CHAPTER 1: INTRODUCTION TO MATERIALS MANAGEMENT

What is wealth? GDP = production = profits

What is the source of wealth? The conversion process is the source of wealth; it is the residual of sales minus cost called profit.

How can we increase our wealth? Value-added conversion process, called manufacturing or production, makes a society wealthier and creates a better standard of living.

How can we add value? Efficient production processes that are managed effectively.
  • Managing the operation means planning and controlling the resources: labor, capital, and material.
  • Flow of materials controls the performance of the process. The right materials in the right quantities are not available at the right time, the process cannot produce what it should.

Operating environment (the external environment)

Organizations operate in environments that are influenced by many factors.

1. Government = laws and regulation
2. Economy = % rate, business cycles, and demographics
3. Competition = global and virtual
4. Customers = fickle, price, delivery, etc.
5. Quality = a moving target

Additional operating environmental criteria include:

1. Order qualifiers customer requirements may be based on price, quality, delivery, and so forth.
2. Order winners are characteristics that encourage customers to choose its products and services over competitors'. They provide a competitive advantage for the firm.
**Manufacturing strategy**

A highly market oriented company must have a strategy that allows it to supply the needs of the marketplace and provide fast on-time delivery. Customer involvement in the product design, delivery lead-time, and inventory are influenced by each strategy. Figure 1.1 page 4 shows the effect of each strategy on delivery lead-time.

There are four basic manufacturing strategies:

1. **Engineer-to-order** means that the customer's specifications require unique engineering design or significant customization. Delivery lead-time is long because it includes not only purchase lead-time, but design lead-time as well.

2. **Make-to-order** means that the manufacturer does not start to make the product until a customer's order is received. Delivery lead-time is reduced because there is little design time required and inventory is held as raw material.

3. **Assemble-to-order** means that the product is made from standard components that the manufacturer can inventory and assemble according to a customer order.

4. **Make-to-stock** means that the supplier manufactures the goods and sells from finished goods inventory. Delivery lead-time is shortest. The customer has little direct involvement in the product design.

**The supply chain concept**

There are three phases to the flow of materials as shown in Figure 1.2 on page 5.

- Phase 1: raw materials flow into a manufacturing company from a physical supply system
- Phase 2: manufacturing processes add value to materials
- Phase 3: finished goods are distributed to end consumers through a physical distribution system

This system constitutes the supply chain. Important factors of the supply chain include:

1. Includes all activities and processes to provide a product or service to the customer.
2. Any number of organizations can be linked by the “chain”
3. Customers’ and suppliers are interchangeable
4. The chain can contain any number of intermediaries but material usually flows from producer to customer
What is the current supply chain concept?

The supply chain can be viewed as linked chain of activities which results in a network of suppliers and distributors for every product. Three critical issues emerge:
1. Flow of materials.
2. Flow of information, mostly electronically.
3. Fund transfers.

To manage a supply chain one need to manage information. Page 10 Figure 1-3

Conflicts in traditional systems

To get the most profit (profit = revenue – expense), a company must have at least four main objectives:
1. Provide best customer service.
2. Provide lowest production costs.
3. Provide lowest inventory investment.
4. Provide lowest distribution costs.

These objectives create conflict among the marketing, production, and finance departments because each has different responsibilities in these areas. Review Figure 1.3 page 10.

One way to resolve conflicting objectives is to condense the responsibilities of the supply, production, and distribution functions into a single area of responsibility called logistics.

Materials management

Is the area of responsibility for material flow from supplier through production to the customer. Its objectives are as follows:
1. Maximize the use of the firm's resources.
2. Provide the required level of customer service.

Materials management can do much to improve a company's profit (see pages 11 –12).

Reducing cost (through effective materials management) contributes directly to profit. Increasing sales increases direct costs of labor and materials so profit does not increase directly.
Manufacturing Planning and Control

The primary activities are as follows:
1. Production planning which involves:
   A. Forecasting.
   B. Master planning.
   C. Material requirements planning.
   D. Capacity planning.
2. Implementation and control involves putting into action and achieving the plans made by
   production planning.
3. Inventory management aids in providing a buffer against the differences in demand rates
   and production rates.

Production planning, implementation, control, and inventory management work together
managing inventories if the organization is to be effective.

Inputs to the manufacturing planning and control system include:

1. The product description and its bill of materials. As used in materials management, this
document does two things:
   • describes the components used to make the product.
   • describes the subassemblies at various stages of manufacture.
2. Process specifications describe the steps necessary to make the end product. For example:
   • operations required to make the product.
   • sequence of operations.
   • equipment and accessories required.
   • standard time required to perform each operation.
3. The time needed to perform operations usually standard times which are obtained from the
routing file.
4. Available facilities. Manufacturing planning and control must know what plant, equipment,
and labor will be available to process work.
5. Quantities required usually obtained from forecasts, customer orders, orders to replace
finished goods inventory and the material requirements plan.
Physical supply/distribution

Physical supply/distribution includes all the activities involved in moving goods, from the supplier to the beginning of the production process, and from the end of the production process to the consumer. The activities involved are as follows:
• transportation.
• distribution inventory.
• warehousing.
• packaging.
• materials handling.
• order entry.

Materials management is a balancing act. The objective is to be able to deliver what customers want, when and where they want it, and do so at minimum cost.
To achieve this objective, materials management must make tradeoffs between the level of customer service and the cost of providing that service.

Supply Chain Metrics.... Page 14-16.
CHAPTER 2: PRODUCTION PLANNING SYSTEM

Manufacturing can be complex and in order to be profitable a firm must organize its machinery, equipment, labor skills, and material to make the right goods at the right time at right quality and do so as economically as possible. This requires a good planning and control system.

A good planning system must answer four questions:
1. What are we going to make?
2. What does it take to make it?
3. What do we have?
4. What do we need?

These four questions relate to priority (demand) and capacity (resources).

Priority relates to what products are needed, how many are needed, and when they are needed. The marketplace establishes the priorities.

Capacity is the capability of manufacturing to produce goods and services see Figure 2.1 page 20. In the long and short run, manufacturing must devise plans to balance the demands of the marketplace with its resources and capacity.
Manufacturing planning and control system

There are five major levels in the manufacturing planning and control (MPC) system:
1. Strategic business plan.
2. Production plan (sales and operations plan).
3. Master production schedule.
4. Material requirements plan.
5. Purchasing and production activity control.

As we move from strategic planning to production activity control, the purpose changes from general planning to specific detailed planning.

As we progress the time span decreases from years to days to hours, and the level of detail increases from general categories to individual components and workstations and parts.

Since each level is for a different time span and for different purposes, each can differ in the following ways:
- Purpose of the plan.
- Planning horizon-the time span from now to some time in the future for which the plan is created.
- Level of detail-the detail about products required for the plan.
- Planning cycle-the frequency with which the plan is reviewed.

At each level the following three questions must be answered. Figure 2.2 page 21 shows the planning hierarchy.
1. What are the priorities-how much of what is to be produced and when?
2. What is the available capacity-what resources do we have?
3. How can differences between priorities and capacity be resolved?
Level 1: The Strategic Business Plan

The strategic business plan a very broad statement of the major goals (marketing, finance, production, and engineering) and objectives the company expects to achieve over the next two to ten years or more. The level of detail is not high.

Marketing makes decisions regarding products & markets, levels of customer service, pricing, promotion strategies, etc.

Finance makes decisions regarding sources and uses of funds, cash flows, profit, return on investment, budgets, etc.

Production must satisfy the demands of the marketplace. It does so by using plants, machinery, equipment, labor, and materials as efficiently as possible.

Engineering must work with marketing and production to make decisions regarding the design of new products, modifications to existing products and which can generate the most profit.

Figure 2.3 page 23 shows the relationship between

Level 2: The Production Plan (will be covered in chapter 2)

Production management is concerned with the following:
• The quantities of each product group that must be produced in each period.
• The desired inventory levels.
• The resources of equipment, labor, and material needed in each period.
• The availability of the resources needed.

The plan must balance the resources available with market demands; between priority and capacity. The planning horizon is usually six to 18 months and is reviewed perhaps each month or quarter.
Level 3: The Master Production Schedule (covered in chapter 3)

The master production schedule (MPS) is a plan for the production of individual end items, by quantity and period.

Inputs to the MPS are the production plan, the forecast for individual end items, sales orders, inventories, and existing capacity.

The level of detail for the MPS is higher than for the production plan because the master production schedule is developed for individual end items (each model of tricycle).

The planning horizon usually extends from three to 18 months but primarily depends on the purchasing and manufacturing lead-times.

The term master scheduling describes the process of developing a master production schedule. The term master production schedule is the end result of this process. Usually, the plans are reviewed and changed weekly or monthly.

Level 4: The Material Requirements Plan (be covered in chapter 4)

MRP is a plan for the production and purchase of the components used in making the items in the MPS. It shows the quantities needed and when manufacturing intends to make or use them.

The level of detail is high. The material requirements plan establishes when the components and parts are needed.

The planning horizon is at least as long as the combined purchase and manufacturing lead-times. As with the master production schedule, it usually extends from three to 18 months.
**Level 5: Purchasing And Production Activity Control (PAC) [will be covered in chapters 6 &7]**

PAC represent the implementation and control phase of the production planning and control system.

Purchasing is responsible for establishing and controlling the flow of raw materials into the factory.

Whereas production activity control is responsible for planning and controlling the flow of work through the factory.

The planning horizon is very short, perhaps from a day to a month. The level of detail is high since it is concerned with individual components, workstations, and orders. Plans are reviewed and revised daily.

Figure 2.4 page 25 shows the relationship among the various planning tools, planning horizons, and level of detail.

**Capacity management**

For now, it is sufficient to understand that the basic process is one of calculating the capacity needed to manufacture the priority plan and of finding methods to make that capacity available.

**Sales and Operations Planning (SOP)**

Sales and Operations Planning (SOP) is a cross-functional process for continually revising the strategic business. Usually updated on a regular basis at least monthly.

The process starts with the review of actual demand with the sales plan and then forecasting future demand. The updated marketing plan is then communicated to manufacturing, engineering, and finance, which adjust their plans to support the revised marketing plan.

Figure 2.5 page 27 shows the relationship between the strategic business plan and the sales and operations plan.

Sales and Operations Planning has several benefits:

- It provides a means of updating the strategic business plan as conditions change.
- It provides a means of managing change. Rather than reacting to changes in market conditions or the economy after they happen, the SOP forces management to look at the economy at least monthly and places it in a better position to plan changes.
- Planning ensures the various department plans are realistic, coordinated, and support the business plan.
- It provides a realistic plan that can achieve the company objectives.
- It permits better management of production, inventory, and backlog.
**Manufacturing Resource Planning (MRP II)**

Is a fully integrated planning and control system that works from the top down and has feedback from the bottom up. It provides tools to coordinate between marketing and production in order to adjust the plan.

The phrase "MRP II" is used to distinguish the "manufacturing resource plan" (MRP II) from the materials requirement plan" (MRP).

Figure 2.6 page 29 shows a diagram of an MRP II system. Note the feedback loops that exist.

**Enterprise Resource Planning (ERP)**

ERP is similar to the MRP II system except it does not dwell on manufacturing. The whole enterprise is taken into account.

**Making the production plan**

This section will discuss some details involved in making production plans.

Based on the market plan and available resources, the production plan integrates the capabilities and capacity of the factory with the market and financial plans while setting the general levels of production and inventories over the planning horizon.

These include inventory levels, backlogs (unfilled customer orders), market demand, customer service, low-cost plant operation, labor relations, and so on. The plan must extend far enough in the future to plan for the labor, equipment, facilities, and material needed to accomplish it. Typically 6 to 18 months and is done in monthly and sometimes weekly periods.
Establishing Product Groups

Usually manufacturing firms produce a limited number of products which makes it easy to measure output in units of production that can be used for planning purposes. A brewery, for instance, might use barrels of beer as a common denominator.

Many companies, however, make several different products, and a common denominator for measuring total output may be difficult or impossible to find. Product groups need to be established based on the similarity of manufacturing processes.

Manufacturing must provide the capacity to produce the goods needed.

Capacity is the ability to produce goods and services. It means having the resources available to satisfy demand. The demand for goods must be translated into the demand for capacity.

At the production planning level, where little detail is needed, this requires identifying product groups, or families, of individual products based on the similarity of manufacturing process.

Over the time span of the production plan, large changes in capacity (i.e. plant, equipment, etc) are usually not possible. However, some things can be altered, and it is the responsibility of manufacturing management to identify and assess them relative to associated benefits and costs. Usually the following can be varied:

• People can be hired and laid off, overtime and short time can be worked, and shifts can be added or removed.
• Inventory can be built up in slack periods and sold or used in periods of high demand.
• Work can be subcontracted or extra equipment leased.
Basic strategies

In summary, the production planning problem typically has the following characteristics:

- A time horizon of 12 months is used, with periodic updating perhaps every month or quarter.
- Production demand consists of one or a few product families or common units.
- Demand is fluctuating or seasonal.
- Plant and equipment are fixed within the time horizon.
- A variety of management objectives exist such as low inventories, efficient plant operation, good customer service, and good labor relations.

Suppose a product group has the demand forecast shown in Figure 2.7 page 32. Note that the demand is seasonal. There are three basic and one hybrid strategies that can be used in developing a production plan:

1. Chase strategy.
2. Production leveling strategy.
3. Subcontracting strategy.
4. Hybrid strategy

1. Chase (demand matching) strategy means producing the amounts demanded at any given time. Inventory levels remain stable while production varies to meet demand.

   Figure 2.8 page 33 shows this strategy. The firm manufactures just enough at any one time to meet demand exactly and chooses not to stockpile or inventory their products or services. The company must have enough capacity to be able to meet the peak demand. If not they may have to put on extra shifts and overtime which add cost.

   The advantage to the chase strategy is that inventories can be kept to a minimum.

2. Production leveling is continually producing an amount equal to the average demand as shown in Figure 2.9 page 34.

   The advantage of a production leveling strategy is that it results in a smooth level of operation that avoids the costs of changing production levels and the costs related to excess capacity. The disadvantage is that inventory will build up in low demand periods which costs money to carry.
Example problem #1 (page 34)

A company wants to produce 10,000 units of an item over the next three months at a level rate. The first month has 20 working days; the second, 21 working days; and the third, 12 working days because of an annual shutdown. On the average, how much should the company produce each day to level production?

Answer
Total production = 10,000 units
Total working days 20 + 21 + 12 = 53 days
Average daily production = 10,000/53 = 188.7 units
3. **Subcontracting** means always producing at the level of minimum demand and meeting any additional demand through subcontracting. Shown in Figure 2.10 page 35.

The major advantage of this strategy is cost; the firm avoids layoff and hiring costs associated with inadequate/excess capacity.

The main disadvantage is that the cost of purchasing (item cost, purchasing, transportation, and inspection costs) may be greater than if the item were made in the plant.

4. **Hybrid** strategy in reality, there are many possible hybrid or combined strategies. Each will have its own set of cost characteristics. Production management is responsible for finding the combination of strategies that minimizes the sum of all costs involved, providing the level of service required, and meeting the objectives of the financial and marketing plans.

Figure 2.11 page 36 shows a possible hybrid plan. Demand is matched to some extent, production is partially smoothed, and in the peak period, some subcontracting takes place. The plan is only one of many that could be developed.

A. **Developing a make-to-stock production plan**

In a make-to-stock environment, products are made and put into inventory before an order is received from a customer. Off the rack clothing, frozen foods, and bicycles are examples of this kind of manufacturing.

Generally firms make to stock when:

- demand is fairly constant and predictable.
- there are few product options.
- delivery times demanded by the marketplace are much shorter than the time needed to make the product.
- product has a long shelf life.

The information needed to make a production plan is as follows:

- forecast by period for the planning horizon.
- opening inventory.
- desired ending inventory.
- any past-due customer orders. These are orders that are late for delivery and are sometimes called back orders.

The objective in developing a production plan is to minimize the costs of carrying inventory, changing production levels, and stocking out (not supplying the customer what is wanted when it is wanted).

This section develops a plan for (1) the production leveling strategy and (2) the chase strategy.
Strategy 1: level production plan.

Following is the general procedure for developing a plan for level production.

1. Total the forecast demand for the planning horizon.
2. Determine the opening inventory and the desired ending inventory.
3. Calculate the total production required as follows:
   Total production = total forecast + back orders + ending inventory - opening inventory
4. Calculate the production required each period by dividing the total production by the number of periods.
5. Calculate the ending inventory for each period.
Example problem #2  (page 37)

Amalgamated fish sinkers makes a product group of fresh fish sinkers and wants to develop a production plan for them. The expected opening inventory is 100 cases, and they want to reduce that to 80 cases by the end of the planning period. The number of working days is the same for each period. There are no back orders. The expected demand for the fish sinkers is as follows:

<table>
<thead>
<tr>
<th>Period</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forecast (cases)</td>
<td>110</td>
<td>120</td>
<td>130</td>
<td>120</td>
<td>120</td>
<td>600</td>
</tr>
</tbody>
</table>

A) how much should be produced each period?
B) what is the ending inventory for each period?
C) if the cost of carrying inventory is $5 per case per period based on ending inventory, what is the total cost of carrying inventory?
D) what will be the total cost of the plan?

Answer
A. Total production required = 600 + 80 - 100 = 580 cases
Production each period = 580/5 = 116 cases

B. Ending inventory = opening inventory + production – demand ending inventory after the first period = 100 + 116 - 110 = 106 cases

Similarly, the ending inventories for each period are calculated as shown in Figure 2.12 page 38 presented below. The ending inventory for period 1 becomes the opening inventory for period 2:

Ending inventory (period 2) = 106 + 116 - 120 = 102 cases

C. The total cost of carrying inventory would be:
(106 + 102 + 88 + 84 + 80)($5) = $2300

D. Since there were no stock-outs and no changes in the level of production, this would be the total cost of the plan.

<table>
<thead>
<tr>
<th>Period</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forecast (cases)</td>
<td>110</td>
<td>120</td>
<td>130</td>
<td>120</td>
<td>120</td>
<td>600</td>
</tr>
<tr>
<td>Production</td>
<td>116</td>
<td>116</td>
<td>116</td>
<td>116</td>
<td>116</td>
<td>580</td>
</tr>
<tr>
<td>Ending inventory</td>
<td>100</td>
<td>106</td>
<td>102</td>
<td>88</td>
<td>84</td>
<td>80</td>
</tr>
</tbody>
</table>
**Strategy 2: Chase strategy.**

Example Problem (continued)

Amalgamated fish sinkers makes another line of product called "fish stinkers." Unfortunately, they are perishable, and the company cannot build inventory. They must use a chase strategy and make only enough to satisfy demand in each period. Inventory costs will be a minimum, and there should be no stock-out costs. However, there will be costs associated with changing production levels.

Let us suppose in the preceding example that changing the production level by one case costs $20. For example, a change from 50 to 60 would cost \((60 - 50) \times 20 = 200\)

<table>
<thead>
<tr>
<th>Period</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forecast (cases)</td>
<td>110</td>
<td>120</td>
<td>130</td>
<td>120</td>
<td>120</td>
<td>600</td>
</tr>
<tr>
<td>Production</td>
<td>116</td>
<td>116</td>
<td>116</td>
<td>116</td>
<td>116</td>
<td>580</td>
</tr>
<tr>
<td>Ending inventory</td>
<td>100</td>
<td>106</td>
<td>102</td>
<td>88</td>
<td>84</td>
<td>80</td>
</tr>
</tbody>
</table>

Figure 2.12 page 38 level production plan: make-to-stock.

The opening inventory is 100 cases, and the company wishes to bring this down to 80 cases in the first period. The required production in the first period would then be:

\[
\text{Ending inventory} = \text{Opening inventory} + \text{Production} - \text{demand}
\]

80 cases = 100 + ? - 110

Assuming that production in the period before period 1 was 100 cases, Figure 2.13 page 37 shows the changes in production levels and in ending inventory.

The cost of the plan would be:

- Cost of changing production level = \((60)(20) = 1200\)
- Cost of carrying inventory = \((80 \text{ cases})(5 \text{ periods})(5) = 2000\)
- Total cost of the plan = $1200 + $2000 = $3200

Problems 2.1 – 2.12
B. Developing a Make-To-Order Production Plan

In a make-to-order environment, manufacturers wait until an order is received from a customer before starting to make the goods. Very expensive items are usually made to order. Generally, firms make to order when:

- goods are produced to customer specification.
- the customer is willing to wait while the order is being made.
- the product is expensive to make and to store.
- several product options are offered.

Assemble-to-order is one type of make to order plan. Where several product options exist, such as in automobiles, and where the customer is not willing to wait until the product is made, manufacturers produce and stock standard component parts. When manufacturers receive an order from a customer, they assemble the component parts from inventory according to the order. Since the components are stocked, the firm needs only time to assemble before delivering to the customer.

The following information is needed to make a production plan for make-to-order products:

- forecast by period for the planning horizon.
- opening backlog of customer orders.
- desired ending backlog.

Backlog. In a make-to-order environment, a company does not build an inventory of finished goods. Instead, it has a backlog of unfilled customer orders for delivery in the future. As additional orders are taken they join the queue or backlog.

Level production plan utilizes backlog as a buffer. Following is a general procedure for developing a level production plan:

1. Total the forecast demand for the planning horizon.
2. Determine the opening backlog and the desired ending backlog.
3. Calculate the total production required as follows:

   \[ \text{Total production} = \text{total forecast} + \text{opening backlog} - \text{ending backlog} \]

4. Calculate the production required each period by dividing the total production by the number of periods.
5. Spread the existing backlog over the planning horizon according to due date per period.
Example problem #3 (page 40)

A local printing company provides a custom printing service. Since each job is different, demand is forecast in hours per week. Over the next five weeks, the company expects that demand will be 100 hours per week. There is an existing backlog of 100 hours, and at the end of five weeks, the company wants to reduce that to 80 hours. How many hours of work will be needed each week to reduce the backlog? What will be the backlog at the end of each week?

<table>
<thead>
<tr>
<th>Period</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sales forecast</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>500</td>
</tr>
<tr>
<td>Planned production</td>
<td>104</td>
<td>104</td>
<td>104</td>
<td>104</td>
<td>104</td>
<td>520</td>
</tr>
<tr>
<td>Projected backlog</td>
<td>100</td>
<td>96</td>
<td>92</td>
<td>88</td>
<td>84</td>
<td>80</td>
</tr>
</tbody>
</table>

Figure 2.14 level production plan: make-to-order.

Answer

Total production = 500 + 100 - 80 = 520 hours
Weekly production = 520/5 = 104 hours
The backlog for each week can be calculated as:
Projected backlog = old backlog + forecast - production
For week 1: projected backlog = 100 + 100 - 104 = 96 hours
For week 2: projected backlog = 96 + 100 - 104 = 92 hours

Problem 2.14 – 2.18
Resource planning
Once the preliminary production plan is established, it must be compared to the existing resources of the company. This step is called resource requirements planning or resource planning.

Two questions must be answered:

1. Are the resources available to meet the production plan?
2. If not, how will the difference be reconciled?

If enough capacity to meet the production plan cannot be made available, the plan must be changed.

A tool often used is the resource bill. This shows the quantity of critical resources (materials, labor, and "bottleneck" operations) needed to make one average unit of the product group. Figure 2.15 page 41 shows an example of a resource bill for a company that makes tables, chairs, and stools as a three-product family.

<table>
<thead>
<tr>
<th>Product</th>
<th>Wood (board feet)</th>
<th>Labor (standard hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tables</td>
<td>20</td>
<td>1.31</td>
</tr>
<tr>
<td>Chairs</td>
<td>10</td>
<td>0.85</td>
</tr>
<tr>
<td>Stools</td>
<td>5</td>
<td>0.55</td>
</tr>
</tbody>
</table>

Figure 2.15 resource bill.

