21. Three items in inventory have the following characteristics:

	A	B	C
Average demand per year	51,000	25,000	9,000
Lead time, weeks	0.5	0.5	0.5
Carrying cost per year	25%	25%	25%
Delivered purchase price per unit	\$1.75	\$3.25	\$2.50
Procurement cost per order	\$10	\$10	\$10

The average investment in these items is not to exceed \$3,000. The items are purchased from different vendors and are not jointly ordered. Determine the order quantities for these items so that the investment limit is not exceeded.

22. A company has three items in its inventory that are purchased from the same vendor and are shipped together on the same delivery truck. The truck has a capacity of 30,000 lb. The items are under the periodic review method of inventory control and are purchased with a single purchase order that costs \$60 to prepare. The annual carrying cost is 25 percent of each item's value. Other information about the items is as follows:

Item	Product Value, C_i	Product Weight, w_i	Weekly Demand Forecast, d_i
1	\$50/case	70 lb/case	100 cases
2	30	60	300
3	25	100	200

Due to economic considerations, the shipment size is not to exceed the truck capacity for the combined order. What size should the order quantity be for each item? [*Hint*: Equation 9-29 becomes $\sum_i D_i T^* w_i \leq$ Truck capacity, Equation (9-30) can be restated as

$$\alpha = \frac{2O}{\left(\frac{\text{Truck capacity}}{\sum_i D_i w_i}\right)^2 \sum_i C_i D_i} - I$$

and recall that $Q^* = D \times T^*$. Product weight is w_i and D_i is annual demand.]

23. Five items in a retail inventory make up the bulk of the items maintained. The inventory levels are controlled using the reorder point method. They have a fixed lead time of 15 days, a purchase order cost of \$35 per order per item, and a daily inventory carrying cost of 0.08219 percent. Other information about the items is as follows:

selected for evaluation. From the monthly forecasts of the demand in the two warehouse territories, the following statistics are known:

Product	WAREHOUSE 1 Monthly Demand, Units	WAREHOUSE 1 Monthly Standard Deviation, Units	WAREHOUSE 2 Monthly Demand, Units	WAREHOUSE 2 Monthly Standard Deviation, Units	Product value, Units $/Unit
A	3,000	500	5,000	700	15
B	8,000	250	9,500	335	30
C	12,500	3,500	15,000	2,500	25

The product order quantities are determined locally at each warehouse using the *EOQ* formula and are ordered from separate vendors with an order-processing cost of $25 per order. Replenishment lead times average three weeks, or 0.75 months. Inventory carrying costs are 24 percent per year. The service level during the order cycle is set at 95 percent.

How much inventory can be saved through risk pooling if the inventory is consolidated into a central facility?

28. A distributor is positioned in the supply channel between his customers and suppliers. He knows that the customers maintain inventory that should be taken into account in planning his own inventory levels. In the spirit of cooperation, the customers share their end demand data with the distributor. For a particular item supplied by the distributor to three customers in his territory, the monthly demand for an item valued at the customer echelon at $35 per unit is as follows:

Customer	Avg. Demand, Units/Mo.	Demand Std. Dev., Units/Mo.
1	425	65
2	333	52
3	276	43
Combined	1,034	94[a]

[a]Estimated as $\sqrt{65^2 + 52^2 + 43^2} = 94$

The item is valued a little less at the distributor ($30 per unit) since some costs such as transportation to customers have not yet been added. Inventory-carrying cost is estimated at 20 percent per year at both echelons. Order-placement cost for the customers is $50 per order. The distributor can supply the customers within two weeks, but it takes vendors four weeks to fill the distributor's replenishment orders. Customers set their in-stock probability during the order cycle at 95 percent, whereas the distributor uses 90 percent. Both echelons use the reorder point method of inventory control. The distributor places orders on the vendor for 2,000 units to realize a purchase discount.

How much inventory of this item should the distributor stock if no inventory is assumed to be in transit to customers?

CASES

*Complete Hardware Supply, Inc.**

Tim O'Hare is the distribution manager for Complete Hardware Supply (CHS), with headquarters in Cleveland, Ohio. Consolidated, Inc., a holding company, recently acquired CHS. Consolidated's management has insisted that tighter control procedures be instituted to limit inventory investment at CHS.

CHS is a distributor of various hardware items to local hardware stores in the northeastern Ohio area. It purchases a wide variety of hardware items from a number of vendors located throughout the country. Hardware store orders are filled from the inventories held at CHS's Cleveland warehouse. Historically, Tim has used a reorder point method of inventory control to determine reorder quantities acquired from vendors and to control inventory levels.

To deal with the new investment limit placed on inventories, Tim selects for analysis 30 representative items from 500 in the product line. He collected the data on demand, product value, and lead times as shown in Fig. 1.

The cost for preparing and transmitting a purchase order is $15, and each item is purchased from a separate vendor on a separate order. The company's annual inventory-carrying cost is 25 percent, or 0.0048 per week. Tim currently uses a 98 percent in-stock probability during the lead time as a control on customer service, which was set in consultation with the company's salespersons.

The 30 products are sourced from various vendor-shipping points as follows:

Product Number	Vendor Shipping Area	Distance to CHS[a]
1, 2, 3, 5, 22, 23	New York, New York	471 mi
4,6,13	Cleveland, Ohio	25
7, 8, 9, 10, 11, 12, 20,30	Chicago, Illinois	348
19,24,29	Atlanta, Georgia	728
14, 15, 16, 18, 25, 26, 27, 28	Los Angeles, California	2,382
17,21	Dallas, Texas	1,189

[a]Approximate road distances.

The lead time to receive a replenishment order is composed of three elements: (1) the time to prepare and transmit an order, (2) the time to fill the order at the vendor location, and (3) the time to transport the order to Cleveland. Currently, orders are prepared by hand and mailed to vendors, a system where preparation takes two days and transmittal takes two days. Trucking is used to transport products to CHS. It takes approximately one day to transport product for every 300 miles of distance. Vendor order filling requires five working days.

Prorating the restrictions that Consolidated has placed on all items, the total investment for these 30 items should not exceed $18,000. However, to maintain revenues, Tim would like to have no more stockouts per year than he currently is experiencing.

*Paraphrased from a case study by Professor A. Dale Flowers, Case Western Reserve University.

Item Number	Weekly Demand Forcast	Weekly Forcast Error,[a] Std. Dev.	Unit Price,[b]	Lead Time,[c] Days
1	18	6	$37.93	10.6
2	9	2	85.06	10.6
3	113	30	1.32	10.6
4	20	5	2.41	9.5
5	7	2	5.19	10.6
6	490	101	0.51	9.5
7	44	11	2.36	10.2
8	68	23	1.30	10.2
9	48	15	7.38	10.2
10	7	1	9.69	10.2
11	6	2	1.38	10.2
12	4	1	3.25	10.2
13	90	22	7.79	9.5
14	5	1	5.48	16.9
15	3	1	19.04	16.9
16	7	2	2.03	16.9
17	6	2	68.97	13.0
18	3	1	21.65	16.9
19	14	4	56.28	11.4
20	5	1	19.85	10.2
21	104	35	35.51	13.0
22	30	9	2.19	10.6
23	8	2	14.24	10.6
24	15	6	12.16	11.4
25	6	2	4.04	16.9
26	4	1	66.13	16.9
27	7	2	68.10	16.9
28	5	1	11.18	16.9
29	20	5	26.41	11.4
30	14	4	40.86	10.2

[a]Forecast error is approximately normally distributed.
[b]Includes a transportation rate to Cleveland of 5% on the average.
[c]Lead times are expressed as the average number of working days. Assume 5 working days per week.

Figure 1 Sales, Price, and Lead Time Data at CHS

Reflecting on his dilemma, Tim has a number of action courses open to him to lower inventory levels:

- Transmit orders more rapidly
- Insist that vendors use a faster method of transportation
- Reduce the forecast error
- Compromise on customer service

Tim can buy electronic equipment (computer and software, facsimile machine, etc.) for approximately $1,500 (with a five-year life) and make order-transmittal time negligible. Of course, he figures that other related costs (EDI, Internet connection, telephone, etc.) will raise the purchase order cost from $15 to $17.

If special arrangements are made with United Parcel Service, a guaranteed delivery service of two days anywhere in the United States can be arranged. This would affect shipments over 600 miles and would add another 5 percent to the price of the items involved.

Finally, Tim has a line on a new forecasting software package that he can acquire for $50,000. If the software is implemented, he expects that the forecast error can be reduced by 30 percent. ■

QUESTION

1. What course of action should Tim take, and how should he argue his case to Consolidated's management?

*American Lighting Products**

"I just love challenges like this—take out 20 percent of our finished-goods inventory without hurting customer service. I don't know how we are going to do it!" Sue Smith exclaimed to inventory analyst Bryan White. Sue had just returned from a meeting with the vice president of finance who had issued the directive, and she now had to come up with a plan.

BACKGROUND

Sue and Bryan work for American Lighting Products (ALP), a manufacturer of fluorescent lamps. ALP has two factories, both in Ohio. The Cleveland area plant produces the high-volume two-, three-, and four-foot lamps, with four-foot lamps accounting for 90 percent of the production. The Columbus area plant handles the low-volume types, ranging from six inches long to eight feet. Between both plants, ALP offers over 700 product line items, through three main sales channels: commercial and industrial (C&I), consumer, and original equipment manufacturers (OEM). The C&I market has long been the mainstay of the business, however with the emergence of home centers and deep discount merchants, the consumer channel is gaining in size and importance in the overall marketing strategy. The OEM market is small, but it is an important first step in the replacement market, since, as bulbs burn out, customers tend to purchase exactly what comes out of the fixture.

ALP is part of a larger corporation, American Electric Products (AEP), which manufactures a variety of other consumer and industrial products. Each division of AEP is run as a stand-alone business, and each fits into the overall strategy of AEP in its own way. ALP is a mature industry that provides AEP with a steady income from its operations. While the division's income earned is its primary measure of success, management also launches other major initiatives that focus on ways to increase the profitability of the corporation. The latest such initiative is a corporation-wide push to reduce inventories. The enhanced cash flow to be gained from reducing inventory is seen as a critical factor to the company's overall profitability.

To Sue Smith and her team at ALP, the inventory initiative is a new challenge. In the past, the focus has been on making sure that the inventory

*Prepared by Cheryl Glanton under the supervision of Professor Ronald H. Ballou, Weatherhead School of Management, Case Western Reserve University, as a basis for class discussion rather than as an illustration of either effective or ineffective handling of an administrative situation. Data have been disguised.

levels were sufficient to cover the seasonal peaks in demand and to cover the plant's three-week summer shutdown. Until this point, the costs of inventory have not been closely monitored, so reducing the overall inventory level is a completely new idea.

THE DISTRIBUTION SYSTEM

ALP warehouses its finished goods inventory in eight master distribution centers (MDCs) located throughout the United States, each servicing sales for its entire region. MDC and plant locations are shown in Figure 1. Each plant ships product to MDCs in full truckload quantities of 35,000 lamps. Shipping in large quantities allows the plants to manufacture product in economic lot sizes. Each plant schedules its production in weekly increments in order to minimize the impact of forecast errors that occur when production is based on monthly schedules.

Each MDC is set up as a hub to support its region, and the size of the center is based on the size of the region served. For instance, the Hagerstown distribution center serves the northeastern United States as well as European and Middle Eastern exports. This large region results in Hagerstown being the largest inventory location for ALP. On the opposite end of the scale is the Seattle distribution center. It has the smallest region to serve and, therefore, the smallest inventory allotment. Table 1 shows the annual shipments and inventory by MDC.

For ease of control, inventory is primarily expressed in lamp quantities. The finance department assesses the average lamp value to be $0.88. The current carrying cost of an item held in inventory is 18 percent per year of lamp value before taxes.

As product is manufactured, the amount allocated to a certain distribution center is based on the following considerations:

1. The volume of current customer orders that exceeds available inventory
2. The volume that an MDC's inventory is below base stock levels
3. The volume of the sales forecast for an MDC service region

Figure 1 Production and Distribution Center Locations

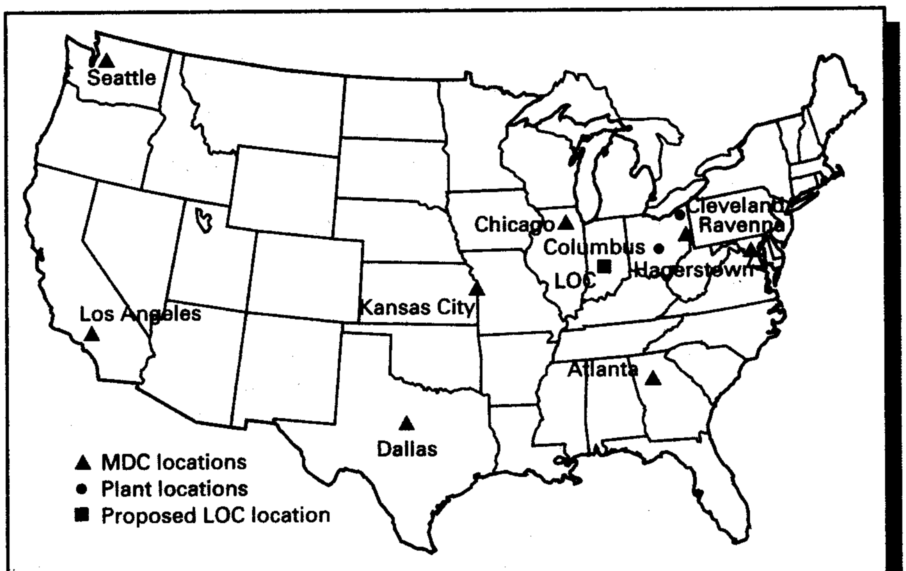


Table 1
Annual Units Shipped and Average Inventory by MDC (in Lamps)

Master Distribution Center	Shipments	Inventory
Atlanta	26,070,000	3,784,333
Chicago	23,321,000	2,188,417
Dallas	13,244,000	2,159,250
Hagerstown	38,193,000	5,824,583
Kansas City	15,950,000	1,592,333
Los Angeles	21,470,000	3,666,500
Ravenna	25,853,000	2,918,250
Seattle	4,922,000	959,833
Totals	169,023,000	23,093,499

The base stock level is set for each product item at each MDC based on historical sales levels. In the case of new products, stocking locations are based on the target customers and their estimated sales. The sum of the base stocks at all MDCs is the desired net system inventory objective (NSO) for a product. The NSO is the reorder point for the factory to produce another lot of product. Therefore, the average system inventory for a product is the NSO + 1/2 a lot size. The lot size was based on the plant's setup cost and manufacturing constraints.

ALP has a forecasting system that takes into account the past three years of sales history. Management adjusts the forecast when a known abnormality is expected, for instance, a special sales promotion. In general, the higher the level of the forecast, the more accurately sales can be predicted. For the total market, the forecast accuracy is in the 90 to 100 percent range. For product families, it is in the 70 to 90 percent range. For individual products, it is in the 50 to 70 percent range. For individual product items by MDC, the forecast accuracy is below 50 percent.

Customers place orders through regional salespeople, who send the orders to a central customer service center. The account specialists at the service center place the order in the order/ship/bill system. While inputting the order, they assign it to the MDC that serves the region for that customer. The system uses the customer zip code to determine the correct MDC. In the case of an order that consists of an entire truckload of one product, the order will be assigned to the plant producing the item instead of an MDC. The account specialist also enters the desired delivery date at the customer's site. If no future date is requested, the order is then scheduled for immediate delivery.

Inventory is allocated to each MDC based on the forecast for that region, as well as other considerations. Because of the high forecast error at the item level of detail, actual sales might be unexpectedly high in one region and low in another. When this happens, there may be a stockout at one warehouse while there is excessive stock at another, causing some orders to be back ordered at the primary location or filled from another location having the excess inventory.

CUSTOMER SERVICE

ALP measures its performance by first-time delivery rate, known at ALP simply as customer service. First-time delivery is defined as the proportion of line items delivered to the customer by the requested date. If an item is delivered from a source other than the assigned source, it does not count as a first-time delivery. Any back-ordered items are also not considered as first-time delivery. Figure 2 shows ALP's customer service level for the past two years.

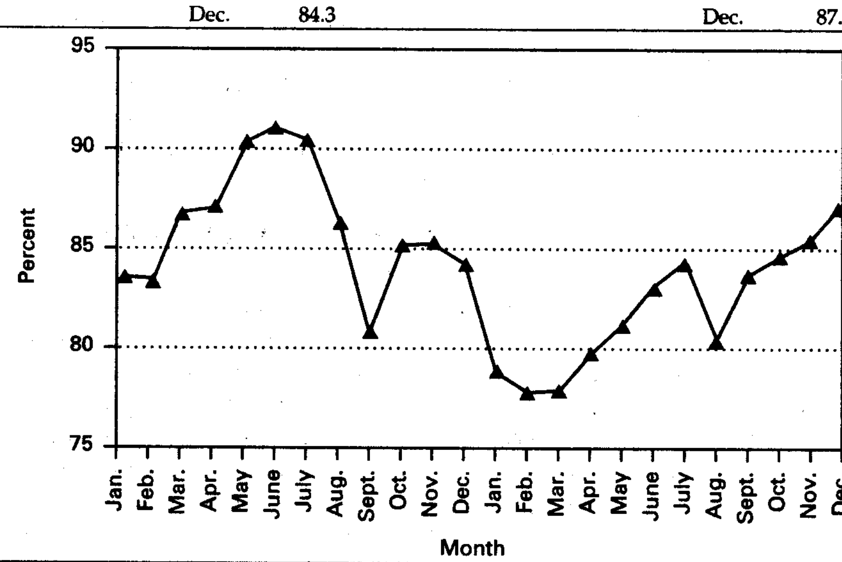
The lighting business is extremely competitive and customers are becoming increasingly demanding of their suppliers. One of the demands is a high first-time delivery rate. The consumer channel expects 98 percent or better, while the C&I and OEM channels expect 95 percent first-time delivery. Over the past several years, ALP has struggled to meet these expectations. As customers become more sophisticated in their own ordering and inventory policies, they demand more of their suppliers. ALP is raising expectations. The current goal is to meet or exceed 95 percent service in all channels. The largest consumer accounts are being served at the 98 to 100 percent rate, but it has taken extra inventory and resources to accomplish this result. Table 2 shows the items ordered and customer service level by channel for the past year.

INVENTORY POLICIES

Each channel of distribution has unique needs and inventory requirements. For instance, the consumer channel has a smaller variety of products, but the customer demands are the highest in the industry. Many consumer accounts have a ship-or-cancel policy. If an order is not delivered in the requested time window, it is canceled and the sale is lost. Many customers also release

Figure 2 First-Time Delivery Percentages by Month for the Last Two Years

	Month	%		Month	%
2 years ago	Jan.	83.6	Last year	Jan.	78.6
	Feb.	83.4		Feb.	77.8
	Mar.	87.0		Mar.	77.9
	Apr.	87.1		Apr.	79.6
	May	90.3		May	81.0
	June	91.2		June	83.0
	July	90.5		July	84.3
	Aug.	86.4		Aug.	80.4
	Sep.	81.0		Sep.	83.5
	Oct.	85.2		Oct.	84.4
	Nov.	85.1		Nov.	85.3
	Dec.	84.3		Dec.	87.2



By Channel		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
C&I	Items ordered	46307	55013	44683	54528	48492	42230	46709	50983	46792	65775	57932	47152
	B/O[a]	10795	13084	11083	11974	10173	7759	7979	11382	8719	10850	9571	6910
	%Service[b]	76.7%	76.2%	75.2%	78.0%	79.0%	81.6%	82.9%	77.7%	81.4%	83.5%	83.5%	85.3%
Consumer	Items ordered	24709	28023	21511	23487	29644	21204	24089	25958	26182	37272	33650	25482
	B/O	4214	5081	3331	3651	4373	2801	2925	3480	3196	4797	3652	2074
	%Service	82.9%	81.9%	84.5%	84.5%	85.2%	86.8%	87.9%	86.6%	87.8%	87.1%	89.1%	91.9%
OEM	Items ordered	1038	1396	1028	1260	1058	1019	1208	1215	1147	1526	1279	1122
	B/O	301	387	289	325	252	225	256	278	228	315	224	193
	%Service	71.0%	72.3%	71.9%	74.2%	76.2%	77.9%	78.8%	77.1%	80.1%	79.4%	82.5%	82.8%

[a] B/O = back orders.
[b] %Service = % first-time deliveries.

Table 2 Order Information by Channel

their orders weekly, based on point-of-sale information. Therefore, an order released on Friday has a shipping window of the following Monday through Wednesday. To meet these customer needs, ALP commits to having 4.5 weeks of inventory on hand of each consumer product.

On the other extreme is the OEM market. In this case, customer orders are typically of one product and shipped in a truckload quantity. However, OEM's want the product on the day they call. If the product is unavailable, they call a competing supplier.

The C&I market is not clear-cut. Some customers have sophisticated ordering schemes, but the majority use regular order procedures to replenish their shelves. Additional orders are placed because an end user is awarded a certain contract, for either a new building or a relamping project, and needs product. If the distributor does not carry the item, or is low on stock, it is ordered from ALP. Like the OEM customers, the contractor wants immediate delivery.

Historically, ALP's inventory management policy has been to maintain inventories to enable level production loading, while supporting heavy seasonal demand. Traditionally, the first and fourth quarters are the peak demand seasons for ALP. Also factoring into the inventory profile is summer plant shutdowns. Each year in the summer, both ALP plants take from two to three weeks for equipment maintenance and vacations. An inventory buildup precedes this shutdown period to allow continuous product shipments. Figure 3 shows the system inventory levels by month for the past two years.

Reducing total inventories by 20 percent is going to be challenging. If the inventory levels are cut haphazardly, customer service will be at risk. Even though there is not a perfect correlation, inventory levels and service levels are somewhat related. So the question remains, How can ALP reduce inventory and increase service?

OPTIONS

Sue and Bryan both agree that in order to meet these new challenges, evaluating the distribution system is a good place to start looking for ways to make changes that will meet both goals. The first alternative Sue and Bryan developed is to create a large order center (LOC) for the national consumer accounts. The LOC would be a new MDC that serves only consumer accounts. The thought behind the LOC is to consolidate the consumer products in one warehouse and distribute from this central location.

	Month	Inventory		Month	Inventory
2 years ago	Jan.	22,886	Last year	Jan.	18,830
	Feb.	24,395		Feb.	18,352
	Mar.	26,869		Mar.	20,235
	Apr.	27,889		Apr.	22,196
	May	29,490		May	25,589
	June	30,514		June	27,059
	July	33,142		July	27,631
	Aug.	21,853		Aug.	24,141
	Sep.	21,522		Sep.	25,070
	Oct.	22,660		Oct.	23,838
	Nov.	18,766		Nov.	21,482
	Dec.	20,741		Dec.	22,699

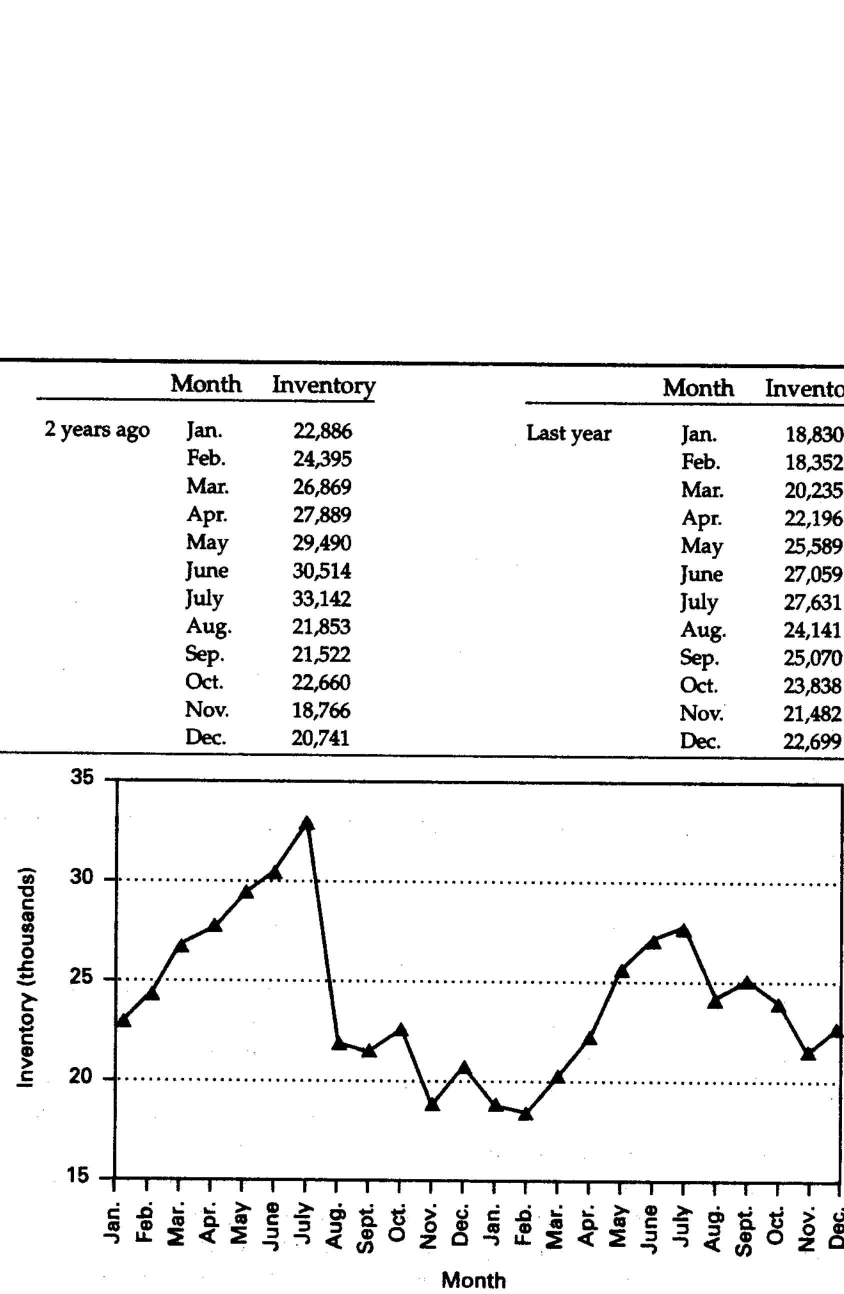


Figure 3 System Inventory for the Past Two Years

The advantage is that the consumer accounts typically had regular ordering patterns and the number of SKUs ordered by each account was defined at the beginning of the year. In the current distribution system, the inventory of the consumer items is kept at a higher level at each MDC. Sue and Bryan feel confident that the LOC will enable ALP to achieve 98 percent or greater customer service levels for the consumer channel, while reducing the total inventory, but it is unknown how much inventory can be taken out of the distribution system. Based on the warehouse locations of ALP's major consumer customers, Batesville, Indiana, was selected as the site for a future warehouse.

The risk of using a LOC is that it does not equally affect all product lines. In the case of C&I and OEM customers, another strategy is needed. The original theory in locating the MDCs was to have a distribution center at the hub of every major region in the country. The system worked well in shipping product to the customer, but the current inventory level is not sufficient to maintain a 95 percent service level. If the current distribution system is maintained, inventory needs to be added to reach the 95 percent goal.

Master Distribution Center	Transport Rate, $/Truckload	Inbound Lead Time, Days	Outbound Lead Time, Days
Atlanta	600	2	2
Chicago	350	1	2
Dallas	1200	3	2
Hagerstown	475	1	2
Kansas City	700	2	3
Los Angeles	1800	5	2
Ravenna	250	1	2
Seattle	1800	6	2
LOC	600	1	2

Table 3 Transportation Cost and Lead Times by MDC

Inventory reduction is the major concern of upper management, so this option is not feasible. An alternative is to reduce the number of MDCs and consolidate the inventory in such a way that each remaining MDC has a higher inventory level than before, but the total system inventory is lower.

MDC consolidation affects transportation costs and lead times as well as inventory levels. In order for MDC consolidation to be an economical alternative, the dollar value of the inventory reduction needs to be considered in light of any increase in transportation costs. Bryan and Sue investigated the current transportation costs and lead times, and the results are shown in Table 3. Inbound transportation is the in-transit time from the plant to an MDC, and outbound transportation is the in-transit time from the MDC to the customer. The outbound transportation costs are not shown since they represent thousands of rates to hundreds of customers from many existing and potential MDC locations.

The inbound lead-time varies from one day to four days around the average lead time, with the average variance being 2.5 days. On the outbound side, the majority of the territory is served within two days, with a variance of one day.

Sue and Bryan know that MDC consolidation might reduce total inventory, but they also know that the idea of building new MDCs around the country may not be easy to sell to upper management. At ALP, the investment constraint is that all projects must have at least a two-year payback.[1] Any plan to achieve MDC consolidation has to meet the investment criteria. Sue and Bryan feel that the best strategy is to consolidate MDCs at existing sites. For instance, the Chicago MDC could serve both its territory and Kansas City's from the current center. Consolidations like this minimize the investment needed.

What would happen to the warehousing cost is another concern with MDC consolidation. Currently, the finance department allocates a flat rate of $0.10 per lamp in inventory to warehousing cost. This rate covers the overhead of the distribution centers and the direct labor needed to handle product. If the number of MDCs were reduced, there would also be a reduction in the total warehousing costs for the entire system. However, the MDC selected as a consolidation site would have higher costs than before consolidation because of holding more lamps. The selected site is the one currently

[1]A two-year payback means that the cost savings associated with a project must equal or exceed the investment made in a project within two years.

having the greatest number of shipments among the consolidated group.

