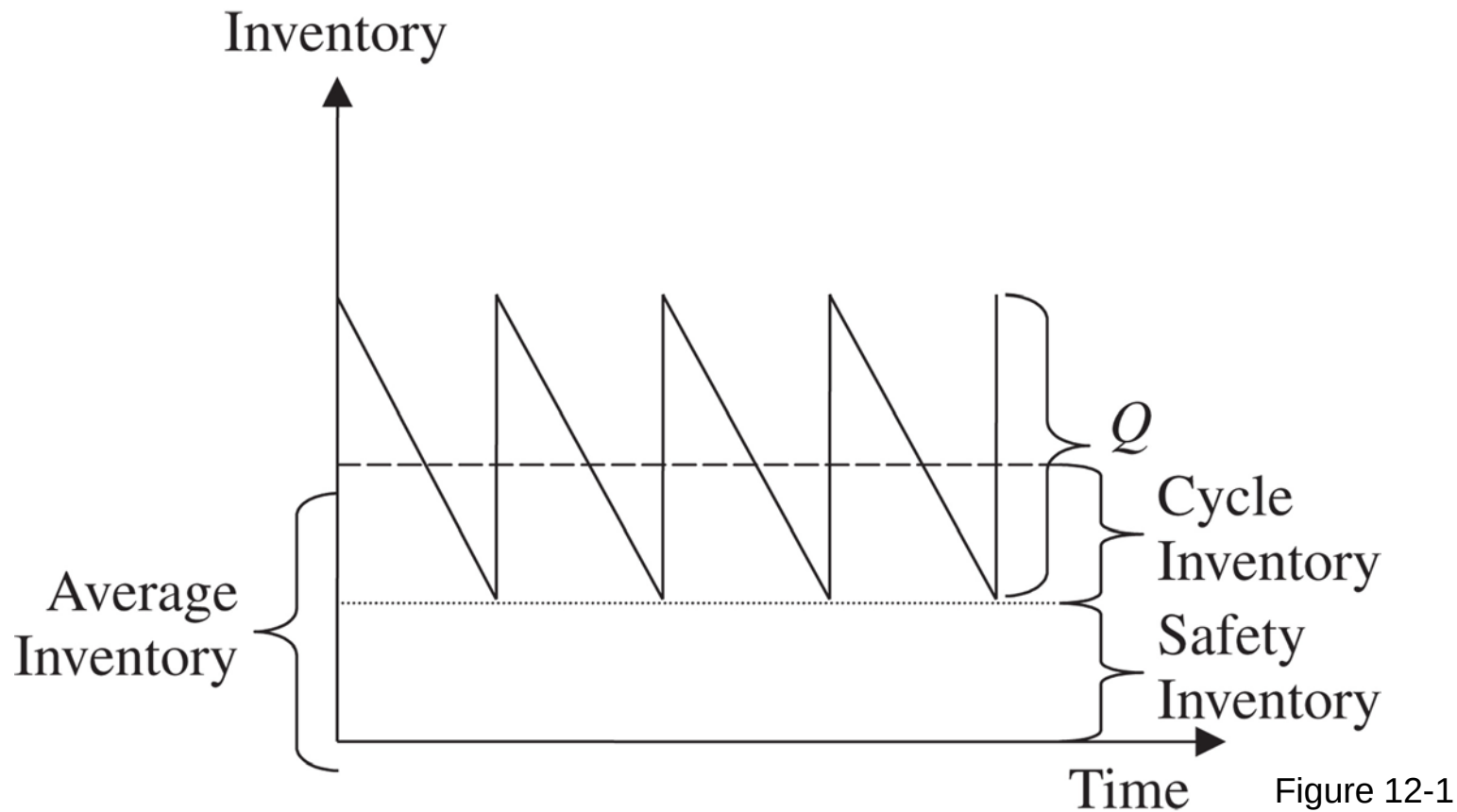


- The lead time can vary by plus or minus two days
- When the order arrived 2 days late, on day 12, the firm would experience stockouts for 2 days (40 units)
- If the management believed that shipments would never arrive more than two days late, a safety stock of 40 units would ensure a stockout would not occur. This would require holding an average inventory of 140 units

The Role of Safety Inventory

- Three key questions
 1. What is the appropriate level of product availability?
 2. How much safety inventory is needed for the desired level of product availability?
 3. What actions can be taken to improve product availability while reducing safety inventory?

The Role of Safety Inventory



Determining the Appropriate Level of Safety Inventory

- ◆ Measuring demand uncertainty
- ◆ Measuring product availability
- ◆ Replenishment policies
- ◆ Evaluating cycle service level and fill rate
- ◆ Evaluating safety level given desired cycle service level or fill rate
- ◆ Impact of required product availability and uncertainty on safety inventory

Determining the Appropriate Level of Demand Uncertainty

- ◆ Appropriate level of safety inventory determined by:
 - supply or demand uncertainty
 - desired level of product availability
- ◆ Higher levels of uncertainty require higher levels of safety inventory given a particular desired level of product availability.
- ◆ Higher levels of desired product availability require higher levels of safety inventory given a particular level of uncertainty.

Measuring Demand Uncertainty

- ◆ Demand has a systematic component and a random component
- ◆ The estimate of the random component is the measure of demand uncertainty
- ◆ Random component is usually estimated by the standard deviation of demand
- ◆ Notation:
 - D = Average demand per period
 - σ_D = standard deviation of demand per period
 - L = lead time = time between when an order is placed and when it is received
- ◆ Uncertainty of demand during lead time is what is important

Evaluating Demand Distribution Over L Periods

$$D_L = \sum_{i=1}^L D_i \quad \sigma_L = \sqrt{\sum_{i=1}^L \sigma_i^2 + 2 \sum_{i>j} \rho_{ij} \sigma_i \sigma_j}$$

$$D_L = DL \quad \sigma_L = \sqrt{L\sigma_D}$$

The *coefficient of variation*

= *size of uncertainty relative to demand*

$$cv = \sigma / \mu$$

Measuring Product Availability

- Product availability: A firm's ability to fill a customer's order out of available inventory.
- Stockout: A customer order arrives when product is not available.
- ◆ Product fill rate (fr): Fraction of demand that is satisfied from product in inventory.
- ◆ Order fill rate: Fraction of orders that are filled from available inventory.
- ◆ Cycle service level (CSL): Fraction of replenishment cycles that end with all customer demand met.

Replenishment Policies

Replenishment policy: Decisions regarding when to reorder and how much to reorder.

- ◆ Continuous review: Inventory is continuously monitored and an order of size Q is placed when the inventory level declines to the reorder point ROP.
- ◆ Periodic review: Inventory is checked at regular (periodic) intervals and an order is placed to raise the inventory to a specified threshold (the “order-up-to” level).

Evaluating Cycle Service Level and Fill Rate

- Evaluating Safety Inventory Given a Replenishment Policy.