If the firm planned to make 500 tables, 300 chairs, and 1500 stools in a particular period, they could calculate the quantity of wood and labor that will be needed. For example, the amount of wood needed is:
- Tables: 500 x 20 = 10,000 board feet
- Chairs: 300 x 10 = 3000 board feet
- Stools: 1500 x 5 = 7500 board feet
Total wood required = 20,500 board feet

The amount of labor needed is:
- Tables: 500 x 1.31 = 655 standard hours
- Chairs: 300 x 0.85 = 255 standard hours
- Stools: 1500 x 0.55 = 825 standard hours
Total labor required = 1735 standard hours

The company must now compare the requirements for wood and labor with the availability of these resources. For instance, suppose the labor normally available in this period is 1600 hours. The priority plan requires 1735 hours, a difference of 135 hours, or about 8.4%. Extra capacity must be found, or the priority plan must be adjusted.
Summary
Production planning is the first step in a manufacturing planning and control system. The level of detail is not high. Usually, the plan is made for families of products based on the similarity of manufacturing process or on some common unit.
CHAPTER 3: MASTER SCHEDULING
(Level 3 of the MPC system see page 22, Fig. 2.2)

After production planning, the next step in the manufacturing planning and control process is to prepare a master production schedule (MPS).

The MPS forms the basis for communication between sales and manufacturing and is the link between production planning and what manufacturing will actually build. It also becomes the basis for calculating capacity and resources required.

The MPS drives the material requirements plan and in conjunction with the bills of material determine what components are needed from manufacturing and purchasing. It keeps priorities valid.

The MPS works with end items and breaks down the production plan into requirements for individual end items, for each family, by date and quantity.

The production plan limits the MPS. Therefore the total of the items in the MPS should not be different from the total shown on the production plan.

It is important to remember the end items made by the company are assembled from component and sub-component parts that must be available in the right quantities at the right time to support the master production schedule.

The material requirements planning system plans the schedule for these components based on the needs of the MPS. Thus the MPS drives the material requirements plan.

The MPS forms a vital link between sales and production as follows:
• it makes possible valid order promises. The MPS is a plan of what is to be produced and when. As such, it tells sales and manufacturing when goods will be available for delivery.
• it is a contract between marketing and manufacturing…an agreed upon plan.

Information needed to develop an MPS is provided by:
• the production plan
• forecasts for individual end items
• actual orders received from customers and for stock replenishment
• inventory levels for individual items
• capacity restraints
Relationship to production plan

Example Problem #1 (pg 50 – 51)

Suppose the following production plan is developed for a family of 3 items:

<table>
<thead>
<tr>
<th>Week</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cases</td>
<td>160</td>
<td>160</td>
<td>160</td>
<td>160</td>
<td>215</td>
<td>250</td>
</tr>
<tr>
<td>Prod</td>
<td>205</td>
<td>205</td>
<td>205</td>
<td>205</td>
<td>205</td>
<td>205</td>
</tr>
<tr>
<td>Units</td>
<td>545</td>
<td>590</td>
<td>635</td>
<td>680</td>
<td>670</td>
<td>625</td>
</tr>
</tbody>
</table>

Opening inventories (units) are:

- Product A = 350
- Product B = 100
- Product C = 50
- Total = 500

The next step is to forecast demand for each item in the product family.

<table>
<thead>
<tr>
<th>Week</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prod a</td>
<td>70</td>
<td>70</td>
<td>70</td>
<td>70</td>
<td>70</td>
<td>80</td>
</tr>
<tr>
<td>Prod b</td>
<td>40</td>
<td>40</td>
<td>40</td>
<td>40</td>
<td>95</td>
<td>120</td>
</tr>
<tr>
<td>Prod c</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Total</td>
<td>160</td>
<td>160</td>
<td>160</td>
<td>160</td>
<td>215</td>
<td>250</td>
</tr>
</tbody>
</table>

With these data, the master scheduler must now devise a plan to fit the constraints. The following illustrates a possible solution.

Master schedule

<table>
<thead>
<tr>
<th>Week</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prod a</td>
<td>205</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prod b</td>
<td>205</td>
<td>205</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prod c</td>
<td>205</td>
<td>205</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>205</td>
<td>205</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Inventory

<table>
<thead>
<tr>
<th>Week</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prod A</td>
<td>280</td>
<td>210</td>
<td>140</td>
<td>70</td>
<td>0</td>
<td>125</td>
</tr>
<tr>
<td>Prod B</td>
<td>265</td>
<td>430</td>
<td>595</td>
<td>555</td>
<td>460</td>
<td>340</td>
</tr>
<tr>
<td>Prod C</td>
<td>0</td>
<td>-50</td>
<td>-100</td>
<td>55</td>
<td>210</td>
<td>160</td>
</tr>
<tr>
<td>Total</td>
<td>545</td>
<td>640</td>
<td>735</td>
<td>680</td>
<td>670</td>
<td>625</td>
</tr>
</tbody>
</table>
This schedule is satisfactory for the following reasons:
   It tells the plant when to start and stop production of individual items and capacity is consistent with the production plan.

It is unsatisfactory for the following reasons:
   It has a poor inventory balance compared to total inventory. It results in a stock-out for product C in periods 2 and 3.

The term "master production schedule" refers to the last line of the matrix. The term "master schedule" refers to the process of arriving at that line. Thus the total matrix is called a master schedule.
Example problem #2 (page 52)

The Hotshot Lightning Rod Company makes a family of two lightning rods, models “H” and “I”. It bases its production planning on months. For the present month, production is leveled at 1000 units. Opening inventory is 500 units, and the plan is to reduce that to 300 units by the end of the month. The MPS is made using weekly periods. There are four weeks in this month, and production is to be leveled at 250 units per week. The forecast and projected available for the two lightning rods follows. Calculate an MPS for each item.

Answer

Production plan

<table>
<thead>
<tr>
<th>Week</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forecast</td>
<td>300</td>
<td>350</td>
<td>300</td>
<td>250</td>
<td>1200</td>
</tr>
<tr>
<td>Projected available</td>
<td>500</td>
<td>450</td>
<td>350</td>
<td>300</td>
<td>1200</td>
</tr>
<tr>
<td>Production plan</td>
<td>250</td>
<td>250</td>
<td>250</td>
<td>250</td>
<td>1000</td>
</tr>
</tbody>
</table>

Master schedule: model H

<table>
<thead>
<tr>
<th>Week</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forecast</td>
<td>200</td>
<td>300</td>
<td>100</td>
<td>100</td>
<td>700</td>
</tr>
<tr>
<td>Projected available</td>
<td>200</td>
<td>250</td>
<td>200</td>
<td>100</td>
<td>700</td>
</tr>
<tr>
<td>Production plan</td>
<td>250</td>
<td>250</td>
<td>100</td>
<td>100</td>
<td>600</td>
</tr>
</tbody>
</table>

Master schedule: model I

<table>
<thead>
<tr>
<th>Week</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forecast</td>
<td>100</td>
<td>50</td>
<td>200</td>
<td>150</td>
<td>500</td>
</tr>
<tr>
<td>Projected available</td>
<td>300</td>
<td>200</td>
<td>150</td>
<td>200</td>
<td>850</td>
</tr>
<tr>
<td>Production plan</td>
<td></td>
<td>250</td>
<td>150</td>
<td></td>
<td>400</td>
</tr>
</tbody>
</table>
Developing a master production schedule

The objectives in developing an MPS are as follows:
- to maintain the desired level of customer service by maintaining finished goods inventory levels or by scheduling to meet customer delivery requirements.
- to make the best use of material, labor, and equipment.
- to maintain inventory investment at the required levels.

To reach these objectives, the plan must satisfy customer demand, be within the capacity of manufacturing, and be within the guidelines of the production plan.

There are three steps in preparing an MPS:
1. Develop a preliminary MPS.
2. Check the preliminary MPS against available capacity.
3. Resolve differences between the preliminary MPS and capacity availability.

Preliminary master production schedule

To show the process of developing an MPS, an example is used that assumes the product is made to stock, an inventory is kept, and the product is made in lots.
Example Problem #3  (pg54)

A particular item is made in lots of 100, and the expected opening inventory is 80 units.
Figure 3.1 page 54 shows the forecast of demand, the projected available on hand, and the preliminary MPS.

<table>
<thead>
<tr>
<th>Week</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forecast</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Projected available</td>
<td>80</td>
<td>20</td>
<td>60</td>
<td>0</td>
<td>40</td>
<td>80</td>
</tr>
<tr>
<td>MPS</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 3.1 MPS example.

Fill in the blanks of the chart below. Period 1 begins with an inventory of 80 units. After the forecast demand for 60 units is satisfied, the projected available is 20 units. A further forecast demand of 60 in period 2 is not satisfied, and it is necessary to schedule an MPS receipt of 100 for week 2. This produces a projected available of 60 units (20 + 100 - 60 = 60) at the end of period 2.

<table>
<thead>
<tr>
<th>Week</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forecast</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Projected available</td>
<td>80</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MPS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In period 3, the forecast demand for 60 is satisfied by the projected 60 on hand, leaving a projected available of zero. In period 4, a further 100 must be received, and when the forecast demand of 60 units is satisfied, 40 units remain in inventory.

This process of building an MPS occurs for each item in the family. If the total planned production of all the items in the family and the total ending inventory do not agree with the production plan, some adjustment to the individual plans must be made so the total production is the same.

Once the preliminary master production schedules are made, they must be checked against the available capacity. This process is called rough-cut capacity planning.
Example problem #4 (page 54)

Amalgamated nut crackers, inc., Makes a family of nut crackers. The most popular model is the walnut, and the sales department has prepared a six-week forecast. The opening inventory is 50 dozen (dozen is the unit used for planning). As master planner, you must prepare an MPS. The nutcrackers are made in lots of 100 dozen.

Answer (fill in the blanks)

<table>
<thead>
<tr>
<th>Week</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forecast</td>
<td>75</td>
<td>50</td>
<td>30</td>
<td>40</td>
<td>70</td>
<td>20</td>
</tr>
<tr>
<td>Projected available</td>
<td>50</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MPS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Problem 3.1 – 3.4
Rough-Cut Capacity Planning (page 55)

Rough-Cut Capacity Planning checks whether critical resources are available to support the preliminary master production schedules. Critical resources include bottleneck operations, labor, and critical materials (perhaps material that is scarce or has a long lead-time).

Suppose a firm manufactures four models of desktop computers assembled in a work center that is a bottleneck operation. The company wants to schedule to the capacity of this work center and not beyond. Figure 3.2 page 55 displays a resource bill for that work center showing the time required to assemble one computer.

Suppose that in a particular week the master production schedules show the following computers are to be built:

- Model D24: 200 units
- Model D25: 250 units
- Model D26: 400 units
- Model D27: 100 units

The capacity required on this critical resource is:

- Model D24: $200 \times 0.203 = 40.6$ standard hours
- Model D25: $250 \times 0.300 = 75.0$ standard hours
- Model D26: $400 \times 0.350 = 140.0$ standard hours
- Model D27: $100 \times 0.425 = 42.5$ standard hours

Total time required = 298.1 standard hours

![Table](https://example.com/table.png)

<table>
<thead>
<tr>
<th>Computer</th>
<th>Assembly time (standard hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model D24</td>
<td>0.203</td>
</tr>
<tr>
<td>Model D25</td>
<td>0.300</td>
</tr>
<tr>
<td>Model D26</td>
<td>0.350</td>
</tr>
<tr>
<td>Model D27</td>
<td>0.425</td>
</tr>
</tbody>
</table>

Figure 3.2 Resource Bill.
Example problem #5 (pg 56)

The Acme Tweezers Company makes tweezers in two models, medium and fine. The bottleneck operation is in work center 20. Following is the resource bill (in hours per dozen).

The master production schedule for the next four weeks is:

<table>
<thead>
<tr>
<th>Work center</th>
<th>Medium</th>
<th>Fine</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>0.5</td>
<td>1.2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Week</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medium</td>
<td>40</td>
<td>25</td>
<td>40</td>
<td>15</td>
<td>120</td>
</tr>
<tr>
<td>Fine</td>
<td>20</td>
<td>10</td>
<td>30</td>
<td>20</td>
<td>80</td>
</tr>
</tbody>
</table>

Using the resource bill and the master production schedule, calculate the number of hours required in work center 20 for each of the four weeks. Use the following table to record the required capacity on the work center.

Answer (fill in the blanks)

<table>
<thead>
<tr>
<th>Week</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medium</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fine</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total hours</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Problem 3.6
Resolution of differences

The next step is to compare the total time required to the available capacity of the work center. If available capacity is greater than the required capacity, the MPS is workable. If not, methods of increasing capacity have to be investigated.

Finally, the master production schedule must be judged by three criteria:
1. Resource use. Is the MPS within capacity restraints in each period of the plan? Does it make the best use of resources?
2. Customer service. Will due dates be met and will delivery performance be acceptable?
3. Cost. Is the plan economical, or will excess costs be incurred for overtime, subcontracting, expediting, or transportation?

Master Schedule Decisions
The MPS should represent as efficiently as possible what manufacturing will make. Figure 3.3 page 58 shows the level at which items should be master scheduled.

1. Make-To-Stock products: in this environment, a limited number of standard items are assembled from many components. Televisions and other consumer products are examples. The MPS is usually a schedule of finished-goods items.

2. Make-To-Order products: in this environment, many different end items are made from a small number of components. Custom-tailored clothes are an example. The MPS is usually a schedule of the actual customer orders.

3. Assemble-To-Order products: in this environment, many end items can be made from combinations of basic components and subassemblies. For example, suppose a company manufactures paint from a base color and adds tints to arrive at the final color. Once a customer's order is received, the base color and the required tints can be combined (assembled) according to the order.

Final Assembly Schedule (FAS): the last step in the assembly to order is generally planned using a final assembly schedule (FAS). This is a schedule of what will be assembled. It is used when there are many options and it is difficult to forecast which combination the customers will want.

Master production scheduling is done at the component level, for example, the base color and tint level. The final assembly takes place only when a customer order is received.
Planning Horizon

The planning horizon is the time span for which plans are made. For master production scheduling, the minimum planning horizon is the longest cumulative or end-to-end lead-time (LT).

For example, in Figure 3.5 page 59, the longest cumulative lead-time path is a to d to f to g. The cumulative lead-time is $1 + 2 + 3 + 6 = 12$ weeks. The minimum planning horizon must be 12 weeks; otherwise, raw material g is not ordered in time to meet delivery.

Production planning, master scheduling, and sales

The production plan reconciles total forecast demand with available resources. It is dependent on the forecast and, within capacity limits, must plan to satisfy the forecast demand. It is not concerned with the detail of what will actually be made. It is intended to provide a framework in which detailed plans can be made in the MPS.

The MPS is built from forecasts and actual demands for individual end items. It reconciles demand with the production plan and with available resources to produce a plan that manufacturing can fulfill.

The MPS is concerned with what items will actually be built, in what quantities, and when, to meet expected demand … it establishes the manufacturing plan.

Figure 3.6 page 60 shows the relationship between the sales forecast, production plan, and MPS.

It is the point at which manufacturing and marketing must agree what end items are going to be produced.

The MPS and delivery promises

In a make-to-order, or assemble-to-order environment, demand is satisfied from productive capacity.

Using the MPS, sales and distribution can determine the available to promise (ATP). Available to promise is that portion of a firm's inventory and planned production that is not already committed and is available to the customer.

The ATP is calculated by adding scheduled receipts to the beginning inventory and then subtracting actual orders scheduled before the next scheduled receipt.

A scheduled receipt is an order that has been issued either to manufacturing or to a supplier.
Example Problem #6 (pg. 63)

Figure 3.8 page 62 illustrates a calculation of an ATP:

ATP for period 1 = on hand - customer orders due before next MPS
= 100 – 80 = 20 units

ATP for period 2 = MPS scheduled receipt - customer orders due before next MPS
= 100 – (10 + 10) = 80 units

ATP for period 4 = 100 – 30 = 70 units

Inventory on hand: 100 (fill in blanks)

<table>
<thead>
<tr>
<th>Period</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Customer orders</td>
<td>80</td>
<td>10</td>
<td>10</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>MPS</td>
<td>(100)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ATP</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 3.8 available-to-promise calculation.

This method assumes that the ATP will be sold before the next scheduled receipt arrives. It is there to be sold, and the assumption is that it will be sold. If it is not sold, whatever is left forms an on-hand balance available for the next period.
Example Problem #7 (pg. 62)

Continuing with the example problem from page 54, Amalgamated Nut Crackers, Inc., has now received customer orders. Following is the schedule of orders received and the resulting available-to-promise calculation: (assume you have an on-hand inventory of 50 for period 0)

<table>
<thead>
<tr>
<th>Week</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Customer orders</td>
<td>80</td>
<td>45</td>
<td>40</td>
<td>50</td>
<td>50</td>
<td>5</td>
</tr>
<tr>
<td>MPS</td>
<td>(50)</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ATP</td>
<td>25</td>
<td>10</td>
<td></td>
<td></td>
<td>45</td>
<td></td>
</tr>
</tbody>
</table>

Sometimes, customer orders are greater than the scheduled receipts. In this case, the previous ATP is reduced by the amount needed. Consider the following example:

<table>
<thead>
<tr>
<th>Week</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Customer orders</td>
<td>50</td>
<td>20</td>
<td>40</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>MPS</td>
<td>100</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ATP</td>
<td>30</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Can the master planner accept an order for another 20 for delivery in week 3? Yes because ten of the units are available from week 3, and ten can be taken from the ATP in week 1, so the order can be accepted.
Example problem #8 (page 63)

Calculate the available to promise for the following example. Can an order for 30 more be accepted for delivery in week 5? What will be the ATP if the order is accepted?

<table>
<thead>
<tr>
<th>Week</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Customer orders</td>
<td>50</td>
<td>20</td>
<td>30</td>
<td>30</td>
<td>15</td>
</tr>
<tr>
<td>MPS</td>
<td>100</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ATP</td>
<td>30</td>
<td>25</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Answer

<table>
<thead>
<tr>
<th>Week</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Customer orders</td>
<td>50</td>
<td>20</td>
<td>30</td>
<td>30</td>
<td>15</td>
</tr>
<tr>
<td>MPS</td>
<td>100</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ATP</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Problems 3.7 – 3.13
Projected available balance

Customer orders will sometimes be greater than forecast and sometimes less. Projected available balance is now calculated based on whichever is the greater.

For example, if the beginning projected available balance is 100 units, the forecast is 40 units, and customer orders are 50 units, the ending projected available balance is 50 units, not 60.

The projected available balance (PAB) is calculated in one of two ways, depending on whether the period is before or after the demand time fence.

The demand time fence is the number of periods, beginning with period 1, in which changes are not excepted due to excessive cost caused by schedule disruption.

For periods before the demand time fence it is calculated as:
\[ PAB = \text{prior period PAB or on-hand balance} + \text{MPS} - \text{customer orders} \]

This process ignores the forecast and assumes the only effect will be from the customer orders. Any new orders will have to be approved by senior management.

For periods after the demand time fence forecast will influence the PAB so it is calculated using the greater of the forecast or customer orders. Thus the PAB becomes:
\[ PAB = \text{prior period PAB} + \text{MPS} - [\text{greater of customer orders or forecast}] \]
Example problem #9 (page 64)

Given the following data, calculate the projected available balance. The demand time fence is the end of week 3, the order quantity is 100, 40 are available at the beginning of the period.

<table>
<thead>
<tr>
<th>Week</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forecast</td>
<td>40</td>
<td>40</td>
<td>40</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>Customer orders</td>
<td>39</td>
<td>42</td>
<td>39</td>
<td>33</td>
<td>32</td>
</tr>
</tbody>
</table>

Answer (fill in the blanks)

<table>
<thead>
<tr>
<th>Week</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Projected available balance</td>
<td>40</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MPS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

So far we have considered how to calculate scheduled receipts and available to promise. Using the amalgamated nut cracker, inc., Example, we now combine the two calculations into one record. The demand time fence is at the end of three weeks.

<table>
<thead>
<tr>
<th>Week</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forecast demand</td>
<td>75</td>
<td>50</td>
<td>30</td>
<td>40</td>
<td>70</td>
<td>20</td>
</tr>
<tr>
<td>Customer orders</td>
<td>80</td>
<td>45</td>
<td>40</td>
<td>50</td>
<td>50</td>
<td>5</td>
</tr>
<tr>
<td>Projected available balance</td>
<td>50</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ATP</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MPS</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Problems 3.14 – 3.16
Time fences

Consider the product structure shown in Figure 3.9 page 65 (look at). Item A is a master-scheduled item and is assembled from b, c, and d. Item d, in turn, is made from raw material “E”. The lead-times to make or to buy the parts are shown in parentheses. The longest cumulative lead-time is thus 26 weeks \((a + d + e = 2 + 8 + 16 = 26\text{ weeks})\). Since the cumulative lead-time is 26 weeks, the MPS must have a planning horizon of at least 26 weeks.

Therefore, the cost of making a change increases and the company's flexibility decreases as production gets closer to the delivery time.

Changes to the master production schedule will occur. For example:

- customers cancel or change orders.
- machines break down or new machines are added, changing capacity.
- suppliers have problems and miss delivery dates.
- processes create more scrap than expected.

Changes to production schedules can result in the following:

- cost increases due to rerouting, rescheduling, extra setups, expediting, and buildup of work-in-process inventory.
- decreased customer service. A change in quantity of delivery can disrupt the schedule of other orders.
- loss of credibility for the MPS and the planning process.

To help in the decision-making process, companies establish zones divided by time fences. Figure 3.10 page 66 shows how this concept might be applied to product a. The zones and time fences are as follows:

**Frozen zone**: capacity and materials are committed to specific orders. Since changes would result in excessive costs, reduced manufacturing efficiency, and poor customer service, senior management's approval is usually required to make changes. The extent of the frozen zone is defined by the demand time fence. Within the demand time fence, demand is usually based on customer orders, not forecast.

**Slushy zone**: capacity and material are committed to less extent. This is an area for tradeoffs that must be negotiated between marketing and manufacturing. Materials have been ordered and capacity established; these are difficult to change. However, changes in priorities are easier to change. The extent of the slushy zone is defined by the planning time fence. Within this time fence the computer will not reschedule MPS orders.

**Liquid zone**: any change can be made to the MPS as long as it is within the limits set by the production plan. Changes are routine and are often made by the computer program.
Error management

Errors in customer orders occur all the time and require constant attention. Three general types of errors occur:
1. Wrong product or specification.
2. Wrong amount (too little or too much).
3. Wrong shipping date (too early or too late).

They require different responses, reengineering, or alteration, negotiation of partial shipment, or expediting of shipment.

Summary

The master production schedule (MPS) is a plan for the production of individual end items. It must match demand for the product in total, but it is not a forecast of demand. The MPS must be realistic. It must be achievable and reflect a balance between required and available capacity.

Because the MPS works with individual end items it facilitates order promising and becomes an agreed upon plan for sales and production. It provides a plan from which realistic delivery promises can be made to customers. If adjustments have to be made in deliveries or the booking of orders, they are done through the MPS.

The MPS must be realistic and based on what production can and will do. If it is not, the results will be as follows:
• overload or under-load of plant resources.
• unreliable schedules resulting in poor delivery performance.
• high levels of work-in-process (WIP) inventory.
• poor customer service.
• loss of credibility in the planning system.
CHAPTER 4: MATERIAL REQUIREMENTS PLANNING  
(Level 4 of the MPC – see page 21) 

Material requirements planning (MRP) is the system used to avoid missing parts. It establishes a schedule, based on a priority plan, showing the components required at each level of the assembly and, based on lead-times, calculates the time when these components will be needed.

Nature of demand

There are two types of demand: independent and dependent.

Independent demand items are not related to the demand for any other product. Master production schedule items are independent demand items.

Dependent demand are related to the production of other products and thus are usually MRP items.

Some items can have both a dependent and an independent demand. (see Figure 4.1 page 78)

Dependency can be horizontal or vertical. The dependency of a component on its parent is vertical. However, components also depend on each other (horizontal dependency).

If one component is going to be a week late then the final assembly is a week late and the other components are not needed until later. This is also a dependency, and is called horizontal dependency.

Planners are concerned with horizontal dependency when a part is delayed or there is a shortage, for then other parts will have to be rescheduled.
Objectives of MRP

Material requirements planning has two major objectives: determine requirements and keep priorities current.

1. Determine requirements needed to meet the master production schedule and, based on lead-time, to calculate the periods when the components must be available. The MRP must determine the following:
   • what to order.
   • how much to order.
   • when to order.
   • when to schedule delivery.