Options like the LOC and MDC consolidation have been brought up before, but they have always been discarded because of the additional costs involved. Upper management has had a feeling that transportation costs would increase. However, an in-depth analysis, considering inventory reduction, might yield a different answer. The new focus on inventory reduction provides an opportunity to question the status quo of the distribution system. At $0.88 per lamp inventory value, a 20 percent inventory reduction would yield a $4 million improvement in cash flow. However, any major construction projects required, as part of the MDC consolidation, would not be easily justified on a two-year payback basis. It would be acceptable to management to consolidate demand at the existing MDCs if the change can be economically supported and customer service maintained at least at current levels. Sue and Bryan know they need to find a solution that will meet both customer expectations and the business goals. ■

QUESTIONS

1. Evaluate the company's current inventory management procedures.
2. Should establishing the LOC be pursued?
3. Does reducing the number of stocking locations have the potential for reducing system inventories by 20 percent? Is there enough information available to make a good inventory reduction decision?
4. How might customer service be affected by the proposed inventory reduction?

*American Red Cross: Blood Services**

Dr. Amy Croxton, the medical director of American Red Cross regional blood center for the northern Ohio region located in Cleveland, was in low spirits. In March, a severe outdating[1] of blood products had taken place; she now faced an extreme shortage of blood in April. The substantial outdating of blood products in March and their severe shortage in April had proved very costly. She reflected upon the stated mission of the American Red Cross (ARC) "to fulfill the needs of the American people for the safest, most reliable, most cost-effective blood, plasma, and tissue services through voluntary donations." She wondered if some changes in its blood inventory management program would reduce operating costs for the ARC and increase the availability of blood to the hospitals that it supplies.

INTRODUCTION

The American Red Cross is a nonprofit organization collecting 48 percent of the blood supply in the United States. The remainder is collected using independent members of America's Blood Centers (35%), by members of the Council of Community Blood Banks (15%), and by commercial blood banks (2%). Each year, over 2 million hospitalized Americans depend on the timely availability of the right type of blood products at over 6,000 hospital blood banks in the United States. If the right blood products are not available when required, then medical complications or postponements of surgical procedures can result. This translates to extra days of hospitalization and expense.

*This case was prepared with the assistance of Manish Batra and Benjamin Flossie.
[1]Outdating occurs when a blood product, due to age, is no longer usable for its intended purpose and is declared out of date.

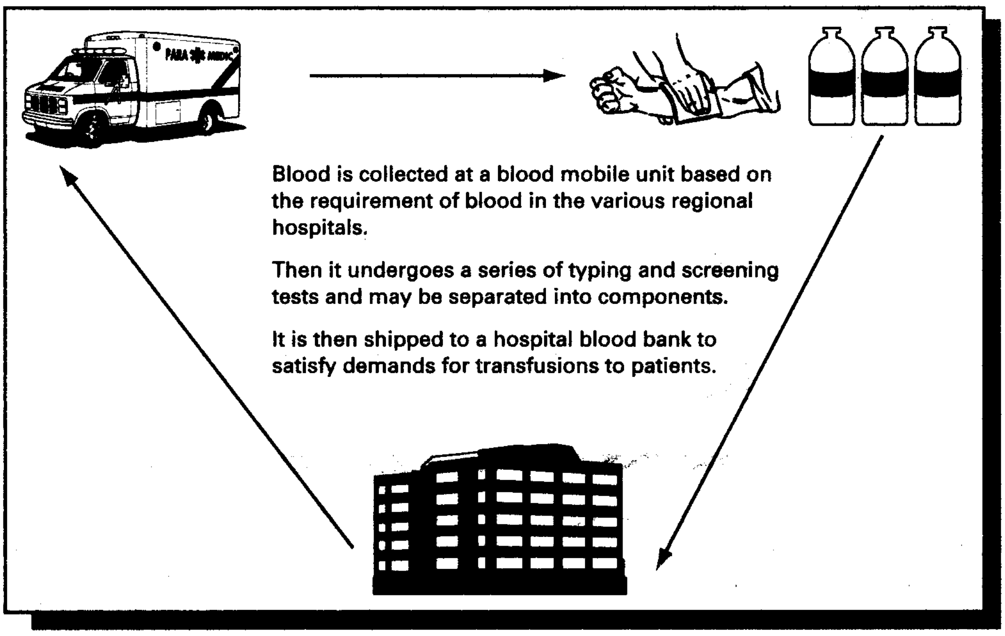


Figure 1 Collection, Testing, and Distribution of Blood

Human blood is a perishable product. It is collected in units of one pint per donor at collection sites such as churches, factories, schools, and regional blood centers; after undergoing a series of tests, it is ready to be processed and distributed to the various hospital blood banks in the region, as diagrammed in Figure 1.

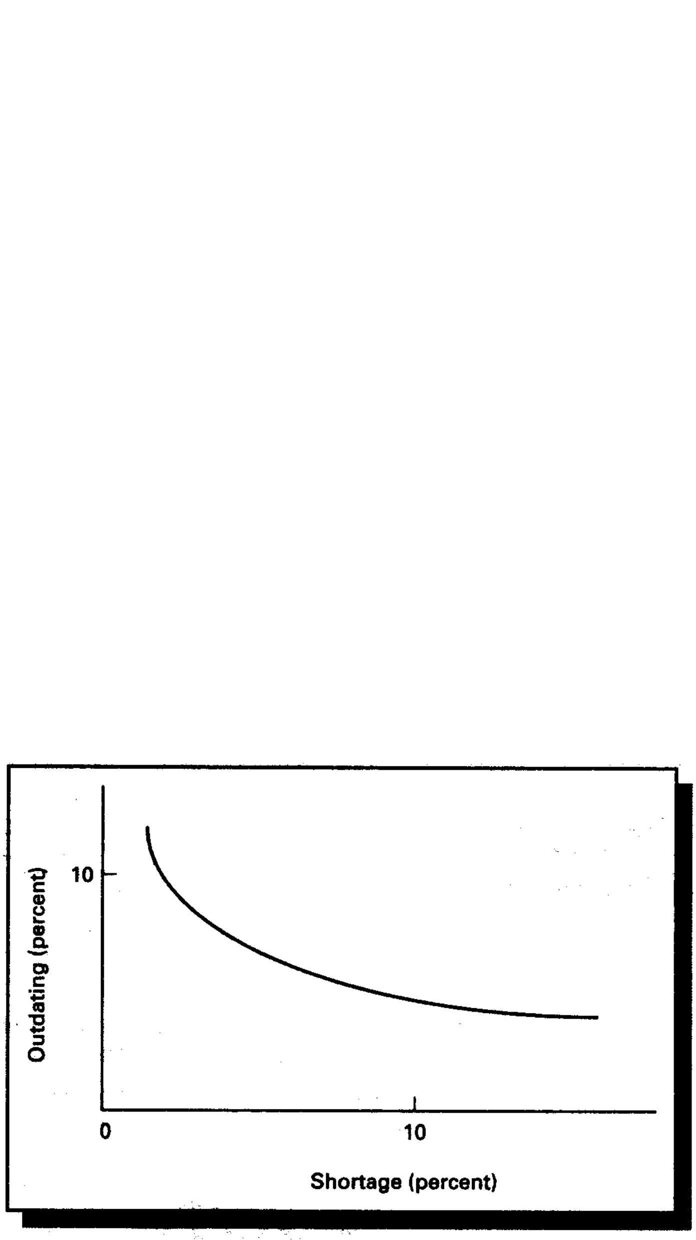
There are eight major blood types, and their frequencies in the U.S. population vary from 38 percent for O+ to 0.5 percent for AB–, as shown in Table 1. Regional blood banks attempt to maintain inventories of some or all of the eight different types of blood in order to meet the variable daily demand for blood without incurring excessive outdating. The factors that affect the quantities to be maintained in inventory are as follows:

- ***Demand.*** The number of blood units (1 unit = 1 pint) of any one type that is required by the various hospital blood banks.
- ***Shortage.*** An occurrence when the demand exceeds the number of units of blood in inventory.
- ***Shortage rate.*** The long-term fraction (or percentage) of days on which a shortage occurs, that is, shortage rate = number of days a shortage occurs ÷ total number of days.
- ***Outdate.*** A blood unit discarded because of exceeding its shelf life (e.g., 35 days for whole blood).
- ***Outdate Rate.*** The ratio of mean number of blood units outdated to mean number of

Table 1 Relative Frequency of Blood Type in the U.S. Population

Blood Type	O+	A+	B+	AB+	O–	A–	B–	AB–	Total
	38%	34%	9%	4%	7%	6%	1.5%	0.5%	100%

Figure 2
Generalized Relationship Between Outdating and Shortage



blood units collected, that is outdate rate = mean number of units outdated ÷ mean number of units collected.

When the shortage rate is decreased, the outdate rate is increased, and vice versa. The relationship between shortage and outdating is shown in Figure 2. The optimal inventory level for a specific blood product is found as a compromise between the shortage rate and the outdate rate. Shortage cost per unit equals the cost of acquiring one unit (I) from another source, and outdating cost per unit equals the cost of processing one unit (P). The number of units that can be processed and outdated to cover the acquisition cost of one unit is $I \div P$. For example, the cost of acquiring one platelet unit from another source is $30 and its processing cost is $3. Since the ratio of I to P is 10 to 1, ten platelets could have been processed and outdated for the cost of acquiring just one unit from another source.

Once delivered to a hospital, a unit is stored, under the appropriate conditions, in the hospital's inventory. It is available to satisfy physicians' requests for units to be put on reserve for specific patients. These requests arrive randomly during the course of each day, each for a variable number of units. Upon arrival of a request, the specified number of units is selected from inventory according to a first in, first out (FIFO) selection rule and put on reserve. The units demanded but not used are returned to inventory the next day.

A hospital is concerned with maintaining a sufficient blood inventory to meet the variable daily demand without outdating a large fraction of the perishable blood. In trying to reach a working compromise between the anticipated outdate rate and shortage rate, most hospitals exercise some judgment of their own in determining the quantities to order from the ARC. As a result, the ideal blood distribution system is one in which a hospital requests accuracy quantity of blood and the ARC tries to fulfill the request as it occurs. This system results in a high degree of uncertainty in the availability of blood, and in inefficiencies in utilizing blood resources, personnel, and facilities. To remedy this situation, alternative methods are employed, including the centralized management of blood, especially of the rare types, rather than management by individual hospitals; prescheduled deliveries; and a distribution system in which blood is "rotated" among the hospitals.

The timely availability and careful preservation of blood are crucial to human life. Due to blood's perishable nature, blood bank administrators find blood inventory management a pressing problem. Shortages of blood often force blood banks to adopt emergency procurement procedures that result in high costs. Additional cost resulting from the adverse effects of shortages on patients is difficult to measure. Outdated blood causes blood centers to incur losses due to costs involved in procuring, processing, and storing blood.

BLOOD SOURCING: WHOLE BLOOD AND WHOLE BLOOD COMPONENTS

Whole blood is the blood drawn directly from a donor. This blood may be separated into various components: red blood cells, plasma, platelets, cryo, and so on. Unseparated whole blood is used directly for transfusion only in pediatric cases. In fact, less than 1 percent of total transfusions use whole blood.

Red blood cells are prepared by centrifugal or gravitational separation of the red cells from the plasma. Red blood cells are used for patients with a symptomatic deficit of oxygen-carrying capacity. They are also used for exchange transfusion and for helping to restore blood volume following significant hemorrhage.

Plasma is the liquid part of the blood. It consists of the anticoagulated, clear portion of blood that is separated by centrifugation or sedimentation no later than five days after the expiration date of the whole blood. It is used for patients with coagulation factors deficiency (deficiency in proteins that help in blood clotting). Plasma is stored frozen, while liquid plasma is refrigerated. *Fresh frozen plasma* is the plasma that is separated and frozen within eight hours after collection of whole blood. It contains plasma proteins including all coagulation factors.

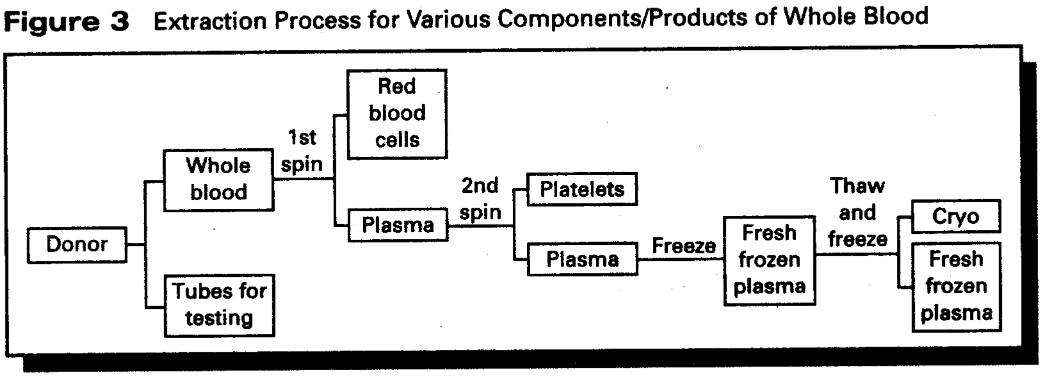
Platelets occur on a concentrate separated from a single unit of whole blood and suspended in a small amount of the original plasma. These platelets are also known as *random platelets*. They are used for patients with bleeding problems and for patients requiring platelet transfusion, for example, certain cancer patients. Another type of platelets, called *pheresis platelets*, are also used.

Cryoprecipitate (or *cryo*) is prepared by thawing fresh frozen plasma between 1°C and 6°C and recovering the precipitate. The insoluble precipitate is refrozen. It is used for treatment of hemophilia and in the control of bleeding.

The above whole blood components are routinely extracted from the whole blood through appropriate procedures, which involve centrifuging, or spinning, the blood. The process used to extract various components/products from whole blood is shown in Figure 3.

The first spin should be completed within eight hours and the second within ten hours after drawing the blood. All of these components are perishable, with their lifetimes varying from five days (platelets) to one year (plasma and cryo). The lifetimes of the various components of blood are given in Table 2.

Figure 3 Extraction Process for Various Components/Products of Whole Blood



Product	Lifetime
Random platelets	5 days
Pheresis platelets	5 days
Whole blood	35 days
Red cells	42 days
Cryo	1 year
Fresh frozen plasma	1 year

Table 2 Lifetimes of Various Blood Products

Pheresis platelets have a lifetime of five days and serve the same purpose as random platelets. In fact, they are a better product than random platelets. Transfusion of one unit of pheresis platelets is equivalent to transfusing six units of random platelets. As a result, pheresis platelets required for a transfusion come from the same donor, and, thus, are safer to use. On the downside, pheresis platelets are more expensive to produce. From the prices of the various blood components in Table 3, one unit of pheresis platelets is priced at $408, while its equivalent of six units of random platelets is priced at $360. Because of this trade-off between cost of production and safety of use, pheresis platelets compete with random platelets. Deciding inventory levels for these two competing products, each with a short lifetime of five days, is a critical problem faced by the regional blood banks.

Product	Price
Random platelets	$60/unit
Pheresis platelets	408
Whole blood	169

Table 3 Prices of Various Blood Products

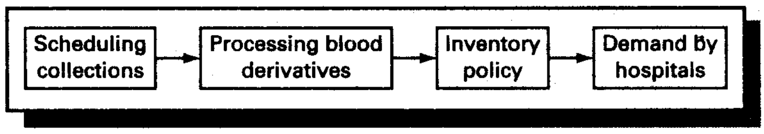
A SUPPLY-DRIVEN INVENTORY SYSTEM

Collecting blood for the region is one of the regional center's most important functions. It is done by (1) scheduled visits to organizations where donors have already signed up to give blood; (2) walk-in donors at the center's donor facilities; and (3) invited donors (or donor groups) who respond to emergency calls for blood. Out of these sources, the biggest portion of the center's supply comes from scheduled visits to schools, factories, churches, and the like. Collection sites are selected from a few months to up to a year in advance of a visit. Final scheduling must be done at least three to four weeks in advance. These long lead times and the resulting uncertainty make it difficult to collect the appropriate amount of blood needed at the time of collection. Since donors are volunteers and are not turned away, blood is collected from all qualified donors who arrive at a site. The number of collection sites is not easily changed with demand requirements since they too are volunteer in nature. In addition, the number of sites available and the quantities collected vary throughout the year. Often, demand for blood is at its highest, for example, in summer, a period with high accident rates, when the fewest sites are available (schools are in recess and factories are closed for vacation). The result can be substantial mismatches between supply and demand with little opportunity to adjust supply. Collection schedules are not easily adjusted to reduce supply; and when demand exceeds supply, emergency calls are made to donors to increase supply. Both are undesirable.

The various elements that affect the overall planning of this supply-driven inventory system are shown in Figure 4. All stages must be synchronized so that costs are controlled, and the need for blood is met.

An important aspect of uncertainty in the collection process comes from the fact that the center schedules collections from donors whose blood

Figure 4
Overview of the Planning Process



type is known only after the blood unit has been collected and typed. This means that the result of the blood drive, in terms of units collected for each blood type, can only be estimated, even if the exact number of donors is known beforehand. Even this knowledge is generally not possible, since the number of actual donors is usually less than the number of people who originally signed up. Approximately 14 percent of the people who signed up are not allowed to donate blood on that day and are deferred. This may happen because they are anemic, unhealthy, have engaged in risky behavior, have abnormal blood pressure, or have donated blood within the last 56 days.

DEMOGRAPHICS OF BLOOD DONORS

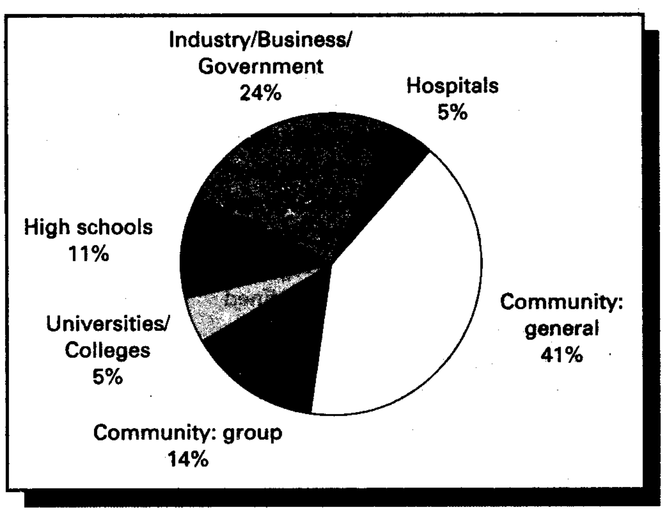
Only about 5 percent of the total U.S. population donates blood every year. Fifteen percent of these blood donors are first-time donors, while the rest are repeat donors. A person must be at least 17 years old to donate; there is no upper age limit. Average age of a blood donor is 35. Fifty-two percent of the blood donors are male. Average number of donations per year per donor is 1.9. About 60 percent of the blood donors sign up to be V.I.P. donors (those who commit to donate blood at least four times a year). The average number of donations per year per V.I.P. donor is 2.9, a number less than four, since not all of the V.I.P. donors keep their commitment.

A majority of the donors belong to a community group. Donors also come from high schools; universities and colleges; and hospitals, industrial, business, and governmental organizations. Figure 5 gives a proportion of the various blood donor groups based on 203,018 units collected by the regional blood center over one year.

A COMPLEX DISTRIBUTION PROBLEM

The complexity of blood distribution is due to blood's perishable nature, the uncertainty in its availability to the regional blood center, and the

Figure 5
Blood Donor Groups



demand variability at each of the hospital blood banks. The situation is further complicated by the large variation in the size of the hospital blood banks supplied, the incidence of the different blood groups, the requirements for whole blood and its various components at individual hospitals, and competition from other blood banks.

Since it is the ARC's policy for blood to be derived from volunteer donors, its availability is uncertain and donation is a function of a number of factors that cannot be controlled by the regional blood center, for example, public perception of the blood industry's quality control and fear of acquiring AIDS. The demand and usage of blood at hospital blood banks is also uncertain and varies from day to day and between hospital facilities. The hospital blood banks within a region may range from those transfusing a few hundred units per year to those transfusing tens of thousands of units per year.

A GENERAL APPROACH TO BLOOD INVENTORY MANAGEMENT

The transfusion services throughout the nation are characterized by diversity. Each regional blood center has independently evolved its own philosophies and techniques for blood distribution. Each region strives for self-sufficiency in supplying the blood needs of the hospitals in its region from regional donors. Because of these factors, it is essential that any strategy devised for inventory management be defensible from the point of view of both the regional blood center and each of the wide range of hospital blood banks that it serves. Furthermore, any strategy that involves interactions between regional blood centers must provide for clearly defined benefits for all participants. In addition, it is desirable that the implemented strategy be characterized by two management concepts: rotation of blood products between hospital blood banks and prescheduled deliveries to the hospital blood banks.

In the case of small usage hospital blood banks (these account for the largest part of the overall blood usage), any strategy that allocates blood products to be retained until transfused or outdated will result in low utilization. Consequently, some form of blood rotation is required, whereby freshly processed blood is sent to hospital blood banks, from which it may be returned some time later for redistribution according to the regional strategy. It is also desirable that a significant portion of the periodic deliveries to the hospital blood banks be prescheduled. This way, the uncertainty of supply faced by the hospital blood banks is reduced, with a resulting improvement in the planning of operations and the utilization of their resources.

Outdating of blood is undesirable and the ARC tries hard to avoid it. The uncertainties in supply and demand can result in too much blood that exceeds its acceptable use date. This usually occurs for specific blood types. That is, type O+ blood may be in short supply while type AB+ has excess inventory and is likely to be outdated. There is some opportunity at the time blood is collected to convert it into derivative products, considering different levels of anticipated product demand and the amount of product inventory on hand. However, outdating still can occur. When it does, there are several options available as the expiration date approaches. First, certain products can be converted into others with a longer shelf life, for example, whole blood may be converted into plasma. Second, the blood products may be sold to other regions of the American Red Cross, especially those having chronic blood supply deficits. Third, some, but not all, products may be sold to research laboratories. Fourth, they may be sold for a reduced price. Selling products outside of the local region generally results in less revenue for the products than if they were used to meet local demand.

Table 4 The ARC's Product Distribution to Its Largest Customers in Number of Units of Red Blood Cells Supplied to the Six Largest Customers Over One Year

Hospitals	Red Blood Cells	Total
A	30,000 units	15.00%
B	14,500	7.25
C	10,000	5.00
D	9,000	4.50
E	8,500	4.25
F	8,000	4.00
Others	120,000	60.00
Total	200,000 units	100.00%

AMERICAN RED CROSS REGIONAL BLOOD CENTER IN CLEVELAND, OHIO

The American Red Cross regional blood center in Cleveland supplies blood components to over 60 hospitals in the northern Ohio region. It supplies over 200,000 units of red blood cells per year, almost 40 percent of which is consumed by the six largest hospitals (see Table 4). The regional center decides on what the inventory levels at the hospitals should be, based on their past data of demand and usage. There are two options available for any hospital dealing with the ARC.

> *Option 1.* The hospital decides its normal inventory levels based on past usage, and bears the risk of outdating. It is shipped blood daily to refill depleted quantities and rebuild inventories to their normal levels. This option is typically chosen by hospitals transfusing anywhere from a few hundred to a couple of thousand blood units per year.
> *Option 2.* The hospital has a standing order, or a contract for a predetermined number of units of each blood component, to be delivered to it every day. This predetermined number of units is adjusted quarterly, based on the past usage. This option is the one chosen by hospitals transfusing anywhere from a couple of thousand to tens of thousands units of blood per year.

INVENTORY MANAGEMENT AT THE ARC'S REGIONAL BLOOD CENTER IN CLEVELAND, OHIO

Inventory management at the ARC's regional blood center uses a top-down planning approach (see Figure 6), which involves planning collections for the next year down to managing shortages and outdates that occur on a particular day.

Yearly Planning

An estimated usage for the next year is obtained from all the 60 hospitals that the ARC in Cleveland supplies. Then, using the historical data of demand and the estimated usage for the next year, collections are planned for the coming year. This takes into account the donors who

Figure 6 Top-Down Planning Approach to Inventory Management

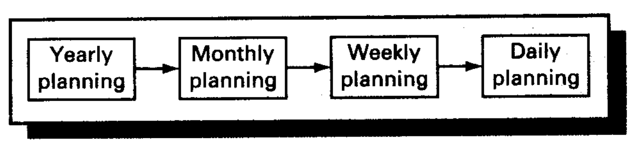
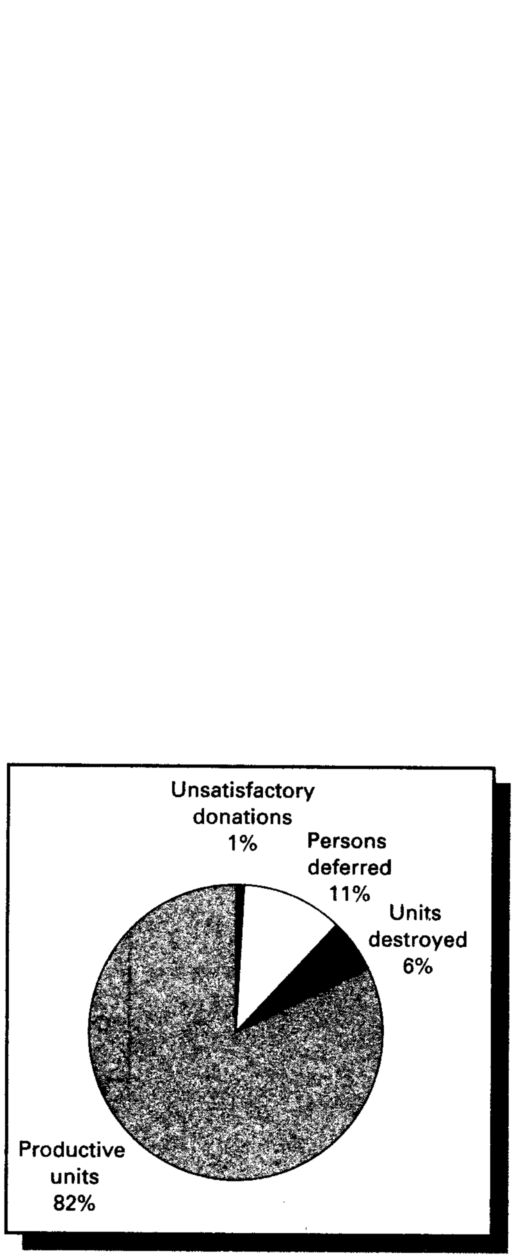


Figure 7
Recruitment and Collections Analysis



might be deferred due to illness or who have recently donated blood, the blood units that might be destroyed during testing, and the donations that might be unsatisfactory because less than one pint is collected. Figure 7, based on 233,352 yearly donors, shows that only 82 percent of the estimated collections result in productive units.

Monthly Planning

Monthly planning involves looking one month ahead and making sure that on every workday (Monday–Friday) in the next month, the estimated collections will exceed a predetermined number of units. This predetermined number of units is obtained by averaging the yearly requirements over the number of workdays in a year. If on a particular day in the coming month, the estimated collections are less than the predetermined number of units, ARC tries to recruit donors for that day. Collections are made on Saturdays and Sundays, but generally not as many units are collected on weekends as during the week.

Weekly Planning

Weekly planning involves looking at the inventory levels of various blood types, planning production of blood components, and planning distribution to the various hospitals for the whole week. A projection of demand is made at the beginning of a week. Then, collections and production are planned based on projected demand in that week.

Daily Planning

Daily planning involves looking at the inventory and taking appropriate action in the case of shortages and products nearing their expiration date. A daily inventory report (see Table 5), which gives the inventory of each blood product by blood type, is generated during every shift. A product inventory report (see Table 6), which gives the inventory of a product by blood type and expiration date, is generated on every shift for platelets and at least once daily for all other products. A shipping report (see Table 7), which gives the number of units of each blood product shipped to the ARC's various customers on the previous day, is generated daily. A production report, which gives the number of units produced by blood type for a particular product, is generated daily.

A FIFO issuing policy is followed for all products, unless superseded by a standing order, which has to be fulfilled by relatively fresh units (with at least three days of remaining shelf life for platelets and 21 days for red cells).

Product	O+	A+	B+	AB+	O–	A–	B–	AB–	Total
Red cells	472	1,349	99	539	142	91	83	105	2,880
Random platelets	77	67	16	17	13	14	2	9	215
Plasma	185	398	246	217	46	85	45	50	1,272
Pheresis platelets	4	7	5	0	1	3	0	0	20
Cryo	478	346	106	22	119	72	25	11	1,179

Table 5 Example of a Daily Inventory Report of Each Product by Blood Type (in Units)

An inventory, equal to at least three times the average daily demand, is maintained for each product and blood type. If the inventory falls below three times the average daily demand, a shortage is said to have occurred. Furthermore, if the inventory falls below the average daily demand, it is called an emergency, or a critical shortage. This may require emergency procedures for donor recruitment.