Expected demand during lead time = DL

Safety inventory, $ss = ROP - DL$

Evaluating Cycle Service Level and Fill Rate

- Evaluating Cycle Service Level Given a Replenishment Policy.

$$CSL = Prob(\text{ddlt of } L \text{ weeks} \leq ROP)$$

$$CSL = F(ROP, D_L, \sigma_L) = NORMDIST(ROP, D_L, \sigma_L, 1)$$

(ddlt = demand during lead time)

Evaluating Fill Rate Given a Replenishment Policy

$$ESC = \int_{x=ROP}^{\infty} (x - ROP) f(x) dx$$

$$ESC = -ss \left[1 - F_s \left(\frac{ss}{\sigma_L} \right) \right] + \sigma_L f_s \left(\frac{ss}{\sigma_L} \right)$$

$$ESC = -ss[1 - NORMDIST(ss / \sigma_L, 0, 1, 1)] \\ + \sigma_L NORMDIST(ss / \sigma_L, 0, 1, 0)$$

-
-
- ◆ A continuous random variable X has a normal distribution with Mean μ and standard deviation $\sigma > 0$ if the probability density function $f(x, \mu, \sigma)$ of the random variable is given by:

$$f(x, \mu, \sigma) = \frac{1}{\sigma \sqrt{2\pi}} \exp\left[-\frac{(x - \mu)^2}{2\sigma^2}\right] \quad (11.18)$$

-
-
- ◆ The *cumulative normal distribution function* is denoted by $F(x, \mu, \sigma)$ and is the probability that a normally distributed random variable with mean μ and standard deviation σ .

Impact of Desired Product Availability and Uncertainty on Safety Inventory

◆ Managerial levers ...

- Reduce supplier lead time, L (better relationships with suppliers).
- Reduce uncertainty in demand, σ_L (better forecasts, better information collection and use).

Benefits of Reducing Lead Time

- Returns the inverse of the standard normal cumulative distribution.
- The distribution has a mean of zero and a standard deviation of one.
- Syntax : NORMSINV(probability)**
- Probability** is a probability corresponding to the normal distribution.

IMPACT OF SUPPLY UNCERTAINTY ON SAFETY INVENTORY

Impact of Supply Uncertainty on Safety Inventory

- We incorporate supply uncertainty by assuming that lead time is uncertain.

D : Average demand per period

σ_D : Standard deviation of demand per period

L : Average lead time for replenishment

σ_L : Standard deviation of lead time

$$D_L = DL \quad \sigma_L = \sqrt{L\sigma_D^2 + D^2s_L^2}$$

IMPACT OF AGGREGATION ON SAFETY INVENTORY

Impact of Aggregation on Safety Inventory

- Supply chains have varying degree of inventory aggregation.

Impact of Aggregation on Safety Inventory

- Consider k regions with demand in each region normally distributed with the following characteristics:

D_i : Mean weekly demand in region i , $i = 1, \dots, k$

σ_i : Standard deviation of weekly demand in region i ,
 $i = 1, \dots, k$

ρ_{ij} : Correlation of weekly demand for regions i, j ,
 $1 \leq i \neq j \leq k$

Impact of Aggregation on Safety Inventory

As per the accepted definition of Inverse Normal F^{-1} Function obtained through the aid of MS Excel.

$$\text{Total safety inventory in decentralized option} = \sum_{i=1}^k F_S^{-1}(CSL) \times \sqrt{L} \times \sigma_i$$

Impact of Aggregation on Safety Inventory

- If all inventories are aggregated in a central location, we need to evaluate the distribution of aggregated demand.
- The aggregate demand is normally distributed, with a mean of D^c , Standard deviation of σ Superscript C subscript D and variance of $\text{var}(D^c)$ as follows:

Impact of Aggregation on Safety Inventory

$$D^C = \sum_{i=1}^k D_i; \quad \text{var}\left(D^C\right) = \sum_{i=1}^k \sigma_i^2 + 2 \sum_{i>j} \rho_{ij} \sigma_i \sigma_j;$$

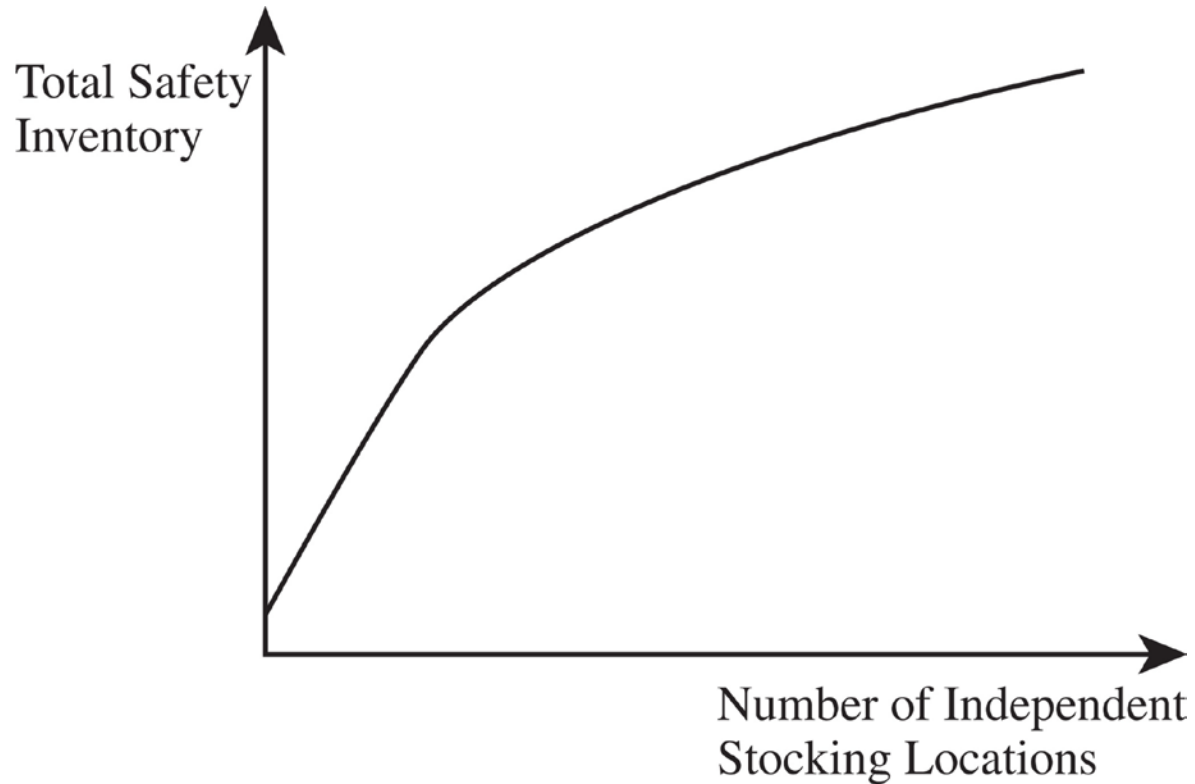
$$\sigma_D^C = \sqrt{\text{var}\left(D^C\right)}$$

Impact of Aggregation on Safety Inventory

- The safety inventory savings on aggregation increase with the desired cycle service level CSL .
- The safety inventory savings on aggregation increase with the replenishment lead time L .
- The safety inventory savings on aggregation increase with the holding cost H .
- The safety inventory savings on aggregation increase with the coefficient of variation of demand.
- The safety inventory savings on aggregation decrease as the correlation coefficients increase.