2. Keep priorities current due to the demand for, and supply of, components which change daily because customers enter or change orders, components get used up, suppliers are late with delivery, scrap occurs, orders are completed, and machines break down.

Inputs to the material requirements planning system
There are three inputs to MRP systems:

1. Master production schedule (MPS): drives the MRP system by providing the initial input for the items needed.

2. Inventory records: there are two kinds of information needed. The first is called planning factors and includes information such as order quantities, lead-times, safety stock, and scrap. This information does not change often; however, it is needed to plan what quantities to order and when to order for timely deliveries.

   The second kind of information necessary is on the status of each item. The MRP system needs to know how much is available, how much is allocated, and how much is available for future demand. This type of information is dynamic and changes with every transaction that takes place.

   These data are maintained in an inventory record file, also called a part master file or item master file. Each item has a record and all the records together form the file.

3. Bills of material: the bill of material is one of the most important documents in a manufacturing company. (Figure 4.3 page 81)
Bills of Material

The American Production And Inventory Control Society (APICS) defines a bill of material as "a listing of all the subassemblies, intermediates, parts, and raw materials that go into making the parent assembly and showing the quantities of each required." Figure 4.3 shows a simplified bill of material. There are three important points:
1. The bill of material shows all the parts required to make one of the item.
2. Each part or item has only one part number.
3. A part is defined by its form, fit, or function. For example, A part when painted becomes a different part and must have a different number. If the part could be painted in three different colors, then each must be identified with its unique number.

Bills of Material Structure

There can be several formats, or ways, to present the bill of materials. The following are some important formats for bills.

1. **Product tree**: Figure 4.4 page 82 shows a product tree for the bill of material shown in Figure 4.3. The product tree is a convenient way to think about bills of material, but it is seldom used except for teaching and testing. In this text, it is used for that purpose.

2. **Parent component relationship**: an assembly is considered a parent, and the items that comprise it are called its component items. Figure 4.4 page 79 shows the parent component relationship of the table (P/N 100).

3. **Multilevel bill**: Figure 4.5 page 83 shows the same product as the single-level bill shown in Figures 4.3 and 4.4. However, the single-level components have been expanded into their components.

   Multilevel bills are formed as logical groupings of parts into subassemblies based on the way the product is assembled.

   One convention used with multilevel bills of material is that the last items on the tree (legs, leg bolts, ends, sides, glue, and boards) are all purchased items. Generally, a bill of material is not complete until all branches of the product structure tree end in a purchased part.

   Each level in the bill of material is assigned a number starting from the top and working down. The top level, or end product level, is level zero, and its components are at level one.

4. **Multiple bill** is used when companies usually make more than one product, and the same components are often used in several products. Using our example of a table, this
company makes two models. They are similar except the tops are different. Figure 4.6 page 84 shows the two bills of material. Because the boards used in the top are different, each top has a different part number.

5. Single-level bills contain only the parent and its immediate components, which is why it is called a single-level bill. The tables shown in Figure 4.6 page 81 have six single-level bills, and these are shown in Figure 4.7 page 85.

The computer stores information describing the product structure as a single-level bill. A series of single-level bills is needed to completely define a product. These can be chained together to form a multilevel, or indented, bill. Using this method, the information has to be stored only once.

There are several advantages to using single-level bills including the following:

• duplication of records is avoided. For instance, base 200 is used in both table 100 and table 150. Rather than have two records of base 200 one in the bill for table 100 and one in the bill for table 150 only one record need be kept.
• the number of records and, in computer systems, the file size is reduced by avoiding duplication of records.
• maintaining bills of material is simplified. For example, if there is a change in base 200, the change need be made in only one place.
Example problem #1 (Pg 85) (notes)

Using the following product tree, construct the appropriate single-level trees. How many K’s are needed to make 100 X’s and 50 Y’s?

Problem 4.1 – 4.2
6. Indented bill uses indentations as a way of identifying parents from components. Figure 4.8 page 87 shows an indented bill for the table in Figure 4.5.

7. Summarized parts list lists all the parts needed to make one complete assembly Figure 4.3 page 81. The parts list is produced by the product design engineer and does not contain any information about the way the product is made or assembled.

8. Planning bill are an artificial grouping of components for planning purposes. Figure 4.9 page 88.

Where-Used and Pegging Reports
1. Where-used report conveys the same information as a bill of material, but the where-used report gives the parents for a component whereas the bill gives the components for a parent.
2. Pegging report is similar to a where-used report except the pegging report shows only those parents for which there is an existing requirement whereas the where-used report shows all parents for a component. The pegging report shows the parents creating the demand for the components, the quantities needed, and when they are needed. Figure 4.10 page 88 shows an example of a product tree in which part c is used twice and a pegging report.

Uses for bills of material
The bill of material is one of the most widely used documents in a manufacturing company. Some major uses are as follows:
• product definition: the bill specifies the components needed to make the product.
• engineering change control:
• service parts:
• planning:
• order entry and pricing:
• manufacturing: the bill provides a list of the parts needed to make or assemble a product.
• costing: product cost is usually broken down into direct material, direct labor, and overhead.
Material requirements planning process

The purpose of material requirements planning is to determine the components needed, quantities, and due dates so items in the master production schedule are made on time. Techniques will be discussed under the following headings:
1. Exploding and offsetting
2. Gross and net requirements
3. Releasing orders
4. Low-level coding and netting

Basic MRP technique #1: exploding and offsetting

Figure 4.11 page 90 displays lead-times (LT) for each component which is the span of time needed to perform a process such as order preparation, queuing, processing, moving, receiving and inspecting, and any expected delays.

Exploding the requirements is the process of multiplying the requirements by the usage quantity and recording the appropriate requirements throughout the product tree.

Offsetting is the process of placing the exploded requirements in their proper periods based on lead-time.

Planned orders: if it is planned to receive 50 of part A in week 5 and the lead-time to assemble an a is one week, the order will have to be released and production started no later than week 4. Look at Figure 4.12 page 92.

Thus, there should be a planned order receipt for 50 in week 5 and a planned order release for that number in week 4. Figure 4.12 shows when orders must be released and received so the delivery date can be met.
Example problem #2 (Pg. 91)

Using the product tree and lead-times shown in Figure 4.11 page 87, complete the following table to determine the planned order receipts and releases. There are 50 A’s required in week 5 and 100 in week 6. Use the blank form to fill in.

<table>
<thead>
<tr>
<th>Part number</th>
<th>Week</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Planned order receipt</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>50</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Planned order release</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>Planned order receipt</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Planned order release</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>Planned order receipt</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Planned order release</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>Planned order receipt</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Planned order release</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>Planned order receipt</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Planned order release</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Problem 4.3
Basic MRP technique #2: **gross and net requirements**

The previous section assumed that no inventory was available for the A’s or any of the components. Often inventory is available and must be included when calculating quantities to be produced. If, for instance, there are 20 A’s in stock, only 30 need to be made. The requirements for component parts would be reduced accordingly. The calculation is as follows:

Gross requirements = 50

Inventory available = 20

Net requirements = gross requirements - available inventory

Net requirements = 50 - 20 = 30 units

Since only 30 A’s need to be made, the gross requirement for B’s and C’s is only 30. The planned order release of the parent becomes the gross requirement of the component.
Example Problem 2.5 (pg. 92 – 93)

The time-phased inventory record shown in Figure 4.12 page 92 can now be modified to consider any inventory available. For example, suppose there are 10 B’s available as well as the 20 A’s. The requirements for the components D and E would change. Figure 4.13 page 93 shows the change in the MRP record. Fill in the blanks.

<table>
<thead>
<tr>
<th>Part no</th>
<th>Week</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>A</td>
<td>Gross requirements</td>
</tr>
<tr>
<td></td>
<td>Projected available</td>
</tr>
<tr>
<td></td>
<td>Net requirements</td>
</tr>
<tr>
<td></td>
<td>Planned order receipt</td>
</tr>
<tr>
<td></td>
<td>Planned order release</td>
</tr>
<tr>
<td>B</td>
<td>Gross requirements</td>
</tr>
<tr>
<td></td>
<td>Projected available</td>
</tr>
<tr>
<td></td>
<td>Net requirements</td>
</tr>
<tr>
<td></td>
<td>Planned order receipt</td>
</tr>
<tr>
<td></td>
<td>Planned order release</td>
</tr>
<tr>
<td>C</td>
<td>Gross requirements</td>
</tr>
<tr>
<td></td>
<td>Projected available</td>
</tr>
<tr>
<td></td>
<td>Net requirements</td>
</tr>
<tr>
<td></td>
<td>Planned order receipt</td>
</tr>
<tr>
<td></td>
<td>Planned order release</td>
</tr>
<tr>
<td>D</td>
<td>Gross requirements</td>
</tr>
<tr>
<td></td>
<td>Projected available</td>
</tr>
<tr>
<td></td>
<td>Net requirements</td>
</tr>
<tr>
<td></td>
<td>Planned order receipt</td>
</tr>
<tr>
<td></td>
<td>Planned order release</td>
</tr>
<tr>
<td>E</td>
<td>Gross requirements</td>
</tr>
<tr>
<td></td>
<td>Projected available</td>
</tr>
<tr>
<td></td>
<td>Net requirements</td>
</tr>
<tr>
<td></td>
<td>Planned order receipt</td>
</tr>
<tr>
<td></td>
<td>Planned order release</td>
</tr>
</tbody>
</table>
Example problem #3 (Pg. 93)

Compare the following table. Lead-time for the part is two weeks. The order quantity (lot size) is 100 units.

<table>
<thead>
<tr>
<th>Week</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross requirements</td>
<td>50</td>
<td>45</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Projected available</td>
<td>75</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Net requirements</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planned order receipt</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planned order release</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Problem 4.4 – 4.5
Basic MRP technique #3: **released orders**

A computer-based material requirements planning system automatically recalculates the requirements for subassemblies and components and recreates planned order releases to meet the shifts in demand.

Planned order releases are just planned; they have not been released. It is the responsibility of the material planner to release planned orders, not the computer and these should not be released until the planned order release date arrives. Thus, an order is not normally released until the planned order is in the current week (week 1).

Releasing an order means that authorization is given to purchasing to buy the necessary material or to manufacturing to make the component.

Before a manufacturing order is released, component availability must be checked. The computer program checks the component inventory records to be sure that enough material is available and, if so, to allocate the necessary quantity to that work order. If the material is not available, the computer program will advise the planner of the shortage.

When the authorization to purchase or manufacture is released, the planned order receipt is canceled, and a scheduled receipt is created in its place. For the example shown in Figure 4.13 page 93, parts D and E have planned order releases of 20 scheduled for week 1. These orders will be released by the planner, and then the MRP records for parts D and E will appear as shown in Figure 4.14 page 95. Notice that scheduled receipts have been created, replacing the planned order releases.

**A. Scheduled receipts:** scheduled receipts are orders placed on manufacturing or on a vendor and represent a commitment to make or buy. For an order in a factory, necessary materials are committed, and work-center capacity allocated to that order.

For purchased parts, similar commitments are made to the vendor. The scheduled receipts row shows the quantities ordered and when they are expected to be completed and available. On the MRP record it is the 1st record of receipt after that becomes “Planned Order Receipt.”

**B. Open orders:** scheduled receipts on the MRP record are open orders on the factory or a vendor and are the responsibility of purchasing and of production activity control

**C. Net requirements:** the calculation for net requirements can now be modified to include scheduled receipts.

Net requirements = gross requirements - scheduled receipts - available inventory
Example problem #4 ( Pg. 96)

Complete the following table. Lead-time for the item is two weeks, and the order quantity is 200. What action should be taken?

<table>
<thead>
<tr>
<th>Week</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross requirements</td>
<td>50</td>
<td>250</td>
<td>100</td>
<td>50</td>
</tr>
<tr>
<td>Scheduled receipts</td>
<td></td>
<td></td>
<td>200</td>
<td></td>
</tr>
<tr>
<td>Projected available</td>
<td></td>
<td></td>
<td>150</td>
<td></td>
</tr>
<tr>
<td>Net requirements</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planned order receipt</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planned order release</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The order for 200 units should be released in week 1.

Problems 4.6 – 4.7
Basic MRP record

Figure 4.15 page 97 shows a basic MRP record. There are several points that are important:
1. The current time is the beginning of the first period.
2. The top row shows periods, called time buckets, these are often a week but can be any length of time convenient to the company. Some companies are moving to daily time buckets.
3. The number of periods in the record is called the planning horizon, which shows the number of future periods for which plans are being made. It should be at least as long as the cumulative product lead-time. Otherwise, the MRP system is not able to release planned orders of items at the lower level at the correct time.
4. An item is considered available at the beginning of the time bucket in which it is required.
5. The quantity shown in the projected on-hand row is the projected on-hand balance at the end of the period.
6. The immediate or most current period is called the action bucket. A quantity in the action bucket means that some action is needed now to avoid a future problem.

Capacity requirements planning
The MRP priority plan must be checked against available capacity. At the MRP planning level, the process is called capacity requirements planning (CRP).
Basic MRP technique #4: **low-level coding and netting**

A component may reside on more than one level in a bill of material. If this is the case, it is necessary to make sure that all gross requirements for that component have been recorded before netting takes place. Consider the product shown in Figure 4.16 page 95. Component “C” occurs twice in the product tree and at different levels. It would be a mistake to net the requirements for the C’s before calculating the gross requirements for those required for parent b.

The process of collecting the gross requirements and netting can be simplified by using low-level codes. The low-level code is the lowest level on which a part resides in all bills of material. Every part has only one low-level code. The low-level codes for the parts in the product tree shown in Figure 4.16 page 98 are:

<table>
<thead>
<tr>
<th>Part</th>
<th>low-level code</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0</td>
</tr>
<tr>
<td>B</td>
<td>1</td>
</tr>
<tr>
<td>C</td>
<td>2</td>
</tr>
<tr>
<td>D</td>
<td>2</td>
</tr>
</tbody>
</table>

Low-level codes are determined by starting at the lowest level of a bill of material and, working up, recording the level against the part. If a part occurs on a higher level, its existence on the lower level has already been recorded.

Once the low-level codes are obtained, the net requirements for each part can be calculated using the following procedure.

For the purpose of this exercise, there is a gross requirement for part a of 50 in week 5, all lead-times are one week, and the following amounts are in inventory: a, 20 units; b, 10 units; and c, 10 units.

**Procedure**

1. Starting at level zero of the tree, determine if any of the parts on that level have a low-level code of zero. If so, those parts occur at no lower level, and all the gross requirements have been recorded. These parts can, therefore, be netted and exploded down to the next level, that is, into their components. If the low-level code is greater than zero, there are more gross requirements, and the part is not netted. In this example, a has a low-level code of zero so there is no further requirement for a’s; it can be netted and exploded into its components. Figure 4.17 page 99 shows the results.
2. The next step is to move down to level 1 on the product tree and to repeat the routine followed in step 1. Since b has a low-level code of one, all requirements for b are recorded, and it can be netted and exploded. The bill of material for b shows that it is made from one “c” and one “d”. Figure 4.18 page 100 shows the result of netting and exploding the b’s. Part c has a low-level code of two, which tells us there are further requirements for c’s and at this stage they are not netted.

3. Moving down to level 2 on the product tree, we find that part c has a low-level code of two. This tells us that all gross requirements for c’s are accounted for and that we can proceed and determine its net requirements. Notice there is a requirement for 30 c’s in week 4 to be used on the a’s and a requirement of 20 c’s in week 3 to be used on the b’s. Looking at its bill of material, we see that it is a purchased part and no explosion is needed.

<table>
<thead>
<tr>
<th>Low-level code</th>
<th>Part no.</th>
<th>Week</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1 2 3 4 5</td>
</tr>
<tr>
<td>1</td>
<td>B</td>
<td>10 10 10 30</td>
</tr>
<tr>
<td></td>
<td></td>
<td>20 0 20</td>
</tr>
<tr>
<td>2</td>
<td>C</td>
<td>20 30</td>
</tr>
<tr>
<td>2</td>
<td>D</td>
<td>20</td>
</tr>
</tbody>
</table>

Figure 4.18 netting and exploding first-level parts (for “b” only)

Figure 4.19 page 101 shows the completed material requirements plan. The process of level-by-level netting is now completed using the low-level codes of each part. The low-level codes are used to determine when a part is eligible for netting and exploding. In this way, each part is netted and exploded only once. There is no time-consuming re-netting and re-exploding each time a new requirement is met.
Multiple bills of material

Most companies make more than one product and often use the same components in many of their products. The material requirements planning system gathers the planned order releases from all the parents and creates a schedule of gross requirements for the components. Figure 4.20 page 102 illustrates what happens. Part f is a component of both c and b.

The same procedure used for a single bill of material can be used when multiple products are being manufactured. All bills must be netted and exploded level by level as was done for a single bill.

Figure 4.21 page 102 shows the product trees for two products. Both are made from several components, but, for simplicity, only those components containing an f are shown in the product tree. Note both have f as a component but at different levels in their product tree. All lead-times are one week. The quantities required are shown in parentheses; that is, two C’s are required to make an a, one F is required to make a C, and two F’s are needed to make a B. Figure 4.22 page 100 shows the completed material requirements plan that would result if 50 as were required in week 5 and 30 B’s in week 3.
Example Problem #5 (Pg. 103)

Fill in the blanks

<table>
<thead>
<tr>
<th>Low-level code</th>
<th>Part no.</th>
<th>Gross requirements</th>
<th>Scheduled receipts</th>
<th>Projected available</th>
<th>Net requirements</th>
<th>Planned order receipt</th>
<th>Planned order release</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>A</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>0</td>
<td>B</td>
<td>10</td>
<td>10</td>
<td>30</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>C</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>F</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 4.22 partial material requirements plan (page 103)

Problems 4.8 – 4.16

Scrap is usually stated as a scrap allowance. For example, a process may generate 15% scrap. The net requirement might be for 300 units. With a scrap allowance of 15% the process would be required to make \( \frac{300}{(100 - .15)} = 353 \) units.
Using the material requirements plan

In many companies where there are thousands of parts to manage, planners are usually organized into logical groupings based on the similarity of parts or supply.

The basic responsibilities of a planner are to:
1. Launch (release) orders to purchasing or manufacturing.
2. Reschedule due dates of open (existing) orders as required.
3. Reconcile errors and try to find their cause.
4. Solve critical material shortages by expediting or replanning.
5. Coordinate with other planners, master production schedulers, production activity control, and purchasing to resolve problems.

The material planner works with three types of orders: planned, released, and firm.
1. **Planned orders** are automatically scheduled and controlled by the computer. It recalculates the timing and quantities of planned order releases and in conjunction with the MRP program recommends the release of an order when the order enters the action bucket but does not release the order.

2. **Releasing or launching** a planned order is the responsibility of the planner. When released the order becomes an open order to the factory or to purchasing and appears on the MRP record as a scheduled receipt. It is then under the control of the planner, who may expedite, delay, or even cancel the order.

3. **Firm planned orders**: the computer-based MRP system automatically recalculates planned orders as the gross requirements change. At times, the planner may prefer to hold a planned order firm against changes in quantity and time despite what the computer calculates. This might be necessary because of future availability of material or capacity or special demands on the system. The planner can tell the computer that the order is not to be changed unless the planner advises the computer to do so. The order is "firmed" or frozen against the logic of the computer.

**Exception messages**: sometimes there are problems that need the attention of the planner therefore a good MRP system generates exception messages to advise the planner when some event needs attention. Following are some examples of situations that will generate exception messages.

- components for which planned orders are in the action bucket and which should be considered for release.
- open orders for which the timing or quantity of scheduled receipts does not satisfy the plan. Perhaps a scheduled receipt is timed to arrive too early or late, and its due date should be revised.
- situations in which the standard lead-times will result in late delivery of a zero-level part. This situation might call for expediting to reduce the standard lead-times.
Transaction messages: transaction messages mean that the planner must tell the MRP software of all actions taken that will influence the MRP records. For example, when the planner releases an order, or a scheduled receipt is received, or when any change to the data occurs, the MRP program must be told. Otherwise, the records will be inaccurate, and the plan will become unworkable.

Managing the material requirements plan

The planner receives feedback from many sources such as suppliers', changes to open orders, or from some management action such as changing the master production schedule. Therefore the planner must evaluate this feedback and take corrective action if necessary. The planner must consider three important factors in managing the material requirements plan.

1. **Priority** refers to maintaining the correct due dates by constantly evaluating the true due-date need for released orders and, if necessary, expediting or de-expediting.

Consider the following MRP record. The order quantity is 300 units and the lead-time is three weeks. Fill in the record from page 105.

<table>
<thead>
<tr>
<th>Week</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross requirements</td>
<td>100</td>
<td>50</td>
<td>100</td>
<td>150</td>
<td>200</td>
</tr>
<tr>
<td>Scheduled receipts</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Projected available</td>
<td>150</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Net requirements</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planned order receipt</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planned order release</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

What will happen if the gross requirements in week 2 are changed from 50 units to 150? The MRP record will look like the following. Fill in the record.

<table>
<thead>
<tr>
<th>Week</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross requirements</td>
<td>100</td>
<td>150</td>
<td>100</td>
<td>150</td>
<td>200</td>
</tr>
<tr>
<td>Scheduled receipts</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Projected available</td>
<td>150</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Net requirements</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planned order receipt</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planned order release</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note that there is a shortage of 100 units in week 2 and that the planned order release originally in week 2 is now in week 1. What can the planner do? One solution is to expedite the scheduled receipt of 300 units from week 3 to week 2. If this is not possible, the extra 100 units wanted in week 2 must be rescheduled into week 3. Also, there is now a planned order release in week 1, and this order should be released.
2. **Bottom-up replanning**: action to correct for changed conditions should occur as low in the product structure as possible. Suppose the part in the previous example is a component of another part. The first alternative is to expedite the scheduled receipt of 300 into week 2. If this can be done, there is no need to make any changes to the parent. If the 300 units cannot be expedited, the planned order release and net requirement of the parent must be changed.

3. **Reducing system nervousness**: sometimes requirements change rapidly and by small amounts, causing the material requirements plan to change back and forth. The planner must judge whether the changes are important enough to react to and whether an order should be released. One method of reducing system nervousness is firm planned orders.
Example problem #6 (Pg. 106)

As the MRP planner, you arrive at work Monday morning, look at the MRP record for part 2876 as shown below. Fill in the record from page 103.

Order quantity = 30 units
Lead-time = 2 weeks

<table>
<thead>
<tr>
<th>Week</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross requirements</td>
<td>35</td>
<td>10</td>
<td>15</td>
<td>30</td>
<td>15</td>
<td>20</td>
</tr>
<tr>
<td>Scheduled receipts</td>
<td>30</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Projected available</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>20</td>
</tr>
<tr>
<td>Net requirements</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planned order receipt</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planned order release</td>
<td>30</td>
<td>30</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The computer draws attention to the need to release the planned order for 30 in week 1. Either you release this order, or there will be a shortage in week 3. During the first week, the following transactions take place:

A. Only 25 units of the scheduled receipt are received into inventory. The balance is scrapped.
B. The gross requirement for week 3 is changed to 10.
C. The gross requirement for week 4 is increased to 50.
D. The requirement for week 7 is 15.
E. An inventory count reveals there are ten more in inventory than the record shows.
F. The 35 gross requirement for week 1 is issued from inventory.
G. The planned order release for 30 in week 1 is released and becomes a scheduled receipt in week 3.
As these transactions occur during the first week, you must enter these changes in the computer record. At the beginning of the next week, the MRP record appears as follows:
Fill in the record.

Order quantity = 30 units  
Lead-time = 2 weeks

<table>
<thead>
<tr>
<th>Week</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross requirements</td>
<td>10</td>
<td>10</td>
<td>50</td>
<td>15</td>
<td>20</td>
<td>15</td>
</tr>
<tr>
<td>Scheduled receipts</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>Projected available</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>20</td>
</tr>
<tr>
<td>Net requirements</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planned order receipt</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planned order release</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The opening on-hand balance for week 2 is 20 \((20 + 25 + 10 – 35=20)\). The planned order release originally set in week 4 has shifted to week 3. Another planned order has been created for release in week 5. More importantly, the scheduled receipt in week 3 will not be needed until week 4. You should reschedule this to week 4. The planned order in week 2 should be released and become a scheduled receipt in week 4.