Products having excess inventory or nearing their expiration dates are sometimes reduced in price. This may be a $20 discount on red blood cells of blood type A+ to reduce excess inventory, or there may be a 50 percent

Table 6 Example of an Inventory Report of Products by Blood Type and Expiration Date (in Units)

Product	Expiration Date	O+	O–	A+	A–	B+	B–	AB+	AB–	Total
Random platelets	02/15	—	—	4	—	2	—	—	—	6
Random platelets	02/16	48	7	5	3	35	11	4	2	115
Pheresis platelets	02/17	—	—	—	—	—	2	—	—	2
Random platelets	02/18	6	1	4	—	6	3	2	1	23
Random platelets	02/19	84	16	65	19	34	5	11	1	235
Pheresis platelets	02/19	3	1	3	3	2	—	—	—	12

Table 7 An Example Report on the Number of Daily Units of Each Blood Product Shipped to the ARC's Various Customers

Time Ordered	Time Shipped	Customer Number	Red Cells/ Whole Blood	Random Platelets	Pheresis Platelets	Frozen Plasma	Cryo
12:28 A.M.	01:06 a.m.	19	0	12	0	0	0
01:33 A.M.	02:24 a.m.	31	57	0	0	0	0
02:16 A.M.	03:12 a.m.	31	1	0	0	0	0
01:38 A.M.	03:28 a.m.	5	94	0	0	0	0
02:19 A.M.	04:19 a.m.	5	1	0	0	0	0
01:32 A.M.	05:48 a.m.	20	25	0	0	0	0
07:06 A.M.	08:06 a.m.	6	12	0	0	0	0

	Red Blood Cells	Frozen Plasma	Cryo	Random Platelets	Pheresis Platelets
Total number of orders received	704	236	175	325	266
Number of orders filled at 100%	651	233	175	306	252
Percent filled at 100%	92.47	98.73	100.00	94.15	94.74

Table 8 Fill Rate As Determined by the Number of Orders Filled at 100% As Compared to the Total Number of Orders Received for Each Product Category in March

discount on platelets ready to expire. Shipping on consignment may also be initiated.

ASSESSING CUSTOMER SERVICE AT THE AMERICAN RED CROSS

The way customer service levels are assessed at the ARC's regional blood centers is by computation of a customer fill rate. This is done in two ways:

1. Fill rate is given by the ratio of the number of orders filled at 100 percent to the total number of orders received for each product category over a given month. It is computed for each of the five product categories (see Table 8).

2. Fill rate is given by the ratio of the number of units shipped to the number of units requested by the customer. Red blood cells constitute the only product for which the fill rate is computed by blood type, or ABO/Rh (i.e., for each of the eight blood types). For the other four product categories, the breakdown of the fill rate by the blood type, or ABO/Rh, is not done (see Table 9).

The regional blood center develops standards for fill rates by customer category, by product category, and by blood type (or ABO/Rh for red blood cells). This percentage may vary for different customers (depending on the negotiated standard for fill rates included in the customer's contract with the region), by

Table 9 Fill Rate As Determined by the Number of Units Shipped As Compared to the Number of Units Requested for Each Product Category in March

Red Blood Cells	O+	A+	B+	AB+	O–	A–	B–	AB–	Total
Units requested	2673	2988	2058	0	2425	270	247	56	10717
Units shipped	2461	2752	1864	0	1801	234	202	46	9360
Fill rate, %	92.07	92.10	90.57	—	74.27	86.67	81.78	82.14	87.34
Regional standard for fill rate, %	90	100	95	100	75	85	80	85	88.75
Percent difference	2.07	–7.90	–4.43	—	–0.73	1.67	1.78	–2.86	–1.41

	Frozen Plasma	Cryo	Random Platelets	Pheresis Platelets
Units requested	345	325	285	517
Units shipped	326	325	267	495
Fill rate, %	94.49	100.00	93.68	95.74
Regional standard for fill rate, %	100	100	95	98
Percent difference	–5.51	0.00	–1.32	–2.26

product, and by ABO/Rh. The difference between the negotiated or contract standard at the regional blood center and the regional blood center's actual performance is then computed. Monitoring fill rates provides valuable information to the regional blood center in its continuous effort to improve customer service.

COMPETITION

The American Red Cross guarantees an average fill rate of 97 percent to its customers, operating according to its stated mission. The smaller local blood banks are not capable of competing with the ARC on its high fill rate. However, since the local blood banks have lower fixed costs and provide no service level guarantee to their customers, they compete with the ARC on price. The ARC needs to collect the quantity and mix of blood products demanded by the hospitals (because of its high customer service level guarantee), while the local blood banks collect what they can. Very often, the hospitals shop arounded for the lowest price, and they might take their business, or a part of it, to the local blood banks that offer prices lower than the ARC.

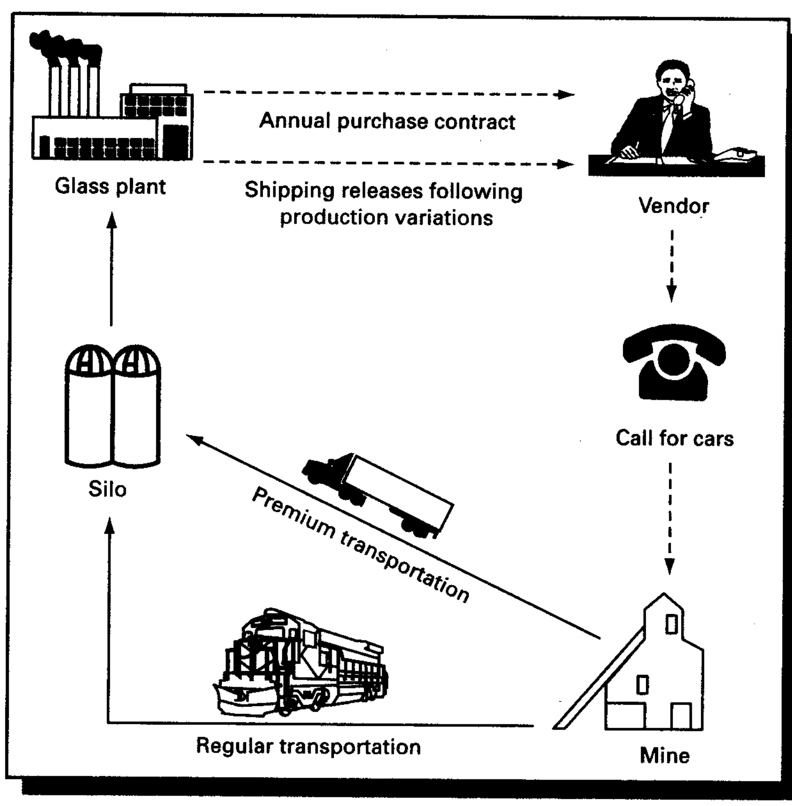
CONCLUSION

Dr. Croxton realized that she needed to do some major reflanking of her planning strategy. The amount of blood outdating that took place in March disturbed her. Volunteers donated blood with good intentions, but a good part of the blood became outdated. In April, when she tried to reduce outdating, extreme shortages occurred, resulting in lost revenue and lost goodwill. She could not forget that this was a business with a bottom line and that she must cover costs, or was it gradually becoming like any other business where the objective is making profits? More than ever before, competition existed in blood services. What was the best way to manage the blood supply? How should prices be set in the face of competition? She knew that the answers to some of the above questions were not easy and she had to do a lot of thinking. ■

QUESTIONS

1. Describe the inventory management problem facing blood services at the American Red Cross.
2. Evaluate the current inventory management practices in light of the ARC's mission.
3. Can you suggest any changes in ARC's inventory planning and control practices that might lead to cost reduction or service improvement?
4. Is pricing policy an appropriate mechanism to control inventory levels? If so, how should price be determined?

Figure 10-1
The Materials Cycle for a Glassware Manufacturer



schedule were avoided by using premium transportation with its associated higher-than-rail cost. Due to a perceived shortage of rail hopper cars in the country's rail system, management was willing to invest in its own railcars and place them in dedicated service.[2] The question that management posed was: How many rail cars are needed to minimize the cost of premium transportation?

The question presumes that railcar capacity was the answer to the marked increase in premium transportation costs. To a degree, it was. However, careful investigation showed that production schedulers at the plants were not allowing the 14 days between the time the material was to be shipped by a vendor and when it was needed in production. In fact, only about five days were being allowed, which was inadequate for shipping soda ash from Wyoming to plants in the East. Production schedulers appeared to be reacting to production requirements rather than adequately anticipating them. Adding to silo capacity so additional inventory could be stored was not practical because of the high investment cost. Therefore, with no change in scheduling procedures, an investment in 82 railcars could be justified. If good requirements planning techniques were used to guide shipment

[2]These cars were to be company owned, but the railroad would move them at a discount from its regular rate.

releases, only 40 railcars would be needed. Putting discipline in the shipment release methodology would reduce by 42 the number of railcars needed, thus reducing by one-half the potential investment.

The lesson of the Anchor Hocking case study is that poor production scheduling procedures can cause unnecessary transportation equipment investment. The transportation manager was trying to solve the problem entirely by acquiring more transportation capacity. Coordination among all the activities that affect physical supply was needed to realize a good solution to the problem.

Supply Scheduling

The popularity of just-in-time, quick response, and time compression concepts highlights scheduling as an important activity in supply channels. Scheduling to requirements is an alternative to meeting requirements from inventories. Each represents the end points in a range of alternatives considered for meeting the demand, or requirements, of a supply channel. Chapter 9 was devoted to inventory management concepts, so we now turn our attention to the scheduling techniques referred to as requirements planning, which may minimize the inventory needed in a supply channel.

In the supply channel, it is the production requirements (or in the case of service firms, the operations requirements) that represent the demand to be met. A materials manager typically meets this demand in two ways. First, supplies are timed to be available just when they are needed for production. A popular technique for handling the mechanics of the scheduling process is materials-requirements planning. Second, requirements are met from supplies carried in inventory. The inventory replenishment rules maintain the stock levels. These rules specify when and in what quantities the materials will flow within the supply channel.

Many firms use both of these approaches simultaneously. To illustrate, consider how a manufacturer of industrial motors controlled its production output.

Example

The Power Equipment Division of the Lear Siegler Corporation produced a line of fractional horsepower motors for use in floor cleaners and polishers. These motors were sold as subcomponents to other manufacturers who produced the finished product. Because of this, the motors were custom-made to the buyers' specifications. Buyers typically placed firm orders several months in advance of their needs to ensure meeting their production schedules. Standard motors can be forecasted with reasonable accuracy and then produced to anticipated sales.

With this information, a build schedule (also called a master production schedule) was prepared for the coming three months. This build schedule, along with a materials list for each motor order, showed the production scheduler how much of each component was needed and when it was required. At this point, the production scheduler checked the available inventory for the necessary supplies. Normally, about 3,000 out of 3,300 parts, or about 90 percent, were made available through inventories. The remaining 300 parts were critical items of high value and were specific to each order, such as the motor shaft. These items were placed on a vendor shortage list until they were actually received and available to production. The same was true of any materials that were unavailable in inventory.

Offsetting by the length of the lead time, the production scheduler issued a purchase release order to the purchasing department so that the supplies were timed to arrive as needed for production. When all materials, parts, and supplies were on hand, the production scheduler released the customer orders to production for manufacture and assembly. As stocks were depleted from inventories, they were replenished according to a min-max inventory control policy.

The role of purchasing was to select the sources of supply, develop ordering procedures, negotiate price and terms of sale, specify the transportation services to be used, and estimate lead times. In this case, purchasing coordinates with production scheduling the flow of materials in the supply channel. The relationship of production scheduling to material supply is diagrammed in Figure 10-2.

In 2004, Mahindra & Mahindra, Hero Honda, and Marico Industries completed the deployment of their supplier relationship management (SRM) solutions that enable automated demand generation and supply scheduling. The highlights of these systems include automated order management, advance shipping notifications, reduced pipeline inventories, and, consequently, more working capital.[3]

Just-In-Time Supply Scheduling

Just-in-time (JIT) scheduling is an operating philosophy that is an alternative to the use of inventories for meeting the goal of having the right goods at the right place at the right time. It is a way of managing the materials supply channel that was first made popular by the Japanese, perhaps because of particular economic and logistical circumstances that have prevailed in that country in the last 40 years. Just-in-time scheduling may be defined as

> a *philosophy* of scheduling where the entire supply channel is synchronized to respond to the requirements of operations or customers.

It is characterized by

- Close relationships with a few suppliers and transport carriers
- Information that is shared between buyers and suppliers
- Frequent production/purchase and transport of goods in small quantities with resulting minimal inventory levels

[3]Available at http://www.networkmagazineindia.com/200502/coverstory05.shtml.

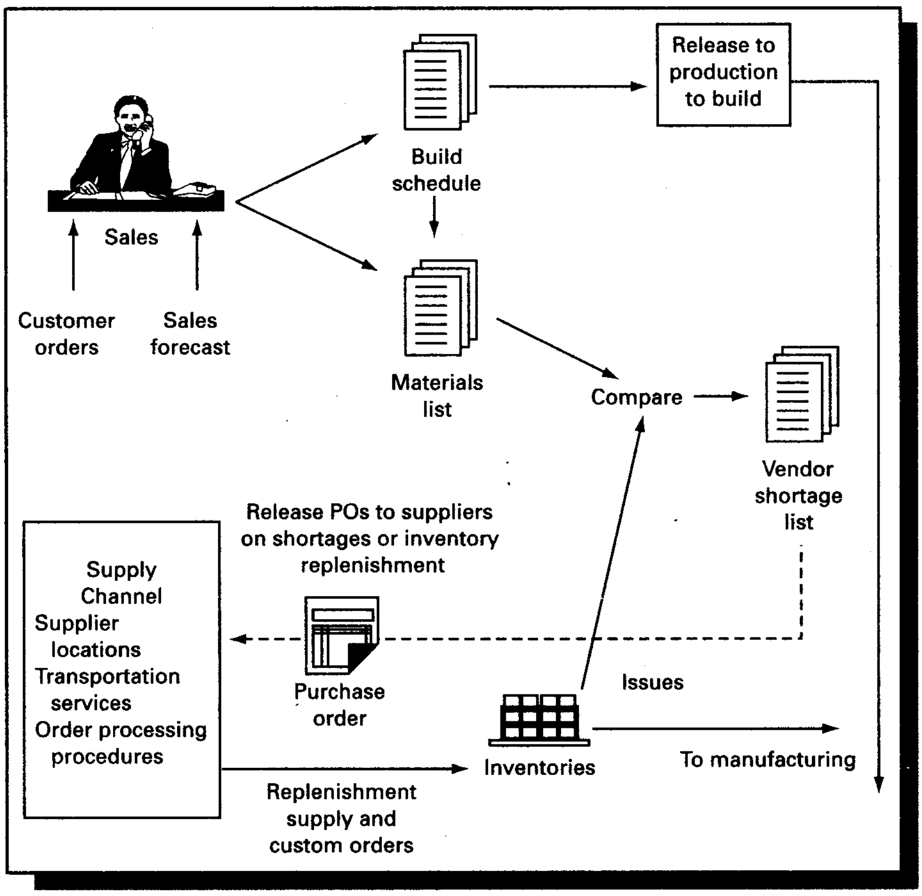


Figure 10-2 Relationship of Production Scheduling to Materials Supply

- Elimination of uncertainties wherever possible throughout the supply channel
- High-quality goals

Economical replenishment quantities are driven toward single units as production setup and purchase-ordering costs are reduced to insignificant levels. Where there are economies of scale in purchasing or production, these economies are exploited to the maximum by using a few suppliers that are usually located in close proximity to the buyer's demand points. A close working relationship is developed with relatively few suppliers and carriers. Information from the buyer, mainly in the form of the production/operating schedule, is shared with the suppliers so that they might anticipate the buyer's needs, thereby reducing response time and its variability. The few selected suppliers are expected to perform with little variance in providing on-time deliveries. The overall effect of scheduling under a just-in-time philosophy is to create product flows that are carefully synchronized to their demands. Although more effort is likely to be expended in managing the supply channel under a JIT philosophy than with a supply-to-inventory philosophy, the benefit is to operate the channel with minimal inventory and with the attendant savings and/or service improvements. However, some of these benefits realized by the manufacturer may be a result of shifting costs and inventory onto the suppliers upstream in the supply channel.

Application

General Motors, a U.S. auto manufacturer, decided to implement a just-in-time supply scheduling system when it planned a major redesign of one of its best-selling cars. A previously used manufacturing plant, too small by today's standards, was reopened after installing doors along the long side of the building. This allowed materials to move a short distance to the production line, but there was little space for production inventories. A staging warehouse was constructed near the assembly building into which materials from suppliers would arrive and be unpacked prior to being moved, on demand, to the assembly line.

A significant reduction (to a few hundred from several thousand) in the number of suppliers and carriers was made, and suppliers could be no farther than 300 miles from the plant. For example, one supplier was selected as the sole provider of paint. However, this status came at a price. The paint supplier was required to maintain an inventory near the assembly plant. To assist in the supplier's planning, the automaker provided the supplier with the future auto production schedule. This established a level of trust between supplier and buyer not generally known in the industry.

Chennai-based Sona Koyo Steering Systems, part of the Sona Group, is witnessing improved productivity with lead-time reduction from sales to purchase and better shop floor management because of the just-in-time (JIT) exercise it began in 2004. The overall productivity improvement is to the tune of 47 percent and the changeover time has come down from 102 minutes to 9 minutes, an improvement of 91 percent. The company has won the "JIT-Kaikaku" award from the JIT Management Laboratory of Japan for the best innovation on the shop-floor leading to improved productivity and better man–machine separation.[4]

Example

Hewlett-Packard applied just-in-time scheduling concepts to its distribution center operations. Over a one-and-a-half-year period, the company was able to achieve a 40 percent reduction in finished goods inventory, a 2 percent per month compounded growth in labor productivity, and a 44 percent improvement in the quality of customer shipments.[5]

[4] *The Economic Times* (July 14, 2006), p. 4.
[5] Patrick Guerra, "Just-In-Time Distribution," *Annual Proceedings*, Vol. 1 (St. Louis: Council of Logistics Management, October 27–30, 1985), p. 444.

Kanban

KANBAN is Toyota's production scheduling system and is perhaps the best-known example of just-in-time scheduling. KANBAN itself is a card-based production control system. A KAN card instructs a work center or supplier to produce a standard quantity of an item. The BAN card requests a predefined standard quantity of a component part or subassembly be brought to a work center. These cards are used as triggers for the production and movement of items.

The KANBAN/JIT scheduling system uses the reorder point method of inventory control to determine standard production-purchase quantities and involves very low setup costs and very short lead times. Several additional characteristics make it effective as a just-in-time system. First, models in the master production schedule are repeated frequently and compared with a schedule built to take advantage of economies of scale. That is, a schedule of product models A and B that would exploit economies of scale and reduce setup costs might be

AAAAAAABBBBBBBAAAAAAABBBBBBBAAAAAAABBBBBBB

However, the KANBAN schedule might look like this:

ABABABABABABABABABABABABABABABABABABABABAB

Second, lead times are highly predictable because they are short. Suppliers are located near the site of operations and deliveries can be made frequently, often once an hour, without incurring great transportation expense.

Third, order quantities are small because setup and procurement costs are kept low. Since order quantities are related to setup or procurement costs, they become the target for cost reduction. Small order quantities mean low inventories. The classic reorder point method of inventory control is used to set the replenishment quantities.

Fourth, few vendors are used, with correspondingly high expectations of them. A high level of cooperation between the manufacturer and vendor is developed to assure that the desired level of product and logistical performance is achieved.

Just-in-time scheduling is in contrast with supply-to-inventory scheduling. Table 10-1 compares KANBAN/JIT to the supply-to-inventory approach for scheduling. Remember, they are alternatives, and one is not necessarily better than the other.

Mahindra & Mahindra (M&M) is into tractor business since 1963. The company has grown to be the second largest tractor manufacturer in the world driven by its farm equipment sector and long-term strategy. M&M is the only tractor manufacturing company to win the popular Deming Application Prize. The company was able to achieve zero rejection levels and higher efficiency per person by initiatives like Kaizen, Kanban, and PokaYoke. Its main facility at Kandivali in Mumbai has separate plants for engines, transmissions, and tractors. DC torquing tools is

Table 10-1 A Comparison of KANBAN/JIT Supply Scheduling and Supply-to-Inventory Scheduling Philosophies

Factors	KANBAN/JIT Scheduling	Supply-to-Inventory Scheduling
Inventory	A liability. Every effort must be expended to do away with it.	An asset. It protects against forecast errors, equipment problems, and late vendor deliveries. More inventory is "safer."
Lot sizes, purchase quantities	Meet immediate needs only. A minimum replenishment quantity is desired for both manufactured and purchased goods, but it is determined from the EOQ formula.	Quantities determined by economies of scale or from the EOQ formula. No attempt is made to change setup costs to realize smaller production or purchase quantities.
Setups	Make them insignificant. This requires either extremely rapid changeover to minimize the impact on operations, or availability of extra machines already set up. Fast change over permits small lot sizes to be practical, and allows a wide variety of parts to be made.	A low priority. Maximize output is the usual goal, so setup costs may be a secondary consideration.
Work-in-process inventory	Eliminate them. When there is little inventory accumulation between processes, the need to identify and fix problems surfaces early.	A necessary investment. Inventory accumulation between processes permits succeeding operations to continue in the event of a problem with the feeding operation. Also, by providing a selection of jobs, the factory management has a greater opportunity to match varying operator skills and machine capabilities, and to combine setups so as to contribute to the operation's efficiency.
Vendors	Considered to be coworkers. The vendor takes care of the needs of the customer, and the customer treats the vendor as an extension of his factory. Few are used, but the risk of supply interruptions may increase.	A professional arm's-length relationship is maintained. Multiple sources are the rule, and it's typical to play them against each other to achieve the lowest prices.
Quality	Zero defects is the goal. If quality is not 100%, production and distribution are in jeopardy.	Tolerate some defects to keep products flowing and to avoid excessive costs to guarantee an exceedingly high level of quality.
Equipment maintenance	Preventive maintenance or excess capacity is essential. Process shutdown jeopardizes downstream operations when no inventory is available to act as a buffer.	As required. Not critical since inventories are maintained.
Lead times	Keep them short. This increases response times throughout the supply/distribution channel, and reduces uncertainties and the need for safety stocks.	Long lead times are not serious since they may be compensated for with additional inventories.

among the error proofing measures adopted by the company. M&M makes specially designed engines of 45 bhp and above for export markets.[6]

Bajaj Auto's (BA) Chakan plant employs 700 workmen and manufactures 1,200–1,300 Pulsar brand motorcycles per day. In Chakan work in progress never exceeds 0.2 days. The inventories are less than half a day's. About 30 percent of BA's vendors at Chakan use the Kanban card and deliver JIT. The ratio of indirect to direct workforce is four percent, lower than at most other plants.[7]

Observation

Since just-in-time systems operate with minimum inventory levels and few suppliers, the risk of immediate channel shutdown from interruptions in the supply chain is great. Toyota was at risk of shutting down 20 of its auto plants when a fire incinerated the main source of its supply of a crucial $5 brake valve. But five days after the fire, the factories started up again. The secret lay in Toyota's close-knit family of parts suppliers. In the corporate equivalent of an Amish barnraising, suppliers and local companies rushed to the rescue. Within hours, they had begun taking blueprints for the valve, improvising tooling systems, and setting up makeshift production lines. Thirty-six suppliers, aided by more than 150 other subcontractors, had nearly 50 separate lines producing small batches of the brake valve. The quick recovery is attributable to the power of the group, which handled the problem without thinking about money or business contracts.[8]

Requirements Planning

In the mid-1970s, requirements planning, which had been carried out for years, was formalized as materials requirements planning (MRP). Although MRP deals with supply scheduling, its logic base is different from that of KANBAN. It is a method primarily used for scheduling high-valued custom-made parts, materials, and supplies whose demand is reasonably well known. The purpose of MRP, from a logistics viewpoint, is to avoid, as much as possible, carrying these items in inventory. Theoretically, inventories do not need to be created when the amount and timing of the end-product requirements are known. Offsetting by the lead time the request for parts, materials, and supplies, the end-product requirements can be met at the time they develop. Precise timing of materials flows to meet production requirements is the principle behind materials requirements planning.

MRP is an important scheduling alternative to the supply-to-inventory scheduling philosophy. Except for the manner in which statistical inventory control procedures are

[6]*Autocar Professional* (July 1, 2005), p. 24.
[7]*Business Today* (September 12, 2004), p. 80.
[8]Valerie Reitman, "Toyota's Fast Rebound After Fire at Supplier Shows Why It Is Tough," *Wall Street Journal*, May 8, 1997, A1.

used in KANBAN, they do not perform as well in the physical supply channel as they do in the physical distribution channel. The reason is that the assumptions on which statistical inventory control is based too often are not met. That is, demand is not regular, random, independent, and unbiased. Rather, demand patterns for parts, materials, and supplies that go into end products are derived from the end-product demand.

Derived demand patterns result from the knowledge that a predetermined number of parts, materials, and supplies, as specified on the bill of materials, goes into an end product. Therefore, the demand patterns for these materials of production are lumpy. If statistical inventory control procedures were used to set inventory levels, these levels would be unacceptably high due to the high variance of the lumpy demand patterns.

This demand lumpiness may also be caused from the application of standard inventory policies at multiple levels in the supply distribution channel. To illustrate, consider Figure 10-3. An end product is stocked in a field warehouse and is controlled using a reorder point inventory control procedure. The result of this policy is to send intermittent replenishment orders to the inventories at the plant. If only a few warehouses are being replenished from the plant stocks, or the orders from multiple warehouses occur simultaneously, a stair-step stock availability pattern results, as shown in Figure 10-3(b). Consequently, the supply inventory for a component that goes into the production of the end product must be even larger to meet the production requirements brought about through the replenishment of the plant end-product inventories [see Figure 10-3(c)]. Because of the intermittent depletions of the component inventory, high inventory levels must be maintained when they are not needed. If the depletion rate of the inventory level can even roughly be anticipated, components may be ordered just ahead of the depletion with a resulting substantial saving in inventory carrying costs.

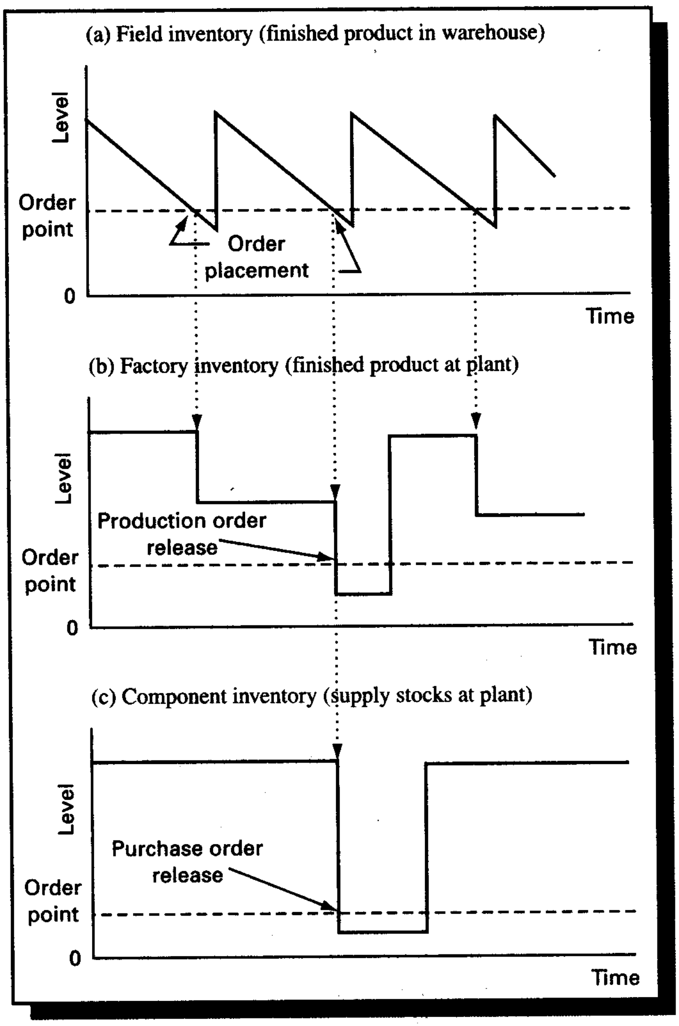
MRP Mechanics

Only recently has the materials requirements planning methodology been formalized and computerized, although the requirements planning concept has been applied for many years. It can be described as

> . . . a formal, mechanical method of supply scheduling whereby the timing of purchases or of production output is synchronized to meet period-by-period operating requirements by offsetting the request for supply from the requirements by the length of the lead time.

MRP has also been referred to as time-phased replenishment planning. Many computer software suppliers (e.g., SAP) now have programs that can readily be installed in a production environment to handle the MRP arithmetic required for thousands of items. To illustrate the basic concepts of the method, consider a simplified example.

Figure 10-3 Lumpy Demand for a Component When the End Product Is Under Reorder Point Control



Example

Colonial Clocks produces and distributes, through catalogs, a line of authentic mechanical clock reproductions. Two clock styles, M21 and K36, use the same clock mechanism, R1063. Because these mechanisms wear out or are damaged in use, there is an independent replacement demand for the clock mechanism of 100 per week. Colonial assembles M21 and K36 in minimum production run quantities, but the clock mechanism is purchased from an outside supplier subject to a minimum purchase quantity. The estimated demand for M21 and K36 for the next eight weeks is itemized next.