Impact of Aggregation on Safety Inventory

- The Square-Root Law



Impact of Correlation on Value of Aggregation

- Two possible disadvantages to aggregation:
 1. Increase in response time to customer order.
 2. Increase in transportation cost to customer.

Information Centralization

Specialization

- ◆ **Stock all items in each location or stock different items at different locations?**

Specialization

◆ **Benefits of aggregation can be affected by:**

- **Coefficient of variation of demand (higher cv yields greater reduction in safety inventory from centralization).**
- **Value of item (high value items provide more benefits from centralization).**

Product Substitution

The use of one product to satisfy demand for a different product.

1. Manufacturer-driven substitution

- Allows aggregation of demand**

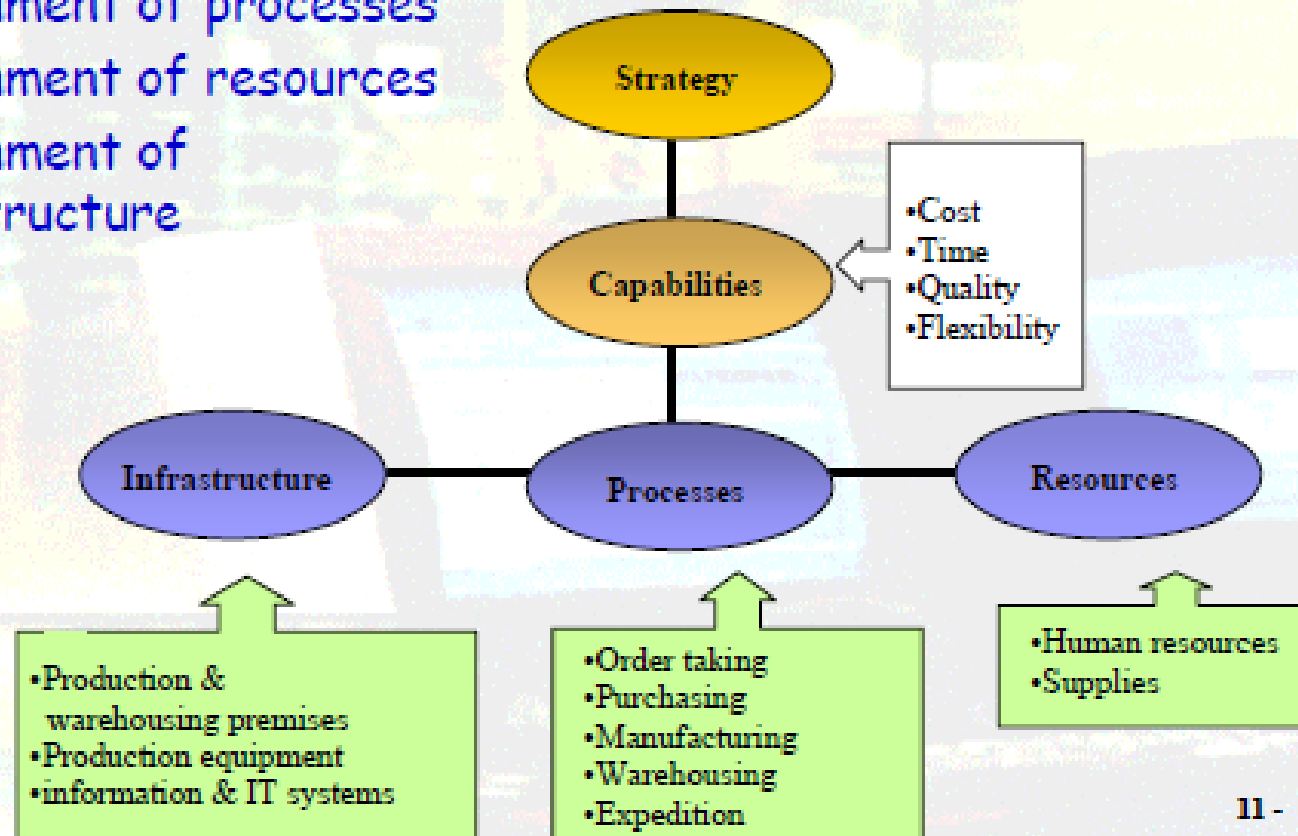
2. Customer-driven substitution

Postponement

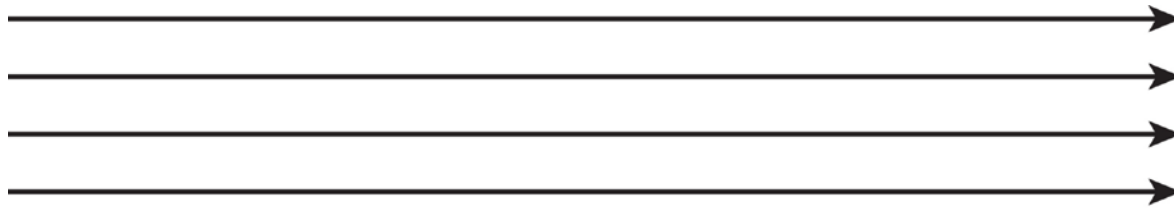
- Also known as delayed differentiation.

Postponement implementation

- Realignment of processes
- Realignment of resources
- Realignment of infrastructure



Postponement



Supply Chain Flows Without Postponement



Supply Chain Flows with Component
Commonality and Postponement

Figure 12-5

IMPACT OF REPLENISHMENT POLICIES ON SAFETY INVENTORY

Impact of Replenishment Policies on Safety Inventory

- Continuous Review Policies

D : Average demand per period

σ_D : Standard deviation of demand per period

L : Average lead time for replenishment

Mean demand during lead time, $D_L = DL$

Standard deviation of demand during lead time, $\sigma_L = \sqrt{L}\sigma_D$

$$ss = F_s^{-1}(CSL) \times \sigma_L = NORMSINV(CSL) \times \sqrt{L}\sigma_D, ROP = D_L + ss$$

Managing Safety Inventory in a Multi-echelon Supply Chain

- **Ech·e·lon pronounced as [Esh-uh-lon]**
- Echelon comes from the French *échelon*, a word whose literal meaning is “rung of a ladder.” Initially it was confined to military use, to refer to a step-like formation of troops.