Problem 4.17 – 4.18
Summary

The job of the MRP is to produce the right components at the right time so that the MPS can be maintained. The MRP depends on accurate bills of material and on accurate inventory records.

The MRP exploding and offsetting processes outlined in this book are largely done by the computer.
Chapter 5: Capacity Management

Definition of capacity

Capacity is the amount of work that can be done in a specified time period. In the ninth edition of the APICS dictionary, capacity is defined as "the capability of a worker, machine, work center, plan, or organization to produce output per period of time."

Capacity is a rate of doing work, not the quantity of work done.

Two kinds of capacity are important: capacity available and capacity required.

1. Capacity available is the capacity of a system or resource to produce a quantity of output in a given time period. It is the rate at which work can be withdrawn from the system.
2. Capacity required is the capacity of a system or resource needed to produce a desired output in a given time period.

Load is the sum of all the required capacities. Capacity is often pictured as a funnel as shown in Figure 5.1 page 126. Load is the amount of work in the system.

Capacity management: the eighth edition of the APICS dictionary defines capacity management as "the function of establishing, measuring, monitoring, and adjusting limits or levels of capacity in order to execute all manufacturing schedules.

Capacity control is the process of monitoring production output, comparing it with capacity plans, and taking corrective action when needed.
Capacity planning

Capacity planning is the process of determining the resources required to meet the priority plan and the methods needed to make that capacity available.

Priority plans are usually stated in units of product or some standard unit of output.

Capacity can be stated in units of output but is usually stated in terms of standard hours available. This requires the translation of the priority plan into standard hours of work required.

Planning levels

Resource planning translates monthly, quarterly, or annual product priorities from the production plan into some total measure of capacity, such as gross labor hours.
Level 1. Rough-cut capacity planning checks the feasibility of the MPS.
Level 2. Capacity requirements planning is very detailed forces planning down to the lowest level.

Figure 5.2 page 128 shows the relationship between the different levels of priority planning and capacity planning.
Capacity requirements planning (CRP)

Capacity requirements plan (CRP) occurs at the level of the material requirements plan and is the process of determining in detail the amount of labor and machine resources needed to achieve the required production.

Planned orders from the MRP and open shop orders (scheduled receipts) are converted into demand for time in each work center in each time period.

The inputs needed for a CRP are open shop orders, planned order releases, routings, time standards, lead-times, and work center capacities. This information can be obtained from the following:
1. Open order file.
2. Material requirements plan.
4. Work center file

1. Open order file appears as a scheduled receipt on the material requirements plan. It is a released order for a quantity of a part to be manufactured and completed on a specific date. Displays relevant information such as quantities, due dates, and operations. The open order file is a record of all the active shop orders and can be maintained manually or as a computer file.

2. Planned order releases are determined by the computer's MRP logic based upon the gross requirements for a particular part.

3. Routing file is the path that work follows from work center to work center as it is completed and contain the following information for each component:
   • operations to be performed.
   • sequence of operations.
   • work centers to be used.
   • possible alternate work centers.
   • tooling needed at each operation.
   • standard times: setup times and run times per piece.

   Figure 5.3 page 130 shows an example of a routing file.

4. Work center file contains information on the capacity and move, wait, and queue times associated with the center.
   • move time is the time normally taken to move material from one workstation to another.
   • wait time is the time a job is at a work center after completion and before being moved.
   • queue time is the time a job waits at a work center before being handled.
   • lead-time is the sum of queue, setup, run, wait, and move times.

   Shop calendar displays the number of working days available. Figure 5.4 page 131 is typical.
Capacity available

Available capacity is the capacity of a system or resource to produce a quantity of output in a given time period. It is affected by the following:
1. Product specifications
2. Product mix
3. Plant and equipment
4. Work effort

Measuring capacity

1. Units of output
2. Standard time

Levels of capacity

Capacity needs to be measured on at least three levels:
1. Machine or individual worker
2. Work center
3. Plant, which can be considered as a group of different work centers

Determining capacity available

There are two ways of determining the capacity available:
1. Measurement: demonstrated (or measured) capacity is figured from historical data.
2. Calculation: calculated or rated capacity is the product of available time, utilization and efficiency.

Available time: is the number of hours a work center can be used. For example, a work center working one eight-hour shift for five days a week is available 40 hours a week.
Example problem #1

A work center has three machines and is operated for eight hours a day five days a week. What is the available time?

**Available time** = 3 x 8 x 5 = 120 hours per week

**Utilization** : the percentage of time that the work center is active divided by the available time in hours.

**Utilization** = [hours actually worked/available hours] x 100%
Example problem #2

A work center is available 120 hours but actually produced goods for 100 hours. What is the utilization of the work center?

Utilization = 100/120 x 100% = 83.3%

**Efficiency**: can be defined as the number of standard hours of work (a work center produces or earns) divided by the number of hours actually worked by that work center.

Efficiency = [90 units of production x 1 std. Hr per unit/ 100 hours actually worked] x 100%

= [90 / 100] x 100% = 90%

**Efficiency** = [actual rate of production/ standard rate of production] x 100%
Example problem #3

A work center produces 120 units in a shift. The standard for that item is 100 units a shift. What is the efficiency of the work center?

Efficiency = \[\frac{120}{100}\] x 100% = 120%

Rated capacity is calculated by taking into account the work center utilization and efficiency:

Rated capacity = available time x utilization x efficiency

Problem 5.1 – 5.2
Example problem #4

A work center consists of four machines and is operated eight hours per day for five days a week. Historically, the utilization has been 85% and the efficiency 110%. What is the rated capacity?

Available time = 4 x 8 x 5 = 160 hours per week

Rated capacity = 160 x 0.85 x 1.10 = 149.6 standard hours

Problem 5.3 – 5.5

Demonstrated capacity

Examine the previous production records and to use that information to compute the average capacity of the work center. It also depends on the utilization and efficiency of the work center, although these are not included in the calculation.
Example problem #5

Over the previous four weeks, a work center produced 120, 130, 150, and 140 standard hours of work. What is the demonstrated capacity of the work center?

Answer
Demonstrated capacity = \( \frac{120 + 130 + 150 + 140}{4} = 135 \) standard hours

Problem 5.6

Example Problem #6

Problem 5.8 – 5.10
Capacity required (load)

Determining the capacity required is a two-step process. First, determine the time needed for each order at each work center; then, sum up the capacity required for individual orders to obtain the load.

Time needed for each order

The time needed for each order is the sum of the setup time and the run time. The run time is equal to the run time per piece multiplied by the number of pieces in the order.

Example problem #7

A work center is to process 150 units of gear shaft SG 123 on work order 333. The setup time is 1.5 hours, and the run time is 0.2 hours per piece. What is the standard time needed to run the order?

Total standard time = setup time + run time
= 1.5 + (150 x 0.2)
= 31.5 standard hours

Example Problem #8

Problem 5.11 – 5.12

The load on a work center is the sum of the required times for all the planned and actual orders to be run on the work center in a specified period. The steps in calculating load are as follows:
1. Determine the standard hours of operation time for each planned and released order for each work center by time period.
2. Add all the standard hours together for each work center in each period. The result is the total required capacity (load) on that work center for each time period of the plan.
Example problem #9  (Page 136)

A work center has the following open orders and planned orders for week 20. Calculate the total standard time required (load) on this work center in week 20. Order 222 is already in progress, and there are 100 remaining to run.

<table>
<thead>
<tr>
<th>Order</th>
<th>Quantity</th>
<th>Setup time (hours)</th>
<th>Run time (hours/piece)</th>
<th>Total time (hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Released orders</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>222</td>
<td>100</td>
<td>0</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>333</td>
<td>150</td>
<td>1.5</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>Planned orders</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>444</td>
<td>200</td>
<td>3</td>
<td>0.25</td>
<td></td>
</tr>
<tr>
<td>555</td>
<td>300</td>
<td>2.5</td>
<td>0.15</td>
<td></td>
</tr>
</tbody>
</table>

Answer: fill in the blanks.

Total time = setup + runtime

Stand. Time required

Released orders
- 222
- 333

Planned orders
- 444
- 555

Total time

In week 20, there is a load (requirement) for 152 standard hours.

Problem 5.13 – 5.14
Work center load report

The work center load report shows future capacity requirements based on released and planned orders for each time period of the plan.

The load of 152 hours calculated in the previous example is for week 20. Similarly, loads for other weeks can be calculated and recorded on a load report such as is shown in Figure 5.5 & Figure 5.6 page 137-138.

Note that the report shows released and planned load, total load, rated capacity and (over)/under capacity. The term over capacity means that the work center is overloaded and the term under capacity means the work center is under loaded.

Problem 5.15 – 5.16
**Scheduling orders**

It is necessary to calculate when orders must be started and completed on each work center so the final due date can be met. This process is called scheduling. In the ninth edition of the APICS dictionary, scheduling is defined as "a timetable for planned occurrences."

There are several scheduling techniques that will be discussed in the next chapter. However the authors chose to introduce “back scheduling” in this chapter.

**Back scheduling** begins with the due date and, using the lead-times, to work back (last operation is scheduled first) to find the start date for each operation. To schedule, we need to know for each order:

- the quantity and due date.
- sequence of operations and work centers needed.
- setup and run times for each operation.
- queue, wait, and move times.
- work center capacity available (rated or demonstrated).

The information needed is obtained from the following:

- order file. Quantities and due dates.
- route file. Sequence of operations, work centers needed, setup time, and run time.
- work center file. Queue, move, and wait times and work center capacity.

The process is as follows:

1. For each work order, calculate the capacity required (time) at each work center.
2. Starting with the due date, schedule back to get the completion and start dates for each operation.
Example problem #10

Suppose there is an order for 150 of gear shaft sg 123. The due date is day 135. The route sheet, shown in Figure 5.3 page 140, gives information about the operations to be performed and the setup and run times. The work center file, shown in Figure 5.7 page 140, gives lead-time data for each work center. Calculate the start and finish dates for each operation. Use the following scheduling rules.

A. Operation times are rounded up to the nearest eight hours and expressed as days on a one-shift basis. That is, if an operation takes 6.5 standard hours, round it up to eight hours, which represents one day.

B. Assume an order starts at the beginning of the day and finishes at the end of a day. For example, if an order starts on day 1 and is finished on day 5, it has taken five days to complete. If move time is one day, the order will be available to the next workstation at the start of day 7.

Answer
The calculations for the operation time at each work center are as follows: fill in the record

\[
\begin{array}{|c|c|c|c|c|}
\hline
\text{Work center} & \text{Operation} & \text{Quantity} & \text{Setup time} & \text{Run time} & \text{Total time} & \text{Days} \\
\hline
12 & 10 & 150 & 1.5 & 0.20 & \\
\hline
14 & 20 & 150 & 0.50 & 0.25 & \\
\hline
17 & 30 & 150 & 0.30 & 0.50 & \\
\hline
03 & 40 & 150 & 0.45 & 0.10 & \\
\hline
\end{array}
\]

The next step is to schedule back from the due date (day 135) to get the completion and start dates for each operation. To do so, we need to know not only the operation times just calculated, but also the queue, wait, and move times. These are in the work center file. Suppose the information shown in Figure 5.7 page 140 is obtained from these files.

Figure 5.8 page 140 shows the resulting schedule and Figure 5.9 page 141 shows the same thing graphically.

Problem 5.17 – 5.18
Making the plan

There are two ways of balancing capacity available and load: alter the load, or change the capacity available.

Altering the load means shifting orders ahead or back so the load is leveled. If orders are processed on other work stations the schedule and load on the other work stations have to be changed as well. It may also mean that other components should be rescheduled and the master production schedule changed. Consider the bill of material shown in Figure 5.10 page 142. If component B is to be rescheduled to a later date, then the priority for component C is changed, as is the master production schedule for a.

Remember in the short run, capacity can be adjusted. Some ways that this may be done are as follows:
1. Schedule overtime or under time.
2. Adjust the level of the workforce by hiring or laying off workers.
3. Shift workforce from under loaded to overloaded work centers
4. Use alternate routings to shift some load to another work center.
5. Subcontract work when more capacity is needed or bring in previously subcontracted work to increase required capacity.

Summary

Capacity planning is concerned with translating the priority plan into the hours of capacity required in manufacturing to make the items in the priority plan and with methods of making that capacity available.

Capacity available depends upon the number of workers and machines, their utilization, and efficiency.

Capacity requirements planning occurs at the material requirements planning level. It takes planned orders from the MRP and open shop orders from the open order file and converts them to a load on each work center. It considers lead-times and actual order quantities. It is the most detailed of the capacity planning techniques.

Material requirements planning and capacity requirements planning should form part of a closed loop system which not only includes planning and control functions but also provides feedback so planning can always be current. Figure 5.11 page 138 illustrates the concept.
Chapter 6: production activity control  
(Level 5 of the MPC system see page 21)

Production Activity Control (PAC) is responsible for executing the master production schedule and the material requirements plan (Figure 6.1 page 154). It must also make good use of labor and machines, minimize work-in-process inventory, and maintain customer service.

The Material Requirements Plan authorizes PAC:
• to release work orders to the shop for manufacturing
• to take control of work orders and make sure they are completed on time
• to be responsible for the immediate detailed planning of the flow of orders through manufacturing, carrying out the plan, and controlling the work as it progresses to completion
• to manage day-to-day activity and provide the necessary support.

The activities of the PAC system can be classified into planning, implementation, and control functions.

1. Planning: the flow of work through each of the work centers must be planned to meet delivery dates, which means production activity control must do the following:
   • ensure that the required materials, tooling, personnel, and information are coordinated.
   • schedule start and completion dates for each shop order which will require developing a load profile for each work center.

2. Implementation: instructions are given to the shop floor by issuing shop orders. Production activity control will:
   • gather the information needed by the shop floor to make the product.
   • release orders to the shop floor as authorized by the material requirements plan. This is called dispatching.

3. Control: the manufacturing process must be monitored to learn what is actually happening. The results are compared to the plan to decide whether corrective action is necessary. Production activity control will do the following:
   • rank the shop orders in desired priority sequence by work center and establish a dispatch list based on this information.
   • track the actual performance of work orders and compare it to planned schedules.
   • monitor and control work-in-process, lead-times, and work center queues.
   • report work center efficiency, operation times, order quantities, and scrap.

The functions of planning, implementing, and controlling are shown schematically in Figure 6.2 page 155.
Manufacturing systems

Manufacturing processes can be conveniently broken down into three categories:

1. Flow manufacturing
2. Intermittent manufacturing
3. Project manufacturing

1. **Flow manufacturing** is concerned with the production of high-volume standard products. Two types discrete and continuous.

   There are four major characteristics to flow manufacturing:
   1. Routings are fixed, and work centers are arranged according to the routing. The time taken to perform work at one work center is almost the same as at any other work center in the line.
   2. Work centers are dedicated to producing a limited range of similar products. Machinery and tooling are especially designed to make the specific products.
   3. Material flows from one workstation to another using some form of mechanical transfer. There is little buildup in work-in-process inventory, and throughput times are low.
   4. Capacity is fixed by the line.

   Production activity control concentrates on planning the flow of work and making sure that the right material is fed to the line as stated in the planned schedule.

2. **Intermittent manufacturing** is characterized by many variations in product design, process requirements, and order quantities. This kind of manufacturing is characterized by the following:
   A. Flow of work through the shop is varied and depends on the design of a particular product. As orders are processed, they will take more time at one workstation than at another. Thus, the work flow is not balanced.
   B. Machinery and workers must be flexible enough to do the variety of work. Machinery and work centers are usually grouped according to the function they perform (e.g., all lathes in one department).
   C. Throughput times are generally long. Scheduling work to arrive just when needed is difficult, the time taken by an order at each work center varies, and work queues before work centers, causing long delays in processing. Work-in-process inventory is often large.
   D. The capacity required depends on the particular mix of products being built and is difficult to predict.

   Production activity control is complex, because of the number of products made, the variety of routings, and scheduling problems, therefore PAC is a major activity in this type of manufacturing.

3. Project manufacturing usually involves the creation of one or a small number of units. Large shipbuilding is an example.
Data requirements

PAC must have the following information:
- what and how much to produce.
- when parts are needed so the completion date can be met.
- what operations are required to make the product and how long the operations will take.
- what the available capacities of the various work centers are.

Production activity control usually organizes data into two types of database: planning and control.

A. Planning files
Four planning files are needed: item master file, product structure file, routing file, and work center master file.

1. Item master file contains one record for each part number which contains all of the pertinent data related to the part. For PAC, this includes the following:
   - part number, a unique number assigned to a component.
   - part description.
   - manufacturing lead-time, the normal time needed to make this part.
   - quantity on hand.
   - quantity available.
   - allocated quantity, quantities assigned to specific work orders but not yet withdrawn from inventory.
   - on-order quantities, the balance due on all outstanding orders.
   - lot-size quantity, the quantity normally ordered at one time.

2. Product structure file (bill of material file) contains a list of the single-level components and quantities needed to assemble a parent. It forms a basis for a "pick list" to be used by storeroom personnel to collect the parts required to make the assembly.

3. Routing file contains a step-by-step set of instructions describing how the product is made. It gives details of the following:
   - the operations required to make the product and the sequence in which those operations are performed.
   - a brief description of each operation.
   - equipment, tools, and accessories needed for each operation.
   - setup times, the standard time required for setting up the equipment for each operation.
   - run times, the standard time to process one unit through each operation.
   - lead-times for each operation.
4. **Work center master file** collects all of the relevant data on a work center. For each work center, it gives details on the following:
   • work center number.
   • capacity.
   • number of shifts worked per week.
   • number of machine hours per shift.
   • number of labor hours per shift.
   • efficiency.
   • utilization.
   • queue time, the average time that a job waits at the work center before work is begun.
   • alternate work centers, work centers that may be used as alternatives.

B. Control files
Control is exercised through the use of two kinds of files: the shop order master file and the shop order detail file.
1. **Shop order master file** provides summarized data on each shop order such as the following information:
   • shop order number, a unique number identifying the shop order.
   • order quantity.
   • quantity completed.
   • quantity scrapped.
   • quantity of material issued to the order.
   • due date, the date the order is expected to be finished.
   • priority, a value used to rank the order in relation to others.
   • balance due, the quantity not yet completed.
   • cost information.

2. **Shop order detail file** contains a record for each operation needed to make the item. Each record contains the following information:
   • operation number.
   • setup hours, planned and actual.
   • run hours, planned and actual.
   • quantity reported complete at that operation.
   • quantity reported scrapped at that operation.
   • due date or lead-time remaining.
Scheduling

The objective of scheduling is to meet delivery dates and to make the best use of manufacturing resources. It involves establishing start and finish dates for each operation required to complete an item.

Manufacturing lead-time (cycle time) is the time normally required to produce an item in a typical lot quantity. Typically, mlt consists of five elements:

1. Queue time.
2. Setup time.
3. Run time.
4. Wait time.
5. Move time.

Figure 6.3 page 160 shows the elements making up manufacturing lead-time.

The largest of the five elements is queue time (85%-95% of the total lead-time).
Example problem #1

An order for 100 of a product is processed on work centers a and b. The setup time on a is 30 minutes, and run time is ten minutes per piece. The setup time on b is 50 minutes, and the run time is five minutes per piece. Wait time between the two operations is four hours. The move time between a and b is ten minutes. Wait time after operation b is four hours, and the move time into stores is 15 minutes. There is no queue at either workstation. Calculate the total manufacturing lead-time for the order.

Answer:

<table>
<thead>
<tr>
<th>Operation</th>
<th>Time Calculation</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Work center a operation time</td>
<td>$30 + (100 \times 10)$</td>
<td>1030 minutes</td>
</tr>
<tr>
<td>Wait time</td>
<td></td>
<td>240 minutes</td>
</tr>
<tr>
<td>Move time from a to b</td>
<td></td>
<td>10 minutes</td>
</tr>
<tr>
<td>Work center b operation time</td>
<td>$50 + (100 \times 5)$</td>
<td>550 minutes</td>
</tr>
<tr>
<td>Wait time</td>
<td></td>
<td>240 minutes</td>
</tr>
<tr>
<td>Move time from b to stores</td>
<td></td>
<td>15 minutes</td>
</tr>
<tr>
<td>Total manufacturing lead-time</td>
<td></td>
<td><strong>2085 minutes</strong></td>
</tr>
</tbody>
</table>

34 hours, 45 minutes

Problem 6.1
Scheduling techniques

Scheduling techniques require an understanding of forward and backward scheduling as well as finite and infinite loading.

1. **Forward scheduling** assumes that material procurement and operation scheduling for a component start when the order is received and that operations are scheduled forward from this date.

   Figure 6.4 page 162 illustrates this method. The result is completion before the due date, which usually results in a buildup of inventory. This method is used to decide the earliest delivery date for a product.

   Forward scheduling is used to calculate how long it will take to complete a task. The technique is used for purposes such as developing promise dates for customers or figuring out whether an order behind schedule can be caught up.

2. **Backward scheduling** is accomplished by scheduling the last operation on the routing first and is scheduled for completion at the due date. Previous operations are scheduled back from the last operation. Work-in-process inventory is reduced, but because there is little slack time in the system, customer service may suffer. Backward scheduling is common in industry because it reduces inventory.

3. **Infinite loading** does not consider the existence of other shop orders competing for capacity at work centers. It assumes infinite capacity will be available. Figure 6.5 page 162 shows a load profile for infinite capacity. Notice the over and under load.

4. **Finite loading** assumes there is a defined limit to available capacity at any workstation. If there is not enough capacity available at a workstation the order has to be scheduled. Figure 6.6 page 163 illustrates the condition.

   Figure 6.7 page 163 shows a load profile for finite loading. Notice the load is smoothed so there is no overload condition.
Example problem #2

A company has an order for 50 brand x to be delivered on day 100. Draw a backward schedule based on the following:
A. Only one machine is assigned to each operation
B. The factory works one 8-hour shift five days a week
C. The parts move in one lot of 50.

<table>
<thead>
<tr>
<th>Part</th>
<th>Operation</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>3</td>
</tr>
<tr>
<td>B</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Assembly x</td>
<td></td>
<td>5</td>
</tr>
</tbody>
</table>

Draw your schedule here:

Two methods to reduce manufacturing lead time:
1. Operation overlapping occurs when the next operation is allowed to begin before the entire lot is completed on the previous operation. Figure 6.8 page 155 shows schematically how it works and the potential reduction in lead-time.

   Operation overlapping is a method of expediting an order, but there are some costs involved.
   1. Move costs are increased, especially if the overlapped operations are not close together.
   2. It may increase the queue and lead-time for other orders.
   3. It does not increase capacity but potentially reduces it if the second operation is idle waiting for parts from the first operation.

The problem is deciding the size of the sublot. If the run time per piece on operation b is shorter than that on a, the first batch must be large enough to avoid idle time on operation b.
Example problem #3

Refer to the data given in the example problem in the section on manufacturing lead-time (page 161). It is decided to overlap operations a and b by splitting the lot of 100 into two lots of 70 and 30. Wait time between a and b and between b and stores is eliminated. The move times remain the same. Setup on operation b cannot start until the first batch arrives. Calculate the manufacturing lead-time. How much time has been saved?

Answer

<table>
<thead>
<tr>
<th>Description</th>
<th>Calculation</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Setup + operation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operation time for a lot of 70</td>
<td>$30 + (70 \times 10)$</td>
<td>730 minutes</td>
</tr>
<tr>
<td>Move time from a to b</td>
<td>10 minutes</td>
<td></td>
</tr>
<tr>
<td>Operation time for b lot of 100</td>
<td>$50 + (100 \times 5)$</td>
<td>550 minutes</td>
</tr>
<tr>
<td>Move time from b to stores</td>
<td>15 minutes</td>
<td></td>
</tr>
<tr>
<td>Total manufacturing lead-time</td>
<td></td>
<td>1305 minutes</td>
</tr>
</tbody>
</table>

Total manufacturing lead-time = 21 hours, 45 minutes

Time saved = 2085 – 1305 = 780 minutes

2. Operation splitting is the splitting the order into two or more lots and run on two or more machines simultaneously. If the lot is split in two, the runtime component of lead-time is effectively cut in half, although an additional setup is incurred. Figure 6.9 page 166 shows a schematic of operation splitting.