Weeks from Now	M21	K36
1	200	100
2	200	150
3	200	120
4	200	150
5	200	100
6	200	90
7	200	110
8	200	120

Other vital information about each item follows:

Clock Style M21

Minimum production run quantity = 600 units
Production run time = 1 week
Inventory on hand = 500 units
Scheduled receipts = 600 units in period 2

Clock Style K36

Minimum production run quantity = 350 units
Production run time = 2 weeks
Inventory on hand = 400 units
Scheduled receipts = 0 units

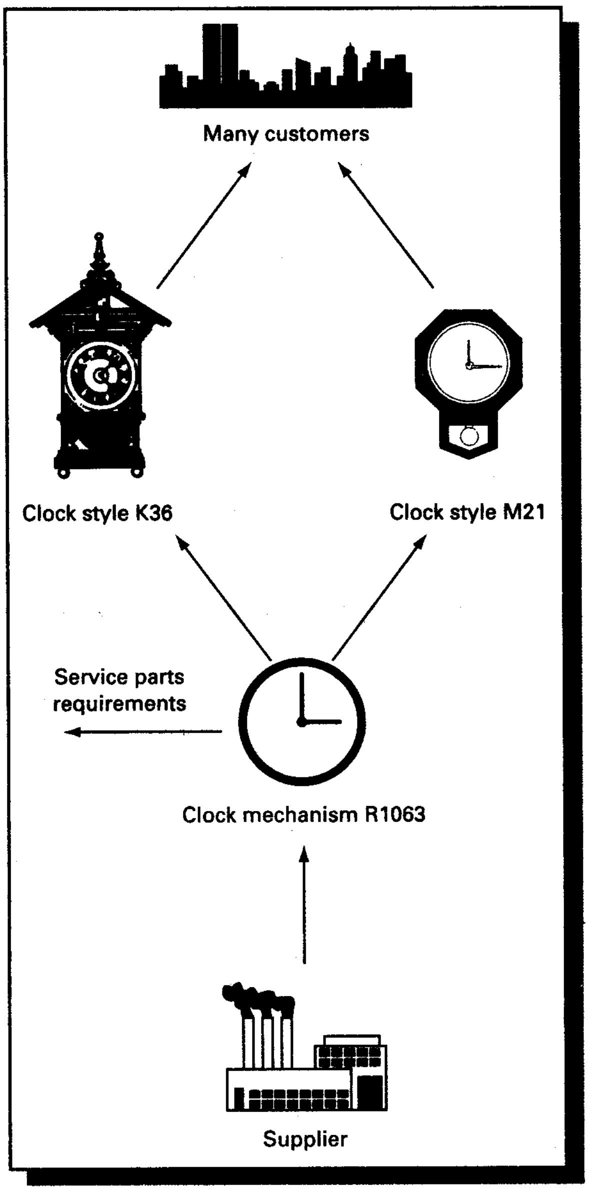
Clock Mechanism R1063

Minimum purchase order quantity = 1,000 units
Purchase lead time = 2 weeks
Safety stock = 200 units to be maintained at all times
Inventory on hand = 900 units
Service parts demand = 100 units per week

The critical question for Colonial is, When and for what quantities should purchase orders be released to suppliers?

The MRP methodology begins with a product structure tree (bill of materials) that defines the quantity relationships between components and end product, as shown in Figure 10-4. Considering only one component (the clock mechanism), its derived demand comes from the production of the two clock models plus service parts requirements. Thus, if it is known when and in what quantities each model will be produced, a schedule for the purchase of the clock mechanisms can be developed. To organize these time-phased events and to keep track of incoming materials, on-hand materials, and the requirements that must be met, a base chart is used, such as

Figure 10-4
Product Structure Tree and Quantity Relationships for Colonial Clocks



that in Figure 10-5(a). The projected requirements for the K36 clock are shown in their respective weekly "time buckets" (intervals of time, such as a week or month). The current on-hand inventory of these clocks is also noted.

To meet these end-product requirements, a product schedule needs to be developed showing when production should begin and when and in what quantities

Figure 10-5 Computations for Determining the Planned Production Releases for Clock Style K36

(a) Initial MRP form

	Week							
	1	2	3	4	5	6	7	8
Projected gross clock requirements	100	150	120	150	100	90	110	120
Scheduled receipts								
Quantity on hand 400								
Planned production releases								

(b) Completed MRP form

	Week							
	1	2	3	4	5	6	7	8
Projected gross clock requirements	100	150	120	150	100	90	110	120
Scheduled receipts				*350*				
Quantity on hand 400	*300*	*150*	*30*	*230*	*130*	*40*	*280*	*160*
Planned production releases		*350*			*350*			

clock mechanisms should be available. To do this, begin with week 1 and deduct the requirements for week 1 from the available inventory on hand. Record the quantity on hand, as shown in Figure 10-5(b). This procedure is repeated for each subsequent week until the projected quantity on hand drops below zero. At this time, a scheduled receipt of finished K36 clocks is needed. Because a two-week lead time is required for production, the clock mechanisms must be available for production two weeks in advance of the scheduled receipt. Production determines the lot size quantity. The scheduled receipt adds to the quantity on hand so that enough stock is available to meet the requirements. Decreasing on-hand quantities continues until week 7, at which time another scheduled receipt must be planned. And so it goes to the end of the planning horizon.

Clock Style K36

Minimum production run quantity = 350 units
Production run time = 2 weeks
Inventory on hand = 400 units
Scheduled receipts = 0 units

Next, the procedure is repeated for clock style M21, as shown in Figure 10-6. The major differences here are that a previously scheduled receipt is due in week 2, and the lead time offset is one week.

With the planned production releases now known for both clock styles, the gross requirements for the clock mechanism can be developed for each week. That is, the releases for K36 and M21 are summed into the corresponding week of the R1063

Figure 10-6 Computations for Determining the Planned Production Releases for Clock Style M21

		Week							
		1	2	3	4	5	6	7	8
Projected gross clock requirements		200	200	200	200	200	200	200	200
Scheduled receipts			*600*				*600*		
Quantity on hand	500	*300*	*700*	*500*	*300*	*100*	*500*	*300*	*100*
Planned production releases						*600*			

gross requirements time buckets. To these are added the demand for service parts. Once the projected gross requirements are established, the computations to determine when and how much should be purchased of the clock mechanisms proceed in the same manner as for K36 and M21. The result is to place a purchase order for 1,000 units in weeks 2 and 3 (Figure 10-7).

Clock Style M21

Minimum production run quantity = 600 units
Production run time = 1 week
Inventory on hand = 500 units
Scheduled receipts = 600 units in period 2

It should now be clear that the flow of materials is controlled through offsetting by the length of the lead time the call for materials from requirements. End-product requirements are assumed to be known for sure, as are lead times. Production-purchase lot sizes are given. Even though certainty is assumed, the effects of uncertainty in the requirements levels and in the lead times are always present. Transport rate breaks may alter the order release quantity. Consider how the MRP approach might be modified to handle these realities.

Demand Uncertainty in MRP

The MRP approach to purchase timing assumes that the requirements in the master schedule are known. To the extent that they may vary throughout the planning horizon, some safety stock protection is needed if the requirements are to be met. If the variability in requirements can be represented by a probability distribution, then the amount of safety stock needed in the schedule can be determined in a way that is similar to inventory control. However, this may be impractical, because the requirements for any product or component are likely to show wide variations due to changes in production schedules, canceled customer orders, and missed forecasts. This will lead to inaccurate estimates of the safety stock levels.

As an alternative, a fixed on-hand inventory level can be maintained that is determined from either practical experience or some other means. Once the minimal on-hand quantity is established, order releases are triggered in the normal MRP

Figure 10-7 Determination of Gross Requirements and Purchase Order Releases for Clock Mechanisms R1063

CLOCK STYLE K36		Week 1	2	3	4	5	6	7	8
Projected gross clock requirements		100	150	120	150	100	90	110	120
Scheduled receipts					*350*			*350*	
Quantity on hand	400	*300*	*150*	*30*	*230*	*130*	*40*	*280*	*160*
Planned production releases			*350*			*350*			

CLOCK STYLE M21		Week 1	2	3	4	5	6	7	8
Projected gross clock requirements		200	200	200	200	200	200	200	200
Scheduled receipts			*600*				*600*		
Quantity on hand	500	*300*	*700*	*500*	*300*	*100*	*500*	*300*	*100*
Planned production releases						*600*			

Minimum purchase order quantity = 1,000 units

Purchase leadtime = 2 weeks

Safety stock = 200 units to be maintained at all times

Inventory on hand = 900 units

Service parts demand = 100 units per week

CLOCK MECHANISM R1063		Week 1	2	3	4	5	6	7	8
Projected gross clock requirements		100 0 0 100	100 350 0 450	100 0 0 100	100 0 0 100	100 350 600 1,050	100 0 0 100	100 0 0 100	100 0 0 100
Scheduled receipts					*1,000*	*1,000*			
Quantity on hand	900	*800*	*350*	*250*	*1,150*	*1,100*	*1,000*	*900*	*800*
Planned production releases			*1,000*	*1,000*					

Service parts requirements

manner, except that the on-hand quantity drops to the minimum quantity rather than to zero. Although this method is approximate, it is probably the best that can be done considering the inherent lumpy nature of derived demand.

Lead Time Uncertainty in MRP

Lead times are not likely to be known for sure. When to release the request for materials depends on the uncertainty in lead time as it affects over- and under-stocking. The optimal time T^* to release the request for materials ahead of requirements is a matter of balancing the expected cost associated with having the materials arrive before they are needed, thereby incurring a holding charge, with the expected cost of having the materials arrive after they are needed, thereby incurring a late-penalty charge. Assuming that requirements during a time bucket are filled at a constant rate and lead times are normally distributed, the expected number of units short of meeting production requirements is $s_{LT}E_{(z)}$, where s_{LT} is the standard deviation of the lead time distribution and $E_{(z)}$ is the normal unit loss integral. The expected number of units arriving too soon is $s_{LT}\, E_{(-z)}$. The total relevant cost then is

$$TC = P_c s_{LT} E_{(z)} + C_c s_{LT} E_{(-z)} \qquad \textbf{(10-1)}$$

where

P_c = cost per unit of having materials *after* they are needed ($ per unit per day)
C_c = cost per unit of having materials *before* they are needed ($ per unit per day)

Using calculus to find the minimum cost yields

$$P = \frac{P_c}{C_c + P_c} \qquad \textbf{(10-2)}$$

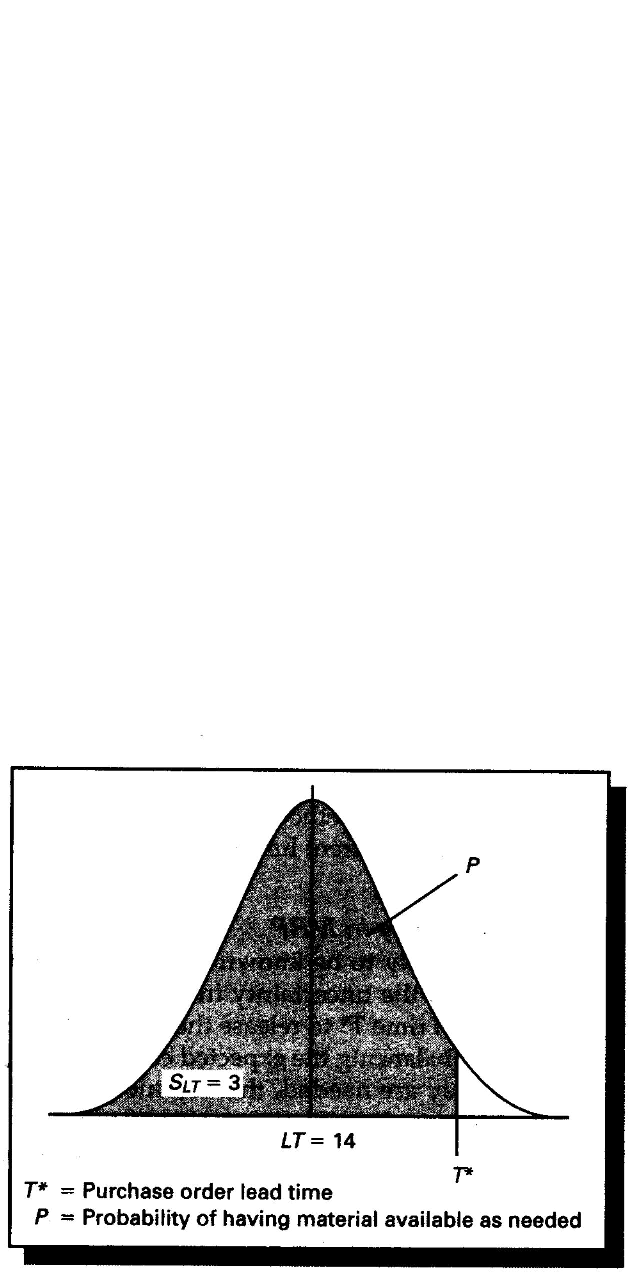
where P is the probability of having clock mechanisms available at the time needed for production. Given P, the number of standard deviations z is found from Appendix A such that the optimum release time T^* is

$$T^* = LT + z(s_{LT}) \qquad \textbf{(10-3)}$$

Example

Suppose that in the Colonial Clocks illustration the average purchase lead time for the clock mechanism is normally distributed with an average of 14 days and a standard deviation of three days. There is a penalty cost for delaying or interrupting production: $500 per unit per day for each clock mechanism that is not available when needed. If the clock mechanisms arrive ahead of schedule, a holding cost of $5 per unit per day is incurred.

Figure 10-8
Lead Time Distribution with Order Release Point T^*



The problem is one of determining how much time should be added to the average purchase lead time to protect against lead time variability. Specifically, we are looking for the optimum purchase order release time T^* on the lead-time distribution, as shown in Figure 10-8. This can be found after first determining P. That is,

$$P = \frac{P_c}{C_c + P_c} = \frac{500}{5 + 500} = 0.99$$

From the area under the normal distribution curve in Appendix A, $z_{@P = 0.99} = 2.33$. Therefore,

$$\begin{aligned} T^* &= LT + z(s_{LT}) \\ &= 14 + 2.33(3) \\ &= 21 \text{ days before production} \end{aligned}$$

Over- and understocking costs will not always be known for sure. In such a case, P may be assigned a value and T^* computed according to Equation (10-3).

Order Release Quantity

Although production-purchase order quantities may be established through order quantity minimums or contractual amounts, they may also be established through balancing ordering costs against the inventory-carrying costs. This process has been referred to as part period cost balancing.

Example

Suppose that no minimum order release quantity has been specified for clock mechanisms, as previously shown in Figure 10-7. These clock mechanisms cost Colonial $15 each and the annual carrying charge is 25 percent, or $0.07 per unit per week. An order-processing cost of $150 is incurred every time an order is placed.

When an order is to be released in week 2 to meet the requirements for week 4, the question is whether the order quantity should be just large enough to meet the requirements for one week or whether the order quantity should be sufficient to cover the requirements for several weeks into the future. This can be determined by testing several obvious options, that is, testing order quantities equal to one week's requirements, two weeks' requirements, and so on. Assume the average inventory for the week is (beginning inventory + ending inventory)/2, where beginning inventory is scheduled receipts + quantity on hand. Ending inventory is beginning inventory – requirements. Starting with R1063 requirements for week 4, the strategies would be to order for week 4 only; weeks 4 and 5; weeks 4, 5, and 6; and so on. Given that a safety stock of 200 units is to be maintained, the order quantities to meet periods 4, 5, and 6 would be 50; 50 + 1050 = 1100; and 50 + 1050 + 100 = 1200, respectively.

When the carrying costs equal the ordering costs, the optimum order quantity is found. Find the inventory carrying cost for each strategy.

(Q = 50) Week 4	0.07(300 + 200)/2 = $17.50
(Q = 1,100) Weeks 4 & 5	0.07[(1,350 + 1,250)/2 + (1,250 + 200)/2] = **$141.75**
(Q = 1,200) Weeks 4, 5 & 6	0.07[1,450 + 1,350)/2 + (1,350 + 300)/2 + (300 + 200)/2] = $173.25

Because the carrying costs associated with an order release quantity of 1,100 is closest to the ordering cost of $150, this is the best strategy. If price discounts or transportation rate breaks were also present in this problem, even larger release quantities might be justified, as the additional carrying costs can be offset by these cost reductions.

Just-In-Time Distribution Scheduling

The concepts embodied in just-in-time supply scheduling can also be applied to the physical distribution channel. Compressing the time between when customer orders are placed and when they are received can be a competitive advantage. This quick response is based on many of the same ideas behind just-in-time scheduling. That is, use information to reduce uncertainties and substitute for assets, namely inventories. Use electronic information transmission to reduce the order-cycle time. Use computer technology to speed the production and/or filling of customer orders. Careful application of these concepts to the distribution channel can improve customer service and lower costs.

Integrated Supply Channel Management

From an operating viewpoint, the methods of MRP can be used in the distribution channel, called distribution-requirements planning (DRP), to allow integrated supply scheduling throughout a company's entire logistics channel, from suppliers to customers. Consider the supply channel as generalized in Figure 10-9. It is not rare to see physical distribution scheduling managed separately from production or supply scheduling. Pull methods of inventory management[9] in field warehouses are popularly taught as ways to manage inventory levels and to recommend to production when and in what quantities to produce. Applying the just-in-time concept expressed as DRP to the physical distribution channel offers an alternative with several benefits to the more traditional pull methods. These benefits are

- A similar information base is created for the entire production/logistics channel. This encourages integrated planning throughout the channel.
- The DRP concepts are compatible with those of MRP used at the plant.
- Since DRP shows planned future shipments, decision making is assisted in such areas as transport capacity planning, vehicle dispatching, and warehouse order filling. Increased flexibility and an improved ability to react to change are also noted.
- When developing a schedule, all demand sources can be incorporated, not just the forecast.
- Whereas ROP/EOQ systems generally manage individual items from independent multiple warehouses, DRP allows them to be managed collectively.

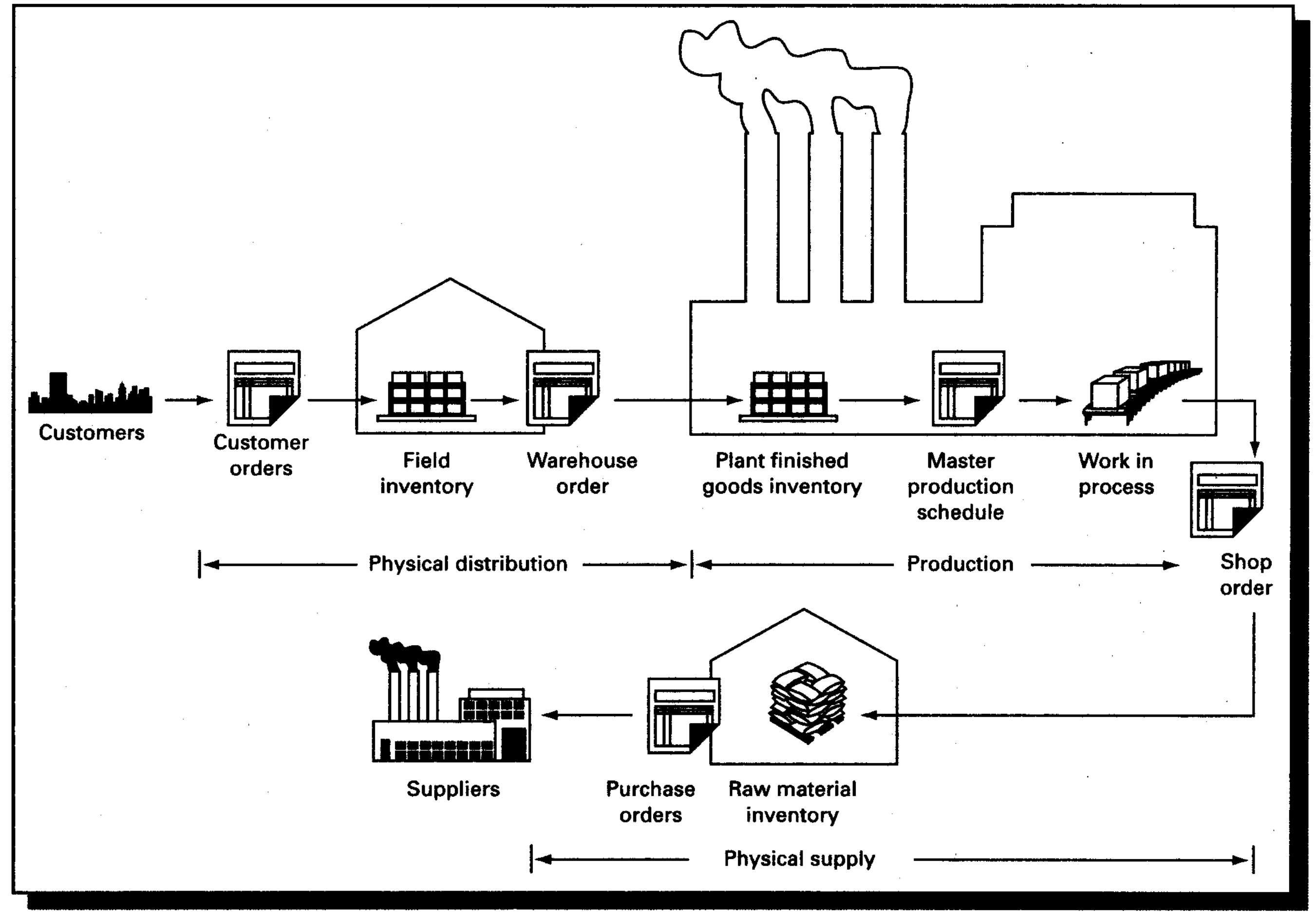
Companies are reporting that significant improvements have been realized when DRP is installed in their operations. Collins and Whybark offer several examples.[10]

Examples

- Abbott Laboratories, Canada, produced products in three plants and distributed them throughout Canada through distribution centers. Its DRP installation improved customer service levels from 85 to 97 percent while reducing inventories by 25 percent. The total distribution costs dropped by 15 percent. In addition, product obsolescence was reduced by 80 percent.
- A Midwest supplier of service parts for farm equipment, Hesston, served 1,200 dealers through eight distribution centers. The benefits of DRP were described both in qualitative and quantitative terms. In addition to a 20 percent cost reduction and an improvement of service levels to 97.5 percent, it noted an improvement in flexibility and ability to react to change. Planning for future requirements improved, and it reported improved productivity from its distribution analysis.

[9]See the discussion of the reorder point and periodic review methods of inventory control in Chapter 9.
[10]Robert S. Collins and D. Clay Whybark, "Realizing the Potential of Distribution Requirements Planning," *Journal of Business Logistics*, Vol. 6, No. 1 (1985), pp. 53–65.

Figure 10-9 A Generalized Supply Chain Order Information Flow from Suppliers to Customers



- Howard Johnson used DRP in distributing its ice cream on the East Coast. It reported a 12 percent improvement in service levels, and a reduction in inventories of 25 percent. The total distribution costs dropped by 10 percent. Improved control over inventories enabled it to realize an 80 percent reduction in obsolescence (freshness control) as well.
- Nicholas Piramal India Limited (NPIL), one of India's leading pharmaceutical companies used vanilla version of MFG/PRO DRP, wherein the requirements generated were collated and made into truckloads taking availability constraints into account. As a result, transportation costs were reduced by 45 percent. Simultaneously, finished goods (FG) inventories reduced by 50 percent, material inventories reduced by 20 percent, and stock-outs at confirmatory factor analyses (CFAs) reduced by 50 percent.

DRP Mechanics

DRP is an extension of the MRP logic that has already been described. Attention here will be drawn to the differences between the two. First, DRP begins with an item demand forecast as close to that of the customer as possible, which we will assume is the demand on a field warehouse. This demand is for a number of periods into the future and is developed from the item forecast, future customer orders, planned promotions, and any other information relevant to the demand pattern. This demand becomes the forecast requirements in the DRP—equivalent to the master production schedule in MRP. An example of the basic DRP record is shown in Figure 10-10. Note the similarity with the MRP record given in Figure 10-5(a).

The planned shipments for a single item from more than one warehouse are combined to generate the gross requirements on the central inventory, such as the plant finished-goods inventory. Suppose that plant inventories are used to meet field warehouse planned shipments and that production supplies plant finished-goods inventories. We then implode the planned shipments of an item for all warehouses to generate the gross requirements for the plant inventory. The imploding

Figure 10-10 Example of a Basic DRP Record for a Single Item in a Field Warehouse

		Period							
		1	2	3	4	5	6	7	8
Forecast requirements		100	200	100	150	100	100	200	200
In transit			*300*		*300*			*300*	*300*
Quantity on hand	250	*150*	*250*	*150*	*300*	*200*	*100*	*200*	*300*
Planned shipments		*300*		*300*			*300*	*300*	

Safety stock = 50 units
Lead time = 1 period
Shipping quantity = 300 units

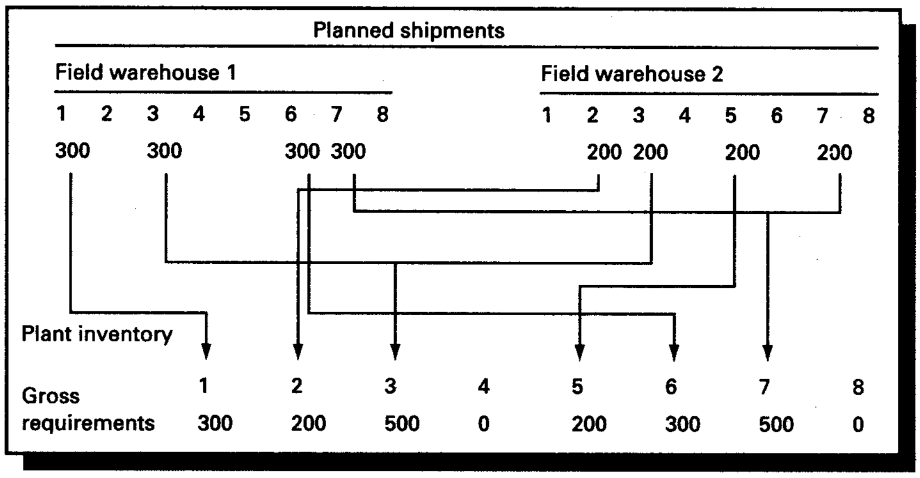


Figure 10-11 Imploding Warehouse Planned Shipments to Generate the Requirements on Central Inventory

process is shown in Figure 10-11. Once the gross requirements are known for central inventory, a requirements planning record is developed to determine the planned order releases at the plant inventory level. These planned order releases are used to generate the master production schedule. The requirements planning process can continue upstream in the supply channel until the suppliers are reached, allowing full-channel scheduling.

PURCHASING

Purchasing involves buying the raw materials, supplies, and components for the organization. The activities associated with it include the following:

- Selecting and qualifying suppliers
- Rating supplier performance
- Negotiating contracts
- Comparing price, quality, and service
- Sourcing goods and services
- Timing purchases
- Setting terms of sale
- Evaluating the value received
- Measuring inbound quality, if this is not a responsibility of quality control
- Predicting price, service, and sometimes demand changes
- Specifying the form in which goods are to be received

Buying indirectly affects the flow of goods in the physical supply channel, although not all buying activities are of direct concern to the logistician. Decisions relating to the selection of vendor shipping points, the determination of purchasing quantities, the timing of supply flows, and the selection of the product form and

This modest price reduction can achieve a 50 percent increase in profits. This is due to the leverage effect. On the other hand, the price reduction lowers the asset base by valuing inventory at 95 percent of its previous value. This increases the velocity of asset turnover to 2.04 from the previous 2.00. The return on assets increases to 15.3 percent from its previous 10 percent, a 53 percent increase.

When companies such as GE, General Motors, and United Airlines undertake cost-saving initiatives, it is common for them to seek price cuts from their suppliers. Recognizing that purchased materials average more than 50 percent of their expenses, suppliers are the obvious focus of cost reductions. Some of the strategies used can be summarized in the following four points.

- *Renegotiate contracts.* Send suppliers letters demanding price cuts of 5 percent or more; rebid the contracts of those who refuse to cut costs.
- *Offer help.* Dispatch teams of experts to suppliers' plants to help reorganize and suggest other productivity-boosting changes; work with suppliers to make parts simpler and cheaper to produce.
- *Keep the pressure on.* To make sure improvements keep coming, set annual, across-the-board cost-reduction targets, often of 5 percent or more a year.
- *Pare down suppliers.* Slash the overall number of suppliers, sometimes by up to 80 percent, and boost purchases from those that remain to improve economies of scale.[11]

It is clear that these companies understand the leverage principle and the return-on-assets effect.

Internet auctioning is another way that firms seek to lower prices for their purchased goods and services. An inherent advantage of the Internet is that many suppliers can be brought together in the purchasing process conveniently and inexpensively. Lower prices are achieved because the marketplace is expanded with more potential sellers offering their services and products. In other words, a perfect marketplace is approached where prices are driven to their lowest levels.

Observation

United Technologies needed suppliers to make $24 million worth of circuit boards. FreeMarkets, an online B2B bidding service, evaluated 1,000 potential suppliers and invited 50 especially qualified to bid. FreeMarkets planned for three hours of on-line competitive bidding. FreeMarkets divided the job into 12 lots, each of which was put up for bid. At 8 A.M., the first lot valued at $2.25 million was put up. The first bid was $2.25 million, which was seen by all. Minutes later, another bidder

[11]"Cut Costs or Else: Companies Lay Down the Law to Suppliers," *Business Week*, March 22, 1993, pp. 28–29.

placed a $2 million bid. Further bidders reduced the price again. Minutes before the bid closed on the first lot, at 8:45 A.M., the forty-second bidder placed a $1.1 million bid. When it all ended, the bids for all 12 lots totaled $18 million (about a 35 percent savings to United Technologies).[12]

Similarly, Ballarpur Industries Limited (BILT), India's largest paper company was not sure if it was able to extract best prices for its purchases. It worked out reverse B2B e-auction for select categories of raw materials with the help of 01markets. It led to 20 percent savings, a new set of suppliers, better lead time and quality.[13]

Where the logistician sees opportunity in the purchasing activities to reduce costs substantially is in the timing of material flows, in determining the buying quantities, in the sourcing of materials, and in setting the terms of sale. That is, the key questions are how much to buy and when, where to buy (shipping point), and what should the weight, shape, and size of delivered material be. To some extent, these questions have been dealt with in previous chapters. The methods for answering these will be supplemented here.

Order Quantities and Timing

The purchase quantities and their timing affect prices paid, transportation costs, and inventory-carrying costs. One strategy is to buy only to meet requirements as they occur. This is the just-in-time strategy, also referred to as hand-to-mouth buying. Alternately, some form of forward, or anticipatory, buying may be used. This can be advantageous when prices are expected to be higher in the future. In addition, speculative buying may be engaged in, where buyers attempt to hedge on future price increases. The materials, often commodities such as copper, silver, and gold, may be resold at a profit. Speculative buying differs from forward buying to the extent that purchase quantities may exceed any reasonable amount dictated by future requirements.