Managing Safety Inventory in a Multi-echelon Supply Chain

- In multi-echelon supply chains stages often do not know demand and supply distributions.
- Inventory between a stage and the final customer is called the *echelon inventory*.
- Reorder points and order-up-to levels at any stage should be based on echelon inventory.
- Decisions must be made about the level of safety inventory carried at different stages.

BEER GAME

- The **Beer Distribution Game** (The Beer Game) is a simulation game created by a group of professors at [MIT Sloan School of Management](#) in early 1960s to demonstrate a number of key principles of [supply chain management](#).

STRATEGY FOR THE LOGISTICAL DRIVER OF INVENTORY

- 1. Reduce lead times**
- 2. Improve reliability of supply**
- 3. Order more frequently**
- 4. Expedite more effectively**
- 5. Forecast more accurately**
- 6. Optimize stock over the range**
- 7. Strangers strategy**
- 8. Understand your customers: change your service proposition**
- 9. For multi-tier operations, change the network configuration**
- 10. For short season markets, back winners with stock (and shun losers)**

Learning Objectives

- 1. Identify the factors affecting the optimal level of product availability and evaluate the optimal cycle service level.**
- 2. Use managerial levers that improve supply chain profitability through optimal service levels.**
- 3. Understand conditions under which postponement is valuable in a supply chain.**
- 4. Setting optimal levels of product availability in practice.**

Lee & Billington Suggests

- **1. No Supply Chain Metrics**
- **2. Inadequate definition of customer service**
- **3. Inaccurate delivery status data**
- **4. Inefficient Information Systems**

Lee & Billington Suggests

- **5. Ignoring the impact of uncertainties**
- **6. Simplistic inventory stocking policies**
- **7. Discrimination against internal customers**

Lee & Billington Suggests

- 8. Poor coordination
- 9. Incomplete shipment method analysis
- 10. Incorrect assessment of inventory costs
- 11. Organizational barriers

Lee & Billington Suggests

- **12.Product process design without supply chain consideration**
- **13.separation of Supply Chain from Operational decisions**

Lee & Billington Suggests

- **14. Incomplete Supply Chain**

PRODUCT AVAILABILITY & SC PROFITABILITY

Two Key Factors

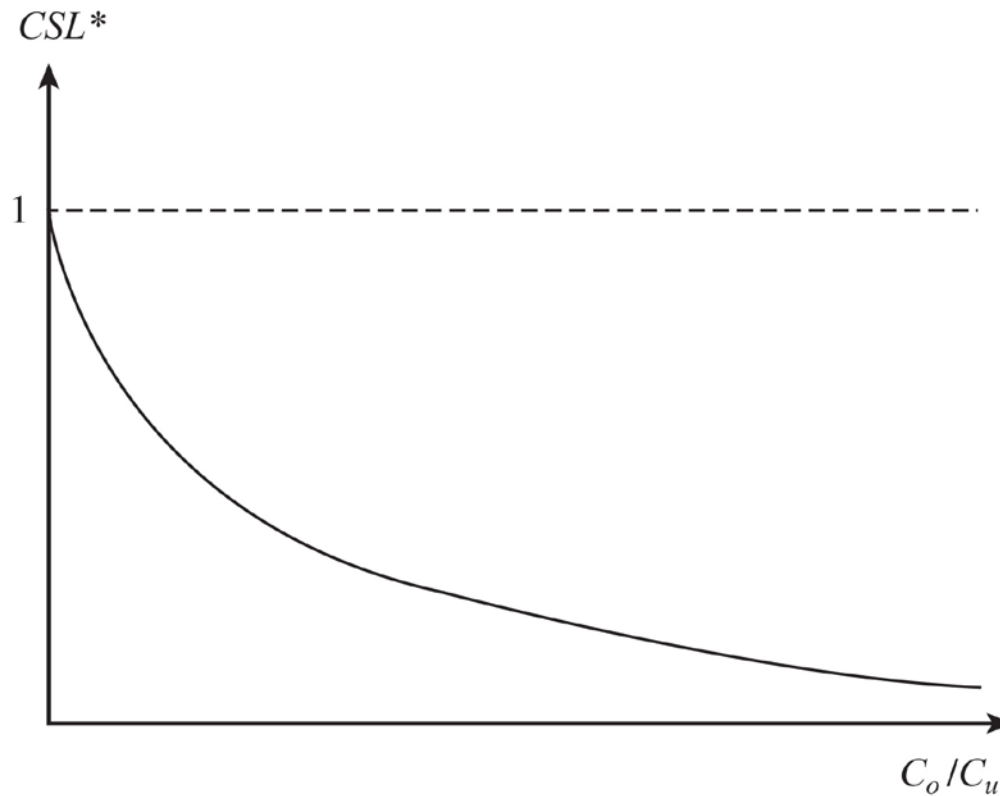
- **1. Cost of overstocking the product**
- **2. Cost of under-stocking the product**

MANAGERIAL LEVERS

Managerial Levers to Improve Supply Chain Profitability

- “Obvious” actions
 1. Increase salvage value of each unit
 2. Decrease the margin lost from a stockout
- Improved forecasting
- Quick response
- Postponement
- Tailored sourcing

Managerial Levers to Improve Supply Chain Profitability



Impact of Improved Forecasts

An importer of Petrol based electricity generators in Quetta is informed by her Supply Chain Manager with the following critical information:

Demand: $\mu = 350$, $\sigma = 150$

Cost: $c = \text{Rs. } 10,000$, Price: $p = \text{Rs. } 25,000$, Salvage: $s = \text{Rs. } 8,000$

Impact of Improved Forecasts

In other words demand can vary from 200 to 500 generators.

$$\text{Cost of understocking} = C_u = p - c = \text{Rs}25000 - \text{Rs}10000 = \text{Rs}15000$$

$$\text{Cost of overstocking} = C_o = c - s = \text{Rs}10000 - \text{Rs}8000 = \text{Rs}2000$$

Quick Response: Multiple Orders Per Season

- 1. The expected total quantity ordered during the season with two orders is less than that with a single order for the same cycle service level.**