Operation splitting is practical when:
- setup time is low compared to run time.
- a suitable work center is idle.
- it is possible for an operator to run more than one machine at a time.
Example problem #4

A component made on a particular work center has a setup time of 100 minutes and a run time of three minutes per piece. An order for 500 is to be processed on two machines simultaneously. The machines can be set up at the same time. Calculate the elapsed operation time.

Answer
Elapsed operation time = 100 + [3 x 250] = 850 minutes = 14 hours 10 minutes

Problem 6.10 – 6.13

Load leveling

Figure 6.10 page 167 is an example of a load report. Notice there is a capacity shortage in week 20 of 30 hours. Perhaps some orders could be released in week 18 or 19, and perhaps some overtime could be worked to help reduce the capacity crunch.

Scheduling bottlenecks

Because it is almost impossible to balance all available capacities of the various workstations some workstations are overloaded and some underloaded.

Overloaded workstations are called bottlenecks and, by definition, are those workstations where (Figure 6.10 page 158) the required capacity is greater than the available capacity.

Throughput is the total volume of production passing through a facility. Bottlenecks control the throughput of all products processed by them therefore, work should be scheduled through the bottleneck at the maximum rate.
Example problem #5

Suppose a manufacturer makes wagons composed of a box body, a handle assembly, and two wheel assemblies. Demand for the wagons is 500 a week. The wheel assembly capacity is 1200 sets a week, the handle assembly capacity is 450 a week, and final assembly can produce 550 wagons a week.

A. What is the capacity of the factory?
B. What limits the throughput of the factory?
C. How many wheel assemblies should be made each week?
D. What is the utilization of the wheel assembly operation?
E. What happens if the wheel assembly utilization is increased to 100%?

Answer
A. 450 units a week.
B. Throughput is limited by the capacity of the handle assembly operation.
C. 900 wheel assemblies should be made each week. This matches the capacity of the handle assembly operation.
D. Utilization of the wheel assembly operation is 900 + 1200 = 75%
E. Excess inventory builds up.
Bottleneck principles since bottlenecks control the throughput of a facility, some important principles should be noted:
1. Utilization of a non-bottleneck resource is not determined by its potential, but by another constraint in the system.
2. Using a non-bottleneck 100% of the time does not produce 100% utilization.
3. The capacity of the system depends on the capacity of the bottleneck.
4. Time saved at a non-bottleneck saves the system nothing.
5. Capacity and priority must be considered together.
6. Loads can, and should, be split.
7. Focus should be on balancing the flow through the shop. The key is throughput that ends up in sales.

Managing bottlenecks since bottlenecks are so important to the throughput of a system, scheduling and controlling them is extremely important. The following must be done:
1. Establish a time buffer before each bottleneck. A time buffer is an inventory (queue) place before each bottleneck.
2. Control the rate of material feeding the bottleneck. A bottleneck must be fed at a rate equal to its capacity so the time buffer remains constant.
3. Do everything to provide the needed bottleneck capacity. Anything that increases the capacity of the bottleneck increases the capacity of the system.
4. Adjust loads. This is similar to item 3 but puts emphasis on reducing the load on a bottleneck by using such things as using alternate work centers and subcontracting.
5. Change the schedule. Do this as a final resort, but it is better to be honest about delivery promises.
Theory of constraints and drum-buffer-rope

The previous section "scheduling bottlenecks" was developed by Eliyahu M. Goldratt in his theory of constraints. The fundamental concept is that every operation producing a product or service is a series of linked processes. Each process has a specific capacity to produce the given defined output for the operation, and that in virtually every case, there is one process that limits or constrains the throughput from the entire operation.

Improve the process

Once a constraint has been identified, there is a five-step process that is recommended to help improve the performance of the operation. The five steps are summarized as follows:
1. Identify the constraint.
2. Exploit the constraint.
3. Subordinate everything to the constraint.
4. Elevate the constraint.
5. Once the constraint is a constraint no longer, find the new one and repeat the steps.

Scheduling with the theory of constraints

Even the scheduling system developed for the theory of constraints has its own specific approach. It is often described as drum-buffer-rope:
- **drum.** The drum of the system refers to the "drumbeat" or pace of production; the master schedule.
- **buffer.** The constraint should never be "starved" for needed inventory, a "time" buffer is often established in front of the constraint. It is called a time buffer because it represents the amount of time that the inventory in the buffer protects the constraint from disruptions.
- **rope.** The analogy is that the rope "pulls" production to the constraint for necessary processing. While this may imply a kanban-type pull system, it can be done by a well-coordinated release of material into the system at the right time.
Example problem #6

Parent x requires one each of component y and z. Both y and z are processed on work center 20 which has an available capacity of 40 hours. The setup time for component y is one hour and the run time 0.3 hours per piece. For component z, setup time is two hours and the run time is 0.20 hours per piece. Calculate the number of ys and zs that can be produced.

Answer
Available capacity for ys and zs = 40 hours
Let x = number of ys and zs to produce
Time (y) + time (x) = 40 hours
1 + 0.3x + 2 + 0.2x = 40 hours
0.5x = 37 hours
X = 74
Therefore, work center 20 can produce 74 ys and 74 zs.
Implementation

The process for releasing an order is shown in Figure 6.12 page 173.

Control

The objectives of production activity control are to meet delivery dates and to make the best use of company resources. If queue can be controlled, delivery dates can be met.

To control queue and meet delivery commitments, production activity control must:

- control the work going into and coming out of a work center. This is generally called input/output control.
- set the correct priority of orders to run at each work center.

Input/output control

Production activity control must balance the flow of work to and from different work centers. It is designed to balance the input rate (in hours) with the output rate so these will be controlled.

The input rate is controlled by the release of orders to the shop floor. Figure 6.13 page 175 shows the idea graphically.

Input/output report compares what actually occurs against what was planned. Figure 6.14 page 175 displays an example of such a report. The values are in standard hours.

**Cumulative variance** is the difference between the total planned for a given period and the actual total for that period. It is calculated as follows:

\[
\text{Cumulative variance} = \text{previous cumulative variance} + \text{actual} - \text{planned}
\]

Cumulative input variance week 2 = -4 + 32 - 32 = -4

**Backlog** is the same as queue and expresses the work to be done in hours. It is calculated as follows:

Planned backlog for period 1 = previous backlog + planned input - planned output
= 32 + 38 - 40
= 30 hours
Example problem #7

Complete the following input/output report for weeks 1 and 2.

<table>
<thead>
<tr>
<th>Week</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planned input</td>
<td>45</td>
<td>40</td>
</tr>
<tr>
<td>Actual input</td>
<td>42</td>
<td>46</td>
</tr>
<tr>
<td>Cumulative variance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planned output</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>Actual output</td>
<td>42</td>
<td>44</td>
</tr>
<tr>
<td>Cumulative variance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planned backlog</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>Actual backlog</td>
<td>30</td>
<td></td>
</tr>
</tbody>
</table>

Answer
Cumulative input variance week 1 = 42 – 45 = -3
Cumulative input variance week 2 = -3 + 46 - 40 = 3
Cumulative output variance week 1 = 42 - 40 = 2
Cumulative output variance week 2 = 2 + 44 - 40 = 6
Planned backlog week 1 = 30 + 45 - 40 = 35
Planned backlog week 2 = 35 + 40 - 40 = 35
Actual backlog week 1 = 30 + 42 - 42 = 30
Actual backlog week 2 = 30 + 46 - 44 = 32

Problem 6.17 – 6.18
**Operation sequencing**

Operation sequencing as a technique for short-term planning of actual jobs to be run in each work center based on capacity and priorities. **Priority** is the sequence in which jobs at a work center should be worked on.

**Dispatching** is the function of selecting and sequencing available jobs to be run at individual work centers see Figure 6.15 page 178 for an example.

**Dispatching rules** are created through the application of priority rules. Some commonly used rules are:

- **first come, first served (FCFS).** Jobs are performed in the sequence in which they are received.
- **earliest job due date (EDD).** Jobs are performed according to their due dates. Due dates are considered, but processing time is not.
- **earliest operation due date (ODD).** Jobs are performed according to their operation due dates. Due dates and processing time are taken into account.
- **shortest process time (SPT).** Jobs are sequenced according to their process time. This rule ignores due dates, but it maximizes the number of jobs processed. Orders with long process times tend to be delayed.

Figure 6.16 page 179 illustrates how these sequencing rules work. Notice that each rule produces a different sequence.

**Critical ratio (CR)** is an index of the relative priority of an order to other orders at a work center.

\[ CR = \frac{\text{due date} - \text{present date}}{\text{lead-time remaining}} \]

\[ CR = \frac{\text{actual time remaining}}{\text{lead-time remaining}} \]

The following summarizes the critical ratio:

1. If the CR is less than 1 (actual time less than lead-time). Order is behind schedule.
2. If the CR is equal to 1 (actual time equal to lead-time). Order is on schedule.
3. If the CR is greater than 1 (actual time greater than lead-time). Order is ahead of schedule.
4. If the CR is zero or less (today's date greater than due date). Order is already late.
Problem 6.19  (similar to Fig 6.16)

Problem 6.20  (No similar Prob in examples)

Summary

Production activity control is concerned with converting the material requirements plan into action, reporting the results achieved, and when required, revising the plans and actions to meet the required results.

Order release, dispatching, and progress reporting are the three primary functions.
Chapter 7 purchasing
(Level 5 of the MPC system see page 21)

Purchasing is obtaining the right material, in the right quantities, with the right delivery (time and place), from the right source, and at the right price are all purchasing functions.

Purchasing and profit leverage

On the average, manufacturing firms spend about 50% of their sales dollar in the purchase of raw materials, components, and supplies. This gives the purchasing function tremendous potential to increase profits. As shown by the example on page 180. In this particular example, a 2% reduction in purchase cost has the same impact on profit as a 10% increase in sales.

Purchasing objectives

Purchasing is responsible for establishing the flow of materials into the firm, following-up with the supplier, and expediting delivery.

The objectives of purchasing can be divided into four categories:
1. Obtaining goods and services of the required quantity and quality.
2. Obtaining goods and services at the lowest cost.
3. Ensuring the best possible service and prompt delivery by the supplier.
4. Developing and maintaining good supplier relations and developing potential suppliers.

To satisfy these objectives, some basic functions must be performed:
1. Determining purchasing specifications: right quality, right quantity, and right delivery (time and place).
2. Selecting supplier (right source).
3. Negotiating terms and conditions of purchase (right price).
4. Issuing and administration of purchase orders.

Purchasing cycle

The purchasing cycle consists of the following seven steps (see page 193):
Step 1. Receiving and analyzing purchase requisitions.
Step 2. Selecting suppliers.
Step 3a. Requesting quotations.
Step 3b. Determining the right price.
Step 4. Issuing a purchase order.
Step 5. Following-up and delivery.
Step 6. Receiving and accepting goods.
Step 7. Approving supplier's invoice for payment.

Establishing specifications

This section looks at the problems that organizations face when developing specifications of products and the types of specifications that may be used.
When purchasing an item or a service from a supplier, several factors are included in the package bought. These must be considered when specifications are being developed and can be divided into three broad categories.

1. **Quantity requirements** are important (1 vs 100’s) because it will be a factor in the way the product is designed, specified, and manufactured.
2. **Price requirements** represent the economic value that the buyer puts on the item—the amount the individual is willing to pay. The economic value placed on the item must relate to the use of the item and its anticipated selling price.
3. **Functional requirements** are concerned with the end use of the item and what the item is expected to do. By their very nature, functional specifications are the most important of all categories and govern the others.

**Functional specification description**

Functional specification can be described in the following four ways or by a combination of them:

1. **Description by brand** is most often used in wholesale or retail businesses but is also used extensively in manufacturing. When buying by brand the customer is relying on the reputation and integrity of the supplier, and most objections center on cost. Usually ask for brand name or “equivalent.” This is particularly true under the following circumstances:
   - items are patented, or the process is secret.
   - the supplier has special expertise that the buyer does not have.
2. **Description by specification** can include one or more of the following:
   - physical and chemical characteristics.
   - material and method of manufacture.
   - performance

Sources of specifications include:

- buyer specifications but these are usually expensive and time consuming.
- standard specifications usually apply to raw or semi-finished products, component parts, or the composition of material. In many cases, they have become de facto standards used by consumers and by industry.

3. Engineering drawings describe in detail the exact configuration of the parts and the assembly. They also give information on such things as finishes, tolerances, and material to be used.
4. Miscellaneous include the "gimme one just like the last one" deal.

**Selecting suppliers**

The objective of purchasing is to get all the right things together: quality, quantity, delivery, and price. Once the decision is made about what to buy, the selection of the right supplier is the next most important purchasing decision.
A good supplier is one that has the technology to make the product to the required quality, has the capacity to make the quantities needed, and can run the business well enough to make a profit and still sell a product competitively.

**Sourcing**

There are three types of sourcing: sole, multiple, and single.

1. **Sole sourcing** implies that only one supplier is available because of patents, technical specifications, raw material, location, and so forth.
2. **Multiple sourcing** is the use of more than one supplier for an item.
3. **Single sourcing** is a planned decision by the organization to select one supplier for an item when several sources are available.

Factors in selecting suppliers

1. Technical ability.
2. Manufacturing capability.
3. Reliability.
4. After-sales service.
5. Supplier location.
6. Other considerations.
7. Price.

**Identifying suppliers**

One major responsibility of the purchasing department is to continue to research all available sources of supply. Some aids for identifying sources of supply follow:

- salespersons of the supplier company.
- catalogues.
- trade magazines.
- trade directories.
- information obtained by the salespeople of the buyer firm.

**Final selection of supplier**

Some factors in evaluating potential suppliers are quantitative, and a dollar value can be put on them. Price is the obvious example. Other factors are qualitative and demand some judgment to determine them.

The ranking method:

1. Select those factors that must be considered in evaluating potential suppliers.
2. Assign a weight to each factor.
3. Rate the suppliers for each factor.
4. Rank the suppliers.

Figure 7.1 page 204 shows an example of this method of selecting suppliers.

**Price determination**
All other things being equal, price is the most important. However, remember that "you only get what you pay for."

**Basis for pricing**

The term "fair price" is sometimes used to describe what should be paid for an item. One definition of a fair price is one that is competitive, gives the seller a profit, and allows the buyer ultimately to sell at a profit.

Prices have an upper and a lower limit. The market decides the upper limit. What buyers are willing to pay is based on their perception of demand, supply, and their needs. The seller sets the lower limit.

One widely used method of analyzing costs is to break them down into fixed and variable costs.

Total cost = fixed cost + (variable cost per unit)(number of units)
Unit (average) cost (uac) = total cost/ number of units
Unit cost (uac) = [fixed cost/ number of units] + variable cost per unit

Figure 7.2 page 205 shows the relationship of fixed and variable costs to sales volume and how revenue will behave.

**Example problem #1  (Pg 192)**

To make a particular component requires an overhead (fixed) cost of $5000 and a variable unit cost of $6.50 per unit. What is the total cost and the average cost of producing a lot of 1000? If the selling price is $15 per unit, what is the breakeven point?

Answer
Total cost = $5000 + (6.5 x $1000) = $11,500
Average cost = $11,500 + 1000 = $11.50 per unit
Breakeven point: let x = number of units sold
$15x = $5000 + $6.5x
$8.5x = $5000
X = 588.2 units

Breakeven occurs when 588.2 units are made and sold.
**Price negotiation**

Prices can be negotiated if the buyer has the knowledge and the clout to do so. Skill and careful planning are required for the negotiation to be successful. It also takes a great deal of time and effort, so the potential profit must justify the expense.

One important factor in the approach to negotiation is the type of product. There are four categories:

1. **Commodities.** Commodities are materials such as copper, coal, wheat, meat, and metals. Price is set by market supply and demand and can fluctuate widely. Negotiation is concerned with contracts for future prices.

2. **Standard products.** These items are provided by many suppliers. Since the items are standard and the choice of suppliers large, prices are determined on the basis of listed catalog prices. There is not much room for negotiation except for large purchases.

3. **Items of small value.** These are items such as maintenance or cleaning supplies and represent purchases of such small value that price negotiation is of little purpose. The prime objective should be to keep the cost of ordering low. Firms will negotiate a contract with a supplier that can supply many items and set up a simple ordering system that reduces the cost of ordering.

4. **Made-to-order items.** This category includes items made to specification or on which quotations from several sources are received. These can generally be negotiated.
Impact of material requirements planning on purchasing

Purchasing can be separated into two types of activities: procurement, and supplier scheduling and follow-up.

**Planner/buyer concept.** The planner's job and the buyer's job are combined into a single job done by one person.

Planner/buyers do the material planning for the items under their control, communicate the schedules to their suppliers, follow up, resolve problems, and work with other planners and the master scheduler when delivery problems arise.

The planner/buyer handles fewer components than either a planner or a buyer, but has the responsibilities of both. The planner/buyer is responsible for:
- determining material requirements.
- developing schedules.
- issuing shop orders.
- issuing material releases to suppliers.
- establishing delivery priorities.
- controlling orders in the factory and to suppliers.
- handling all the activities associated with the buying and production planning functions.
- maintaining close contact with supplier personnel.

**Contract buying.** Usually involves a long-term contract with a supplier and to authorize releases against the contract.

Contract buying assures suppliers a given amount of business and commits them to allocating that amount of their capacity to the customer.

Close relationship with suppliers. Contract buying and the need for supplier flexibility and reliability mean the buyer-supplier relationship must be close and cooperative.

Electronic data interchange (EDI) enables customers and suppliers to electronically exchange transaction information such as purchase orders, invoices, and material requirements planning information.
Chapter 8: Forecasting

Forecasting is a prelude to planning. Why forecast?

Many factors influence the demand for a firm's products and services. Although it is not possible to identify all of them, or their effect on demand, it is helpful to consider some major factors:
  - general business and economic conditions.
  - competitive factors.
  - market trends such as changing demand.
  - the firm's own plans for advertising, promotion, pricing, and product changes.

**Demand management**

Demand management is the function of recognizing and managing all demands for products. It occurs in the short, medium, and long term.

Demand management includes four major activities:
1. Forecasting.
2. Order processing.
3. Making delivery promises. The concept of available to promise was discussed in chapter 3.
4. Interfacing between manufacturing planning and control and the marketplace.

Figure 8.1 page 217 shows this relationship graphically.

A copy of the sales order is sent to the master planner. It is his authorization to go ahead and plan for manufacture. The master planner must know what to produce, how much, and when to deliver. The sales order must be written in language that makes this information clear.

**Demand forecasting**

Forecasts depend upon what is to be done. They must be made for the strategic business plan, the production plan, and the master production schedule.

For manufacturing, it means forecasting those items needed for production planning, such as budgets, labor planning, long lead-time, procurement items, and overall inventory levels.

Master production scheduling is concerned with production activity from the present to a few months ahead. Forecasts are made for individual items, as found on a master production schedule, individual item inventory levels, raw materials and component parts, labor planning, and so forth. Forecasts and plans will probably be reviewed weekly.
Characteristics of demand

Demand patterns

Figure 8.2 page 219 shows a hypothetical historical demand pattern. The pattern shows that actual demand varies from period to period. There are four reasons for this: trend, seasonality, random variation, and cycle.

1. Trend. Figure 8.2 page 219 shows that demand is increasing in a steady pattern of demand from year to year. This graph illustrates a linear trend, but there are different shapes, such as geometric or exponential. The trend can be level, having no change from period to period, or it can rise or fall.

2. Seasonality. The demand pattern in Figure 8.2 shows each year's demand fluctuating depending on the time of year. This fluctuation may be the result of the weather, holiday seasons, or particular events that take place on a seasonal basis.

3. Random variation occurs where many factors affect demand during specific periods and occur on a random basis. The variation may be small, with actual demand falling close to the pattern, or it may be large, with the points widely scattered. The pattern of variation can usually be measured, and this will be discussed in the section on tracking the forecast.

4. Cycle. Over a span of several years and even decades, wavelike increases and decreases in the economy influence demand. However, forecasting of cycles is a job for economists and is beyond the scope of this text.

Stable versus dynamic

The shapes of the demand patterns for some products or services change over time whereas others do not. Those that retain the same general shape are called stable and those that do not are called dynamic.

Dynamic changes can affect the trend, seasonality, or randomness of the actual demand. The more stable the demand, the easier it is to forecast. Figure 8.3 page 203 shows a graphical representation of stable and dynamic demand. Notice the average demand is the same for both stable and dynamic patterns. It is usually the average demand that is forecast.

Dependent versus independent demand

Only independent demand items need be forecast. These are usually end items or finished goods but should also include service parts and items supplied to other plants in the same company (inter-company transfers).
Principles of forecasting

Forecasts have four major characteristics or principles. An understanding of these will allow us to make more effective use of forecasts. They are simple and, to some extent, common sense.
1. Forecasts are usually wrong.
2. Every forecast should include an estimate of error.
3. Forecasts are more accurate for families or groups.
4. Forecasts are more accurate for nearer time periods.

Forecasting techniques

There are many forecasting methods, but they can usually be classified into three categories: qualitative, extrinsic, and intrinsic.
1. Qualitative techniques are projections based on judgment, intuition, and informed opinions. By their nature, they are subjective. Production and inventory forecasting is usually concerned with the demand for particular end items, and qualitative techniques are seldom appropriate.

   Used when forecasting the demand of a new product that has no history on which to base a forecast.

2. Extrinsic techniques are projections based on external (extrinsic) indicators which relate to the demand for a company's products. Examples of correlation are:

   Sales of bricks are proportional to housing starts. The problem is to find an indicator that correlates with demand and one that preferably leads demand, that is' one that occurs before the demand does.

   Extrinsic forecasting is most useful in forecasting the total demand for a firm's products or the demand for families of products. As such, it is used most often in business and production planning rather than the forecasting of individual end items.

3. Intrinsic techniques use historical data to forecast. These data are usually recorded in the company and are readily available. Intrinsic forecasting techniques are based on the assumption that what happened in the past will happen in the future. They are often used as input to master production scheduling where end-item forecasts are needed for the planning horizon of the plan.
Some important intrinsic techniques

1. **Average demand** is a forecast of average demand over some period of time with some estimate of error applied to it.

   Figure 8.4 (Page 224)  A 12- Month Demand History.
   
<table>
<thead>
<tr>
<th>January</th>
<th>February</th>
<th>March</th>
<th>April</th>
<th>May</th>
<th>June</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>92</td>
<td>83</td>
<td>66</td>
<td>75</td>
<td>84</td>
</tr>
<tr>
<td>July</td>
<td>August</td>
<td>September</td>
<td>October</td>
<td>November</td>
<td>December</td>
</tr>
<tr>
<td>84</td>
<td>81</td>
<td>75</td>
<td>63</td>
<td>91</td>
<td>84</td>
</tr>
</tbody>
</table>

2. **Moving averages**: one simple way to forecast is to take the average demand for, say, the last three or six periods and use that figure as the forecast for the next period.

   For example, (page 208) suppose it was decided to use a three-month moving average on the data shown in Figure 8.4. Our forecast for January, based on the demand in October, November, and December, would be: 63 + 91 + 84 = 79

   Suppose that January demand turned out to be 90 instead of 79. The forecast for February would be calculated as: [91 + 84 + 90]/ 3 = 88
Example problem #1 (Pg 225)

Demand over the past three months has been 120, 135, and 114 units. Using a three-month moving average, calculate the forecast for the fourth month.

Answer: forecast for month 4 = \([120 + 135 + 114]/3 = 369/3 = 123\)

Actual demand for the fourth month turned out to be 129. Calculate the forecast for the fifth month.

Forecast for month 5 = \([135 + 114 + 129]/3 = 126\)

Problem 8.1 – 8.3

If a longer period, such as six months, is used the forecast does not react as quickly. The fewer months the faster the forecast reacts to trends. However, the forecast will always lag behind a trend.

Moving averages are best used for forecasting products with stable demand where there is little trend or seasonality. One drawback to using moving averages is the need to retain several periods of history for each item to be forecast. This will require a great deal of computer storage or clerical effort. Also, the calculations are cumbersome.