Purchase quantities may also be affected by the special price reductions that sellers offer from time to time. Buyers may wish to "stock up" at a good price. On the other hand, buyers may wish to negotiate for a good price, but not actually take delivery of the goods until they are needed, thus avoiding an inventory buildup.

A Mixed Buying Strategy

When a commodity has a reasonably predictable seasonable price pattern, engaging in a mixed strategy of hand-to-mouth and forward buying can result in a lower

[12]Jay Heizer and Barry Render, "How E-Commerce Saves Money," *IIE Solutions* (August 2000), pp. 22–27.
[13]Available at http://www.01markets.com/eprocurement/casestudies.

Table 10-3
A Seasonal Price Pattern for the Example Commodity

MONTH	PRICE ($/UNIT)	MONTH	PRICE ($/UNIT)
Jan.	3.00	July	1.00
Feb.	2.60	Aug.	1.40
Mar.	2.20	Sept.	1.80
Apr.	1.80	Oct.	2.20
May	1.40	Nov.	2.60
June	1.00	Dec.	3.00

average price than hand-to-mouth buying alone. Forward buying is the act of buying in quantities exceeding current requirements, but not beyond foreseeable future requirements. It is an attractive strategy when prices are expected to rise so that additional quantities are purchased at low prices, but some inventory is created and must be balanced against the price advantages. On the other hand, hand-to-mouth buying is advantageous when prices are dropping, thus avoiding buying greater quantities now when delayed buying can yield lower prices. Effectively combining these two strategies when requirements are seasonal can yield substantial price advantages.

Example

Suppose that a commodity has a seasonal price pattern, as shown in Table 10-3. Projected requirements for the year are a constant 10,000 units per month. The objective is to choose the best combined strategy of hand-to-mouth and forward buying. Table 10-4 summarizes several forward buying periods: two-month, three-month, and six-month forward buys. Since prices are dropping from January through June, only a hand-to-mouth strategy need be considered for this time period. Selecting the best combined strategy requires balancing the purchase cost reductions achieved from forward buying against the increased inventory-carrying costs resulting from buying ahead of requirements. If the holding cost of a unit is $10 per year, the average inventory-carrying cost for the hand-to-mouth option is (10,000/2) $10 = $50,000 per year. This assumes that a shipment of 10,000 units arrives at the beginning of the month and is depleted to 0 by the end of the month. For the two-month forward buying strategy, the inventory-carrying cost for the year would be

|← First half →|← Second half →|
[(10,000/2) × 6/12 + (20,000/2) × 6/12] × $10 = $75,000/year

The inventory cost for the three-month and six-month forward buying strategies would be $100,000 and $175,000, respectively. The minimum total cost is for the hand-to-mouth buying strategy throughout the entire year. As longer forward

Month	Hand-to-Mouth Purchases Purchase Cost	2-Month Forward Buying Purchase Cost	3-Month Forward Buying Purchase Cost	6-Month Forward Buying Purchase Cost
Jan.	$ 30,000	$ 30,000	$ 30,000	$ 30,000
Feb.	26,000	26,000	26,000	26,000
Mar.	22,000	22,000	22,000	22,000
Apr.	18,000	18,000	18,000	18,000
May	14,000	14,000	14,000	14,000
June	10,000	10,000	10,000	10,000
July	10,000	20,000[a]	30,000b	60,000[c]
Aug.	14,000	—	—	—
Sept.	18,000	36,000	—	—
Oct.	22,000	—	66,000	—
Nov.	26,000	52,000	—	—
Dec.	30,000	—	—	—
Subtotal	$240,000	$228,000	$216,000	$ 180,000
Inventory carrying cost	50,000	75,000	100,000	175,000
Total	$290,000	$303,000	$316,000	$ 355,000

[a] Purchase two months' requirements at the July price.
[b] Purchase three months' requirements at the July price.
[c] Purchase six months' requirements at the July price.

Table 10-4 Mixed Purchase Strategy Using Various Time Periods for Forward Buying When Prices Are Rising

buying periods are explored, the cost of carrying inventory increases more rapidly than the benefits of not paying for price increases. However, if there were price discounts or transportation rate breaks based on the size of the purchase, forward buying might be economical. This possibility should be considered.

Dollar Averaging

Forward buying, to be effective, requires that seasonal price patterns be reasonably stable and predictable. To accomplish the same lowest purchase price goal as forward buying, dollar averaging can be used. This method assumes that prices will generally rise over time, but otherwise they will fluctuate with uncertainty. Purchases are made at fixed intervals, but the quantity to buy depends on the price at the time of the buy. A budget is established based on the average price for a reasonable time into the future—at least a full seasonal cycle. The price is divided into the budget amount to determine the quantity to buy. The result is that more units are purchased when prices are low than are purchased when they are high, if prices are generally rising. The danger in this strategy is that quantities not large enough to meet requirements may occur when prices are high. Protection in the form of carrying some inventory may be necessary.

Example

An office supply product is expected to cost $2.50 for each unit throughout the next year. Usage is also expected to be at the rate of 20,000 units per month, with purchases made every three months. Inventory carrying costs are 25 percent per year.

The first step in dollar averaging is to develop the three-month purchasing budget. Simply put, this is 20,000 × 3 × 2.50 = $150,000. We spend this amount at each purchase. Suppose that the actual prices for the next year unfold as shown next.

Month	Price ($/unit)	Month	Price ($/unit)
Jan.	2.00	July	2.55
Feb.	2.05	Aug.	2.65
Mar.	2.15	Sept.	2.75
Apr.	2.25	Oct.	2.80
May	2.35	Nov.	2.83
June	2.45	Dec.	2.86

If we sum the prices and divide by 12, the actual average price is $2.47 per unit. The first three-month purchase quantity in January would be

$150,000/$2.00 per unit = 75,000 units

Continuing this type of calculation for each three-month period, we would have

Month	No. of Units	Price ($/unit)	Total Cost	Average Inventory
Jan.	75,000	2.00	$150,000	37,500[a] units
Apr.	66,667	2.25	150,000	33,334
July	58,824	2.55	150,000	29,412
Oct.	53,571	2.80	150,000	26,786
	254,062		$600,000	31,758[b] units

[a] 75,000/2 = 37,500 units.

[b] Annual average, or (37,500 + 33,334 + 29,412 + 26,786)/4 = 31,758 units.

The average unit cost is $600,000/254,062 = $2.36. Compared with monthly hand-to-mouth purchases, this gives a price reduction of [(2.47 − 2.36)/2.47] × 100 = 4.45%. The total hand-to-mouth purchase cost would be 254,062 × $2.47/unit = $627,533.

Now we account for inventory-carrying costs. The annual average carrying cost for monthly hand-to-mouth buying is (20,000/2) × 2.47 × 0.25 = $6,175. And for dollar averaging, it is 31,758 × 2.36 × 0.25 = $18,737.

Summarizing the annual costs for the two strategies, we have

Strategy	Purchase Cost	Inventory Cost	Total Cost
Monthly hand-to-mouth	$627,533	+ 6,175	= $633,708
Dollar averaging	$600,000	+ 18,737	= **$618,737**

The most economical strategy in this rising price market is dollar averaging. (*Note:* Adequate inventory will need to be maintained so that demand can be met during periods of small purchase quantities.)

Quantity Discounts

The purchasing agent is frequently encouraged to buy in large quantities. Suppliers may offer lower prices if larger quantities are purchased, since suppliers benefit from economies of scale and pass along some of these benefits to the buyers through price incentives. Two forms of price incentives are popular: inclusive and noninclusive. An inclusive quantity discount-price-incentive plan is one where, for progressively larger purchase quantities, a lower price is offered that applies to all units purchased. It is commonly seen for many consumer items. In contrast, under the noninclusive quantity discount-price-incentive plan, the price reduction applies to only those units within the quantity discount-price interval. The in-excess rate in transportation is an example. If quantities purchased are already large—that is, larger than the last quantity price break—nothing further needs to be considered. However, when purchase quantities are small, the buyer faces the dilemma of whether to pay a high price for the small quantity or to increase the purchase quantity and incur additional inventory carrying costs. We will explore these two pricing policies.

Inclusive Quantity Discount-Price-Incentive Plan. A simple inclusive quantity discount-price schedule can be expressed as

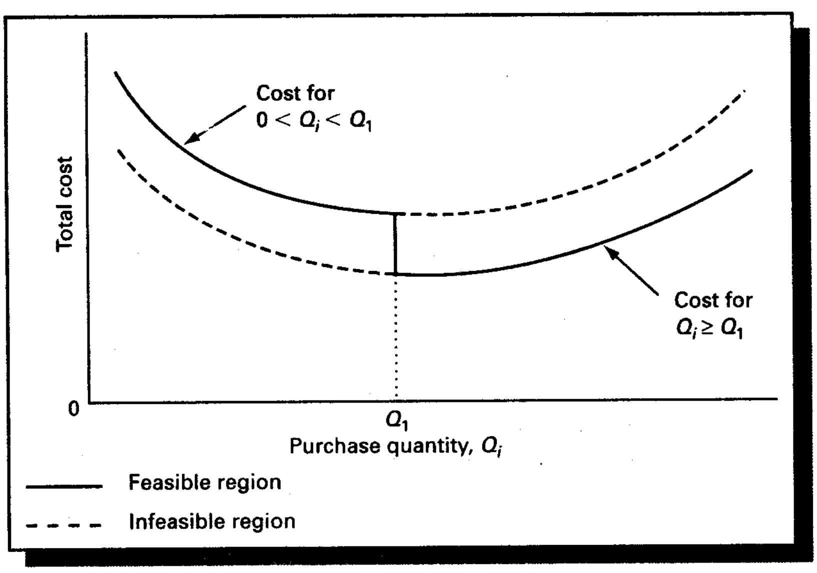
Quantity, Q_i	Price, P_i
$0 < Q_i < Q_1$	P_1
$Q_i \geq Q_1$	P_2

where Q_i is the quantity purchased, and P_i is the price paid per unit for all of Q_i. P_1 ranges from 1 to less than Q_1, otherwise P_2 applies. P_2 is less than P_1.

Finding the optimal purchase quantity requires finding the lowest total cost comprising purchase cost, ordering cost, and inventory-carrying cost. Mathematically, this total cost is

$$TC_i = P_iD + \frac{DS}{Q_i} + \frac{IC_iQ_i}{2} \qquad \textbf{(10-4)}$$

Figure 10-13
A Total Cost Curve for a Single Break, Inclusive Quantity Discount-Price Incentive Plan



where

TC_i = total relevant cost for the quantity Q_i
P_i = price per unit for quantity Q_i
D = average annual demand in units
S = procurement cost in dollar per order
Q_i = quantity to purchase in units
I = carrying cost in percent per year
C_i = cost of the item at the point inventoried in dollars per unit

The total cost curve for an inclusive quantity discount-price-incentive plan is shown in Figure 10-13. Finding the optimal purchase quantity is not as simple as under a single price plan because of the discontinuity point in the total cost curve. However, a computational procedure can be developed that requires a minimal number of calculations. It can be paraphrased as follows:

- Compute the economic order quantity (*EOQ*) for each price, P_i. Find the one *EOQ* that is within the feasible range of its total cost curve. If the feasible *EOQ* is on the lowest cost curve, the optimal *Q* has been found. If it is not, compute TC_{EOQ} and proceed with the next step.
- Set Q_i at the minimum quantity within the quantity price range *i* and compute TC_i. Compare all TC_i and TC_{EOQ}.
- Select the quantity Q_i representing the minimal total cost.

Example

An item is regularly purchased with an estimated demand of 2,600 units per year. Purchase order preparation costs are $10 per order, and the inventory-carrying cost is

20 percent per year. The supplier offers two prices—$5 per unit for a purchase quantity of less than 500 units, and a 5 percent discount that applies to all units when quantities of 500 or more units are purchased. The prices include delivery. What order size should the purchasing agent place?

We first compute the economic order quantities for the prices below and above 500 units. Hence, for P_1,

$$Q_{EOQ1} = \sqrt{\frac{2DS}{IC}} = \sqrt{\frac{2(2600)(10)}{0.20(5)}} = 228 \text{ units (feasible)}$$

And the total cost according to Equation (10-4) is

$$TC_{EOQ1} = 5(2600) + \frac{2600(10)}{228} + \frac{0.20(5)(228)}{2} = \$\ 13,228.04$$

For P_2:

$$Q_{EOQ2} = \sqrt{\frac{2(2600)(10)}{0.20(4.75)}} = 234 \text{ units (infeasible)}$$

Notice that Q_{EOQ2} on the lower cost curve is infeasible considering the price used in the calculation. That is, the price of 4.75 is not consistent with the order quantity of less than 500 units. Q_{EOQ2} is eliminated from further consideration. Now test the quantity just at the break point, or $Q = 500$ units.

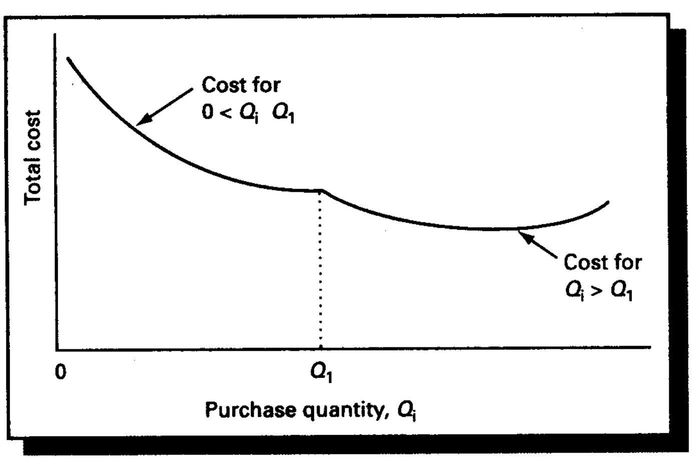
$$TC_{500} = (5 \times 0.95)(2600) + \frac{2600(10)}{500} + \frac{0.20(5 \times 0.95)(500)}{2} = \$12,639.50$$

Since TC_{500} is less than TC_{EOQ1}, a quantity of 500 units should be ordered to minimize costs.

Noninclusive Quantity Discount-Price-Incentive Plan. When the quantity price incentive plan is of the noninclusive type, a slightly modified solution procedure is required. Beyond the price break quantities, the average unit price continues to drop, as shown in Figure 10-14. We can find the optimal purchase quantity by trial and error.[14] That is, the total cost for progressively larger order quantities is computed until the minimum cost is found.

[14] For an exact approach to the noninclusive discount-price problem, see Richard J. Tersine, *Principles of Inventory and Materials Management*, 4th edition (Upper Saddle River, NJ: Prentice Hall, 1994), pp.110–113.

Figure 10-14
A Total Cost Curve for a Single Break, Noninclusive Quantity Discount-Price-Incentive



Example

Using the previous example, the 5 percent price discount now applies only to purchases *greater* than 500 units, that is, to $Q_{i > 500}$. To find the optimal order quantity, we prudently select Q_s to be evaluated. Let's begin with a $Q = 300$ and incrementally add to this quantity until the total cost stops dropping and begins to increase. We use Equation (10-4) for our calculations, where average price *Pi* is found from one of two formulas. If Q_i is less than or equal to 500 units, $P_i = P_1$; otherwise, $P_i = [500 \times P_1 + (Q_i - 500) \times P_2] / Q_i$. The computations can now be summarized as follows:

Q_i	Average Unit Price, P_i	$P_i \times D$	$+D \times S/Q_i$	$+I \times C_i \times Q_i/2$	= Cost
300	5	$13,000.00	$86.67	$150.00a	$13,237
400	5	13,000.00	65.00	200.00	13,265
500	5	13,000.00	52.00	250.00	13,302
600	$\frac{500(5) + 100(4.75)}{600} = 4.96$	12,896.00	43.33	297.60	13,237
800	$\frac{500(5) + 300(4.75)}{800} = 4.91$	12,766.00	32.50	392.80	13,191
900	$\frac{500(5) + 400(4.75)}{900} = 4.89$	12,714.00	28.89	440.10	**13,183** ←
1000	$\frac{500(5) + 500(4.75)}{1000} = 4.88$	12,688.00	26.00	488.00	13,202
1100	$\frac{500(5) + 600(4.75)}{1100} = 4.86$	12,636.00	23.64	534.60	13,194

[a] $P_i = C_i$

Within the increments of 100 units that were tested, the optimum purchase order quantity with the lowest total annual cost is 900 units.

Deal buying. It is quite common for vendors to offer occasional price discounts for the purpose of promoting their business or clearing excess inventory. The purchasing agent for the buyer is faced with the question of how much to buy if the discount appears to be attractive. The purchasing agent may already be buying from the vendor and has optimized the quantities to be purchased under the existing price. For a time, such purchases create higher-than-normal inventory levels. This may be acceptable if the price reduction more than compensates for the added carrying costs. The special order quantity can be found from

$$\hat{Q} = \frac{dD}{(p-d)I} + \frac{pQ^*}{p-d} \qquad \textbf{(10-5)}$$

where

d = unit price decrease, dollars/unit
p = price per unit before the discount, dollars/unit
S = order cost, dollars/order
I = annual carrying cost, percent/year
D = annual demand, units
Q^* = optimal order quantity before the discount, units
$\hat{Q}$ = special order size, units

The offer is a one-time event, the demand for the product is expected to remain unchanged, and after the offer expires, the order pattern returns to its original buying quantity and timing.

Example

Jaymore Drugstores sells a line of coffeemakers in its drugstore chain. The vendor of the coffeemakers normally sells the product for a delivered price of $72 per unit. Jaymore's stores typically sell 4,000 units per year. The purchasing agent finds that carrying costs are 25 percent/year and the cost to prepare purchase orders is $50 per order.

The vendor is offering to give a one-time $5 discount off the regular price to reduce its factory inventory. Jaymore believes that the coffeemakers will continue to sell at the normal sales rate and any excess inventory created from a larger-than-normal purchase quantity will be depleted. How large an order should be placed with the vendor?

The typical order size can be determined by solving for the economic order quantity. That is,

$$Q^* = \sqrt{\frac{2DS}{IC}} = \sqrt{\frac{2(4,000)(50)}{0.25(72)}} = 149 \text{ units}$$

Now, the special order size is found from Equation (10-5), or

$$\hat{Q} = \frac{dD}{(p-d)I} + \frac{pQ^*}{p-d} = \frac{5(4000)}{(72-5)0.25} + \frac{72(149)}{(72-5)} = 1,354 \text{ units}$$

Instead of holding an order quantity for $Q^*/D = (149/4,000) = 0.037$ yr, or two weeks, the units from the special order will be in inventory for $\hat{Q} = (1,354/4,000) = 0.339$ yr, or 18 weeks.

Contract buying. A buyer may wish to negotiate the best possible price but not take delivery of the full purchase amount at one time. Therefore, the buyer offers to purchase a given unit quantity or a dollar amount over time. This contract may be for a specific item or it may be for a variety of items covered under a blanket dollar contract. For example, suppose that a buyer has agreed to purchase $500,000 worth of goods from a particular supplier for the coming year. The quantities of individual items are not known at contract time, only the monetary amount is "guaranteed."[15] As the need develops throughout the year, the buyer calls on the seller to deliver the items requested in the desired quantities. The dollar purchase amount of individual items within the contract may vary considerably. For the buyer, this is *stockless purchasing*, yet the buyer has the advantage of volume buying and its associated price benefits. It is attractive where the just-in-time supply philosophy guides operations and inventories are to be minimized. For the seller, more efficient operations can be expected from better planning due to the certainty of the purchases from its customers.

Sourcing

Fixed Sourcing

Another important decision is selecting the shipping points from which purchased materials should be supplied, when the price policy requires the buyer to do this. Determining these sourcing points may depend on the inventory availability, performance and cost of the transportation services used, and the price

[15]The guaranteed dollar amount often has some flexibility in it, such as ±10 percent.

level and price policy used. For example, if the price policy is a delivered or prepaid one, transportation selection is not likely to be an issue. If there is only one possible shipping point to serve one destination point, the decision is straightforward. However, when there are multiple source and destination points with restrictions on the amount that can be shipped from each source, the decision problem is more complex. One way to approach such a problem is to use linear programming.

Example

The Regal Company has received vendor quotes for a component that is part of a larger assembly. The prices, quoted f.o.b. vendor shipping point, are as follows:

Supplier	Shipping Location	F.o.b. Price
Philadelphia Tool	Philadelphia	$100 each
Houston Tool & Die	Houston	101
Chicago-Argo	St. Louis	99
L.A. Tool Works	Los Angeles	96

Regal has three plants to be supplied—Cleveland, Atlanta, and Kansas City. The transportation rates (in $/cwt.) and the plant requirements for January are

Shipping Point	Cleveland	Atlanta	Kansas City
Philadelphia	$2/cwt.	$3/cwt.	$5/cwt.
Houston	6	4	3
St. Louis	3	3	1
Los Angeles	8	9	7
Requirements	**4000 units**	**2000 units**	**7000 units**

Los Angeles can supply an unlimited amount, as can Houston. However, Philadelphia can supply up to 5,000 units and St. Louis can supply up to 4,000 units. Each unit weighs 100 pounds.

The purchasing department's policy is to buy from the supplier offering the lowest price. What is the optimal sourcing plan, and how much would it save Regal?

This problem type may be dealt with using linear programming's transportation method. The solution matrix for this problem is shown in Figure 10-15. Notice that the cell cost value (the cost of shipping a single unit between two points) includes the f.o.b. price as well as per-unit shipping costs. The available supply from Houston and Los Angeles has been set at arbitrarily high values to represent unrestricted supply. A dummy column has been added as a destination point to absorb the excess supply over requirements. All cell costs of zero are used in the dummy column, although any values will do.

Figure 10-15 The Optimum Sourcing Pattern for the Regal Company

Supply points	Cleveland	Atlanta	Kansas	Dummy	Supply
Philadelphia	102 4,000	103 1,000	105	0	5,000
Houston	107	105	104	0 15,000	15,000
St. Louis	102	102	100 4,000	0	4,000
Los Angeles	104	105 1,000	103 3,000	0 11,000	15,000
Requirements	4,000	2,000	7,000	26,000	39,000

For the company's policy of purchasing from the least expensive source, all purchases would be made from the Los Angeles source with a total landed cost of

From Los Angeles	
To Cleveland	\$104/unit × 4,000 units = \$ 416,000
To Atlanta	105/unit × 2,000 units = 210,000
To Kansas City	103/unit × 7,000 units = 721,000
	Total landed cost \$ 1,347,000

One revised, optimal sourcing plan (there is another equally as good) is shown in Figure 10-15. This plan can be summarized as follows:

Philadelphia to Cleveland	\$102/unit × 4,000 units = \$ 408,000
Philadelphia to Atlanta	103/unit × 1,000 units = 103,000
St. Louis to Kansas City	100/unit × 4,000 units = 400,000
Los Angeles to Atlanta	105/unit × 1,000 units = 105,000
Los Angeles to Kansas City	103/unit × 3,000 units = 309,000
	Total **\$1,325,000**

In this case, Regal could save \$22,000 in the month of January by using multiple sources as indicated. It should also be recognized from Figure 10-15 that both Philadelphia and St. Louis are being sourced to the limit of their available supply. Regal should negotiate for increased supply from these sources to reduce costs further. Houston does not appear to be a particularly attractive source point since it is not used. Perhaps Regal could present this information to Houston Tool & Die and discuss a price reduction of about \$1 or \$2 per unit. This would allow Houston to compete for the Atlanta and Kansas City requirements, which would be desirable if Houston is a favored supplier for reasons other than price.

Flexible Sourcing

It may not always be practical to specifically assign destination requirements to particular sources. Changing requirements during long lead-time periods may lead to a flexible sourcing arrangement. One manufacturer of glass products used this method to keep glass furnaces operating when limited raw materials storage capacity was available at the plant sites. Against an annual purchase quantity, multiple suppliers were requested to ship materials as scheduled by production. Once en route, production schedules could be shifted either as to product mix, and therefore the raw materials needed, or by changes in the volume to be produced. Because of this, it was a common practice to divert in-transit railcar shipments to plants other than those originally scheduled. This method better matched supply to requirements while avoiding a buildup of material shortages at plants. The disadvantage was that higher overall transportation costs would be incurred because a plant was not always tied to a specific source.

Terms of Sale and Channel Management

When we think of terms of sale, it is often with price and financial considerations in mind. However, specifying in the terms of sale the form in which goods are to be supplied and the methods by which they will be handled can be very important to product movement and storage efficiency within the supply channel. Since suppliers have their own logistics systems, there is no guarantee that these systems will be compatible with those of the buying firm. It is possible that package sizes, transport methods, and handling procedures will not match, causing additional time and effort to force compatibility. Where possible, purchasing should specify how shipments must conform to a desired pattern. If such patterns cannot be forced through contractual arrangements, then cooperative efforts should be undertaken with suppliers to encourage the desired system compatibility.

Observation

Constellation Supers, Inc., was a supermarket chain in the Minneapolis area. National Home Food Products was its largest supplier, with a distribution center located just seven miles from Constellation's Edina facility. Yet, National would depalletize Constellation's order from 40 in. by 48 in. pallets and ship it to Constellation using rail. Constellation would repalletize the goods on 32 in. by 40 in. pallets in order to match its handling and storage system. Since Constellation's purchases amounted to less than 1 percent of National's total sales, National was reluctant to incur a charge for repalletizing to 32 in. by 40 in. pallets. Without incurring the cost of retrofitting the Edina warehouse to accommodate the 40 in. by 48 in. pallets, Constellation seemed powerless to overcome the inefficiencies of extra handling. What suggestions can you make to correct this supply channel incompatibility?

CONCLUDING COMMENTS

Purchasing and scheduling involve decisions that can substantially affect the efficient movement and storage of goods within the supply channel. Scheduling ensures that goods arrive at a designated point at the time and in the quantities needed. Using inventory-control methods is one approach to ensuring the availability of goods. Just-in-time scheduling procedures have become popular. Specifically, both Toyota's KANBAN system and the materials-requirements planning (MRP) system are frequently used in the United States. The basic procedures for developing an MRP schedule were presented in this chapter. As an extension of MRP, distribution-requirements planning was also discussed. Combining MRP and DRP allows integrated scheduling of the entire supply chain from suppliers to customers.

Purchasing is primarily a buying activity. This important activity accounts for 40 to 60 percent of the sales dollar. Many of the decisions involving purchasing have an impact on the efficiency with which logistical activities in the supply channel can be conducted. In this chapter, several key purchasing decisions were examined and methods suggested for treating them. Key purchasing decisions include determining purchase quantities, timing purchases, and sourcing shipments.

This chapter suggests a strong relationship between production scheduling, purchasing, and logistics. Integrating these is the essence of supply chain management. The goal is to achieve maximum efficiency effectiveness of product flows through the careful management of cross-functional activities.

QUESTIONS

1. How is just-in-time scheduling different from the supply-to-inventory philosophy of scheduling? How is it that JIT scheduling can eliminate the need for inventories in the supply channel?
2. Why is just-in-time a philosophy and not a technique?
3. How are the methods for determining the optimal purchase quantity different under inclusive and noninclusive quantity discount-price plans?
4. What are the similarities and differences between MRP and DRP?
5. How is KANBAN different from the MRP approach to JIT scheduling?
6. Considering the many parts, components, and supplies that a firm would need in order to supply a production or service operation, what characteristics would these items likely have to be scheduled by requirements planning versus being stocked in supply inventories?
7. What are the characteristics of JIT supply scheduling, and why are they important to the effectiveness of this scheduling approach?
8. What is the leverage principle in purchasing? The return-on-assets effect?
9. Under what circumstances is forward buying a good practice? When is dollar averaging a good buying practice?
10. How do compatibility in the form of goods and the movement methods between supplier and buyer affect logistics efficiency? How might purchasing contribute to improved efficiency in the channel?
11. What is the future of product and service auctioning on the Internet?

Problems

Some of the problems and the case study in this chapter can be solved or partially solved with the aid of computer software. The software packages in LOGWARE that are most important in this chapter are TRANLP (*T*), and INPOL (*I*). The CD icon will appear with the software package designation where the problem analysis is assisted using one of these software programs. A database may be prepared for the problem if extensive data input is required. Where the problem can be solved without the aid of the computer (by hand), the hand icon is shown. If no icon appears, hand calculation is assumed.

1. A furniture manufacturer sells a line of desks with the same general design. The desks are made from veneered plywood sheets, and the purchase plan for the plywood is to be determined for the next seven weeks. The desks are offered in three styles, each with minor modifications in the drawer layout. Marketing forecasts for the three styles are given as follows:

	Weekly Demand Forecast (units)							
Desk	1	2	3	4	5	6	7	8
Style A	150	150	200	200	150	200	200	150
Style B	60	60	60	80	80	100	80	60
Style C	100	120	100	80	80	60	60	40

It takes one week to produce the desks, with a production run of 300 for style *A* and 100 each for styles *B* and C. Currently, 80 style *B* desks and 200 style C desks are on hand. Current production plans will make available 200 style *A* desks in week 1, with none currently on hand. No production is currently scheduled for styles *B* and *C* desks. All other parts for the desks are readily available and cause no delay in producing the finished desks.

For the plywood veneer sheets (three sheets = one desk), there are 2,400 sheets on hand and 600 more are to be received in week 2. Once an order is placed, it takes, on the average, two weeks to obtain a plywood order. Minimum orders are for 1,000 sheets with a safety stock of 200 sheets to be on hand at all times.

a. Develop a schedule for timing the release of plywood purchase orders over the next seven weeks.

b. Suppose the costs for delaying production are $5 per day for each plywood sheet that has not arrived in time to meet production needs. Correspondingly, the cost for carrying plywood that arrives in advance of needs is $0.10 per sheet per day. The average order cycle time on purchase orders is two weeks (14 days) with a standard deviation of two days. These lead times are normally distributed. How should purchase order release time be adjusted to account for this uncertainty?