Quick Response: Multiple Orders Per Season

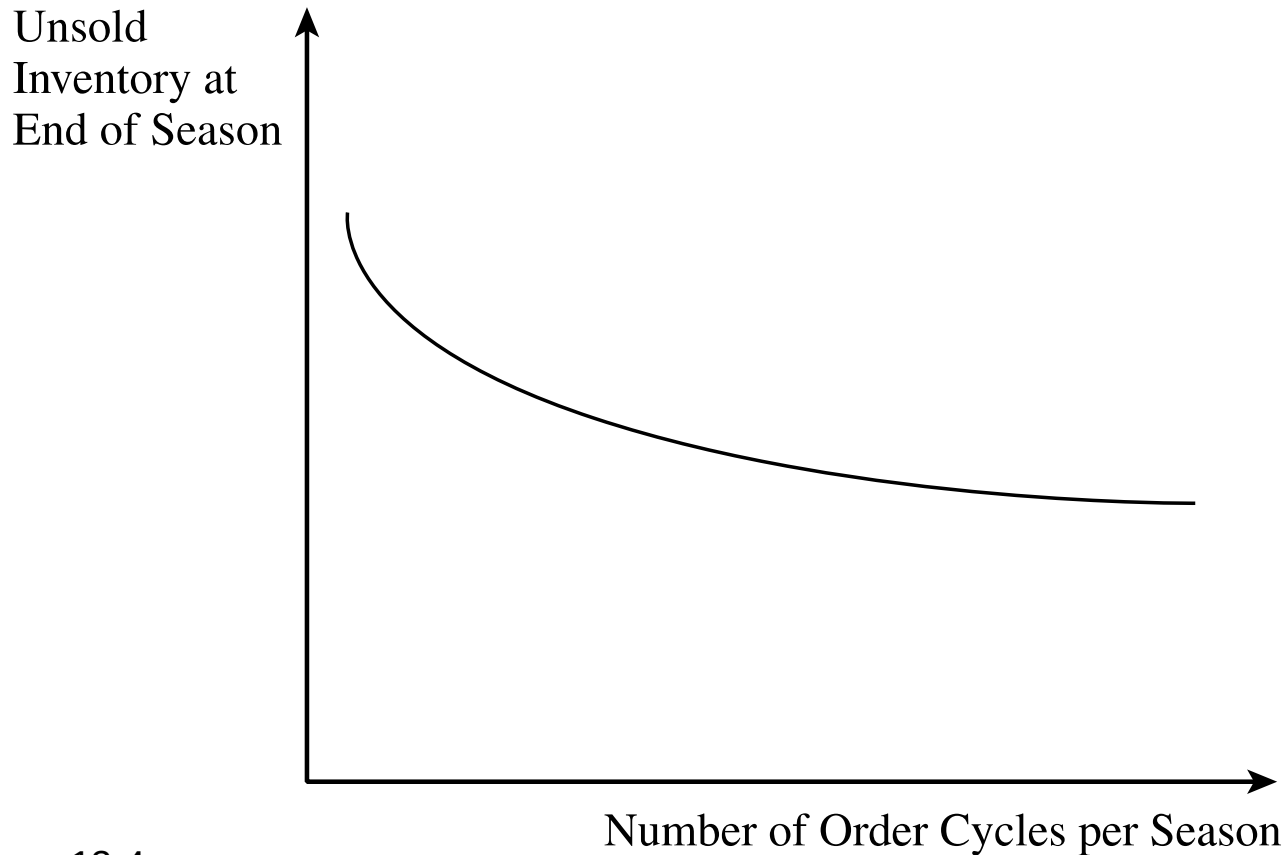


Figure 13-4

Quick Response: Multiple Orders Per Season

Figure 13-5

Managerial Levers

- **1. Increasing the salvage value of each unit increases profitability (as well as the optimal cycle service level).**

Managerial Levers

- **2. Decreasing the margin lost from a stock-out increases profitability.**
- **3. Reducing demand uncertainty.**

Managerial Levers

- **One strategy to increase the salvage value of an unsold product would be selling unsold product to an outlet store.**

Managerial Levers

- **The reduction of demand uncertainty is a significant managerial lever to improve supply chain profitability.**

Managerial Levers

- **A manager can reduce demand uncertainty via the following 4 ways:**
 - **1. Improved forecasting**
 - **2. Quick response**
 - **3. Postponement**
 - **4. Tailored sourcing**

Quick Response (Pros vs Cons)

- **1. The expected total quantity ordered during the season with two orders is less than that with a single order for the same cycle service level.**

TAILORED POSTPONEMENT & TAILORED SOURCING

Tailored Sourcing

- **In product-based tailored sourcing, low-volume products with uncertain demand are obtained from a flexible source, while high-volume products with less demand uncertainty are obtained from an efficient source.**

Numerical 1

- A cell phone manufacturer has introduced a new android phone. The anticipated demand is normally distributed with a mean of $\mu = 100$ and a standard deviation of $\sigma = 50$.
- Each unit costs Rs. 17,500 to manufacture and the introductory price is to be Rs. 22,500 to achieve this level of sales.

Numerical

- Any unsold units at the end of the first year are unlikely to be very valuable and will be disposed of in a sale for Rs. 10,500 each.
- It costs Rs1000 to hold a unit in inventory for the entire year. What is the cost of overstocking? What is the cost of under stocking? What is the optimal cycle service level? How many units should be manufactured for sale?

Numerical

- Step I: Calculate Over Stocking Cost:

$$\begin{aligned}C_o &= c - s \\&= \text{Rs. } 17,500 - \text{Rs. } 9,500 \\&= \text{Rs. } 6,000\end{aligned}$$

- Step II: Calculate Under Stocking Cost :

$$\begin{aligned}C_u &= p - c \\&= \text{Rs. } 22,500 - \text{Rs. } 17,500 \\&= \text{Rs. } 5,000\end{aligned}$$

Numerical

- Step III: Calculate CSL

$$\begin{aligned}\text{CSL}^* &= C_u / (C_u + C_o) \\ &= 5000 / (5000 + 6000) \\ &= 0.4545 \approx .45\end{aligned}$$

Numerical

- Step IV:

$$\begin{aligned} O^* &= \text{NORMINV}(\text{CSL}^*, \mu, \sigma) \\ &= \text{NORMINV}(0.45, 100, 50) \\ &= 93.71693 \\ &\approx 94 \end{aligned}$$

Note: Cannot complete O^* without access to Excel.

Numerical 2

- In the previous problem, the manufacturer performs additional market research. Based on this research, they determine that they can increase the price to Rs. 25,000 and are able to reduce the standard deviation of the forecast to $\sigma = 30$. At the same time, they have made an arrangement with an outlet store that will purchase unsold equipment for Rs.15,000 each.

NORMINV

- NORMINV (p , μ , σ) returns the value x such that, with probability p , a normal random variable with mean μ and standard deviation σ takes on a value less than or equal to x .

Numerical 2

- How will these changes affect the cost of over stocking, cost of under stocking, optimal cycle service level and optimal order size?