3. **Exponential smoothing**: the forecast can be based on the old calculated forecast and the new data by placing only 10% of the weight on the latest month's demand and 90% of the weight on the old forecast.

In general, the formula for calculating the new forecast is:

\[
\text{New forecast} = (\alpha)(\text{latest demand}) + (1 - \alpha)(\text{previous forecast})
\]

February forecast = 0.1 (90) + 0.9(80) = 81

(data from Figure 8.4 page 224 to calculate the average demand of last 6 months)

The weight given to latest actual demand is called a **smoothing constant** and is represented by the Greek letter alpha (\(\alpha\)). It is always expressed as a decimal from 0 to 1.0.
Example problem #2

The old forecast for May was 220, and the actual demand for May was 190. If alpha ($\alpha$) is 0.15, calculate the forecast for June. If June demand turns out to be 218, calculate the forecast for July.

Answer
New forecast = ($\alpha$)(latest demand) + (1 $\alpha$)(previous forecast)
June forecast = (0.15)(190) + (1 - 0.15)(220) = 215.5
July forecast = (0.15)(218) + (0.85)(215.5) = 215.9

Problem 8.5 – 8.8

Exponential smoothing will detect trends, although the forecast will lag actual demand if a definite trend exists.

Figure 8.5 page 228 shows a graph of the exponentially smoothed forecast lagging the actual demand where a positive trend exists. Notice the forecast with the larger $\alpha$ follows actual demand more closely.

A problem exists in selecting the "best" alpha factor. If a low factor such as 0.1 is used, the old forecast will be heavily weighted, and changing trends will not be picked up as quickly as might be desired. If a larger factor such as 0.4 is used, the forecast will react sharply to changes in demand and will be erratic if there is a sizable random fluctuation.
Seasonality

Many products have a seasonal or periodic demand pattern: skis, lawnmowers, bathing suits, and Christmas tree lights are examples.

Seasonal index

A useful indication of the degree of seasonal variation for a product is the seasonal index.

This index is an estimate of how much the demand during the season will be above or below the average demand for the product. For example, swimsuit demand might average 100 per month, but in July the average is 175 and in September, 35. The index for July demand would be 1.75 and for September, 0.35.

The formula for the seasonal index is:
Seasonal index = period average demand / average demand for all periods

The average demand for all periods is a value that averages out seasonality. This is called the deseasonalized demand. The previous equation can be rewritten as:

Seasonal index = period average demand / deseasonalized demand
Example problem #3

A product that is seasonally based on quarterly demand and the demand for the past three years is shown in Figure 8.6 page 230. There is no trend, but there is definite seasonality. Average quarterly demand is 100 units. Figure 8.6 also shows a graph of actual seasonal demand and average quarterly demand. The average demand shown is the historical average demand for all periods. Remember we forecast average demand, not seasonal demand.

<table>
<thead>
<tr>
<th>Year</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>122</td>
<td>108</td>
<td>81</td>
<td>90</td>
<td>401</td>
</tr>
<tr>
<td>2</td>
<td>130</td>
<td>100</td>
<td>73</td>
<td>96</td>
<td>399</td>
</tr>
<tr>
<td>3</td>
<td>132</td>
<td>98</td>
<td>71</td>
<td>99</td>
<td>400</td>
</tr>
<tr>
<td>Average</td>
<td>128</td>
<td>102</td>
<td>75</td>
<td>95</td>
<td>400</td>
</tr>
</tbody>
</table>

Answer

The seasonal indices can now be calculated as follows:

Seasonal index = 128/100 = 1.28 (quarter 1)
= 100/102 = 1.02 (quarter 2)
= 75/100 = 0.75 (quarter 3)
= 95/100 = 0.95 (quarter 4)

Total of seasonal indices = 4.00

Problem 8.9

Note that the total of all the seasonal indices equals the number of periods. This is a good way to check whether the calculations are correct.

Seasonal forecasts

The equation for developing seasonal indices is also used to forecast seasonal demand. If a company forecasts average demand for all periods, the seasonal indices can be used to calculate the seasonal forecasts. Changing the equation around we get:

Seasonal demand = (seasonal index) (deseasonalized demand)
Example problem #4

The company in the previous problem forecasts an annual demand next year of 420 units. Calculate the forecast for quarterly sales.

Answer
Forecast average quarterly demand = 420/4 = 105 units
Expected quarter demand = (seasonal index)(forecast quarterly demand)
   Expected first-quarter demand = 1.28 x 105 = 134.4 units
   Expected second-quarter demand = 1.02 x 105 = 107.1 units
   Expected third-quarter demand = 0.75 x 105 = 78.75 units
   Expected fourth-quarter demand = 0.95 x 105 = 99.75 units
   Total forecast demand = 420.0 units

Problem 8.10 – 8.13

Deseasonal demand- sometimes it is good to compare demands for months when quantity demanded reflects a seasonal demand.
Example Problem #5

If a company sells 5200 tennis rackets in January (index is 0.5) and 24,000 in June (index is 2.5) how can you compare the two months demand? If you “deseasonalize” the demands, you can compare and forecast them.

Deseasonalized demand = \frac{\text{actual seasonal demand}}{\text{Seasonal index}}

<table>
<thead>
<tr>
<th></th>
<th>Seasonal index</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>\frac{5200}{0.5} = 14,000 units</td>
</tr>
<tr>
<td>June</td>
<td>\frac{24,000}{2.5} = 9600 units</td>
</tr>
</tbody>
</table>

Problem 8.14 – 8.15

Deseasonalized data must be used for forecasting. Forecasts are made for average demand and the forecast for seasonal demand is calculated from the average demand using the appropriate seasonal index. Rules for forecasting with seasonality are:

1. Use only deseasonalized data to forecast.
2. Forecast deseasonalized demand, not seasonal demand.
3. Calculate the seasonal forecast by applying the seasonal index to the base forecast.
Example Problem #6

A company uses exponential smoothing to forecast demand for its products. For April, the deseasonalized forecast was 1000, and the actual seasonal demand was 1250 units. The seasonal index for April is 1.2 and for May is 0.7. If alpha is 0.1, calculate:

A. The deseasonalized actual demand for April.
B. The deseasonalized May forecast.
C. The seasonal forecast for May.

Answer:

A. Deseasonalize actual demand for April = 1250/1.2 = 1042
B. Deseasonalized May forecast = $\alpha \times \text{sales} + (1 - \alpha) \times \text{old forecast}$
   = $0.1 \times 1042 + 0.9 \times 1000 = 1004$
C. Seasonalized May forecast = (seasonal index) \times (deseasonalized forecast)
   = $(0.7) \times 1004 = 703$

June and January demand can now be compared. On a deseasonalized basis, January demand is greater than June demand.

Problem 8.16 – 8.17
Tracking the forecast

Tracking the forecast is the process of comparing actual demand with the forecast.

Forecast error

Forecast error is the difference between actual demand and forecast demand. Error can occur in two ways: bias and random variation.

1. Bias. Cumulative actual demand may not be the same as forecast. Consider the data in Figure 8.8 page 234. Actual demand varies from forecast, and over the six-month period, cumulative demand is 120 units greater than expected.

<table>
<thead>
<tr>
<th>Month</th>
<th>Forecast Monthly</th>
<th>Forecast Cumulative</th>
<th>Actual Monthly</th>
<th>Actual Cumulative</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100</td>
<td>100</td>
<td>110</td>
<td>110</td>
</tr>
<tr>
<td>2</td>
<td>100</td>
<td>200</td>
<td>125</td>
<td>235</td>
</tr>
<tr>
<td>3</td>
<td>100</td>
<td>300</td>
<td>120</td>
<td>355</td>
</tr>
<tr>
<td>4</td>
<td>100</td>
<td>400</td>
<td>125</td>
<td>480</td>
</tr>
<tr>
<td>5</td>
<td>100</td>
<td>500</td>
<td>130</td>
<td>610</td>
</tr>
<tr>
<td>6</td>
<td>100</td>
<td>600</td>
<td>110</td>
<td>720</td>
</tr>
<tr>
<td>Total</td>
<td>600</td>
<td>600</td>
<td>720</td>
<td>720</td>
</tr>
</tbody>
</table>

Bias exists when the cumulative actual demand varies from the cumulative forecast. This means the forecast average demand has been wrong. In the example in Figure 8.8, the forecast average demand was 100, but the actual average demand was 720 + 6 = 120 units. Figure 8.9 page 234 shows a graph of cumulative forecast and actual demand.

Bias is a systematic error in which the actual demand is consistently above or below the forecast demand. When bias exists, the forecast should be changed to improve its accuracy.

2. Random variation. Consider the data in Figure 8.10 page 235, showing forecast and actual demand. Notice there is much random variation, but the average error is zero. This shows that the average forecast was correct and there was no bias. The data are plotted in Figure 8.11.
Mean absolute deviation

Forecast error must be measured before it can be used to revise the forecast or to help in planning. There are several ways to measure error, but one commonly used is mean absolute deviation (mad).

Mean implies an average,
Absolute means without reference to plus and minus,
Deviation refers to the error:

\[ \text{MAD} = \frac{\text{sum of absolute deviations}}{\text{number of observations}} \]

Consider the data on variability in Figure 8.10 page 235. Although the total error (variation) is zero, there is still considerable variation each month.

Total error would be useless to measure the variation. One way to measure the variability is to calculate the total error ignoring the plus and minus signs and take the average. This is called mean absolute deviation:

Figure 8.10 forecast and actual sales without bias.

<table>
<thead>
<tr>
<th>Month</th>
<th>Forecast</th>
<th>Actual</th>
<th>Variation (error)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100</td>
<td>105</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>100</td>
<td>94</td>
<td>-6</td>
</tr>
<tr>
<td>3</td>
<td>100</td>
<td>98</td>
<td>-2</td>
</tr>
<tr>
<td>4</td>
<td>100</td>
<td>104</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>100</td>
<td>103</td>
<td>3</td>
</tr>
<tr>
<td>6</td>
<td>100</td>
<td>96</td>
<td>-4</td>
</tr>
<tr>
<td>Total</td>
<td>600</td>
<td>600</td>
<td>0</td>
</tr>
</tbody>
</table>
Example problem #7

Given the data shown in Figure 8.10, calculate the mean absolute deviation.

Answer
Sum of absolute deviations = 5 + 6 + 2 + 4 + 3 + 4 = 24
Mad = 24/6 = 4

Problem 8.18 – 8.19

Normal distribution. There are two important characteristics to normal curves: the central tendency, or average, and the dispersion, or spread, of the distribution.

In Figure 8.12 page 237, the central tendency is the forecast. The dispersion, the fatness or thinness of the normal curve, is measured by the standard deviation.

The greater the dispersion, the larger the standard deviation. The mean absolute deviation is an approximation of the standard deviation and is used because it is easy to calculate and apply.

From statistics we know that the error will be within:
± 1 MAD of the average about 60% of the time
±2 MAD of the average about 90% of the time
±3 MAD of the average about 98% of the time.

Mean absolute deviation has several uses. Some of the most important follow.

1. Tracking signal. Using the mean absolute deviation, we can make some judgment about the reasonableness of the error. Under normal circumstances, the actual period demand will be within ± 3 MAD of the average 98% of the time. If actual period demand varies from the forecast by more than 3 MAD, we can be about 98% sure that the forecast is in error.

A tracking signal can be used to monitor the quality of the forecast. Following is the equation:

Tracking signal = algebraic sum of forecast errors/ MAD
Example problem #8

The forecast is 100 units a week. The actual demand for the past six weeks has been 105, 110, 103, 105, 107, and 115. If MAD is 5, calculate the sum of the forecast error and the tracking signal.

Answer
Sum of forecast error = 5 + 10 + 3 + 5 + 7 + 15 = 45
Tracking signal = 45 / 5 = 9
Example problem #9

A company uses a trigger of ±4 to decide whether a forecast should be reviewed. Given the following history, determine in which period the forecast should be reviewed. MAD for the item is 2. Fill in the blanks.

<table>
<thead>
<tr>
<th>Period</th>
<th>Forecast</th>
<th>Actual</th>
<th>Deviation</th>
<th>Cumulative deviation</th>
<th>Tracking signal</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100</td>
<td>96</td>
<td></td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>100</td>
<td>98</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>100</td>
<td>104</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>100</td>
<td>110</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The forecast should be reviewed in period 4.

Problem 8.20

Summary

Forecasting is an inexact science that is, nonetheless, an invaluable tool if the following is kept in mind:

• forecasts should be tracked.

• there should be a measure of reasonableness of error.

• when actual demand exceeds the reasonableness of error, an investigation should be made to discover the cause of the error.

• if there is no apparent cause of error, the method of forecasting should be reviewed to see if there is a better way to forecast.
Chapter 9: Inventory Fundamentals

Inventories are materials and supplies that a business or institution carries either for sale or to provide inputs or supplies to the production process. On the balance sheet, they usually represent from 20% to 60% of total assets. Therefore good inventory management is essential.

Inventory management is responsible for planning and controlling inventory from the raw material stage to the customer.

Aggregate inventory management

Aggregate inventory management deals with managing inventories (as stated in dollars $) according to their classification (raw material, work-in-process, and finished goods) and the function they perform rather than at the individual item level.

Item inventory management

Inventory is not only managed at the aggregate level but also at the item level. Management must establish decision rules about inventory items so the staff responsible for inventory control can do their job effectively. These rules include the following:

• which individual inventory items are most important.
• how individual items are to be controlled.
• how much to order at one time.
• when to place an order.

This chapter will study aggregate inventory management and some factors influencing inventory management decisions, which include:

• types of inventory based on the flow of material.
• supply and demand patterns.
• functions performed by inventory.
• objectives of inventory management.
• inventory costs.
Inventory and the flow of material

There are many ways to classify inventories. One often-used classification is related to the flow of materials into, through, and out of a manufacturing organization, as shown in Figure 9.1 page 256.

1. **Raw materials.** These are purchased items received which have not entered the production process. They include purchased materials, component parts, and subassemblies.
2. **Work-in-process (WIP).** Raw materials that have entered the manufacturing process and are being worked on or waiting to be worked on.
3. **Finished goods.** The finished products of the production process that are ready to be sold as completed items. They may be held at a factory or central warehouse or at various points in the distribution system.
4. **Distribution inventories.** Finished goods located in the distribution system.
5. **Maintenance, repair, and operational supplies (MRO’s).** Items used in production that do not become part of the product. These include hand tools, spare parts, lubricants, and cleaning supplies.

Functions of inventories

In batch manufacturing, the basic purpose of inventories is to decouple supply and demand.

Inventory serves as a buffer between:
- supply and demand.
- customer demand and finished goods.
- finished goods and component availability.
- requirements for an operation and the output from the preceding operation.
- parts and materials to begin production and the suppliers of materials.

Based on this, inventories can be classified according to the function they perform.

1. **Anticipation inventories** are built up in anticipation of future demand such as peak selling season, promotional program, or plant shut down.
2. **Fluctuation inventory** (safety stock) held to cover random unpredictable fluctuations in supply and demand or lead-time. Safety stock is also called buffer stock or reserve stock.
3. **Lot-size inventory** are items purchased or manufactured in quantities greater than needed immediately to take advantage of quantity discounts, to reduce shipping, clerical, and setup costs, and in cases where it is impossible to make or purchase items at the same rate they will be used or sold. Lot-size inventory is sometimes called cycle stock.
4. **Transportation inventories** exist because of the time needed to move goods from one location to another such as from a plant to a distribution center or a customer and are sometimes called pipeline or movement inventories.
5. **Hedge inventory** is used to protect a company if it thinks the price of some material is expected to rise. They can increase their inventories (hedge inventory) when prices are low.

6. **Maintenance, Repair, and Operating supplies** MRO’s are items used to support general operations and maintenance but which do not become directly part of a product. They include maintenance supplies, spare parts, and consumables such as cleaning compounds, lubricants, pencils, and erasers.

**Objectives of inventory management**

A firm wishing to maximize profit will have at least the following objectives:

1. Maximum customer service.
2. Low-cost plant operation.
3. Minimum inventory investment.

**Inventory costs**

The following five costs are used for inventory management decisions:

1. **Item cost** is the price paid for a purchased item, which consists of the cost of the item and any other direct costs associated in getting the item into the plant. These costs can usually be obtained from either purchasing or accounting.

2. **Carrying costs** include all expenses incurred by the firm because of the volume of inventory carried. As inventory increases, so do these costs. They can be broken down into three categories:
   A. Capital costs
   B. Storage costs
   C. Risk costs. The risks in carrying inventory are obsolescence, damage, pilferage, and deterioration.

   What does it cost to carry inventory? Textbooks tend to use a figure of 20-30% in manufacturing industries.
Example problem #2

A company carries an average annual inventory of $2,000,000. If they estimate the cost of capital is 10%, storage costs are 7%, and risk costs are 6%, what does it cost per year to carry this inventory?

Answer
Total cost of carrying inventory = 10% + 7% + 6% = 23%
Annual cost of carrying inventory = 0.23 x $2,000,000 = $460,000

Problem 9.3 – 9.4

3. Ordering costs are costs associated with placing an order either with the factory or a supplier. The cost of placing an order does not depend upon the quantity ordered.

Ordering costs in a manufacturing environment include:
• production control costs.
• setup and teardown costs.
• lost capacity cost
• purchase order cost.

The annual cost of ordering depends upon the number of orders placed in a year.
Example problem #3

Given the following annual costs, calculate the average cost of placing one order.
Production control salaries = $60,000
Supplies and operating expenses for production control department $15,000
Cost of setting up work centers for an order = $120
Orders placed each year = 2000

Answer
Average cost = \([\text{fixed costs}/ \text{number of orders}] + \text{variable cost}\)
= \([60,000 + 15,000]/2000 + 120\) = $157.50

Problem 9.5 – 9.6

4. **Stock-out costs** occurs when demand during the lead-time exceeds forecast. Stock-outs can be reduced by carrying extra inventory to protect against those times when the demand during lead-time is greater than forecast.

5. **Capacity-associated costs** occur when output levels must be changed, there may be costs for overtime, hiring, training, extra shifts, and layoffs. These capacity-associated costs can be avoided by leveling production, that is, by producing items in slack periods for sale in peak periods. However, this builds inventory in the slack periods.
Example problem #4

A company makes and sells a seasonal product. Based on a sales forecast of 2000, 3000, 6000, and 5000 per quarter, calculate a level production plan, quarterly ending inventory, and average quarterly inventory.

If inventory carrying costs are $3 per unit per quarter, what is the annual cost of carrying inventory? Opening and ending inventories are zero.

Answer

<table>
<thead>
<tr>
<th></th>
<th>Quarter 1</th>
<th>Quarter 2</th>
<th>Quarter 3</th>
<th>Quarter 4</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forecast demand</td>
<td>2000</td>
<td>3000</td>
<td>6000</td>
<td>5000</td>
<td>16,000</td>
</tr>
<tr>
<td>Production</td>
<td>4000</td>
<td>4000</td>
<td>4000</td>
<td>4000</td>
<td>16,000</td>
</tr>
<tr>
<td>Ending inventory</td>
<td>0</td>
<td>2000</td>
<td>3000</td>
<td>1000</td>
<td>0</td>
</tr>
<tr>
<td>Average inventory</td>
<td>1000</td>
<td>2500</td>
<td>2000</td>
<td>500</td>
<td></td>
</tr>
<tr>
<td>Inventory cost (dollars)</td>
<td>3000</td>
<td>7500</td>
<td>6000</td>
<td>1500</td>
<td>18,000</td>
</tr>
</tbody>
</table>

Problem 9.7 – 9.9

Financial statements and inventory

The two major financial statements are the balance sheet and the income statement. The balance sheet shows assets, liabilities, and owners' equity. The income statement shows the revenues made and the expenses incurred in achieving that revenue.

Balance sheet

An asset is something that has value and is expected to benefit the future operation of the business. An asset may be tangible such as cash, inventory, machinery, and buildings, or may be intangible such as accounts receivable or a patent.

Liabilities are obligations or amounts owed by a company. Accounts payable, wages payable, and long-term debt are examples of liabilities.

Owners' equity is the difference between assets and liabilities. After all the liabilities are paid, it represents what is left for the owners of the business. Owners' equity is created either by the owners investing money in the business or through the operation of the business when it earns a profit. It is decreased when owners take money out of the business or when the business loses money.

The accounting equation. The relationship between assets, liabilities, and owners' equity is expressed by the balance sheet equation:

Assets = liabilities + owners' equity

This is a basic accounting equation. Given two of the values the third can always be found.
Example problem #5

A. If the owners' equity is $1,000 and liabilities are $800, what are the assets?

B. If the assets are $1,000 and liabilities are $600, what is the owners' equity?

Answer
A. Assets = liabilities + owners' equity
   assets = $800 + $1,000 = $1,800
B. Owners' equity = assets - liabilities
   = $1,000 - $600 = $400

Problem 9.10 – 9.11

Balance sheet. The balance sheet is usually shown with the assets on the left side and the liabilities and owners' equity on the right side see page 266.

Capital is the amount of money the owners have invested in the company.

Retained earnings are increased by the revenues a company makes and decreased by the expenses incurred. The summary of revenues and expenses is shown on the income statement.
**Income statement (Pg. 267)**

Income (profit). The primary purpose of a business is to increase the owners’ equity by making a profit.

\[ \text{Income} = \text{revenue} - \text{expenses} \]

**Revenue** comes from the sale of goods or services. Payment is sometimes immediate in the form of cash, but often is made as a promise to pay at a later date, called an account receivable.

**Expenses** are the costs incurred in the process of making revenue. They are usually categorized into the cost of goods sold and general and administrative expenses.

Cost of goods sold are costs that are incurred to make the product. They include direct labor, direct material, and factory overhead. Factory overhead is all other factory costs except direct labor and direct material.

General and administrative expenses include all other costs in running a business. Examples of these are advertising, insurance, property taxes, and wages and benefits other than factory.

The following is an example of an income statement.

<table>
<thead>
<tr>
<th>Description</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Revenue</td>
<td>$1,000,000</td>
</tr>
<tr>
<td>Cost of goods sold</td>
<td></td>
</tr>
<tr>
<td>Direct labor</td>
<td>$200,000</td>
</tr>
<tr>
<td>Direct material</td>
<td>400,000</td>
</tr>
<tr>
<td>Factory overhead</td>
<td>$800,000</td>
</tr>
<tr>
<td>Factory overhead $800,000</td>
<td>200,000</td>
</tr>
<tr>
<td>Gross margin (profit)</td>
<td>$200,000</td>
</tr>
<tr>
<td>General and administrative expenses</td>
<td>$100,000</td>
</tr>
<tr>
<td>Net income (profit)</td>
<td>$100,000</td>
</tr>
</tbody>
</table>
Example problem #6

Given the following data, calculate the gross margin and the net income.

<table>
<thead>
<tr>
<th>Item</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Revenue</td>
<td>$1,500,000</td>
</tr>
<tr>
<td>Cost of goods sold</td>
<td></td>
</tr>
<tr>
<td>Direct labor</td>
<td>$300,000</td>
</tr>
<tr>
<td>Direct material</td>
<td>500,000</td>
</tr>
<tr>
<td>Factory overhead</td>
<td>$800,000</td>
</tr>
<tr>
<td>Gross margin (profit)</td>
<td>$?</td>
</tr>
<tr>
<td>General and administrative expenses</td>
<td>$150,000</td>
</tr>
<tr>
<td>Net income (profit)</td>
<td>$?</td>
</tr>
</tbody>
</table>

How much would profits increase if, through better materials management, material costs are reduced by $50,000?

<table>
<thead>
<tr>
<th>Item</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Revenue</td>
<td>$1,500,000</td>
</tr>
<tr>
<td>Cost of goods sold</td>
<td></td>
</tr>
<tr>
<td>Direct labor</td>
<td>$300,000</td>
</tr>
<tr>
<td>Direct material</td>
<td>500,000</td>
</tr>
<tr>
<td>Factory overhead</td>
<td>$1,200,000</td>
</tr>
<tr>
<td>Gross margin (profit)</td>
<td>$300,000</td>
</tr>
<tr>
<td>General and administrative expenses</td>
<td>$150,000</td>
</tr>
<tr>
<td>Net income (profit)</td>
<td>$150,000</td>
</tr>
</tbody>
</table>

If material costs are reduced by $50,000, income increases by $50,000. Materials management can have a direct impact on the bottom line-net income.