		Week							
		1	2	3	4	5	6	7	8
Projected gross requirements		100	450	100	300	850	100	100	100
Scheduled receipts					?				
Quantity on hand	900	800	350	250					
Planned purchase order releases									

Table 10-5 A Materials Requirements Planning Schedule in Units

2. A certain item is scheduled using production-requirements planning with the purchase order releases being time-phased. A schedule is shown in Table 10-5. The materials manager believes that this schedule may not be the most economical from a supply point of view. The following additional information has been obtained:

   Carrying cost = 20% per year
   Year = 365 days
   Production downtime cost = $150 per day per unit
   Item price = $35 per unit
   Purchase order preparation cost = $50 per order

   Lead time is normally distributed with an average of 14 days and a standard deviation of four days
   a. How much time should be allowed in advance of scheduled receipts for the release of orders?
   b. In period 4, a scheduled receipt is needed to maintain a minimal safety level of 200 units. If there are no minimums on the purchase (order release) quantity, what is the most economic order release size?
3. The physical distribution channel of a major food manufacturer consists of plant stocks from which regional warehouses are restocked. These regional warehouses in turn supply the field warehouses assigned to them. There is one plant serving two regional warehouses that, in turn, serve three field warehouses each. The field warehouses have the following weekly demand forecasts for a particular item and the following inventory on hand:

Regional Warehouse	Inventory on Hand (Cases)	Field Warehouse	Inventory on Hand (Cases)	Weekly Forecasted Demand (Cases)
1		1	1,700	1,200
1 →	52,300	2	3,300	2,300
1		3	3,400	2,700
2		4	5,700	4,100
2 →	31,700	5	2,300	1,700
2		6	1,200	900

The regional warehouse will supply its assigned warehouses only when the accumulated order quantity at each warehouse equals or exceeds 7,500 cases, and then in increments of 7,500 cases. The 7,500 cases are equal to a truckload shipment. In turn, the plant will supply regional warehouses in increments of 15,000 cases, which is a railcar shipment. The lead time for the supply of field warehouses is one week. Lead time is two weeks for supplying regional warehouses. Production has a lead time of three weeks for materials in lots of 20,000 cases. No shipments are in the pipeline to field warehouses; however, a previously scheduled shipment of 15,000 cases is due to arrive at regional warehouse 2 in the second week.

Over the next ten weeks, plan the materials flow through the network, estimate the average inventory in the system, and project what the production schedule should be.

4. A firm with annual sales of $55 million pays out 50 percent of its sales dollar as cost of goods sold. Overhead amounts to $8 million. Labor and salaries are $15 million. Thus, a profit of $4.5 million is realized. Assets are $20 million, of which 20 percent are in inventories.
   a. If the firm can (1) increase sales volume, (2) raise price, (3) reduce labor and salaries, (4) decrease overhead, or (5) reduce the cost of goods sold, how much change (in percent) in each category would be required to increase profits to $5 million?
   b. If prices of purchased materials (i.e., cost of goods sold) can be reduced by 7 percent, what return on assets can be realized? How does this compare with the current ROA?
5. A firm purchases a material that shows definite price seasonality throughout the year with relatively minor fluctuations within each month. Requirements for the material are constant throughout the year at 50,000 units per month. The prices throughout the year are projected as follows:

Month	Price ($/unit)	Month	Price ($/unit)
Jan.	4.00	July	6.00
Feb.	4.30	Aug.	5.60
Mar.	4.70	Sept.	5.40
Apr.	5.00	Oct.	5.00
May	5.25	Nov.	4.50
June	5.75	Dec.	4.25

   Inventory-carrying cost is 30 percent per year. The current buying strategy is to purchase directly to requirements at the going price.
   a. Does a mixed strategy of forward and hand-to-mouth buying lower purchasing costs? Which is the best strategy mix?
   b. If a mixed strategy is better, what concerns might there be in using it?
6. A magnet manufacturer purchases copper on the open market at monthly intervals throughout the year. The best estimate of the average price for the next year is $1.10 per lb. A fixed quantity of 25,000 lb per month is needed to meet the expected requirements for a four-month planning horizon. Inventory carrying cost is 20 percent per year.

a. Develop a dollar-averaging budget for future purchases.
b. Suppose, at the time of the purchases, the actual prices per pound for the next four months turn out to be $1.32, $1.05, $1.10, and $0.95, respectively. If dollar averaging is used, what quantities should be purchased in each month? Is there any advantage over a hand-to-mouth strategy?

7. A large medical clinic uses 500 cases of floor polish per year. Purchases are made at an ordering cost of $15 per order. Inventory-carrying cost is 20 percent per year. The price schedule, which includes the transportation cost, shows that orders of less than 50 cases will cost $49.95 per case; between 50 and 79 cases will cost $44.95 per case; and 80 cases or more will cost $39.95 per case. Prices apply inclusively to all units bought. What is the optimum purchase order size that should be placed, and what is the total cost?
8. An East Coast electric company buys motors from a supplier on the West Coast for use in pumping equipment. Production needs 1,400 motors per year. Procurement costs, including clerical and expediting costs, are $75 per order. Inventory-carrying cost is 25 percent per year. The supplier has provided the following price schedule:

Units per Order	Unit Price[a]
First 200	$795
Next 200	750
Over 400	725

[a] Includes transportation

Given this noninclusive price schedule, what is the optimal purchase quantity (to the nearest 50 units), and what is the total annual cost?


or


9. The central purchasing group for Ortega Foods buys cornmeal for the company's four plants that produce taco shells. Three source points are available, but contractual agreements limit supply from some of the sources. The cornmeal is shipped in 100-lb bags. Data on plant requirements, supply availability, and f.o.b. prices for a typical week are shown in Table 10-6. The transportation rates (in $/cwt.) between the various sources and plants are as follows:

	Plants			
Sources	Cincinnati	Dallas	Los Angeles	Baltimore
Minneapolis	0.15	0.19	0.24	0.21
Kansas City	0.10	0.08	0.20	0.18
Dayton	0.05	0.12	0.27	0.15

The purchasing group currently supplies Cincinnati and Baltimore plants from Dayton. Dallas is served by Kansas City, and Los Angeles is served by Minneapolis.

a. What sourcing plan would be best for Ortega, and how much would it save?
b. Are there any actions that the purchasing group might pursue to reduce costs further?

Table 10-6
Supply and Demand Data for Ortega Food Problem

Source	Supply Availability (cwt.)	Price ($/cwt.)
Minneapolis	1,200	$3.25
Kansas City	4,800	3.45
Dayton	Unlimited	3.40

Plant	Requirements (cwt.)
Cincinnati	5,000
Dallas	2,500
Los Angeles	1,200
Baltimore	1,000

c. Is Ortega contracting with too many suppliers? Why or why not? (*Hint*: Use the transportation method of linear programming to help solve this problem.)

10. A-Mart sells small-screen television sets in its many retail outlets. Typical total sales for all stores are projected to be 120,000 units. The vendor in South Korea normally sells the sets for $100US, however, the vendor will offer a $5 discount if a buyer will place a special order of at least 20,000 units. The buyer's carrying cost is 30 percent per year and the cost to prepare purchase orders is $40 per order. Transportation costs are included in the price.
    a. Should the buyer accept the discount? If so, what should the special order size be?
    b. If the special order is placed, how long will the order size need to be held in inventory?

NEED FOR A STORAGE SYSTEM

Do firms really need storage and materials handling as part of the logistics system? If demand for a firm's products were known for sure and products could be supplied instantaneously to meet the demand, theoretically storage would not be required since no inventories would be held. However, it is neither practical nor economical to operate a firm in this manner since demand usually cannot be predicted exactly. Even to approach perfect supply and demand coordination, production would have to be instantly responsive, and transportation would have to be perfectly reliable, with zero delivery time. This is just not available to a firm at any reasonable cost. Therefore, firms use inventories to improve supply and demand coordination and to lower overall costs. It follows that maintaining inventories produces the need for warehousing and the need for materials handling as well. Storage becomes an economic convenience rather than a necessity.

The warehousing and materials handling costs are justified because they can be traded off with transportation and production-purchasing costs. That is, by warehousing some inventory, a firm can often lower production costs through economical production lot sizing and sequencing. By this means, the firm avoids the wide fluctuations in output levels due to uncertainties and variations in demand patterns. In addition, warehousing inventories can lead to lower transportation costs through the shipment of larger, more economical quantities. The object is to use just enough warehousing so that a good, economical balance can be realized among warehousing, production, and transportation costs.

REASONS FOR STORAGE

There are four basic reasons for using storage space: (1) to reduce transportation-production costs; (2) to coordinate supply and demand; (3) to assist in the production process; and (4) to assist in the marketing process.

Transportation-Production Cost Reduction

Warehousing and the associated inventory are added expenses, but they may be traded off with the lower costs realized from the improved efficiency in transportation and production. To illustrate the trade-off idea, consider the distribution problem of Combined Charities, Inc.

Example

The national office of Combined Charities prepared literature for the fund-raising campaigns of a number of well-known charitable and political organizations. The company printed the literature and distributed it to campaign points at the local geographic level. When a job was contracted, the typical procedure was to dedicate the company's entire workforce and printing equipment to preparing the literature for a single campaign. Overtime was often used. After production was completed, the literature was sent directly from the printing site to local distribution points using UPS.

The company's president, who had a good feel for logistics/SC management, thought that overall costs might be lowered if warehouse space could be rented at various regional locations around the country. Although warehousing would be an added expense, he thought that he could ship truckload quantities to the warehouses and use UPS for shipping the short distance from the 35 warehouses he had chosen to the local areas. Production costs could also be reduced because the local areas could draw from warehouse stocks rather than placing orders directly on the printing operation, which often caused a change in the production schedule.

The president made the following rough cost calculations for a typical campaign in which 5 million pieces of literature would be produced:

	Ship Direct from Plant	Ship Through 35 Warehouses	Change in Costs
Production costs	$500,000	$425,000	$ −75,000
Transportation costs:			
To warehouse	0	50,000	+50,000
To local area	250,000	100,000	−150,000
Warehouse costs	0	75,000	+75,000
Total	$750,000	$650,000	$−100,000

The increased warehousing expense is more than offset with reduced production and transportation expenses. Using warehousing appears to be an attractive option.

Coordination of Supply and Demand

Firms with highly seasonal production, along with reasonably constant demand have a problem coordinating supply with demand. For example, food companies producing canned vegetables and fruits are forced to stockpile production output in order to supply the marketplace during the nongrowing season. Conversely, those firms that must supply a product or service to a seasonal and uncertain demand typically produce at a constant level throughout the year in order to minimize production costs and to build inventories needed to meet the demand during a relatively short selling season. Room air conditioners and snowblowers are examples. Whenever it becomes too expensive to precisely coordinate supply and demand, warehousing is needed.

Commodity price considerations may also produce a need for warehousing. Those materials and products that experience wide swings in price from one time to another (copper, steel, and oil) may encourage a firm to purchase these commodities in advance of their needs in order to obtain them at lower prices. Warehousing usually is needed, but its cost can be offset with the better price obtained for the commodities.

Production Needs

Warehousing may be part of the production process. The manufacturing of certain products such as cheeses, wines, and liquors requires time for aging. Warehouses serve not only to hold the product during this manufacturing phase, but in the case where products are taxed, to secure, or "bond," the product until the time of sale. In this way, companies can delay paying taxes on the product until the product is sold.

In certain cases, the warehouse may perform some "value-added" services in addition to holding inventory. Examples of such services for the customer are special packaging, private labeling, and custom product preparation. Value-added services are an extension of the production process that takes place at a forward point in the supply chain.

Marketing Considerations

Marketing is frequently concerned with how readily available the product is to the marketplace. Warehousing is used to put value into a product. That is, by warehousing a product close to customers, delivery time can often be reduced or supply made readily available. This improved customer service through faster delivery can increase sales.

Storage System Functions

The storage system can be separated into two important functions: inventory holding (storage), and materials handling. These functions can be seen when tracing product flow through a typical food distribution warehouse, as shown in Figure 11-1. Materials handling refers to those activities of loading and unloading, moving the product to and from various locations within the warehouse, and order picking. Storage is simply the accumulation of inventory over time. Different locations in the warehouse and different lengths of time are chosen, depending on the purpose for storage. Within the warehouse, these move-store activities are repetitive and are analogous to the move-store activities occurring between various levels of the supply channel (recall Figures 1-2 and 1-4). Thus, in many ways, the storage system is a microlevel distribution system. Specific identification of the major system activities promotes understanding of the system as a whole and helps to provide a basis for generating design alternatives.

Storage Functions

Storage facilities are designed around four primary functions: holding, consolidation, break-bulk, and mixing. Warehouse design and layout often reflect the particular emphasis on satisfying one or more of these needs.

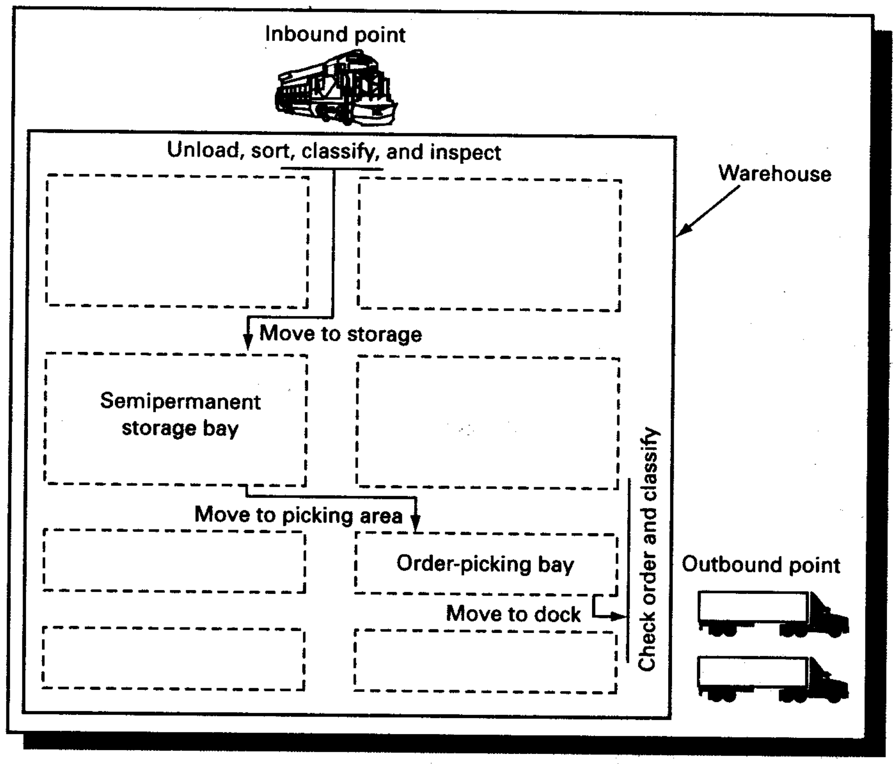


Figure 11-1 Move-Store Activities of a Typical Food Distribution Warehouse

Holding

The most obvious use of storage facilities is to provide protection and the orderly holding of inventories. The length of time for holding goods and the requirements for storage dictate the facility's configuration and layout. Facilities vary from long-term, specialized storage (aging liquors, for example), to general-purpose merchandise storage (seasonal holding of goods), to temporary holding of goods (as in a trucking terminal). In the last case, goods are held only long enough to build efficient truckload quantities. Products stored in these various modes include finished goods ready for the market, semimanufactured goods awaiting assembly or further processing, and raw materials.

Consolidation

Transportation rate structures, especially rate breaks, influence the use of storage facilities. If goods originate from a number of sources, it may be economical to establish a collection point (a warehouse or a freight terminal) to consolidate the small shipments into larger ones (Figure 11-2) and to reduce overall transportation costs. This assumes that the buyer does not purchase enough to warrant volume shipments from each source. The freight differential may more than offset the field warehousing charges.

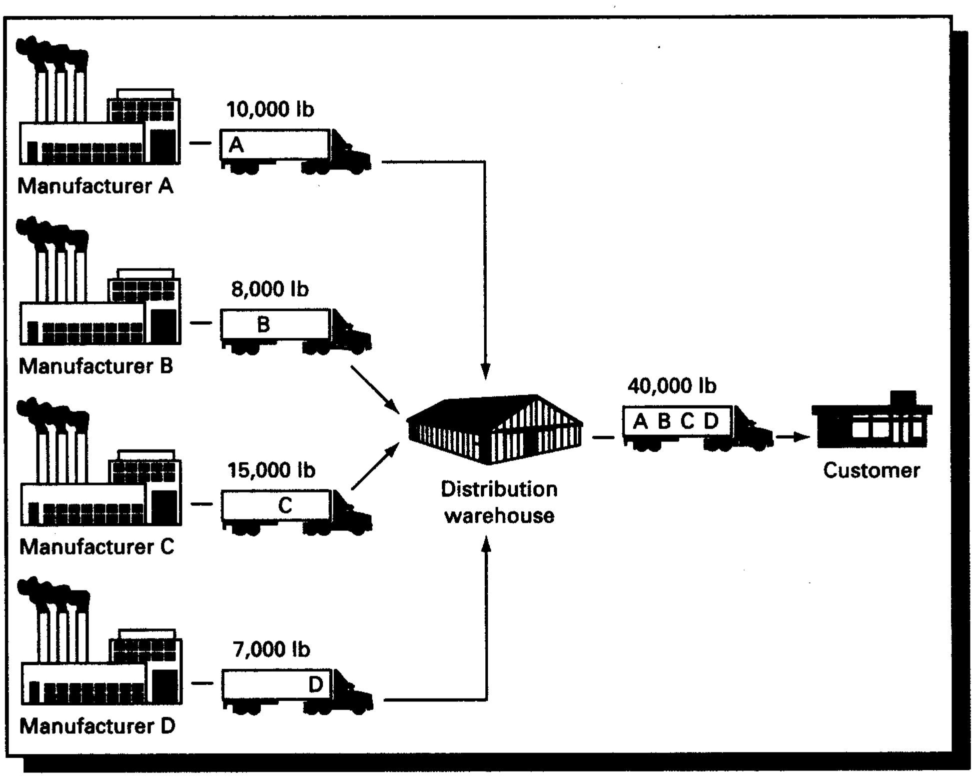


Figure 11-2 Distribution Warehouse Used to Consolidate Small Inbound Shipments into Larger Outbound Shipments

Example

Suppose the customer in Figure 11-2 normally receives mixed-product shipments from the four manufacturers A, B, C, and D, in quantities of 10,000, 8,000, 15,000, and 7,000 lbs, respectively. If all shipments are made less-than-truckload to the customer, the total distribution cost would be $966 per shipment, as shown in Table 11-1(a). By consolidating shipments at a distribution warehouse, the total distribution cost is reduced to $778 per shipment, as shown in Table 11-1(b). In this case, a savings of $188 per shipment results, even after the warehousing cost is considered.

The term *distribution warehouse*[2] is used here primarily to make a contrast with a holding warehouse. The difference is a matter of how much emphasis is placed on holding activities and the time goods are stored. A holding warehouse implies that much of the warehouse space is devoted to semipermanent or long-term storage, as shown in Figure 11-3(a). In contrast, the distribution warehouse has most of its space

[2]*Distribution warehouse* is used synonymously with *field warehouse* and *distribution center*.

(a) Without Consolidation

Manufacturer	Shipping Weight (lb)	LTL Rate to Customer	Cost
A	10,000	$2.00/cwt.	$200
B	8,000	1.80	144
C	15,000	3.40	510
D	7,000	1.60	112
Total			$966

(b) With Consolidation

Manufacturer	Shipping Weight (lb)	LTL Rate to Distribution Center	Total LTL	Distribution Warehouse Charge	TL Rate from Distribution Warehouse to Customer	Total TL	Cost
A	10,000	$0.75	$ 75	$10	$1.00/cwt.	$100	$185
B	8,000	0.60	48	8	1.00	80	136
C	15,000	1.20	180	15	1.00	150	345
D	7,000	0.50	35	7	1.00	70	112
Total	40,000						$778

Table 11-1 Example of the Potential Cost Savings Associated with Consolidating at a Distribution Warehouse

allocated to temporary storage, and more attention is given to speed and ease of product flow in Figure 11-3(b). Obviously, many warehouses operate in both capacities, and the difference is a matter of degree.

At the limit, a warehouse may focus only on receiving and shipping activities, eliminating storage and order picking activities. Such warehouses are referred to as cross docks, or pool points. Goods are transferred directly from inbound to outbound docks with little or no storage. The transfer is typically completed in less than 24 hours. Compared with shipping goods directly from source points, cross docking is justified from the transportation economies that can be achieved.

Integrated fabric and garment manufacturer, Eskay K'n'it has set up a distribution and warehouse center for the company at Guangzhou in China, in a bid to raise its knitwear export volumes to China. It also serves to source products within China for exports to the United States and Europe, and for importing textile products into India.[3]

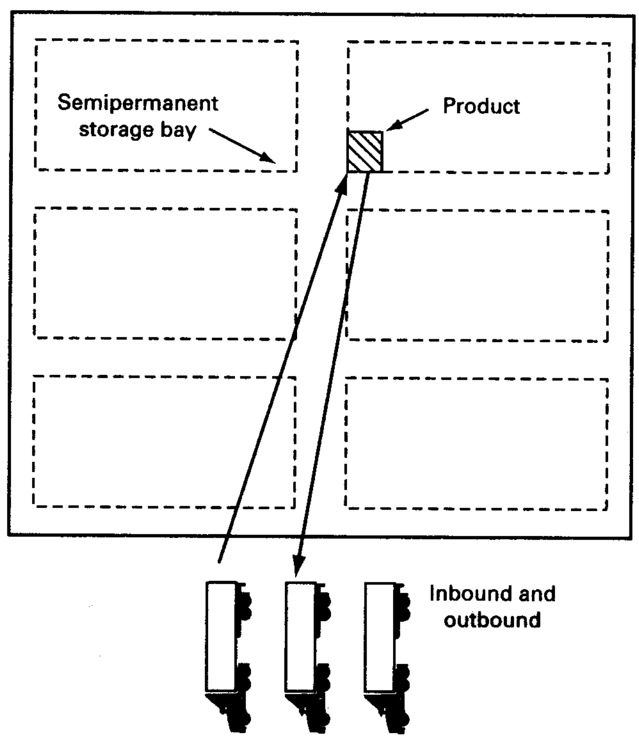
Break-Bulk

Using storage facilities to break-bulk (or transload) is the opposite of using them to consolidate shipments. A generalized break-bulk situation is illustrated in Figure 11-4. Volume shipments having low transport rates are moved to the warehouse and then reshipped in smaller quantities. Break-bulk is common in distribution or terminal

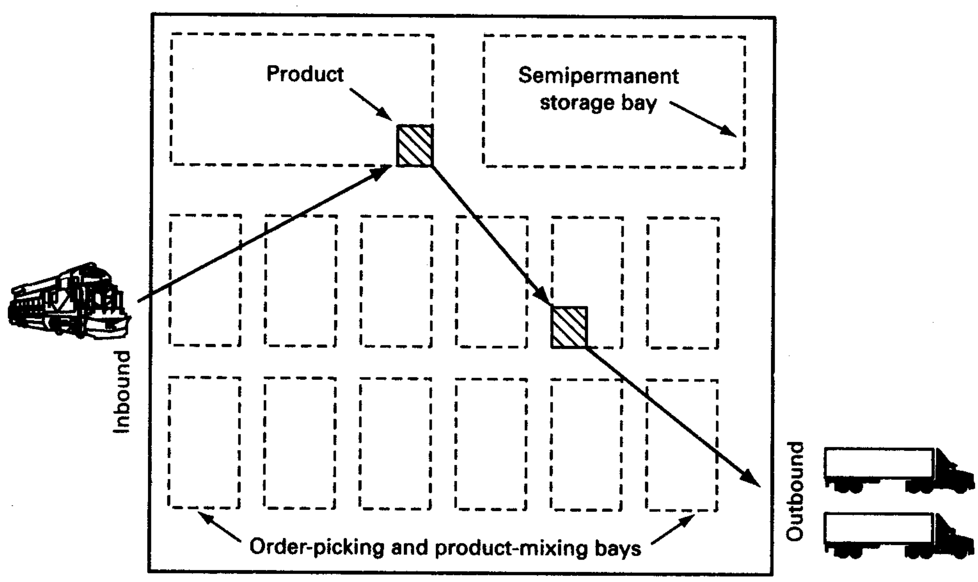
[3] *Business Line* (September 27, 2005), p. 8.

Figure 11-3
Contrast Between Holding Warehouse and Distribution Warehouse

(a) Warehouse with emphasis on long-term storage



(b) Warehouse with emphasis on short-term storage, mixing, and materials flow



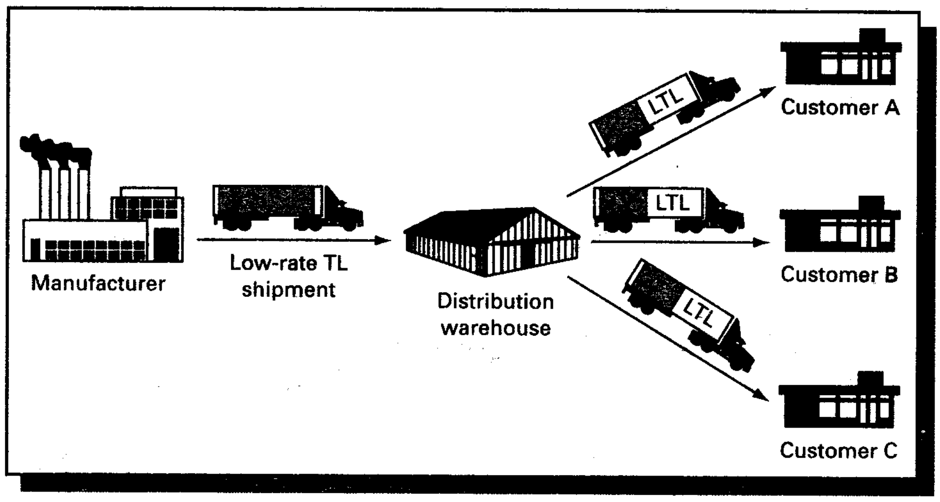


Figure 11-4 Distribution Warehouse (Pool Point, Cross Dock, or Terminal) Used to Break-Bulk

warehouses, especially when inbound transportation rates per unit is less than the outbound rates per unit, customers order in less-than-vehicle-load quantities, and the distance between manufacturer and customers is great. While transportation rate differentials tend to favor a distribution warehouse location near customers for break-bulk operations, the opposite is true for freight consolidation.

Mixing

The use of storage facilities for product mixing is shown in Figure 11-5. Firms that purchase from a number of manufacturers to fill a portion of their product line at each of a number of plants may find that establishing a warehouse as a product mixing point offers transportation economies. Without a mixing point, customer orders might be filled directly from producing points at high transportation rates on small-volume shipments. A mixing point permits volume shipments of portions of the product line to be collected at a single point and then assembled into orders and reshipped to customers.

Materials Handling Functions

Materials handling within a storage and handling system is represented by three primary activities: loading and unloading, movement to and from storage, and order filling.

Loading and Unloading

The first and last activities in the materials-handling events chain are loading and unloading (recall Figure 11-1). When the goods arrive at a warehouse, they must be offloaded from the transportation equipment. In many cases, unloading and movement to storage are handled as one operation. In others, they are separate processes, sometimes requiring special equipment. For example, ships are unloaded at dockside using cranes, and rail hopper cars are turned upside down with mechanical unloaders. Even

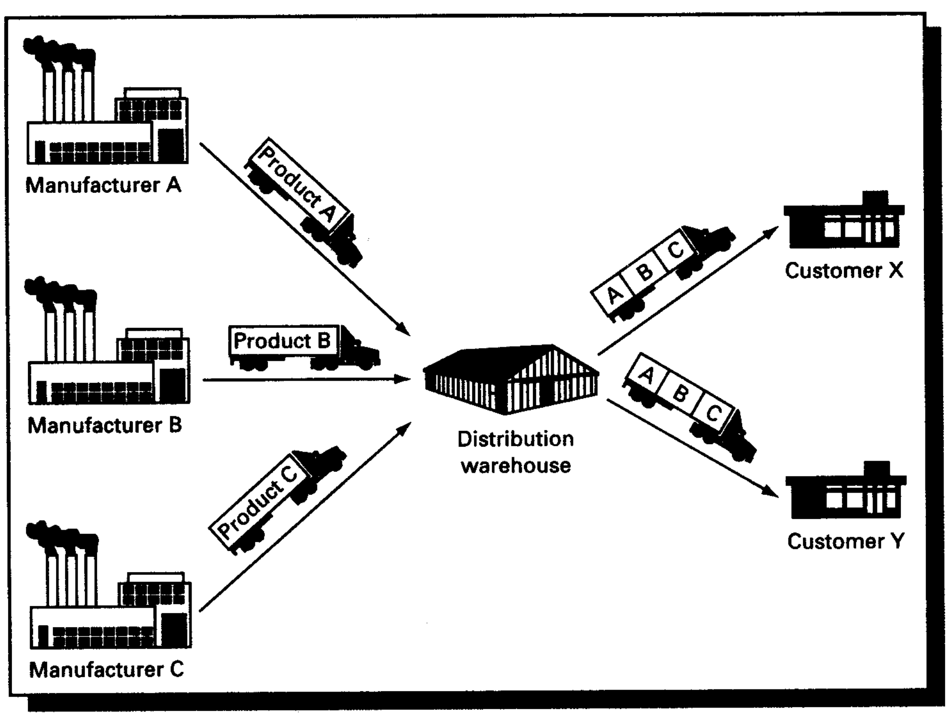


Figure 11-5 Generalized Example of a Distribution Warehouse Used for Product Mixing

when unloading equipment is not different from the equipment used to move goods to storage, unloading may be treated as a separate activity because goods may be offloaded and then sorted, inspected, and classified before moving on to a storage location in the warehouse.