Numerical 2

- *Answer:*

$$\begin{aligned}\text{Step I} \quad C_o &= c - s \\ &= \text{Rs.}17,500 - \text{Rs.}15,000 \\ &= \text{Rs.}2500\end{aligned}$$

$$\begin{aligned}\text{Step II} \quad C_u &= p - c \\ &= \text{Rs.}25,000 - \text{Rs.}17,500 \\ &= \text{Rs.}7,500\end{aligned}$$

Numerical 2

- **The change in price increases the cost of under stocking.**
- **The increase in the salvage value reduces the cost of over stocking.**

Setting Product Availability for Multiple Products Under Capacity Constraints

$$MC_i(Q_i) = p_i \left[1 - F_i(Q_i) \right] + s_i F_i(Q_i) - c_i$$

1. Set quantity $Q_i = 0$ for all products i .
2. Compute the expected marginal contribution $MC_i(Q_i)$ for each product i .
3. If positive, stop, otherwise, let j be the product with the highest expected marginal contribution and increase Q_j by one unit.
4. If the total quantity is less than B , return to step 2, otherwise capacity constraint are met and quantities are optimal.

$$\begin{array}{ll} \text{Max} \sum_{i=1}^n \Pi_i(Q_i) & \text{subject to: } \sum_{i=1}^n Q_i \leq B \\ & Q_i \geq 0 \end{array}$$

Setting Optimal Levels of Product Availability in Practice

1. Beware of preset levels of availability.
2. Use approximate costs because profit-maximizing solutions are quite robust.
3. Estimate a range for the cost of stocking out.
4. Ensure levels of product availability fit with Strategy.
5. Tailor your response to uncertainty.

Learning Objectives

- **Understand the role of transportation in a supply chain.**
- **Evaluate the strengths and weaknesses of different modes of transportation.**

Learning Objectives

- **Identify the relative strengths and weaknesses of various transportation network design options.**
- **Identify trade-offs that shippers need to consider when designing a transportation network.**

UNDERSTAND THE ROLE OF TRANSPORTATION

Understand the Role of Transportation in a Supply Chain

- **Transportation refers to the movement of product from one location to another within a supply chain.**

MODES OF TRANSPORTATION AND THEIR PERFORMANCE CHARACTERISTICS

Strength and Weakness of different modes

- **The various modes of transportation include water, rail, intermodal, truck, air, pipeline, and package carriers.**

Air

- **Cost components**
 - ↗ **Fixed infrastructure and equipment**
 - ↗ **Labor and fuel**
 - ↗ **Variable – passenger/cargo**

Air

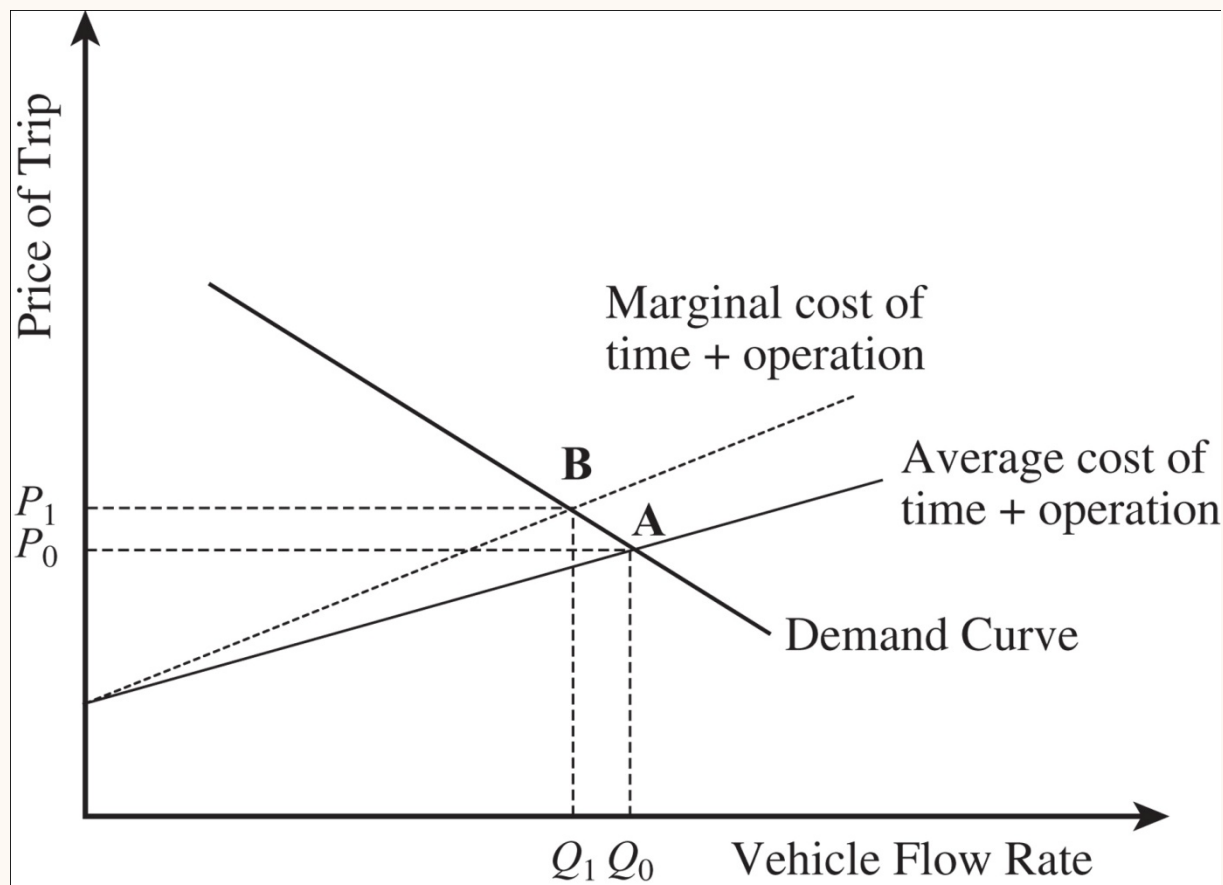
- Key issues
 - ↗ Location/number of hubs
 - ↗ Fleet assignment
 - ↗ Maintenance schedules
 - ↗ Crew scheduling
 - ↗ Prices and availability

Ropeways

- Environment friendly
- Shortest route possible through inaccessible terrain
- Considerably fast movement over short distance
- Most economical
- The obvious disadvantage being safety issues on poor maintenance and upkeep of the ropeway

TRANSPORTATION INFRASTRUCTURE POLICIES

Transportation Infrastructure and Policies



FREIGHT MANAGEMENT

DESIGN OPTIONS

Transportation Networks types

- **Point to Point Networks**
- **Multiple Delivery Points**
- **Trans-shipment Points**
- **Nodal Networks**
- **Hub and Spoke Network**

Design Options for a Transportation Network

- ↗ Should transportation be direct or through an intermediate site?**
- ↗ Should the intermediate site stock product or only serve as a cross-docking location?**