Problem 9.12 – 9.13
Cash flow analysis

Businesses must have the cash to pay their bills. Cash is generated by sales and the flow of cash into a business must be sufficient to pay bills as they become due. Businesses develop financial statements showing the cash flows into and out of the business. Any shortfall of cash must be provided for, perhaps by borrowing or in some other way. This type of analysis is called cash flow analysis.

Financial inventory performance measures

From a financial point of view, inventory is an asset and represents money that is tied up and cannot be used for other purposes therefor it must be managed.

1. Inventory turns. A convenient measure of how effectively inventories are being used is the inventory turns ratio:

   \[ \text{Inventory turns} = \frac{\text{annual cost of goods sold}}{\text{average inventory in dollars}} \]

   For example, if the annual cost of goods sold is $1 million and the average inventory is $500,000, then:

   \[ \text{Inventory turns} = \frac{\$1,000,000}{\$500,000} = 2 \]

   What does this mean? At the very least, it means that with $500,000 of inventory a company is able to generate $1 million in sales. If, through better materials management, the firm is able to increase its turns ratio to 10, the same sales are generated with only $100,000 of average inventory.

   If the annual cost of carrying inventory is 25% of the inventory value, the reduction of $400,000 in inventory results in a cost reduction (and profit increase) of $100,000.
Example problem #7

A. What will be the inventory turns ratio if the annual cost of goods sold is $24 million a year and the average inventory is $6 million?

Answer

\[
\text{Inventory turns} = \frac{\text{annual cost of goods sold}}{\text{average inventory in dollars}} = \frac{24,000,000}{6,000,000} = 4
\]

B. What would be the reduction in inventory if inventory turns were increased to 12 times per year?

Answer

\[
\text{Average inventory} = \frac{\text{annual cost of goods sold}}{\text{inventory turns}} = \frac{24,000,000}{12} = 2,000,000
\]

\[
\text{Reduction in inventory} = 6,000,000 - 2,000,000 = 4,000,000
\]

C. If the cost of carrying inventory is 25% of the average inventory, what will the savings be?

Answer

\[
\text{Reduction in inventory} = 4,000,000
\]

\[
\text{Savings} = 4,000,000 \times 0.25 = 1,000,000
\]

2. Days of supply. Days of supply is a measure of the equivalent number of days of inventory on hand, based on usage.

\[
\text{Days of supply} = \frac{\text{inventory on hand}}{\text{average daily usage}}
\]

Problem 9.14 – 9.15
Example problem #8

A company has 9,000 units on hand and the annual usage is 48,000 units. There are 240 working days in the year. What is the days of supply? 9

Answer
Average daily usage = 48,000/240 = 200 units

Days of supply = [inventory on hand]/ [average daily usage]
= 9,000/200 = 45 days

Problem 9.16
ABC inventory control

Control of inventory is exercised by controlling individual items called stock-keeping units (SKU’s). In controlling inventory, four questions must be answered:
1. What is the importance of the inventory item?
2. How are they to be controlled?
3. How much should be ordered at one time?
4. When should an order be placed?

The ABC inventory classification system answers the first two questions by determining the importance of items and thus allowing different levels of control based on the relative importance of items.

The percentage of items and the percentage of annual dollar usage follows a pattern in which:
A- about 20% of the items account for about 80% of the dollar usage.
B- about 30% of the items account for about 15% of the dollar usage.
C- about 50% of the items account for about 5% of the dollar usage.

Steps in making an ABC analysis

1. Establish the item characteristics that influence the results of inventory management. This is usually annual dollar usage but may be other criteria, such as scarcity of material.
2. Classify items into groups based on the established criteria.
3. Apply a degree of control in proportion to the importance of the group.

The factors affecting the importance of an item include annual dollar usage, unit cost, and scarcity of material. For simplicity, only annual dollar usage is used in this text. The procedure for classifying by annual dollar usage is as follows:
1. Determine the annual usage for each item.
2. Multiply the annual usage of each item by its cost to get its total annual dollar usage.
3. List the items according to their annual dollar usage.
4. Calculate the cumulative annual dollar usage and the cumulative percentage of items.
5. Examine the annual usage distribution and group the items into a, b, and c groups based on percentage of annual usage.
Example problem #9

A company manufactures a line of ten items. Their usage and unit cost are shown in the following table along with the annual dollar usage. The latter is obtained by multiplying the unit usage by the unit cost.

A. Calculate the annual dollar usage for each item.
B. List the items according to their annual dollar usage.
C. Calculate the cumulative annual dollar usage and the cumulative percent of items.
D. Group items into an A, B, C classification.

Answer
A. Calculate the annual dollar usage for each item.

<table>
<thead>
<tr>
<th>Part number</th>
<th>Unit usage</th>
<th>Unit cost $</th>
<th>Annual $ usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1100</td>
<td>2</td>
<td>2200</td>
</tr>
<tr>
<td>2</td>
<td>600</td>
<td>40</td>
<td>24,000</td>
</tr>
<tr>
<td>3</td>
<td>100</td>
<td>4</td>
<td>400</td>
</tr>
<tr>
<td>4</td>
<td>1300</td>
<td>1</td>
<td>1300</td>
</tr>
<tr>
<td>5</td>
<td>100</td>
<td>60</td>
<td>6000</td>
</tr>
<tr>
<td>6</td>
<td>10</td>
<td>25</td>
<td>250</td>
</tr>
<tr>
<td>7</td>
<td>100</td>
<td>2</td>
<td>200</td>
</tr>
<tr>
<td>8</td>
<td>1500</td>
<td>2</td>
<td>3000</td>
</tr>
<tr>
<td>9</td>
<td>200</td>
<td>2</td>
<td>400</td>
</tr>
<tr>
<td>10</td>
<td>500</td>
<td>1</td>
<td>500</td>
</tr>
<tr>
<td>Total</td>
<td>5510</td>
<td></td>
<td>$38,250</td>
</tr>
</tbody>
</table>

B., C., and D.

<table>
<thead>
<tr>
<th>Part number</th>
<th>Annual $ usage</th>
<th>Cumulative $ usage</th>
<th>Cumulative % $ usage</th>
<th>Cumulative % of items</th>
<th>Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>24,000</td>
<td>24,000</td>
<td>62.75</td>
<td>10</td>
<td>A</td>
</tr>
<tr>
<td>5</td>
<td>30,000</td>
<td>33,000</td>
<td>78.43</td>
<td>20</td>
<td>A</td>
</tr>
<tr>
<td>8</td>
<td>3000</td>
<td>33,000</td>
<td>86.27</td>
<td>30</td>
<td>B</td>
</tr>
<tr>
<td>1</td>
<td>2200</td>
<td>35,200</td>
<td>92.03</td>
<td>40</td>
<td>B</td>
</tr>
<tr>
<td>4</td>
<td>1300</td>
<td>36,500</td>
<td>95.42</td>
<td>50</td>
<td>B</td>
</tr>
<tr>
<td>10</td>
<td>500</td>
<td>37,000</td>
<td>96.73</td>
<td>60</td>
<td>C</td>
</tr>
<tr>
<td>9</td>
<td>400</td>
<td>37,400</td>
<td>97.78</td>
<td>70</td>
<td>C</td>
</tr>
<tr>
<td>3</td>
<td>400</td>
<td>37,800</td>
<td>98.82</td>
<td>80</td>
<td>C</td>
</tr>
<tr>
<td>6</td>
<td>250</td>
<td>38,050</td>
<td>99.48</td>
<td>90</td>
<td>C</td>
</tr>
<tr>
<td>7</td>
<td>200</td>
<td>38,250</td>
<td>100.00</td>
<td>100</td>
<td>C</td>
</tr>
</tbody>
</table>

The percentage of value and the percentage of items is often shown as a graph such as in Figure 9.3 page 274.

Problem 9.17 – 9.18
Control based on ABC classification

Using the ABC approach, there are two general rules to follow:
1. Have plenty of low-value items.
2. Use the money and control effort saved to reduce the inventory of high-value items.

Different controls used with different classifications might be the following:
- **A items**: high priority. Tight control including complete accurate records, regular and frequent review by management, frequent review of demand forecasts, and close follow-up and expediting to reduce lead-time.
- **B items**: medium priority. Normal controls with good records, regular attention, and normal processing.
- **C items**: lowest priority. Simplest possible controls-make sure there are plenty. Simple or no records; perhaps use a two-bin system or periodic review system. Order large quantities and carry safety stock.

Summary

There are benefits as well as costs to having inventory. The problem is to balance the cost of carrying inventory with the following:
1. **Customer service**. The lower the inventory level, the higher the likelihood of a stock-out and the potential cost of back orders, lost sales, and lost customers. The higher the inventory level, the higher the level of customer service.
2. **Operating efficiency**. Inventories decouple one operation from another and allow manufacturing to operate more efficiently. They allow leveling production and avoid the costs of changing production levels. Carrying inventory allows longer production runs and reduces the number of setups. Finally, inventories let manufacturing purchase in larger quantities. The ABC inventory classification system prioritizes individual items so that inventory and costs can be better controlled.
3. **Cost of placing orders**. Inventory can be reduced by ordering less each time an order is placed. However, this increases the annual cost of ordering.
4. **Transportation and handling costs**. The more often goods have to be moved and the smaller the quantities moved, the greater the transportation and material handling costs.

Inventory management is influenced by several factors:
1. The classification of the inventory, whether raw material, work-in-process, or finished goods.
2. The functions that inventory serves: anticipation, fluctuation, lot size, or transportation.
3. Supply and demand patterns. The costs associated with carrying (or not carrying) inventory.
Chapter 10: order quantities

The objectives of inventory management are to provide the required level of customer service and to reduce the sum of all costs involved. To achieve these objectives, two basic questions must be answered:
1. How much should be ordered at one time?
2. When should an order be placed?

Stock-keeping unit (SKU)

are individual items in a particular inventory.

Lot-size decision rules:

a lot, or batch, are defined as a quantity produced together and sharing the same production costs and specifications. Following are some common decision rules for determining what lot size to order at one time.

1. Lot-for-lot says to order exactly what is needed-no more-no less. The order quantity changes whenever requirements change. The best method for planning A items and is also used in a just-in-time environment.
2. Fixed-order quantity rules specify the number of units to be ordered each time an order is placed for an individual item or SKU.

A variation on the fixed-order quantity system is the min-max system. In this system, an order is placed when the quantity available falls below the order point. For example, if the order point is 100 units, the maximum is 300 units, and the quantity actually available when the order is placed is 75, the order quantity is 225 units. If the quantity actually available is 80 units, an order for 220 units is placed.

Economic-order quantity (EOQ)

The assumptions on which the EOQ is based are as follows:
1. Demand is relatively constant and is known.
2. The item is produced or purchased in lots or batches and not continuously.
3. Order preparation costs and inventory-carrying costs are constant and known.
4. Replacement occurs all at once.

These assumptions are usually valid for finished goods whose demand is independent and fairly uniform.
Development of the EOQ formula

Suppose for a particular item, the order quantity is 200 units, and the usage rate is 100 units a week. Figure 10.1 page 263 shows how inventory would behave.

From the preceding,

Average lot size inventory = \( \frac{\text{order quantity}}{2} = \frac{200}{2} = 100 \) units

Number of orders per year = \( \frac{\text{annual demand}}{\text{order quantity}} = \frac{100 \times 52}{200} = 26 \) times per year
Example problem #1

The annual demand for an SKU is 10,075 units, and it is ordered in quantities of 650 units. Calculate the average inventory and the number of orders placed per year.

Answer

Average inventory = order quantity $650/2 = 325$ units

Number of orders per year = \[
\frac{\text{annual demand}}{\text{order quantity}}
\]

\[
= \frac{10,075}{650} = 15.5
\]

For EOQ the relevant costs are as follows:

• annual cost of placing orders.

• annual cost of carrying inventory.

Let:

\[A = \text{annual usage in units}\]
\[S = \text{ordering cost in dollars per order}\]
\[I = \text{annual carrying cost rate as a decimal of a percentage}\]
\[C = \text{unit cost in dollars}\]
\[Q = \text{order quantity in units}\]

Then:

Annual ordering cost = \[
\frac{\text{number of orders}}{\text{costs per order}}
\]

\[
= \frac{a}{q} \times s
\]

Annual carrying cost = \[
\frac{\text{average inventory}}{\text{cost of carrying one unit for one year}}
\]

\[
= \frac{\text{average inventory}}{\text{unit cost}} \times \text{carrying cost}
\]

\[
= \frac{q}{2} \times c \times i
\]

Total annual costs = \[
\text{annual ordering costs} + \text{annual carrying costs}
\]

\[
= \frac{a}{q} \times s + \frac{q}{2} \times c \times i
\]
Example problem #2

The annual demand is 10,000 units, the ordering cost $30 per order, the carrying cost 20%, and the unit cost $15. The order quantity is 600 units.

Calculate:
A. Annual ordering cost
B. Annual carrying cost
C. Total annual cost

Answer
A = 10,000 units
S = $30
I = 0.20
C = $15
Q = 600 units

Annual ordering cost = [number of orders] x [costs per order]
= [a/q] x s =\([10,000/600] \times 30 = $500\]

Annual carrying cost = [average inventory] x [cost of carrying one unit for one year]
= [average inventory] x [unit cost] x [carrying cost]
= \([q/2] \times c \times i = [600/2] \times $15 \times 0.2 = $900\)

Total annual costs = [annual ordering costs] + [annual carrying costs]
= [a/q] x s + [q/2] x [c] x [i]
=\([10,000/600] \times 30 + [600/2] \times $15 \times 0.2 = $500 + 900 = $1,400\)

Figure 10.2 page 286 is a tabulation of the costs for different order quantities.

Problem 10.1 – 10.3
Economic-order quantity formula

The previous section showed that the EOQ occurred at an order quantity in which the ordering costs equal the carrying costs. This value for the order quantity is the economic-order quantity. Using the formula to calculate the EOQ in the preceding example yields:

\[ EOQ = \sqrt{\frac{2\cdot A \cdot S}{i}} = \sqrt{\frac{2\times100\times20}{0.20\times5}} = 200 \]

Variation of the EOQ model

Monetary unit lot size

The EOQ can be calculated in monetary units rather than physical units. The same EOQ formula given in the preceding can be used, but the annual usage changes from units to dollars.

\[ A = \text{annual usage in dollars} \]
\[ S = \text{ordering costs in dollars} \]
\[ I = \text{carrying cost rate as a decimal of a percent} \]

The EOQ in dollars is:

\[ EOQ = \sqrt{\frac{2\cdot A \cdot S}{i}} \]
Example problem #3

An item has an annual demand of $5000, preparation costs of 20% per order, and a carrying cost of $20. What is the EOQ in dollars?

\[
EOQ = \sqrt{\frac{2AS}{i}} = \sqrt{\frac{2 \times 5000 \times 20}{0.2}} = $1000
\]

Problem 10.4 – 10.5

Quantity discounts

When material is purchased, suppliers often give a discount on orders over a certain size. This can be done because larger orders reduce the supplier’s costs; to get larger orders, they are willing to offer volume discounts.

The buyer must decide whether to accept the discount, and in doing so, must consider the relevant costs:
1. Purchase cost.
2. Ordering costs.
3. Carrying costs.
Example problem #5  (Ex. Prob. #4 skipped intentionally)

An item has an annual demand of 25,000 units, a unit cost of $10, an order preparation cost of $10, and a carrying cost of 20%. It is ordered on the basis of an EOQ, but the supplier has offered a discount of 2% on orders of $10,000 or more. Should the offer be accepted?

Answer

\[ A_c = 25,000 \times 10 = 250,000 \]
\[ S = 10 \]
\[ I = 20\% = 0.20 \]

\[ EOQ = \sqrt{\frac{2AS}{i}} = \sqrt{\frac{2 \times 25000 \times 10}{0.2}} = 5000 \]

Discounted order quantity $10,000 \times 0.98 = 9,800$

<table>
<thead>
<tr>
<th></th>
<th>No discount</th>
<th>Discount lot size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit price</td>
<td>$10</td>
<td>$9.80</td>
</tr>
<tr>
<td>Lot size</td>
<td>$5000</td>
<td>$9800</td>
</tr>
<tr>
<td>Average lot-size inventory (qc / 2)</td>
<td>$2500</td>
<td>$4900</td>
</tr>
<tr>
<td>Number of orders per year</td>
<td>50</td>
<td>25</td>
</tr>
<tr>
<td>Purchase cost</td>
<td>$250,000</td>
<td>$245,000</td>
</tr>
<tr>
<td>Inventory-carrying cost (20%)</td>
<td>500</td>
<td>980</td>
</tr>
<tr>
<td>Order preparation cost ($10 each)</td>
<td>500</td>
<td>250</td>
</tr>
<tr>
<td>Total cost</td>
<td>$251,000</td>
<td>$246,230</td>
</tr>
</tbody>
</table>

Problem 10.6

From the preceding example problem, it can be said that taking the discount results in the following:

1. There is a saving in purchase cost.
2. Ordering costs are reduced because fewer orders are placed since larger quantities are being ordered.
3. Inventory-carrying costs rise because of the larger order quantity.

The buyer must weigh the first two against the last and decide what to do. What counts is the total cost. Depending on the Figures, it may or may not be best to take the discount.
Period-order quantity (POO)

The period-order quantity lot-size rule is used to produce a time interval for which orders are placed.

Instead of ordering the same quantity (EOQ), orders are placed to satisfy requirements for the calculated time interval. The number of orders placed in a year is the same as for an economic-order quantity, but the amount ordered each time varies.

Thus, the ordering cost is the same but, because the order quantities are determined by actual demand, the carrying cost is reduced.

Period-order quantity = EOQ/ [average weekly usage]
Example problem #7  (Ex. Prob. #6 on Product Family skipped intentionally)

The EOQ for an item is 2800 units, and the annual usage is 52,000 units. What is the period-order quantity?

Answer
Average weekly usage = 52,000/ 52 = 1000 per week
Period-order quantity = [EOQ]/ [average weekly usage] = 2800/100 = 2.8 weeks = 3 weeks

When an order is placed it will cover the requirements for the next three weeks.
Example problem #8

Given the following MRP record and an EOQ of 250 units, calculate the planned order receipts using the economic-order quantity. Next, calculate the period-order quantities and the planned order receipts. In both cases, calculate the ending inventory and the total inventory carried over the ten weeks.

<table>
<thead>
<tr>
<th>Week</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net requirements</td>
<td>100</td>
<td>50</td>
<td>150</td>
<td>75</td>
<td>200</td>
<td>55</td>
<td>80</td>
<td>150</td>
<td>30</td>
<td>890</td>
<td></td>
</tr>
<tr>
<td>Planned order receipt</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Answer where EOQ = 250 units

<table>
<thead>
<tr>
<th>Week</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net requirements</td>
<td>100</td>
<td>50</td>
<td>150</td>
<td>75</td>
<td>200</td>
<td>55</td>
<td>80</td>
<td>150</td>
<td>30</td>
<td>890</td>
<td></td>
</tr>
<tr>
<td>Planned order receipt</td>
<td>250</td>
<td>250</td>
<td>250</td>
<td>250</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ending inventory</td>
<td>150</td>
<td>100</td>
<td>200</td>
<td>200</td>
<td>125</td>
<td>175</td>
<td>120</td>
<td>40</td>
<td>140</td>
<td>110</td>
<td>1360</td>
</tr>
</tbody>
</table>

Period-order quantity:
Weekly average demand = 890/ 10 = 89
POQ = 250/ 89 = 2.81 = 3 weeks

<table>
<thead>
<tr>
<th>Week</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net requirements</td>
<td>100</td>
<td>50</td>
<td>150</td>
<td>75</td>
<td>200</td>
<td>55</td>
<td>80</td>
<td>150</td>
<td>30</td>
<td>890</td>
<td></td>
</tr>
<tr>
<td>Planned order receipt</td>
<td>300</td>
<td>330</td>
<td>260</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ending inventory</td>
<td>200</td>
<td>150</td>
<td>0</td>
<td>0</td>
<td>255</td>
<td>55</td>
<td>0</td>
<td>180</td>
<td>30</td>
<td>0</td>
<td>870</td>
</tr>
</tbody>
</table>

Notice in the example problem the total inventory is reduced from 1360 units to 870 units over the ten-week period.
Practical considerations when using the EOQ

1. **Lumpy demand.** The EOQ assumes that demand is uniform and replenishment occurs all at once. When this is not true, the EOQ will not produce the best results. It is better to use the period-order quantity.

2. **Anticipation inventory.** Demand is not uniform, and stock must be built ahead. It is better to plan a buildup of inventory based on capacity and future demand.

3. **Minimum order.** Some suppliers require a minimum order. This minimum may be based on the total order rather than on individual items. Often these are c items where the rule is to order plenty, not an EOQ.

4. **Transportation inventory.** As will be discussed in chapter 13, carriers give rates based on the amount shipped. A full load costs less per ton to ship than a part load. This is similar to the price break given by suppliers for large quantities. The same type of analysis can be used.

5. **Multiples.** Sometimes, order size is constrained by package size. For example, a supplier may ship only in skid-load lots. In these cases, the unit used should be the minimum package size.

**Summary**

The economic-order quantity is based on the assumption that demand is relatively uniform.

The two costs influenced by the order quantity are the cost of ordering and the cost of carrying inventory.

All methods of calculating order quantities attempt to minimize the sum of these two costs. The period-order quantity does this. It has the advantage over the EOQ in that it is better for lumpy demand because it looks forward to see what is actually needed.
Chapter 11: Independent Demand Ordering Systems

When is the best time to place an order in order to prevent stock-out’s or carrying extra inventory? The problem then is how to balance the costs of carrying extra inventory against the costs of a stock-out.

Controlling inventories requires effective reorder systems. Three basic systems are used to determine when to order:
1. Order point system.
2. Periodic review system.
3. Material requirements planning.

The first two are for independent demand items; the last is for dependent demand items.

1. Order point system

When the quantity of an item on hand falls to a predetermined level, called an order point, an order is placed. The quantity ordered is usually precalculated and based on economic-order-quantity concepts.

An order must be placed when there is enough stock on hand to satisfy demand from the time the order is placed until the new stock arrives (called the lead-time).

Suppose the average demand is 100 units a week and the lead-time is four weeks. If an order is placed when there are 400 units on hand, there should be enough stock on hand to last until the new stock arrives.

However, demand varies from the average-sometimes more and sometimes less than the 400. Statistically, half the time the demand is greater, and there is a stock-out; half the time the demand is less than average, and there is extra stock. If it is necessary to provide protection against a stock-out, safety stock can be added. The item is ordered when the quantity on hand falls to a level equal to the demand during the lead-time plus the safety stock:

\[ \text{Op} = \text{DDLT} + \text{SS} \]

Where:
- \( \text{OP} \) = order point
- \( \text{DDLT} \) = demand during the lead-time
- \( \text{SS} \) = safety stock

Demand during the lead-time that is important because it is the only time a stock-out is possible is during the lead-time. If demand during the lead-time is greater than expected, there will be a stock-out unless sufficient safety stock is carried.
Example problem #1

Demand is 200 units a week, the lead-time is three weeks, and safety stock is 300 units. Calculate the order point.

Answer
\[ \text{Op} = \text{DDLT} + \text{SS} = [200 \times 3] + 300 = 900 \text{ units} \]

Figure 11.1 page 282 shows the relationship between safety stock, lead-time, order quantity, and order point. With the order point system:

• order quantities are usually fixed.
• the order point is determined by the average demand during the lead-time. If the average demand or the lead-time changes and there is no corresponding change in the order point, effectively there has been a change in safety stock.
• the time intervals between replenishment are not constant but vary depending on the actual demand during the reorder cycle.
• average inventory = [order quantity/2] + safety stock = Q/2 + SS

Determining the order point depends on the demand during the lead-time and the safety stock required.
Example problem #2

Order quantity is 1000 units and safety stock is 300 units. What is the average annual inventory?