Loading is similar to unloading; however, several additional activities may take place at the loading point. A final check concerning order content and order sequence may be carried out before the shipment is loaded onto the transportation equipment. In addition, loading may include an additional effort to prevent damage, such as bracing and packing the load.

Movement To and From Storage

Between the loading and unloading points in a storage facility, goods may be moved several times. Movement first is from the unloading point to a storage area. Next, movement proceeds from the shipping dock or from the order-picking area for stock replenishment. Using an order-picking area in the handling operation causes an additional movement link and nodal point in the storage system network, as was seen in Figure 11-1.

The actual movement activity can be accomplished using any number of the many materials handling equipment types available. These types vary from manual push trucks and carts to fully automated and computerized stacking and retrieval systems.

Order Filling

Order filling is the selection of stock from the storage areas according to the sales orders. Order selection may take place directly from semipermanent or bulk storage areas or from areas (called order-picking areas) that are especially laid out to enhance orderly materials flow in break-bulk quantities. Order filling is often the most critical materials handling activity because the handling of small-volume orders is labor intensive and relatively more expensive than the other materials handling activities.

STORAGE ALTERNATIVES

Storage may take place under a number of financial and legal arrangements. Each presents a different alternative to the logistician in evaluating his or her logistics system design. Four distinct alternatives are important, though various combinations of the four can create an almost infinite variety. The basic alternatives are ownership, rental, lease, and store in transit.

Space Ownership

Most manufacturing firms and service organizations own storage space in some form, ranging from a back room for office supplies to a finished goods warehouse with space in the hundreds of thousands of square feet. However, the common feature is that the firm or organization has a capital investment in the space and in the facility's materials handling equipment. For this investment, the company expects a number of advantages:

1. Less expensive warehousing than is possible with renting or leasing, especially if there is high utilization of the facility most of the time.
2. A higher degree of control over warehousing operations, which helps to ensure efficient warehousing and a high level of service.
3. Private ownership may be the only practical alternative when the product requires specialized personnel and equipment, such as with pharmaceuticals and certain chemicals.
4. The benefits that accrue from real estate ownership.
5. The space may be converted to other uses at a future time, such as to a manufacturing facility.
6. The space may serve as a base for a sales office, private truck fleet, traffic department, or purchasing department.

In summary, private warehousing has the potential of offering better control, lower costs, and greater flexibility as compared with rented warehouse space, especially under substantial and constant demand conditions or where special warehousing skills are needed.

Rented Space

Thousands of firms are in the business of providing warehousing services to other businesses. These firms may be public warehouses, but they also can be third-party logistics service providers or freight forwarders, both providing warehousing as part of their service offerings. They perform many of the same services that are carried out under a private warehousing arrangement, that is, receiving, storage, shipping, and related activities. These warehouse providers are similar to common carriers in transportation and hold essentially the same relationship to the private warehouse as the common carrier holds to private truck fleet ownership.

Types of Warehouses

Warehouse types for company-owned warehouses exist in an almost infinite variety because of customized designs that follow specialized needs. In contrast, a public warehouse holds itself out to serve a wide range of company needs. Thus, when compared to private warehouses, public warehouses are far more standardized in space configuration and use of multipurpose equipment. Many such warehouses are converted facilities—often buildings that were previously used as manufacturing facilities.

Public warehouses can be classified into a limited number of groups.

1. *Commodity warehouses.* These warehouses limit their services to storing and handling certain commodities, such as lumber, cotton, tobacco, grain, and other products that easily spoil.
2. *Bulk storage warehouses.* Some warehouses offer storage and handling of products in bulk, such as liquid chemicals, oil, highway salts, and syrups. They also mix products and break bulk as part of their service.
3. *Temperature-controlled warehouses.* These are warehouses that control the storage environment. Both temperature and humidity may be regulated. Perishables, such as fruits, vegetables, and frozen foods, as well as some chemicals and drugs, require this type of storage.
4. *Household goods warehouses.* Storage and handling of household items and furniture are the specialty of these warehouses. Although furniture manufacturers may use these warehouses, the major users are the household goods moving companies.
5. *General merchandise warehouses.* These warehouses, the most common type, handle a broad range of merchandise. The merchandise usually does not require the special facilities or the special handling as noted above.
6. *Miniwarehouses.* These are small warehouses, having unit space from 20 to 200 square feet and are often grouped together in clusters. They are intended as extra space, and few services are provided. Convenient location to renters is an attraction, but security may be a problem.

In practice, a public warehouse may not strictly be any one of these types. For example, a general merchandise warehouse handling food products may find the operation of a refrigerated section a necessity. In addition, in some cases it is good practice to combine bulk storage with general merchandise storage.

Inherent Advantages

Public warehousing, or rented warehouse space, offers many advantages, a number of which are the opposites of those for privately owned warehouses. Several of these are noted as follows:

1. *No fixed investment.* The use of public warehousing requires no investment for the firm renting space. All warehousing costs to the using firm are variable, that is, in direct proportion to the extent that warehouse services are used. Having no investment in storage facilities is beneficial when a firm has other preferred uses for the capital or simply does not have the capital to invest in this manner.

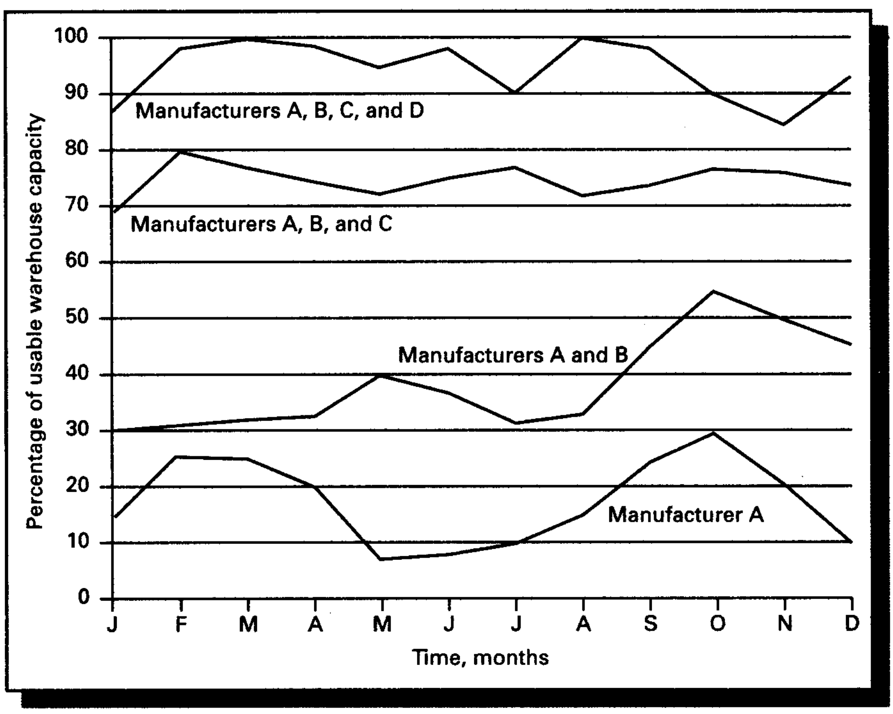
2. *Lower costs.* Public warehousing can offer lower costs than private or leased warehousing when the utilization of private space would be low, as when seasonal inventories must be stored. Inefficiencies may be encountered in private warehousing due to under- or overutilization of space. The public warehouseman attempts to counterbalance seasonal inventory patterns of a number of manufacturers and benefits from relatively constant and full utilization of capacity, as shown in Figure 11-6.

3. *Location flexibility.* Because arrangements with public warehouses are usually on a short-term basis, it is easy and inexpensive to change warehouse locations as markets shift. This lack of a long-term commitment offers important flexibility necessary to maintain an optimal logistics network.

Services

Public warehouses offer a wide variety of services to attract and retain customers. Most warehouses provide such basic services as receiving, storing, shipping, consolidating,

Figure 11-6 Balancing Seasonal Peaks and Valleys in Inventory Levels Among Several Manufacturers to Maintain Full Utilization of Usable Capacity in Public Warehouses



mixing, and break-bulk. Frequently, they offer much more. According to the American Warehousemen's Association, the following services can be expected from a public warehouse:

- Handling, storage, and distribution services, per package or per hundredweight
- In-transit storage
- U.S. Customs bonded storage
- U.S. Internal Revenue bonded storage
- Controlled temperature and humidity space
- Space rental on a square foot basis
- Office and display space; special clerical and telephone service
- Traffic information
- Handling and distribution of pool cars and consolidated shipments
- Physical inventories
- Modern data facilities
- Freight consolidation plan
- Packaging and assembly service
- Fumigation
- Marking, tagging, stenciling, wrapping
- Parcel post, UPS, and express shipments
- Dunnage and bracing
- Loading and unloading of cars and trucks
- Repairing, coopering, sampling, weighing, and inspection
- C.o.d. collections
- Compiling special stock statements
- Maintenance of and delivery to accredited customer lists
- Local and long-distance trucks
- Appliance delivery and installation
- Warehouse receipts forms, negotiable and nonnegotiable
- Overage, shortage, and damage reports prepared
- Prorating freight charges
- Prepaying of freight bills
- Credit information
- Loans on stored commodities
- Field warehousing services
- Waterborne freight terminal services
- Storage of machinery, steel, and other items requiring special handling equipment
- Yard storage
- Dry bulk commodity handling, storage, and bagging
- Liquid bulk handling, storage, drumming, and bottling
- Handling and storage of containerized materials[4]

Several of these services require special mention, either because they are unique to public warehousing or because they are important to potential users.

[4]American Warehousemen's Association, Chicago, IL.

Bonding arrangements are made with the government for certain goods, such as tobacco and liquor, on which taxes or duties are levied. The arrangement is between the merchandise owner and the government, whereby the goods cannot be removed from the warehouse (unless to another bonded warehouse) until the required taxes or duties are paid. The owner of the goods benefits by not having to pay the taxes or duties until the goods are sold, thus minimizing the capital tied up in inventoried goods. Public warehousemen acting as agents assure the government that goods claimed to be in the warehouse are actually there. The concept of bonding extends to goods stored in private warehouses as well.

The concept of bonding can be applied to goods entering the country that are destined for domestic or foreign markets. Free trade zones have been established around the country, usually in port areas. These fenced-in areas may contain manufacturing or warehousing facilities. A foreign company may land goods in the free trade zone, carry on light manufacturing, store the goods, and not pay import duties until the goods enter the country outside the zone. If the goods move on to foreign markets, no import duties are paid.

Field warehousing is a method by which the public warehouseman helps the owner of stored goods increase working capital. It is the conversion of private warehouse space to public warehouse space for securing credit. The public warehouse company usually leases from the owner of the goods a portion of the private warehouse in which goods are stored and issues a warehouse receipt. The owner then can use the receipt to obtain credit, using the goods as collateral for a loan. Because the goods are in legal custody of the public warehouseman, the public warehouse company acts as a third party to guarantee that the collateral for the loan exists. Establishing the warehouse on the owner's property saves the expense of moving the goods to a public warehouse and the storage expenses while in the warehouse. The arrangement is usually temporary, lasting the duration of the loan.

Stock spotting is a collective term for a number of activities related to order filling and is an extension of the break-bulk function. Public warehouses have responded to manufacturers' increasing need to provide a high level of customer service to wholesalers and retailers who maintain little inventory to meet their sales needs. Producers "spot" an assortment of their goods in public warehouses close to their markets. The public warehouse serves as a branch warehouse by performing all the functions normally handled by a producer's own warehouse. The order cycle time is considerably shortened compared with more centralized private warehousing that the producer may be using.

The public warehouseman may also assist in *inventory control*. With many stocks located around the country, keeping accurate records on inventory can be a problem, even if the company has its own record-keeping system. Public warehousemen help in this regard by keeping perpetual inventory balances, noting unsalable stock, noting stock damaged in transit, keeping records of stock arrival at the warehouse, and listing disbursements. Public warehouses use computers for much of the record keeping.

If the public warehouseman, or similar service provider, handles order processing and delivery for his customers, order tracking may also be a service. Such tracking information may interface with other information systems of the supply channel so that end customers can trace their order status from order entry to delivery.

We should not expect all public warehouses to provide the full range of services. Most are small, locally owned and operated enterprises. Only the largest of these have the resources for an extensive service offering. Therefore, it is important for the user of public warehousing services to be selective.

Documentation and Legal Considerations

Public warehouses are custodians of public property. With this responsibility, there are certain liabilities that the public warehouseman agrees to accept. From the standard contract terms and conditions approved by the American Warehousemen's Association, the following section on liability is highlighted:

> The warehouseman shall not be liable for any loss or injury to goods stored however caused unless such loss or injury resulted from failure by the warehouseman to exercise such care in regard to them as a reasonably careful man would exercise in like circumstances, and the warehouseman is not liable for damages which could not have been avoided by the exercise of such care.[5]

The essence of this statement is that the legal responsibility of public warehousemen is to exercise reasonable care in the handling and storage of the goods in their custody. If the damages or losses could not have been avoided through reasonable care, the warehouseman is not held liable unless specific contractual arrangements have been made to cover these. The merchandise owner may wish to extend his or her protection against liability and casualty through insurance protection or by writing into the contract with the public warehouse a provision for added liability, for which the warehouseman makes an additional charge.

Because public warehouses operate in the public interest, several states maintain regulatory control through a public utilities commission in the particular state. However, regulation is not as extensive as it once was and now involves warehouses only in California, Minnesota, and Washington. The Uniform Commercial Code, which covers public warehouses in all states except Louisiana, defines the responsibilities of the public warehouseman, and establishes uniformity in issuing warehouse receipts. In Louisiana, the Uniform Warehouse Receipts Act defines the responsibilities of warehousemen.

Several types of documentation become important to the smooth public warehouse operation. The principal documents are the warehouse receipt; the bill of lading; the over, short, and damage report; and the inventory status report.

The *warehouse receipt* is the primary document identifying what is being stored, where the goods are stored, who owns the goods, to whom they are to be delivered, and the terms and conditions of the storage contract. The contract terms and conditions, specified under the Uniform Commercial Code or the Uniform Warehouse Receipts Act, typically appear on the back of the warehouse receipt.

[5]Ibid.

Warehouse receipts may be negotiable or nonnegotiable. The difference lies in the ease of passing the goods from one person to another. A nonnegotiable receipt is issued to a designated person or company. The goods cannot be passed to another person without written instructions to the warehouse to release the goods. In contrast, the negotiable receipt may be issued to a person or company, or it may not be issued to any specific person. It may simply pass from one person to another by endorsement of the receipt. The warehouseman releases the goods to whoever holds the receipt. The negotiable feature of the warehouse receipt makes it easy to use the goods as collateral for a loan.

The *bill of lading* is the contract document used in the movement of goods. It spells out the terms and conditions under which a carrier moves goods. Because origin, public warehouse, and destination location of goods are usually separated, the public warehouseman often issues this document on behalf of the owner of the goods.

The *over, short, and damage (O.S.&D.) report* is issued upon receipt of the goods at the warehouse, and only if goods do not arrive in good condition or as stated on the bill of lading. The O.S.&D. report serves as a basis for filing a claim with a carrier.

The *inventory status report* shows the inventory position in the warehouse at the end of the month in terms of item, quantity, and weight. It also may be used as the basis for computing storage charges.

Leased Space

Leasing space for many firms represents an intermediate choice between short-term space rental in a public warehouse and the long-term commitment of a private warehouse. The advantage of leasing storage space is that a lower rate may be obtained from the space owner. However, because the space user must guarantee, through a lease contract, that space rental for a specified time will be paid, some location flexibility is lost. However, depending on the length of the lease, the user may also have control over the storage space and the associated operations, which is to the user's advantage.

Storage space for lease may be obtained in a variety of ways. Public warehousemen may offer extended time contracts on their space. Space may be available from manufacturers who cannot fully utilize their private warehouses. Third-party logistics providers offer warehouse space as well as other logistics services. Finally, owners of private warehouses may find it to their advantage to sell their warehouses and lease them back from the buyers.

Storage in Transit

Storage in transit refers to the time that goods remain in the transportation equipment during delivery. It is a special form of warehousing that requires coordination with the choice of a transportation mode or service. Because different transportation choices mean different transit times, it is possible for the logistician to select a transportation service that can substantially reduce or even eliminate the need for conventional warehousing. This alternative is particularly attractive to those companies dealing with seasonal inventories and shipments over long distances.

Example

The United Processors Company harvests and processes a variety of fruits and vegetables in southern and western farming regions of the country. For products such as strawberries and watermelon, there tends to be strong demand in the East and Midwest just ahead of the local growing season. Because United Processors must harvest earlier than in the northern climates, supply builds before demand peaks. Inventories normally build in the growing areas before truck shipments are made to the demand areas. By switching to rail service and the longer transit times associated with it, the company could, in many cases, ship immediately after harvesting and have the products arrive in the marketplace just as strong demand develops. The railroad serves the warehousing function. The result is a substantial reduction in warehousing costs and transportation costs as well.

MATERIALS HANDLING CONSIDERATIONS

Materials handling considerations are an integral part of the storage space decision. If the choice is public warehousing, compatibility of the company's materials handling system with that of the public warehouse is a prime consideration. If a company-controlled warehouse is selected, the efficiency of the entire materials-handling operation is of concern. Materials handling is largely a cost-absorbing activity, although it has some impact on the customer's order cycle time and, therefore, on customer service. Thus, the objectives for materials handling are cost centered, that is, to reduce handling cost and to increase space utilization. Improved materials-handling efficiency develops along four lines: loading unitization, space layout, storage equipment choice, and movement equipment choice.

Load Unitization

A fundamental principle in materials handling is that

> generally, materials handling economy is directly proportional to the size of load handled.[6]

That is, as the load size increases, the fewer the number of required trips to store a given quantity of goods and the greater the economy. The number of trips relates directly to the labor time necessary to move goods, as well as the time that the materials-handling equipment is in service. Efficiency often can be improved through consolidating a number of small packages into a single load and then handling the consolidated load. This is referred to as load unitization and is most commonly accomplished through palletization and containerization.

[6]Stanley M. Weir, *Order Selection* (New York: American Management Association, 1968), pp. 4–5.

Palletization

A pallet (or skid) is a portable platform, usually made of wood or corrugated cardboard, on which goods are stacked for transportation and storage. Goods are often placed on pallets at the time of manufacture and they remain palletized until order filling requires breaking the bulk quantities. Palletization aids movement by permitting the use of standardized mechanical materials handling equipment to handle a wide variety of goods. Further, it aids in load unitization with a resulting increase in weight and volume of materials handled per worker-hour. It also increases space utilization by providing more stable stacking and, hence, higher stacks in storage.

Pallets may be made in any desired size. The most popular size in the United States is 40 by 48 inches, which allows two pallets to be placed side by side in a standard container or truck trailer. Additional common sizes are 32 by 40 inches, 36 by 42 inches, and 48 by 48 inches. Other countries do not necessarily use these sizes. For example, Australia has a standard pallet size of 46 by 46 inches and Brazil favors 1200 mm by 1000 mm. Pallet size and configuration depend on the size, shape, weight, and crushability of the goods and materials handling equipment capacity. In addition, choosing a pallet size should take into account compatibility within one's own materials handling system and compatibility with materials handling systems outside the firm that must also handle the goods, such as those of public warehouses and the firm's customers. After accounting for these needs, the largest suitable pallet size should be selected to minimize the number of pallets required and to minimize handling. Loading the pallet should take into consideration the distribution and stability of the load.

The pallet is an added cost item to the materials handling system. It must be justified based on the savings realized from its use.

Containerization

The ideal in load unitization and materials handling system compatibility is the container. Containers are large boxes in which goods are stored and transported. They can be waterproofed and locked for security so that ordinary warehousing is not necessary. Storage can take place in an open yard. Standardized materials handling equipment can be used to move them, and they are interchangeable among different transportation modes.

Size standardization will be the key to widespread container use. Because of the many interest groups throughout the storage-transportation systems here and abroad, container sizes are still not standardized. Containers are expensive, and probably some cost-sharing plan and container-exchange program will need to emerge before containerization becomes a common materials handling method for other than international movements.

Space Layout

Location of stock in the warehouse directly affects the total materials-handling expense of all goods moving through the warehouse. A balance is sought between the materials handling costs and the warehouse space utilization. Specifically, there are storage space and order-picking considerations in internal warehouse design.

Layout for Storage

In warehouses where the turnover is low, the primary concern is to configure the warehouse for storage. Storage bays may be both wide and deep, and stacking may be as high as ceiling height or load stability permits. Aisles may be narrow. This layout assumes that the extra time required for moving stock in and out of storage areas is more than compensated for by the full space utilization.

As stock turnover increases, such a layout becomes progressively less satisfactory, and modification must be made to keep handling costs reasonable. Thus, aisles will tend to become wider and the stack height may be decreased. These reduce the time spent placing and retrieving the stock.

Layout for Order Picking

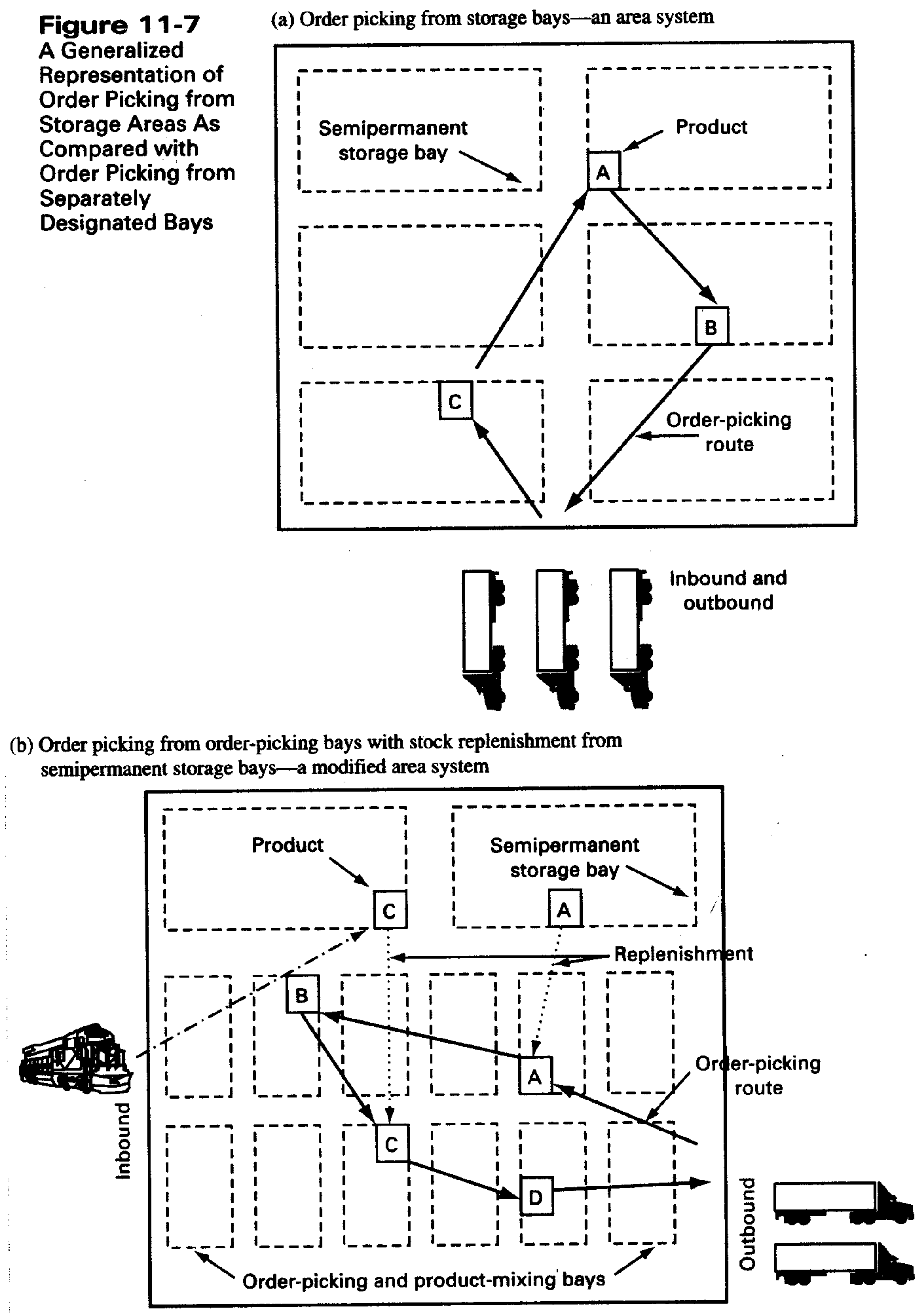
Because the usual flow pattern in a warehouse is for goods to come into the warehouse in larger unit quantities than they leave, order-picking considerations become prime warehouse layout determinants. A disproportionately greater amount of labor time can be spent on filling orders than on receiving and storing the stock. The simplest layout for order picking is to use existing storage areas (referred to as an *area system*), with any modification as to stacking height, location of goods relative to outbound docks, and bay size, as may be needed for efficiency [see Figure 11-7(a)]. If the turnover of goods is high and order filling requires breaking bulk, using storage bays to fulfill both storage and order-picking needs may result in higher than necessary materials handling costs and in poor warehouse space utilization. That is, the traveling time is great as long distances are encountered in routing through the warehouse to fill orders, unit loads are broken such that orderly stacking and placement of goods is diminished, and space utilization is reduced.

An alternate layout plan is to establish stock bays in the warehouse according to their primary function. This is called a *modified area system*. Certain warehouse areas would be designed around storage needs and full space utilization, while others would be designed around storage order-picking requirements and minimum travel time for order filling [Figure 11-7(b)]. The storage (reserve) bays are used for semipermanent storage. When stock is low in the order-picking bays, it is replenished with stock from the storage bays. With the exception of large, bulky items, which may still be picked from storage areas, all unit loads are broken in the order-picking area. Order-picking bays tend to be smaller than storage bays, often only two pallets deep or using storage racks half the size of those in the reserve section. The order-picking stack height is limited to a comfortable reach for the workers. Using order-picking areas separate from the reserve area will minimize the routing time and service time to fill orders.

Order-picking travel time may be further reduced through the choice of specialized order-picking equipment, such as flow racks, conveyors, towlines, scanners, and other materials handling equipment; and through operational design, such as sequencing, zoning, and batching. Because materials handling equipment will be discussed in a later section of this chapter, only operational considerations will be mentioned at this point.

Sequencing is the arrangement of items needed on an order in the sequence in which they appear on the order-picking route through the warehouse. Avoiding

Figure 11-7
A Generalized Representation of Order Picking from Storage Areas As Compared with Order Picking from Separately Designated Bays



backtracking saves order-picking time. This technique may be applied to both area and modified-area systems, however, it does carry a penalty. The sequencing must occur on the sales order itself through cooperation with the customer or salesperson, or else the product item data must be sequenced after the order is received.

Zoning refers to assigning individual order pickers to serve only a limited number of the stock items instead of routing them through the entire stock. An order picker may select the stock in a single aisle or designated area, filling only a portion of the total customer order. Although zoning permits balanced labor utilization and minimum travel time in order picking, it also has some shortcomings. First, it requires that stock be located in zones according to ordering frequency, item weight, item similarity, and the like so that the order picker workload is balanced. Second, sales orders must be subdivided and a picking list for each zone developed. Third, the various portions of the orders must be reassembled into a complete order before leaving the warehouse. If the order filling proceeds from one zone to another to avoid the problem of reassembly, then the order-picking pace becomes dependent on the order-picking pace in other zones.

Batching refers to the selection of more than one order on a single pass through the stock. This practice obviously reduces travel time, but it also increases the complication of reassembling orders and partial orders for shipment. It also may increase order-filling time for any one order because its completion is dependent on the number and size of the other orders in the batch.

Storage Equipment Choice

Storage and materials handling must be considered in concert. In a way, storage is simply a temporary halt in the materials flowing through a warehouse. Storage aids promote the full space utilization and improve the materials handling efficiency.

Probably the most important storage aid is the rack. Racks are shelves, usually of metal or wood, on which goods are placed. When a wide variety of items in small quantities must be stored, stacking loads one on top of another is inefficient. Racks promote floor-to-ceiling stacking, and the items on the top and bottom shelves are equally accessible, though items with high turnover should be placed near the bottom to reduce total service time at the rack. Racks also aid in rotating stock, as in a first-in-first-out inventory control system.

Other available storage aids include shelf boxes, horizontal and vertical dunnage, bins, and U-frames. All such equipment assists the orderly storage and handling of irregularly shaped products.

Movement Equipment Choice

A tremendous variety of mechanical equipment for loading and unloading, picking orders, and moving goods in the warehouse is available. Movement equipment is differentiated by its degree of specialized use and the extent that manual power is required to operate it. Three broad equipment categories can be distinguished: manual equipment, power-assisted equipment, and fully mechanized equipment. A combination of these categories is generally found within a materials handling system rather than a single category used exclusively.

Manual Equipment

Hand-operated, materials handling equipment, such as two-wheeled hand trucks and four-wheeled platform trucks, provides some mechanical advantage in movement of goods and requires only a modest investment. While much of this equipment can be used for a great many goods and under a wide variety of circumstances, some of this equipment is designed for special use, for example, carpet handling, furniture handling, and pipe handling.