Direct Shipment Network to Single Destination

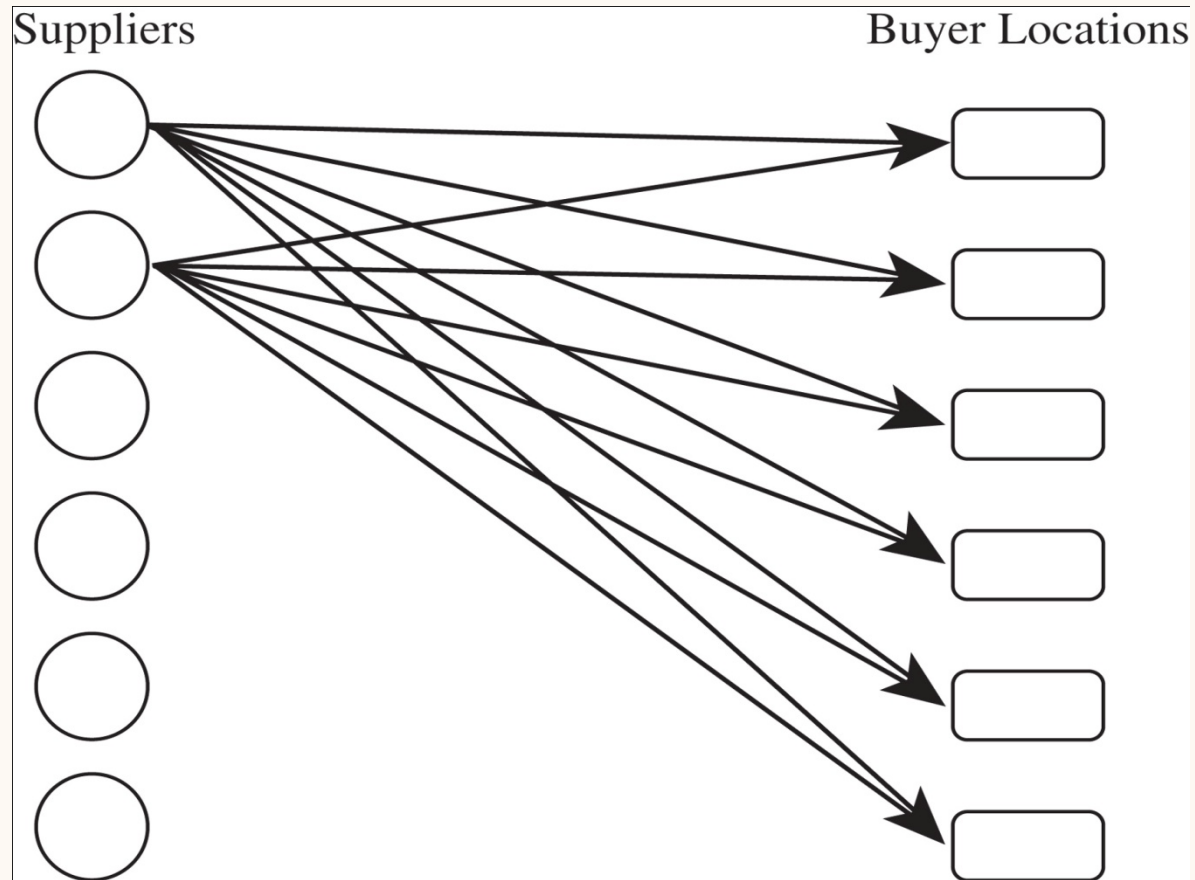


Figure 14-2

Direct Shipping with Milk Runs

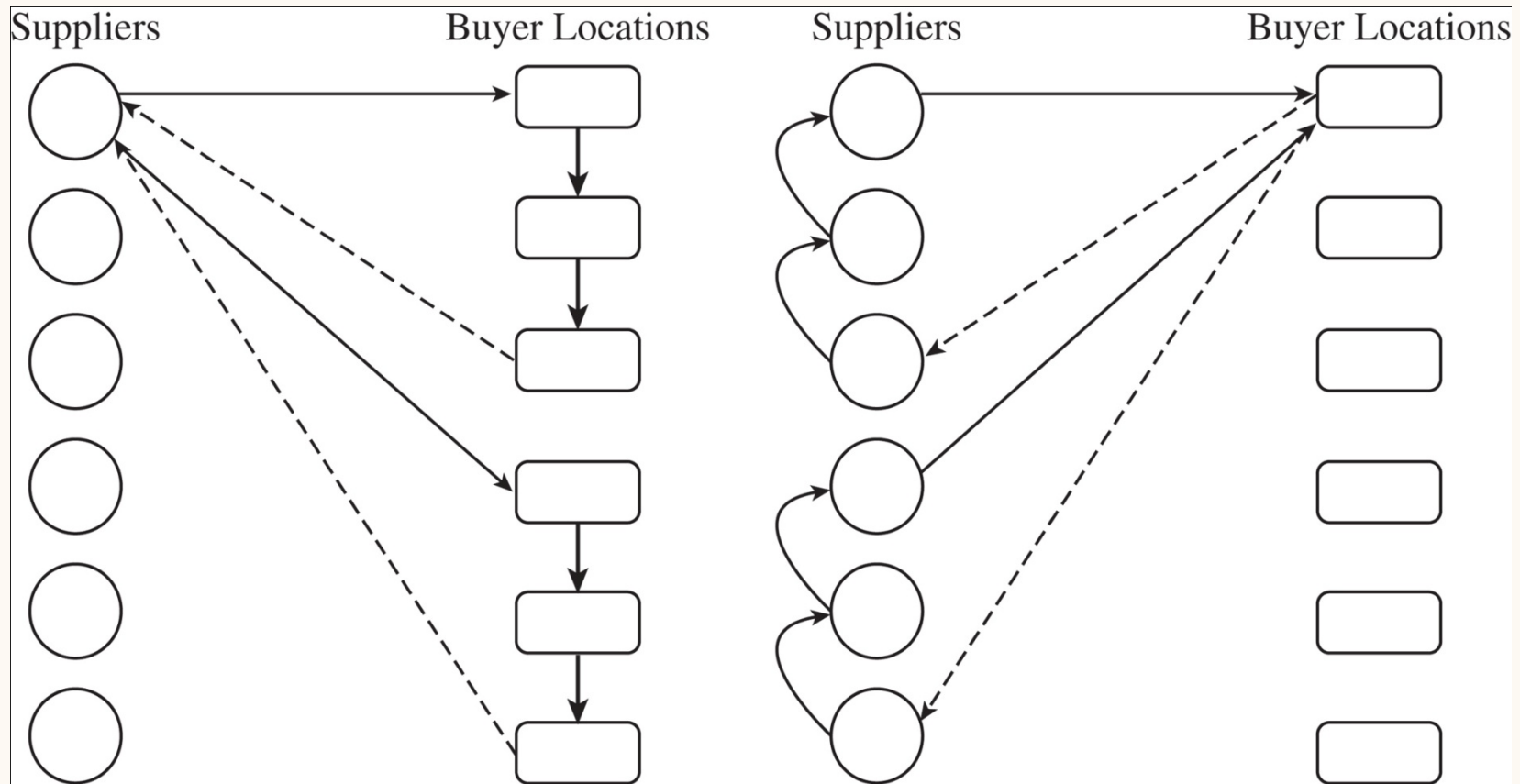


Figure 14-3

All Shipments via Intermediate Distribution Center with Storage

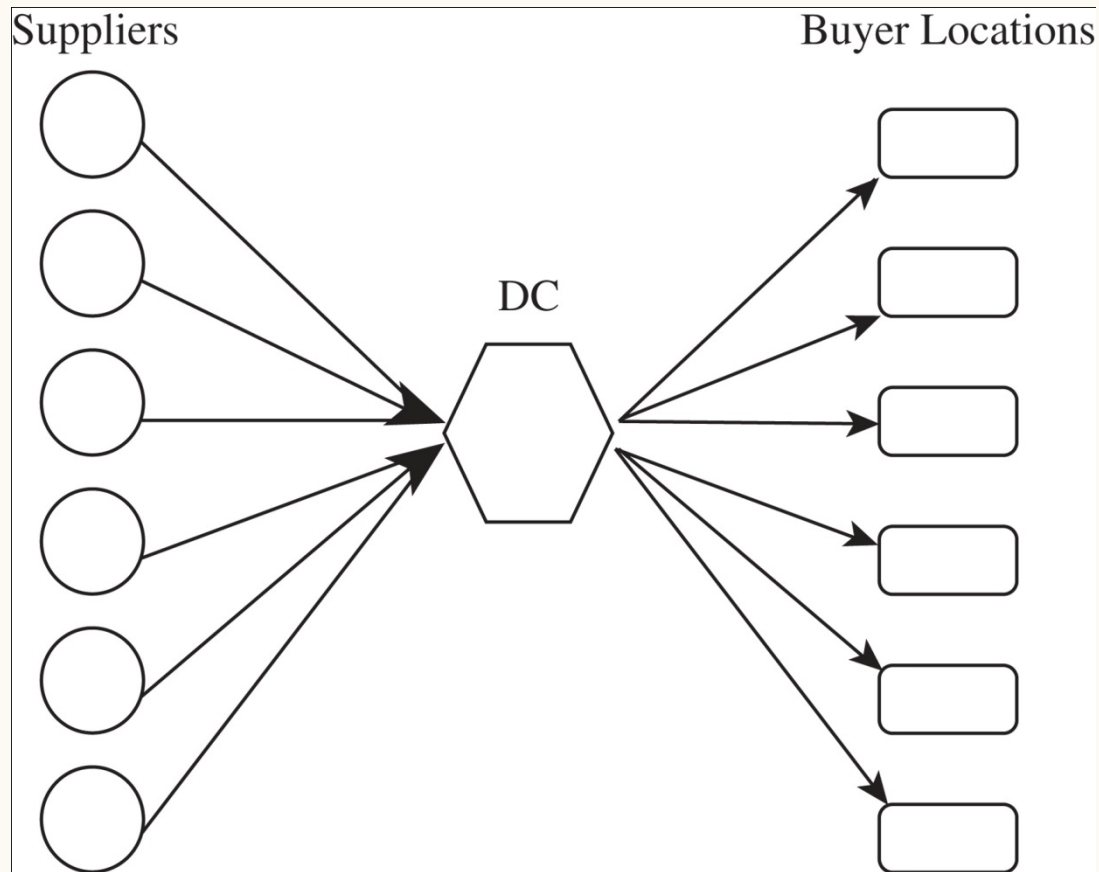


Figure 14-4

Tailored Network

Network Structure	Pros	Cons
Direct shipping	No intermediate warehouse Simple to coordinate	High inventories (due to large lot size) Significant receiving expense
Direct shipping with milk runs	Lower transportation costs for small lots Lower inventories	Increased coordination complexity
All shipments via central DC with inventory storage	Lower inbound transportation cost through consolidation	Increased inventory cost Increased handling at DC
All shipments via central DC with cross-dock	Low inventory requirement Lower transportation cost through consolidation	Increased coordination complexity
Shipping via DC using milk runs	Lower outbound transportation cost for small lots	Further increase in coordination complexity
Tailored network	Transportation choice best matches needs of individual product and store	Highest coordination complexity

Table 14-2

Selecting a Transportation Network

Annual sales = 960,000/store Direct shipping

- Batch size shipped from each supplier to each store
= 40,000 units
- Number of shipments/yr from each supplier to each store
= $960,000/40,000 = 24$

Selecting a Transportation Network

- Annual trucking cost for direct network
$$= 24 \times 1,100 \times 4 \times 8 = \$844,800$$
- Average inventory at each store for each product
$$= 40,000/2 = 20,000 \text{ units}$$
- Annual inventory cost for direct network
$$= 20,000 \times 0.2 \times 4 \times 8 = \$128,000$$
- Total annual cost of direct network
$$= \$844,800 + \$128,000 = \$972,800$$

Selecting a Transportation Network