Answer
Average inventory = Q/2 + SS
= [1000/2] + 300 = 800 units

Problem 11.1 – 11.2
Determining safety stock

Safety stock is intended to protect against uncertainty in supply and demand. Uncertainty may occur in two ways: quantity uncertainty and timing uncertainty.
1. Quantity uncertainty occurs when the amount of supply or demand varies; for example, if the demand is greater or less than expected in a given period.
2. Timing uncertainty occurs when the time of receipt of supply or demand differs from that expected. A customer or a supplier may change a delivery date, for instance.

There are two ways to protect against uncertainty: (1) carry extra stock, called safety stock, or (2) order early, called safety lead-time.
1. Safety stock is a calculated extra amount of stock carried and is generally used to protect against quantity uncertainty.
2. Safety lead-time is used to protect against timing uncertainty by planning order releases and order receipts earlier than required.

Safety stock and safety lead-time both result in extra inventory, but the methods of calculation are different.

Safety stock is the most common way of buffering against uncertainty. The safety stock required depends on the following:
1. Variability of demand during the lead-time.
2. Frequency of reorder.
3. Service level desired.
4. Length of the lead-time. The longer the lead-time, the more safety stock has to be carried to provide a specified service level. This is one reason it is important to reduce lead-times as much as possible.
**Variation in demand during lead-time**

Suppose two items, A and B, have a ten-week sales history, as shown in Figure 11.2 page 308.

Average demand over the lead-time of one week is 1000 per week for both items. However, the weekly demand for A has a range from 700 to 1400 units a week and that for B is from 200 to 1600 units per week.

The demand for B is more erratic. If the order point is 1200 units for both items, there will be one stock-out for A and four for B.

If the same service level is to be provided (the same chance of stock-out for all items), some method of estimating the randomness of item demand is needed.

Figure 11.2 actual demand for two items.

<table>
<thead>
<tr>
<th>Week</th>
<th>Item a</th>
<th>Item b</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1200</td>
<td>400</td>
</tr>
<tr>
<td>2</td>
<td>1000</td>
<td>600</td>
</tr>
<tr>
<td>3</td>
<td>800</td>
<td>1600</td>
</tr>
<tr>
<td>4</td>
<td>900</td>
<td>1300</td>
</tr>
<tr>
<td>5</td>
<td>1400</td>
<td>200</td>
</tr>
<tr>
<td>6</td>
<td>1100</td>
<td>1100</td>
</tr>
<tr>
<td>7</td>
<td>1100</td>
<td>1500</td>
</tr>
<tr>
<td>8</td>
<td>700</td>
<td>800</td>
</tr>
<tr>
<td>9</td>
<td>1000</td>
<td>1400</td>
</tr>
<tr>
<td>10</td>
<td>800</td>
<td>1100</td>
</tr>
<tr>
<td>Total</td>
<td>10,000</td>
<td>10,000</td>
</tr>
<tr>
<td>Average</td>
<td>1000</td>
<td>1000</td>
</tr>
</tbody>
</table>
Variation in demand about the average

Suppose over the past 100 weeks a history of weekly demand for a particular item shows an average demand of 1000 units.

As expected, most of the demands are around 1000; a smaller number would be farther away from the average and still fewer would be farthest away. If the weekly demands are classified into groups or ranges about the average, a picture of the distribution of demand about the average appears. Suppose the demand is distributed as follows:

<table>
<thead>
<tr>
<th>Weekly demand</th>
<th>Number of weeks</th>
</tr>
</thead>
<tbody>
<tr>
<td>725-774</td>
<td>2</td>
</tr>
<tr>
<td>775-824</td>
<td>3</td>
</tr>
<tr>
<td>825-874</td>
<td>7</td>
</tr>
<tr>
<td>875-924</td>
<td>12</td>
</tr>
<tr>
<td>925-974</td>
<td>17</td>
</tr>
<tr>
<td>975-1024</td>
<td>20</td>
</tr>
<tr>
<td>1025-1074</td>
<td>17</td>
</tr>
<tr>
<td>1075-1124</td>
<td>12</td>
</tr>
<tr>
<td>1125-1174</td>
<td>7</td>
</tr>
<tr>
<td>1175-1224</td>
<td>3</td>
</tr>
<tr>
<td>1225-1274</td>
<td>2</td>
</tr>
</tbody>
</table>

These data are plotted to give the results shown in Figure 11.3 page 309. This is a histogram.

**Normal distribution.** The shape of the histogram in Figure 11.3 indicates that although there is variation in the distribution, it follows a definite pattern, as shown by the smooth curve. Such a natural pattern shows predictability.

The most common predictable pattern is similar to the one outlined by the histogram in Figure 11.3 and is called a normal curve, or bell curve, because its shape resembles a bell. The shape of a perfectly normal distribution is shown in Figure 11.4 page 309.

The normal distribution has most of the values clustered near a central point with progressively fewer results occurring away from the center. It is symmetrical about this central point in that it spreads out evenly on both sides.

The normal curve is described by two characteristics. One relates to its central tendency, or average, and the other to the variation, or dispersion, of the actual values about the average.

**Average or mean.** The average or mean value is at the high point of the curve. It is the central tendency of the distribution. The symbol for the mean is \( \bar{x} \) (pronounced "x bar"). See example problem on page 310.
Example Problem #3 (OMIT)

Dispersion. The variation, or dispersion, of actual demands about the average refers to how closely the individual values cluster around the mean or average. It can be measured in several ways:
• as a range of the maximum minus the minimum value.
• as the mean absolute deviation (MAD), which is a measure of the average forecast error.
• as a standard deviation.

Standard deviation (sigma)

Is a statistical value that measures how closely the individual values cluster about the average. It is represented by the Greek letter sigma (σ). The standard deviation formula follows:

\[ \sigma = \sqrt{\frac{\sum (x - \overline{x})^2}{n}} \]

Example problem #4

Given the data from the previous example problem, calculate the standard deviation (sigma).

<table>
<thead>
<tr>
<th>Period</th>
<th>Forecast demand</th>
<th>Actual demand</th>
<th>Deviation</th>
<th>Deviation squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1000</td>
<td>1200</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1000</td>
<td>1000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>1000</td>
<td>800</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>1000</td>
<td>900</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>1000</td>
<td>1400</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>1000</td>
<td>1100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>1000</td>
<td>1100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>1000</td>
<td>700</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>1000</td>
<td>1000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>1000</td>
<td>800</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>10,000</td>
<td>10,000</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Sigma = 200 units

Problem 11.3 – 11.4

From statistics, we can determine that:
• The actual demand will be within 1 sigma of the forecast average approximately 68% of the time.
• The actual demand will be within 2 sigma of the forecast average approximately 98% of the time.
• The actual demand will be within 3 sigma of the forecast average approximately 99.88% of the time.
Determining the safety stock and order point

Now that we have calculated the standard deviation, we must decide how much safety stock is needed.

One property of the normal curve is that a service level of 50% can be attained with no safety stock. If a higher service level is needed, safety stock must be provided to protect against those times when the actual demand is greater than the average.

As stated earlier, we know from statistics that the error is within ± 1 sigma of the forecast about 68% of the time (34% of the time less and 34% of the time greater than the forecast).

Suppose the standard deviation of demand during the lead-time is 100 units and this amount is carried as safety stock.

This much safety stock provides protection against stock-out for the 34% of the time that actual demand is greater than expected.

In total, there is enough safety stock to provide protection for the 84% of the time (50% + 34% = 84%) that a stock-out is possible.

The service level is a statement of the percentage of time there is no stock-out. But what exactly is meant by supplying the customer 84% of the time? On the average we would expect no stock-outs about 84 of the 100 times.
Example problem #5

Using the Figures in the last example problem in which the sigma was calculated as 200 units,

A. Calculate the safety stock and the order point for an 84% service level.

B. If a safety stock equal to two standard deviations is carried, calculate the safety stock and the order point.

Answer

A. Safety stock = 1 sigma
   = 1 x 200 = 200 units

   Order point = DDLT + SS
   = 1000 + 200 = 1200 units

Where DDLT and SS are as defined previously. With this order point and level of safety stock, on the average there are no stock-outs 84% of the time when a stock-out is possible.

B. Safety stock = 2 sigma
   = 2 x 200 = 400 units

   Order point = DDLT + SS
   = 1000 + 400 = 1400 units

Problem 11.5

Safety factor. The service level is directly related to the number of standard deviations provided as safety stock and is usually called the safety factor.

Figure 11.5 page 314 shows safety factors for various service levels. Note that the service level is the percentage of order cycles without a stock-out.

<table>
<thead>
<tr>
<th>Service level</th>
<th>Safety factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>0.00</td>
</tr>
<tr>
<td>75</td>
<td>0.67</td>
</tr>
<tr>
<td>80</td>
<td>0.84</td>
</tr>
<tr>
<td>85</td>
<td>1.04</td>
</tr>
<tr>
<td>90</td>
<td>1.28</td>
</tr>
<tr>
<td>94</td>
<td>1.56</td>
</tr>
<tr>
<td>95</td>
<td>1.65</td>
</tr>
<tr>
<td>96</td>
<td>1.75</td>
</tr>
<tr>
<td>97</td>
<td>1.88</td>
</tr>
<tr>
<td>98</td>
<td>2.05</td>
</tr>
<tr>
<td>99</td>
<td>2.33</td>
</tr>
<tr>
<td>99.86</td>
<td>3.00</td>
</tr>
<tr>
<td>99.99</td>
<td>4.00</td>
</tr>
</tbody>
</table>
Example problem #6

If the standard deviation is 200 units, what safety stock should be carried to provide a service level of 90%? If the expected demand during the lead-time is 1500 units, what is the order point?

Answer
From Figure 11.5, the safety factor for a service level of 90% is 1.28. Therefore:

\[
\text{Safety stock} = \sigma \times \text{Safety factor} \\
= 200 \times 1.28 = 256 \text{ units}
\]

\[
\text{Order point} = \text{DDLT} + \text{SS} \\
= 1500 + 256 = 1756 \text{ units}
\]

Problem 11.6

Determining service levels

Theoretically, we want to carry enough safety stock on hand so the cost of carrying the extra inventory plus the cost of stock-outs is a minimum.

Stock-outs cost money for the following reasons: back-order costs, lost sales, and lost customers.

The only time it is possible for a stock-out to occur is when stock is running low, and this happens every time an order is to be placed. Therefore, the chances of a stock-out are directly proportional to the frequency of reorder. The more often stock is reordered, the more often there is a chance of a stock-out.

Figure 11.6 page 291 shows the effect of the order quantity on the number of exposures per year. Note also that when the order quantity is increased, exposure to stock-out decreases. The safety stock needed decreases, but because of the larger order quantity, the average inventory increases.
Example problem #7

Suppose management stated that it could tolerate only one stock-out per year for a specific item.

For this particular item, the annual demand is 52,000 units, it is ordered in quantities of 2600, and the standard deviation of demand during the lead-time is 100 units. The lead-time is one week. Calculate:

A. Number of orders per year  
B. Service level  
C. Safety stock  
D. Order point

Answer  
A. Number of orders per year = annual demand/ order quantity  
   \[ \frac{52,000}{2600} = 20 \text{ times per year} \]

B. Since one stock-out per year is tolerable, there must be no stock-outs 19 (20 - 1) times per year.  
   Service level = \( \frac{20 - 1}{20} = 95\% \)

C. From Figure 11.5 safety factor = 1.65  
   Safety stock = safety factor x sigma  
   \[ = 1.65 \times 100 = 165 \text{ units} \]

D. Demand during lead-time = (1 week) x (52,000)/52 = 1000 units  
   Order point = demand during lead time + ss  
   \[ = 1000 + 165 = 1165 \text{ units} \]

Problem 11.7 – 11.9
Determining when the order point is reached

In practice, there are many systems, but they all are variations or extensions of two basic systems: the two-bin system and the perpetual inventory system.

1. **Two-bin system**: a quantity of an item equal to the order point quantity is set aside (frequently in a separate or second bin) and not touched until all the main stock is used up.

2. **Perpetual inventory record system**: is a continual account of inventory transactions as they occur. At any instant, it holds an up-to-date record of transactions. At a minimum, it contains the balance on hand, but it may also contain the quantity on order but not received, the quantity allocated but not issued, and the available balance.

   Figure 11.7 page 319 shows this type of record.

**Periodic review system**

Using the periodic review system, the quantity on hand of a particular item is determined at specified, fixed-time intervals, and an order is placed. Figure 11.8 page 320 illustrates this system.

Figure 11.8 shows that the review intervals (t1, t2, and t3) are equal and that q1, q2, and q3 are not necessarily the same. Thus the review period is fixed, and the order quantity is allowed to vary.

The quantity on hand plus the quantity ordered must be sufficient to last until the next shipment is received. That is, the quantity on hand plus the quantity ordered must equal the sum of the demand during the lead-time plus the demand during the review period plus the safety stock.
Target level or maximum-level inventory

The quantity equal to the demand during the lead-time plus the demand during the review period plus safety stock is called the target level or maximum-level inventory:

\[ T = D(R+L) + SS \]

Where
- \( T \) = target (maximum) inventory level
- \( D \) = demand per unit of time
- \( L \) = lead-time duration
- \( R \) = review period duration
- \( SS \) = safety stock

The order quantity is equal to the maximum-inventory level minus the quantity on hand at the review period:

\[ Q = T - I \]

Where
- \( Q \) = order quantity
- \( I \) = inventory on hand

The periodic review system is useful for the following:
- where there are many small issues from inventory, and posting transactions to inventory records are very expensive. Supermarkets and retailers are in this category.
- where ordering costs are small. This occurs when many different items are ordered from one source. A regional distribution center may order most or all of its stock from a central warehouse.
- where many items are ordered together to make up a production run or fill a truckload. A good example of this is a regional distribution center that orders a truckload once a week from a central warehouse.
Example problem #10

A hardware company stocks nuts and bolts and orders them from a local supplier once every two weeks (ten working days). Lead-time is two days. The company has determined that the average demand for 1/2-inch bolts is 150 per week (five working days), and it wants to keep a safety stock of three days' supply on hand. An order is to be placed this week, and stock on hand is 130 bolts.

A. What is the target level?
B. How many 1/2-inch bolts should be ordered this time?

Answer

Let $d = \text{demand per unit of time} = \frac{150}{5} = 30 \text{ per working day}$

$L = \text{lead-time duration} = 2 \text{ days}$

$R = \text{review period duration} = 10 \text{ days}$

$SS = \text{safety stock} = 3 \text{ days' supply} = 90 \text{ units}$

$I = \text{inventory on hand} = 130 \text{ units}$

Then

$\text{Target level } T = D(R + L) + SS = 30(10 + 2) + 90 = 450 \text{ units}$

$\text{Order quantity } Q = [T - L] = 450 - 130 = 320 \text{ units}$
Chapter 12: Physical Inventory and Warehouse Management

Warehousing management
As with other elements in a distribution system, the objective of a warehouse is to minimize cost and maximize customer service. To do this, efficient warehouse operations perform the following:
1. Provide timely customer service.
2. Keep track of items so they can be found readily and correctly.
3. Minimize the total physical effort and thus the cost of moving goods into and out of storage.
4. Provide communication links with customers.

Example Problem #1 (OMIT)

Example Problem #2 (OMIT)

The costs of operating a warehouse can be broken down into capital and operating costs.

Capital costs are those of space and materials handling equipment. The space needed depends on the peak quantities that must be stored, the methods of storage, and the need for ancillary space for aisles, docks, offices, and so on.

The major operating cost is labor, and the measure of labor productivity is the number of units (for example, pallets) that an operator can move in a day. This depends on the type of material handling equipment used, the location and accessibility of stock, warehouse layout, stock location system, and the order-picking system used.

Note: most of this chapter has been (will be) covered in facilities planning therefore the instructor elects to skip those portions.

Inventory record accuracy

Errors in inventory records can be traced to poor record-keeping systems and poorly trained personnel. Some examples of causes of inventory record error are:
• unauthorized withdrawal of material.
• unsecured stockroom.
• poorly trained personnel.
• inaccurate transaction recording.
• poor transaction recording systems.
• lack of audit capability.
Measuring inventory record accuracy

Figure 12.3 page 345 shows ten inventory items, their physical count, and the quantity shown on their record. What is the inventory accuracy? The total of all items is the same, but only two of the ten items are correct. Is the accuracy 100% or 20% or something else?

<table>
<thead>
<tr>
<th>Part number</th>
<th>Inventory record</th>
<th>Shelf count</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100</td>
<td>105</td>
</tr>
<tr>
<td>2</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>3</td>
<td>100</td>
<td>98</td>
</tr>
<tr>
<td>4</td>
<td>100</td>
<td>97</td>
</tr>
<tr>
<td>5</td>
<td>100</td>
<td>102</td>
</tr>
<tr>
<td>6</td>
<td>100</td>
<td>103</td>
</tr>
<tr>
<td>7</td>
<td>100</td>
<td>99</td>
</tr>
<tr>
<td>8</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>9</td>
<td>100</td>
<td>97</td>
</tr>
<tr>
<td>10</td>
<td>100</td>
<td>99</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1000</strong></td>
<td><strong>1000</strong></td>
</tr>
</tbody>
</table>

Tolerance is the amount of permissible variation between an inventory record and a physical count.

Tolerances are set on individual items based on value, critical nature of the item, availability, lead-time, ability to stop production, safety problems, or the difficulty of getting precise measurement.

Figure 12.4 page 346 shows the same data as the previous Figure, but includes tolerances. This information tells us exactly what inventory accuracy is.

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Inventory Record</th>
<th>Shelf Count</th>
<th>Tolerance</th>
<th>Within Tolerance</th>
<th>Outside Tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100</td>
<td>105</td>
<td>±5%</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>100</td>
<td>100</td>
<td>±0%</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>100</td>
<td>98</td>
<td>±3%</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>100</td>
<td>97</td>
<td>±2%</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>100</td>
<td>102</td>
<td>±2%</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>100</td>
<td>103</td>
<td>±2%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>100</td>
<td>99</td>
<td>±3%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>100</td>
<td>100</td>
<td>±0%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>100</td>
<td>97</td>
<td>±5%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>100</td>
<td>99</td>
<td>±5%</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1000</strong></td>
<td><strong>1000</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 12.4 inventory accuracy with tolerances.
Example problem #3

Determine which of the following items are within tolerance. Item a has a tolerance of ±5%; item b, ±2%; item c, ±3%; and item d, ±0%.

<table>
<thead>
<tr>
<th>Part number</th>
<th>Shelf count</th>
<th>Inventory record</th>
<th>Tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1500</td>
<td>1550</td>
<td>±5%</td>
</tr>
<tr>
<td>B</td>
<td>120</td>
<td>125</td>
<td>±2%</td>
</tr>
<tr>
<td>C</td>
<td>225</td>
<td>230</td>
<td>±3%</td>
</tr>
<tr>
<td>D</td>
<td>155</td>
<td>155</td>
<td>±0%</td>
</tr>
</tbody>
</table>

Answer

  Item A. With a tolerance of ±5%, variance can be up to ±75 units. Item a is within tolerance.
  Item B. With a tolerance of ±2%, variance can be up to ±2 units. Item b is outside tolerance.
  Item C. With a tolerance of ±3%, variance can be up to ±7 units. Item c is within tolerance.
  Item D. With a tolerance of ±0%, variance can be up to ±0 units. Item d is within tolerance.

Problem 12.7 – 12.8
Auditing inventory records

There are two basic methods of checking the accuracy of inventory records: periodic (usually annual) counts of all items and cyclic (usually daily) counts of specified items.

It is more important to audit the system to find the causes of record inaccuracy and eliminate them. Cycle counting does this; periodic audits tend not to.

1. Periodic (annual) inventory. The primary purpose of a periodic (annual) inventory is to satisfy the financial auditors that the inventory records represent the value of the inventory.

To planners, the physical inventory represents an opportunity to correct any inaccuracies in the records. There are three factors in good preparation: housekeeping, identification, and training.

Process of taking a physical inventory consists of four steps:
1. Count items and record the count on a ticket left on the item.
2. Verify this count by recounting or by sampling.
3. When the verification is finished, collect the tickets and list the items in each department.
4. Reconcile the inventory records for differences between the physical count and inventory dollars.

Taking a physical inventory has several problems. Because of these problems, the idea of cycle counting has developed.

2. Cycle counting is a system of counting inventory continually throughout the year. Depending on their importance, some items are counted frequently throughout the year whereas others are not. The idea is to count selected items each day.

The advantages to cycle counting are:
- timely detection and correction of problems.
- complete or partial reduction of lost production.
- use of personnel trained and dedicated to cycle counting.

Count frequency. The basic idea is to count some items each day so all items are counted a predetermined number of times each year.

The number of times an item is counted in a year is called its count frequency. Several methods can be used to determine the frequency. Three common ones are the ABC method, zone method, and location audit method.
1. **ABC method.** This is a popular method. Inventories are classified according to the abc system. Some rule is established for count frequency. For example, a items might be counted weekly or monthly; b items, bimonthly or quarterly; and c items, biannually or once a year.

On this basis, a count schedule can be established. Figure 12.5 page 349 shows an example of a cycle count scheduled using the ABC system.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Number Of items</th>
<th>Count frequency</th>
<th>Number of counts</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1000</td>
<td>12</td>
<td>12500</td>
</tr>
<tr>
<td>B</td>
<td>1500</td>
<td>4</td>
<td>6000</td>
</tr>
<tr>
<td>C</td>
<td>2500</td>
<td>1</td>
<td>2500</td>
</tr>
<tr>
<td><strong>Total counts</strong></td>
<td></td>
<td></td>
<td><strong>20,500</strong></td>
</tr>
<tr>
<td><strong>Workdays per year</strong></td>
<td></td>
<td></td>
<td><strong>250</strong></td>
</tr>
<tr>
<td><strong>Counts per day</strong></td>
<td></td>
<td></td>
<td><strong>82</strong></td>
</tr>
</tbody>
</table>

Figure 12.5 scheduling cycle counts.
Example problem #4

A company has classified its inventory into ABC items. They have decided that a items are to be counted once a month; b items, four times a year; and c items, twice a year. There are 2000 a items, 3000 b items, and 5000 c items in inventory. Develop a schedule of the counts for each class of item.

Answer

<table>
<thead>
<tr>
<th>Classification</th>
<th>Number Of items</th>
<th>Count frequency</th>
<th>Number of counts</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2000</td>
<td>12</td>
<td>24000</td>
</tr>
<tr>
<td>B</td>
<td>3000</td>
<td>4</td>
<td>12000</td>
</tr>
<tr>
<td>C</td>
<td>5000</td>
<td>2</td>
<td>10000</td>
</tr>
<tr>
<td>Total counts</td>
<td></td>
<td></td>
<td>46000</td>
</tr>
<tr>
<td>Workdays per year</td>
<td></td>
<td></td>
<td>250</td>
</tr>
<tr>
<td>Counts per day</td>
<td></td>
<td></td>
<td>184</td>
</tr>
</tbody>
</table>

Problem 12.9 – 12.10
2. **Zone method.** Items are grouped by zones to make counting more efficient. The system is used when a fixed-location system is used, or when work-in-process or transit inventory is being counted.

3. **Location audit system.** In a floating-location system, goods can be stored anywhere, and the system records where they are. Because of human error, these locations may not be 100% correct.

    If material is mislocated, normal cycle counting may not find it. In using location audits, a predetermined number of stock locations are checked each period. The item numbers of the material in each bin are checked against inventory records to verify stock point locations.

    A cycle counting program may include all these methods. The zone method is ideal for fast-moving items. If a floating-location system is used, a combination of abc and location audit is appropriate.

**When to count.** Cycle counts can be scheduled at regular intervals or on special occasions. Some selection criteria are:

    **When an order is placed.** Items are counted just before an order is placed. This has the advantage of detecting errors before the order is placed and reducing the amount of work by counting at a time when stock is low.

    **When an order is received.** Inventory is at its lowest level.

    **When the inventory record reaches zero.** Again, this method has the advantage of reducing work.

    **When a specified number of transactions** have occurred. Errors occur when transactions occur. Fast-moving items have more transactions and are more prone to error.

    **When an error occurs.** A special count is appropriate when an obvious error is detected. This may be a negative balance on the stock record or when no items can be found although the record shows some in stock.