In general, manual equipment's flexibility and low cost make it a good choice when the product mix in a warehouse is dynamic, the volume flowing through the warehouse is not high, and the investment in more mechanized equipment is not desirable. However, the use of this equipment is somewhat limited to the operator's physical capabilities.

Power-Assisted Equipment

Materials handling can be speeded up and the output per worker-hour increased with the use of power-assisted materials handling equipment. Such equipment includes cranes, industrial trucks, elevators, and hoists; however, the industry workhorse is the forklift truck and its variations.

The forklift truck is usually only one part of a materials handling system. It is combined with palletized loading and sometimes with pallet racks. The power-assisted equipment permits high load stacking (over 12 feet) and load movements of substantial size. The most common forklift truck has a lifting capacity of about 3,000 pounds. The use of the forklift truck, pallet, and rack in a modified area warehouse layout is shown in Figure 11-8.

The pallet and forklift truck materials handling system has high flexibility. The pallet permits a variety of goods to be moved with standard handling equipment. The system as a whole is not likely to become obsolete or require expensive modification as storage requirements change. In addition, because only a modest investment is required, the system is a popular one.

Fully Mechanized Equipment

With computer-controlled handling equipment, bar coding, and scanning technology, some materials handling systems have been developed that come close to full automation. Such systems are referred to as *automated storage and retrieval systems*, or AS/RS, for short. They represent the most extensive application of technology of all the materials handling alternatives.

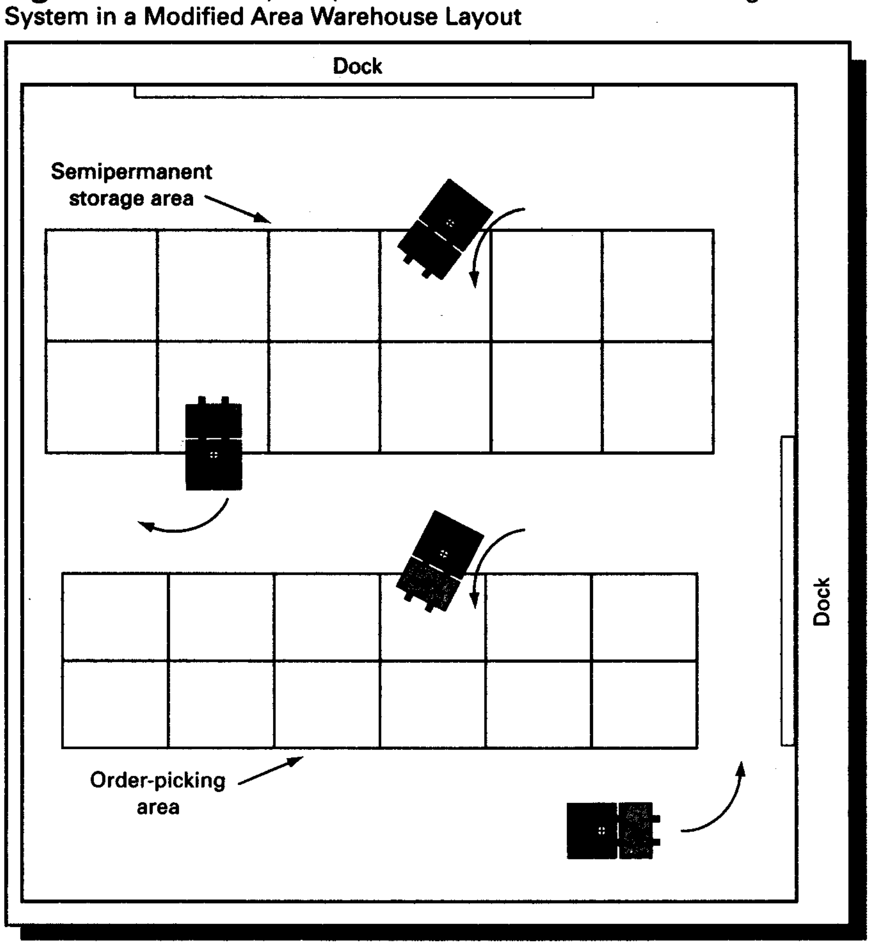
Applications

- At the peak of trading stamp popularity, the huge S&H Green Stamp Distribution Center in Hillsdale, Illinois, served more than 150 stamp redemption centers, stocked 2,000 items from 700 suppliers, and processed more than 16,000 cartons during a single 7 1/2-hour shift. A computerized conveyor system was used to move goods from order-picking areas, to police the flow of orders through the conveyor system, and to control the accumulation of orders at the dock.

- The handling system at Rohr Corporation, which handles 90,000 aircraft parts, represents a step closer to a fully automated storage and retrieval system. With the exception of the shipping and receiving area and the audit area for paperwork and load checking, incoming loads are moved via conveyor to storage racks, stored in racks by automated cranes, and retrieved by the reverse process. A schematic diagram of this system is shown in Figure 11-9.

Stories of high-tech materials handling can excite the imagination, but an AS/RS is not a good alternative for most warehouse operations. Unless a constant

Figure 11-8 Pallet, Rack, and Forklift Truck Materials Handling System in a Modified Area Warehouse Layout



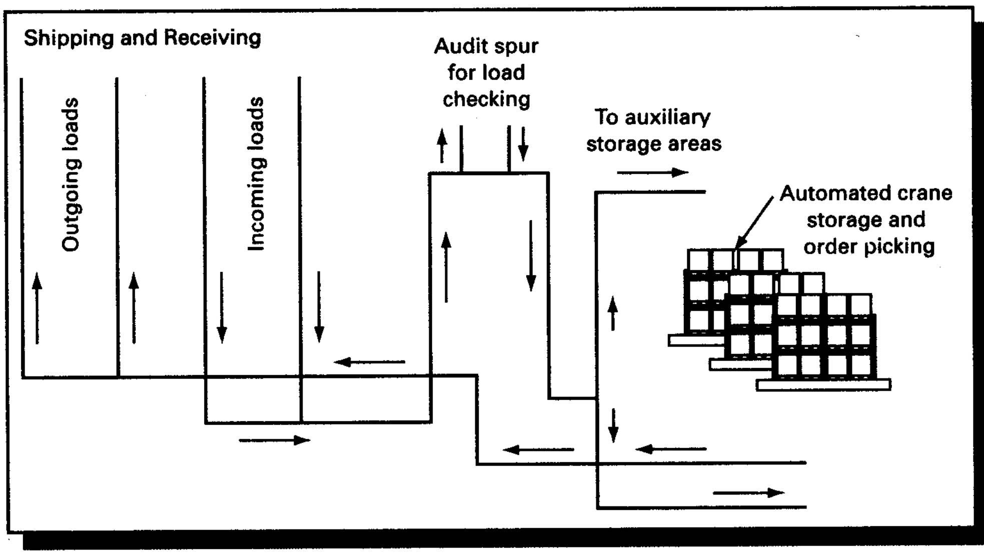


Figure 11-9 Schematic Diagram of an Automated Warehouse

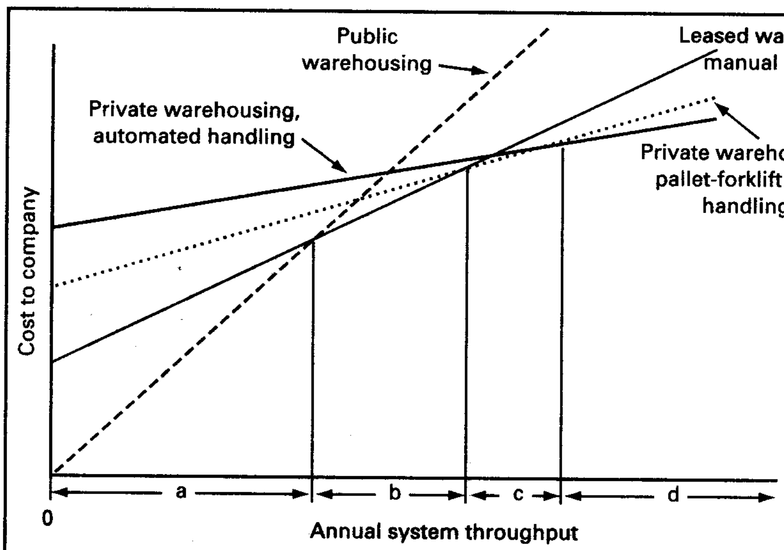
and substantial volume flows through a warehouse, it is difficult to justify the large investment required for such systems. In addition, they have the following drawbacks: inflexibilities in terms of future product mix and volume and in terms of warehouse location, and mechanical failures that can shut down the entire system. However, given favorable circumstances for its development, the fully mechanized warehouse offers more potential for lower operating costs and for faster order picking than any other type of materials handling system.

Storage System Costs and Rates

A company must pay storage system costs either through rates charged by an outside firm offering such services or through internal costs generated from the particular materials handling system in a company-controlled warehouse. To provide an overview of the various storage system costs, four different systems are noted: public warehousing; leased warehousing, manual handling; private warehousing, pallet and forklift truck handling; and private warehousing, automated handling. Each represents a different level of fixed and variable costs, as shown in Figure 11-10. Note that this is not an exhaustive list of all possible combinations of space alternatives and handling methods.

Public Warehousing

With the exception of a few states (for example, Washington and Minnesota) where public warehouse rates are disclosed to the public, warehouse rates are confidential



[a] Economical range for public warehousing.
[b] Economical range for leased warehousing, manual handling.
[c] Economical range for private warehousing, pallet–forklift truck handling.
[d] Economical range for private warehousing, automated handling.

Figure 11-10 Generalized Total Cost Curves for Four Alternative Storage Systems

and a matter of negotiation between the warehouseman and the customer. The agreed-upon rate will be based on such factors as the volume of goods to be handled and stored; the time the warehouse space will be needed; the number of separate items in the product mix; any special requirements or restrictions for storage; the average outbound order size; and the amount of clerical work required.

These cost factors are generally grouped into three basic categories: storage, handling, and accessorial costs. Each exhibits different characteristics and usually separate rates are quoted in the three areas. Specifically, storage rates are often quoted on a per hundredweight, per month basis. The monthly rate reflects the time dimension of storage. In contrast, handling rates are typically quoted on a per hundredweight basis. The number of times that the goods must be handled is the important dimension in handling costs. Clerical costs are charged to the customer on a direct basis. For example, bill of lading preparation costs are charged on a per bill basis.

Public warehousemen may use several other methods of quoting rates:

1. On a per case basis with an in and out per case charge for handling
2. By the actual space merchandise occupies, usually computed on a square foot or cubic foot basis
3. By a lease agreement for space and a contract for the handling function by the warehouse personnel

In all cases except method 3, the customer is billed monthly unless other arrangements have been made.

Public warehousing to the customer is an all-variable-cost storage system. If a company generates a substantial and steady volume of business, public warehousing may become more expensive than private warehousing. Flexibility and improved customer service may be reasons for selecting public warehousing, even if an alternative's costs are higher.

Leased Warehousing, Manual Handling

Another storage system type is to combine leased warehousing space with manual materials handling. Though leasing is a long-term commitment compared with public warehousing, the charges for the space are incurred at regular intervals, so leased space can be treated as a variable cost for a given warehouse throughput. Handling equipment requires a modest investment, if the equipment is company owned, that must be amortized over time. Labor costs tend to be substantial for this system, which imparts a strong variable cost component into the total storage system cost curve (Figure 11-10).

Private Warehousing, Pallet and Forklift Truck Handling

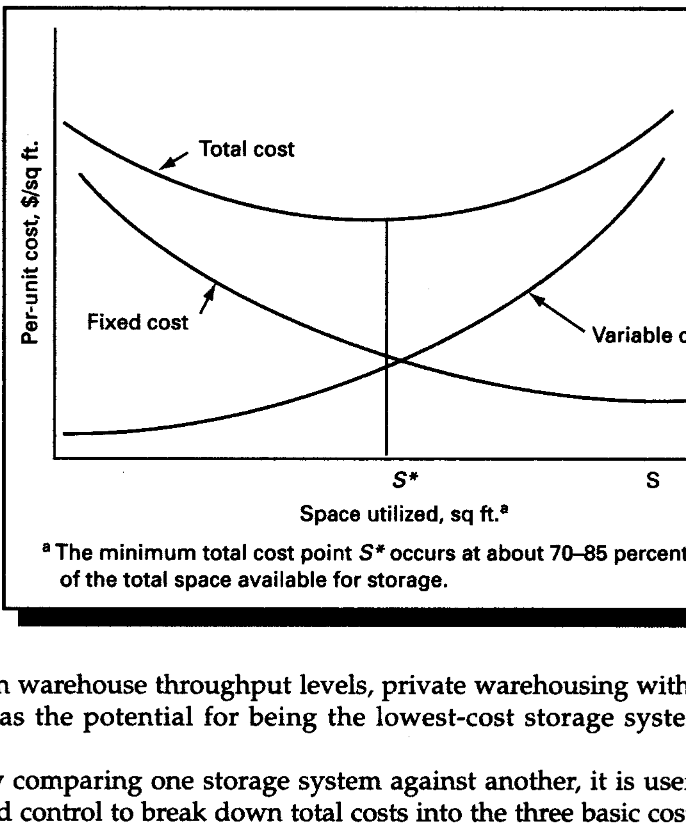
This is a commonly chosen alternative to public warehousing. All costs within this system are internal company costs, provided that handling equipment is not leased or rented. Owning both warehouse and equipment introduces a substantial fixed-cost level in the total cost curve, as shown in Figure 11-10. High levels of mechanization in handling and low direct costs for operating a private warehouse mean low variable costs. However, substantial volume is needed before this alternative becomes economically viable, as compared with those alternatives noted previously.

The pattern of throughput for a private (or leased) warehouse is important in assessing the costs for the storage system. Seasonal variations in warehouse usage cause capacity under- and overutilization. During periods of low utilization, there is idle capacity and indivisibilities of some labor units that create high variable costs. Conversely, straining the warehouse capacity limits again causes high variable costs as materials handling inefficiency and damage to the stored goods increase. (The typical private warehouse per unit cost curve is shown in Figure 11-11.) Therefore, the cost level associated with this alternative depends on the extent of warehouse utilization and the diseconomies caused from fluctuating warehouse throughput.

Private Warehcusing, Automated Handling

In terms of costs, the private warehouse, automated handling storage system is a limiting case of the other alternatives mentioned. It represents a high level of fixed investment in the warehouse and the automated handling equipment, such as computer-controlled conveyors and cranes, and a low level of variable costs, as the system requires little in the way of labor, light, heat, and the like. As Figure 11-10

Figure 11-11
Typical Per Unit Cost Curves for a Privately Owned Storage System Using Automated Handling



ª The minimum total cost point S^* occurs at about 70–85 percent of the total space available for storage.

shows, at very high warehouse throughput levels, private warehousing with automated handling has the potential for being the lowest-cost storage system per throughput unit.

Beyond simply comparing one storage system against another, it is useful for further analysis and control to break down total costs into the three basic cost components in a storage system: storage, handling, and clerical costs. For the public warehouse, these costs provide the basis for establishing rates and providing a ready comparison with the public warehousing alternative. In the private warehouse, they are valuable for controlling the various expenses. Allocation of the various costs incurred in warehouse operation requires a good deal of judgment. One such allocation is illustrated in Table 11-2. Once total storage, handling, and clerical costs are identified, they can be expressed on a per hundredweight basis, a square-foot basis, or any other useful dimension.

Virtual Warehousing

An extension of the concept of a virtual inventory is the virtual warehouse. Whereas virtual inventories satisfy customer requests from alternate inventories in a company's logistics system, a virtual warehouse is one where not all items for sale are stocked in a company's warehouse. Rather, selected items are shipped directly to customers from supplier inventories with no intention of a company stocking them. Some items that are stockout in the warehouse may be handled in a similar manner. Consider a company such as Amazon, which stocks high-volume book titles in its own warehouse but cannot practically stock low-volume and rare titles. Alternately,

Table 11-2 Allocation of a Set of Warehouse Expense Items Into Basic Storage System Cost Categories

Account Code	Account Name	Total	Storage	Handling	Clerical	G & A[b]
1	Rent	$16,281	$13,980	$1,345	$ 506	$ 450
2	Taxes—payroll[a]	2,390[a]	63[a]	1,187[a]	810[a]	330[a]
3	Taxes—highway	10		7	3	
4	Taxes—real estate	2,259	1,852	313	94	
5	Taxes—franchise	775	275			500[a]
6	Maintenance—building	225	25		200	
7	Maintenance—elevator	50	50			
8	Maintenance—tools and equipment	185	70	115		
9	Maintenance—furniture	60			50	10
10	Maintenance—air conditioning	1,500	1,400	50	50	
11	Utilities	950	380	190	380	
12	Insurance—liability[a]	222[a]	4[a]	75[a]	101[a]	42[a]
13	Insurance—worker's comp.[a]	691[a]	35[a]	652[a]	3[a]	1[a]
14	Insurance—other	80	25	26	29	
15	Insurance—group	847[a]	24[a]	434[a]	262[a]	127[a]
16	Labor[a]	34,170[a]	1,200[a]	23,550[a]	9,420[a]	
17	Salaries	6,500				6,500
18	Dues and subscriptions	150				150
19	Motor equipment	500				500
20	Demurrage	110	110			
21	Donations	25				25
22	Legal and accounting	100				100
23	Loss and damage	700	10	690		
24	Miscellaneous	573	33	4		536
25	Packing materials	295		295		
26	Postage	175		25		150
27	Bad accounts	210				210
28	Stationery—supplies	350			350	
29	Telephone	1,125				1,125
30	Subcontracts	500	500			
31	Equipment rental	175		175		
32	Travel	800				800
33	Equipment interchange		200	(200)		
34	Gasoline and oil	400		300	100	
35	Amortization—organization expense	500				500
36	Tires	30		30		
37	Depreciation expense	4,857	507	4,209	141	

Table 11-2 (*cont.*)

Account Code	Account Name	Total	Storage	Handling	Clerical	G & A[b]
38	Garage	500		500		
39	Subtotals	79,270	20,743	33,972	12,499	12,056
40	Prorata G & A		3,721	6,093	2,242	(12,056)
41	Total expense	$79,270	$24,464	$40,065	$14,741	

[a]Denotes labor and labor-related expenses.
[b]General and administration expenses.
Source: Howard Way and Edward W. Smykay, "Warehouse Cost Analysis," *Transportation & Distribution Management*, Vol. 4 (July 1964), p. 32.

the handling is contracted to third parties or shipments are made directly from vendors. The result is that less investment is needed in the logistics infrastructure while high levels of customer service are maintained.

Since the intention is not to stock all products being sold, handling customer orders might proceed as follows: Say, an order contains seven items. The company's order management system (OMS) identifies that two of the items are in the warehouse and sends the requested items to the company's warehouse management system (WMS) for picking, packing, and shipping from a company owned and operated warehouse. Requests for the remaining items are sent to vendors who hold physical inventories of the items. Each vendor's OMS transfers the order request to its WMS for processing.

A key to using the virtual warehousing concept effectively is sharing critical information with vendors. The seller shares information with vendors on what is in transit, what is in the warehouse, what is on order. The vendor, in turn, shares production schedules and his own inventory status. This instant visibility of product availability, often with communication through a Web site, allows quick response to customer demand trends and minimizes capital investment in inventory and warehouses.

Example

Land's End maintains its own well-stocked warehouses, but the catalog retailer also depends on vendors who ship direct to customers. Also an Internet retailer, Land's End uses a demand management process to distribute forecasts to suppliers on a regular basis. Suppliers share their production process with Land's End, which, in turn, distills the information down to product availability dates for customers. Land's End refers to this process of inventory control as *net position management*.[7]

[7]Helen L. Richardson, "Virtually Connected," *Transportation & Distribution* (March 2000), pp. 39–44.

Concluding Comments

This chapter provides a brief overview of the storage and handling system in a supply chain network. The discussion is directed toward the types of systems available, the functions they serve, and their inherent advantages. Storage and handling alternatives are also discussed along with their associated costs. This is the storage and handling system environment. Logistics decision making draws upon this information in generating reasonable courses of action.

Questions

1. Why does the logistician consider the storage system an economic convenience rather than a necessity?
2. Why is the storage system a micrologistics system problem? Compare the storage system with the logistics system network in Figure 2-4.
3. Compare and contrast private ownership of storage space to rented storage space with reference to the following:
   a. Services that can be realized from each
   b. Cost for storage
   c. Degree of administrative control
   d. Flexibility in meeting future uncertainties

   Under what general circumstances is private warehousing a better choice than public warehousing?
4. How is storage in transit an alternative to conventional warehousing?
5. What benefits does containerization offer over conventional forms of load unitization? Why is it not more widely used?
6. For the following situations, indicate whether an area or modified-area layout of a warehouse would likely be used and why.
   a. A food distribution center
   b. A furniture warehouse
   c. Storage of major appliances
   d. Storage of a steel company's products
   e. A drug and sundries distribution center
7. Explain and define the following:
   a. Stock spotting
   b. Negotiable warehouse receipt
   c. O.S.&D. report
   d. Containerization
   e. Unitization
   f. Bonding
   g. Field warehousing
   h. Palletization
   i. Automated storage and retrieval systems
   j. Order picking
   k. Storage in transit
   l. Breaking bulk
   m. Zoning

8. How does storage contribute to the time value of goods? Explain.
9. How can a materials handling system overcome the disadvantages of size, configuration, and shape of storage space?
10. Explain what the logistician should generally know about the storage and materials handling system.
11. What is virtual warehousing? When is it likely to be used? What is required for it to work well?

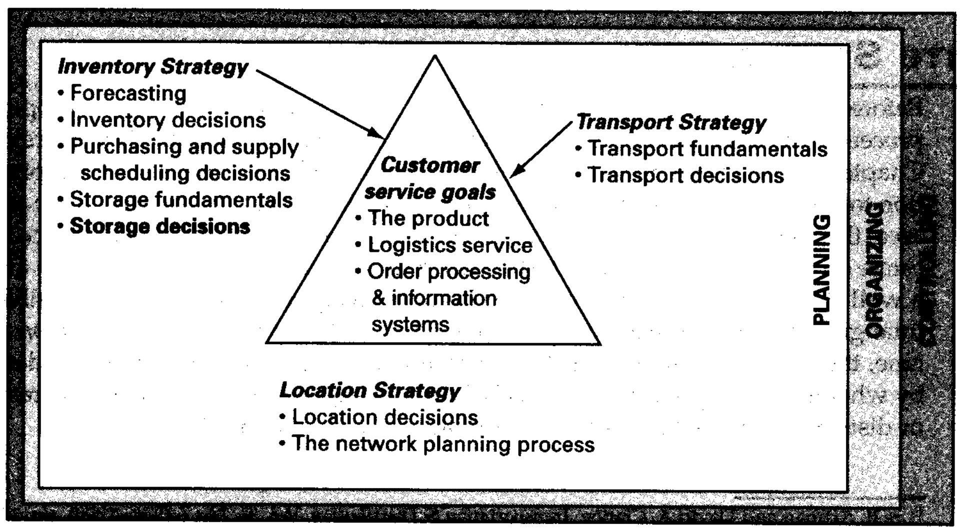
Chapter 12

Storage and Handling Decisions

[illegible] perfection, [illegible]

—VINCE LOMBARDI

The logistician often becomes involved with activities that supplement a firm's primary move-store activities. Storage and materials handling are such activities. They can be quite important since they affect the time that it takes to process customer orders in the distribution channel or to make supplies available in the supply channel. They are cost absorbing and worthy of careful management.



Although storage and handling do not play the same role in all logistics systems, this chapter focuses on these activities as they take place in warehouses and other locations where inventories are held. Warehousing displays the full range of storage and handling decisions that are included in various logistics systems.

The importance of warehousing activities was previously documented. As shown in Table 1-3, storage and materials handling activities account for roughly one-fourth of logistics expenses, excluding the cost of carrying inventories. Of this expense, approximately one-half is for labor, one-fourth is for space, and the remaining is for energy, equipment, material, and other. Neglecting to manage these activities effectively can result in inefficiencies that outweigh gains in good management of such key activities as transportation, inventory maintenance, and information flow. Many storage and handling activities are repetitive, so careful management can produce substantial economies and customer service improvements over time.

We want to consider the planning problems for the design and operation of the nodal points in the logistics network. Nodal points usually are represented by warehouses. However, nodal points also may refer to inventory accumulations in whatever form they may take, whether held outdoors, underground, or within partially protecting shelters. Because warehousing is a complex and widely used storage form, the major emphasis will be on warehouse design and its operation, with implications for other methods of storage and handling. Specifically, this chapter deals with planning for facility design, which includes facility sizing, financial type, configuration, space layout, dock design, materials handling system selection, and stock layout. An overview of storage and handling activities was presented in Chapter 11, and this chapter continues by dealing with many of the associated decisions.

SITE SELECTION

Before a discussion of the detailed decisions about warehouse design and operation proceeds, the question of where the warehouse is to be located needs to be resolved. Chapter 13 presents a number of mathematical models that give a rough approximation to final location in terms of a region, metropolitan area, or city. Within the defined area, the specific site must be selected. Site selection refers to the specific piece of real estate on which the facility will be located, and its methodology is more of an art than a well-defined process. It frequently involves weighing a number of tangible and intangible factors. From a survey of the readers of *Transportation & Distribution* magazine, the most important site selection factors for a distribution center are identified by whether the responding member's firm was engaged in manufacturing, retailing, or distributing.[1] The factors and their ranking are shown in Table 12-1.

[1] Les B. Artman and David A. Clancy, *Transportation & Distribution*, Vol. 31, No. 6 (June 1990), pp. 17–20.

Factor	Overall	Manufacturer	Retailer	Distributor
Transportation access	1	1	2	1
Outbound transportation	2	2	3	5
Customer proximity	3	3	6	6
Labor availability	4	5	1	3
Labor costs	5	6	7	4
Inbound transportation	6	4	4	2
Union environment	7	7	5	9
Taxes	8	8	10	7
State incentive/laws	9	10	—	—
Land costs	10	—	8	8
Utilities	—	—	9	10
JIT requirements	—	9	—	—

Source: Les B. Artman and David A. Clancy, *Transportation & Distribution*, Vol. 31, No. 6 (June 1990), p. 19.

Table 12-1 Distribution Center Site Selection Factors by Industry Type

The cold supply chain project of the Container Corporation of India Limited (CONCOR) for setting up a chain of 14 controlled atmospheric storage plants is finally ready to take off, with the state-owned company finalizing the location for its first plant. It is intended to make Indian farm products competitive in the global market by selling fresh fruits and vegetables. These cold storages, which will have deep freeze storage, will allow for sorting and packing facilities. The plant will be set up in Haryana and is expected to be ready by early 2007. Apple growers from Himachal Pradesh will be the first users of the proposed storage plant at Rai.[2]

Of course, when the warehouse already exists, as in the case of a public warehouse or a facility to be leased, selection is usually restricted to the available facilities. When selection is among public warehouses, site selection is concerned with rates and services to be provided. On the other hand, selecting a facility to be leased involves many of the factors just noted, but the physical characteristics of the buildings to be leased also act as constraints on warehouse operations.

Planning the private warehouse offers the maximum design flexibility of all the warehousing alternatives. Thus, the following discussion of the planning for design and operation is directed primarily toward the privately operated warehouse.

Planning for Design and Operation

Planning for facility design is concerned with the long-range decision making needed to establish the facility for efficient temporary product storage and the flow of products through the facility. Such decisions often require a substantial capital

[2]Available at http://www.etintelligence.com/etig/productsandservices/.

investment that commits the company to a design for many years. However, careful design planning can mean years of efficient warehouse operation.

Sizing the Facility

Size is probably the most important factor in designing a storage facility. Once warehouse size is determined, it acts as a constraint on warehouse operations that may last 20 years or longer. Whereas internal facility layout may be changed with relative ease, altering overall size is much less likely to occur. Although the facility may be expanded later or unused space may be leased to other users, the resulting quality of the space may not be ideal. In general, the result of poor size planning is either to cause higher than necessary materials handling costs (in the case of underbuilding), or to force unnecessary space costs on the logistics system (in the case of constructing more space than needed).

Specifically, what is size? Size simply refers to the overall cubic content of the building—its length, width, and height. Determining the needed building volume is a task complicated by the many factors that affect the size decision. Such factors as the type of materials handling system to be used, aisle requirements, stock layout arrangements, dock requirements, local building codes, office area, and product throughput (both now and in the future) influence the final choice of building size. A starting point is the minimum space required for accommodating the inventory stored in the building over time. The remaining factors influence size by adding to the basic inventory-determined size.

Let us look at inventory-determined warehouse size under two different conditions. The first is when there will be no significant changes in the need for space in the reasonable future. No trend in space needs is expected. However, in the short term there will be seasonal changes in space needs as sales through the warehouse and warehouse stock replenishment vary throughout the year. The second is when average inventory levels are anticipated to change over a period of years. This dynamic sizing problem seeks the best size for the warehouse in each year of the planning horizon.

Before a detailed sizing analysis is carried out, a company typically has made its general location decision, although not necessarily its site selection decision. In the location analysis, it is necessary to assign sales territories to warehouses. This assignment is the basis for projecting the product throughput (demand) for the warehouse. With this throughput and the warehouse's inventory turnover ratio, the amount of inventory can be estimated. Rough warehouse size approximations can be made from these inventory needs, and further analysis begins with this preliminary information.

The No-Trend Sizing Problem

There are generally two basic choices for warehousing. The first is to rent space, such as from a public warehouse or subcontracted operation. The second is to operate owned or leased warehouse space. Depending on which is least expensive, a company may use only one type, assuming there is little fluctuation in the space needs over time. However, when space requirements fluctuate widely, there is the possibility that a mixed strategy would be better. If privately operated space is sized to peak