Annual sales = 960,000/store Milk runs

- Batch size shipped from each supplier to each store
 $= 40,000/2 = 20,000$ units
- Number of shipments/yr from each supplier to each store
 $= 960,000/20,000 = 48$
- Transportation cost per shipment per store (two stores/truck) $= 1,000/2 + 100 = \$600$
- Annual trucking cost for direct network
 $= 48 \times 600 \times 4 \times 8 = \$921,600$
- Average inventory at each store for each product
 $= 20,000/2 = 10,000$ units
- Annual inventory cost for direct network
 $= 10,000 \times 0.2 \times 4 \times 8 = \$64,000$
- Total annual cost of direct network
 $= \$921,600 + \$64,000 = \$985,600$

Selecting a Transportation Network

Annual sales = 120,000/store Direct shipping

- Batch size shipped from each supplier to each store
= 40,000 units
- Number of shipments/yr from each supplier to each store
= $120,000/40,000 = 3$
- Annual trucking cost for direct network
= $3 \times 1,100 \times 4 \times 8 = \$105,600$
- Average inventory at each store for each product
= $40,000/2 = 20,000$ units
- Annual inventory cost for direct network
= $20,000 \times 0.2 \times 4 \times 8 = \$128,000$
- Total annual cost of direct network

Selecting a Transportation Network

Annual sales = 120,000/store Milk runs

- Batch size shipped from each supplier to each store
 $= 40,000/4 = 10,000$ units
- Number of shipments/yr from each supplier to each store
 $= 120,000/10,000 = 12$
- Transportation cost per shipment per store (two stores/truck)
 $= 1,000/4 + 100 = \$350$
- Annual trucking cost for direct network
 $= 12 \times 350 \times 4 \times 8 = \$134,400$
- Average inventory at each store for each product
 $= 10,000/2 = 5,000$ units
- Annual inventory cost for direct network
 $= 5,000 \times 0.2 \times 4 \times 8 = \$32,000$
- Total annual cost of direct network
 $= \$134,400 + \$32,000 = \$166,400$