The automated method has the higher positive net uniform annual cash value. Assuming that money is available to make the larger investment, it would be selected.

The situation depicted in this example is typical of automation projects: A larger initial investment must be made for the sake of lower annual operating costs. Less labor is required to run the automated process.

In many of the problems in this book, we will make use of annual costs or costs per other time period (e.g., cost per hour) which can be determined from the annual cost. The annual cost given will often be a calculated equivalent UAC. Let us consider next the types of costs in manufacturing and how these costs can be reduced to their equivalent annual or hourly rates.

3.2 COSTS IN MANUFACTURING

Fixed and variable costs

Manufacturing costs can be divided into two major categories, fixed costs and variable costs. The difference between the two is based on whether the expense varies in relation to the level of output.

A fixed cost is one that is constant for any level of production output. Examples of fixed costs include cost of the factory building, insurance, property taxes, and the cost of production equipment. All of these fixed costs can be expressed as annual costs. Those items that are capital investments (e.g., factory building and production equipment) can be converted to their equivalent uniform annual costs by the methods of the preceding section.

A variable cost is one that increases as the level of production increases. Direct labor costs (plus fringe benefits), raw materials, and electrical power to operate the production machines are examples of variable costs. The ideal concept of variable cost is that it is directly proportional to output level. When fixed and variable costs are combined, we get the total cost of manufacturing as a function of output. A general plot of the relationship is shown in Figure 3.1.

![Figure 3.1 Plot of fixed and variable costs as a function of production output.](image-url)
Overhead costs

Classification of costs as either fixed or variable is not always convenient for accountants and finance people. Fixed costs and variable costs are valid concepts, but the financial specialists of a manufacturing firm usually prefer to think in terms of direct labor cost, material cost, and overhead costs. The direct labor cost is the sum of the wages paid to the people who operate the production machines and perform the processing and assembly operations. The material cost is the cost of all the raw materials that are used to produce the finished product of the firm. In terms of fixed and variable costs, direct labor and material costs must be considered as variable.

Overhead costs are all the other costs associated with running a manufacturing firm. Overhead can be divided into two categories: factory overhead (sometimes called factory expense) and corporate overhead. Factory overhead includes the costs of operating the factory other than direct labor and materials. The types of expenses included in this category are listed in Table 3.1. It can be seen that some of these costs are variable whereas others are fixed. The corporate overhead cost is the cost of running the company other than its manufacturing activities. A list of many of the expenses included under corporate overhead is presented in Table 3.2. Many manufacturing firms operate more than one plant, and this is one of the reasons for dividing overhead into factory and corporate categories.

**FACTORY OVERHEAD.** The overhead costs of a firm can amount to several times the cost of direct labor. The overhead can be allocated according to a number of different bases, including direct labor cost, direct labor hours, space, material cost, and so on. We will use direct labor cost to illustrate how factory overhead rates are determined. Suppose that the total cost of operating a plant amounts to $900,000 per year. Of this total, $400,000 is direct labor cost. This means that $500,000 is indirect or overhead expense: plant supervision, line foremen, annual cost of equipment, energy, maintenance personnel, and so on. The factor overhead rate for this plant would be figured as

\[
\text{factory overhead rate} = \frac{\$500,000}{\$400,000} = 1.25
\]

<table>
<thead>
<tr>
<th>TABLE 3.1</th>
<th>Typical Factory Overhead Expenses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant supervision</td>
<td>Applicable taxes</td>
</tr>
<tr>
<td>Line foremen</td>
<td>Insurance</td>
</tr>
<tr>
<td>Maintenance crew</td>
<td>Heat</td>
</tr>
<tr>
<td>Custodial services</td>
<td>Light</td>
</tr>
<tr>
<td>Security personnel</td>
<td>Power for machines</td>
</tr>
<tr>
<td>Tool crib attendant</td>
<td>Factory cost</td>
</tr>
<tr>
<td>Materials handling crew</td>
<td>Equipment cost</td>
</tr>
<tr>
<td>Shipping and receiving</td>
<td>Fringe benefits</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TABLE 3.2</th>
<th>Typical Corporate Overhead Expenses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corporate executives</td>
<td>Applicable taxes</td>
</tr>
<tr>
<td>Sales personnel</td>
<td>Cost of office space</td>
</tr>
<tr>
<td>Accounting department</td>
<td>Security personnel</td>
</tr>
<tr>
<td>Finance department</td>
<td>Heat</td>
</tr>
<tr>
<td>Legal counsel</td>
<td>Light</td>
</tr>
<tr>
<td>Research and development</td>
<td>Air conditioning</td>
</tr>
<tr>
<td>Design and engineering</td>
<td>Insurance</td>
</tr>
<tr>
<td>Other support personnel</td>
<td>Fringe benefits</td>
</tr>
</tbody>
</table>
Overhead rates are often expressed as percentages, so this equals 125%. This rate could be applied to a particular production job, as illustrated in Example 3.6.

**CORPORATE OVERHEAD.** The corporate overhead rate can be determined in a manner similar to that used for factory overhead. We will use an oversimplified example to illustrate. Suppose that the firm operates two plants with direct labor and factory overhead expenses as follows:

<table>
<thead>
<tr>
<th></th>
<th>Plant 1</th>
<th>Plant 2</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct labor</td>
<td>$400,000</td>
<td>$200,000</td>
<td>$600,000</td>
</tr>
<tr>
<td>Factory expense</td>
<td>$500,000</td>
<td>$300,000</td>
<td>$800,000</td>
</tr>
<tr>
<td>Total cost</td>
<td>$900,000</td>
<td>$500,000</td>
<td>$1,400,000</td>
</tr>
</tbody>
</table>

In addition, the cost of management, sales staff, engineering, accounting, and so on, amounts to $960,000. The corporate overhead rate would be based on the total direct labor of the two plants:

\[
\text{corporate overhead rate} = \frac{$960,000}{$600,000} \times 100\% = 160\% 
\]

Overhead rates, both factory and corporate, are simply a means for allocating expenses that are not directly associated with production. The principal concern in this book will be with determining the appropriate allocation of factory expenses, not corporate overhead.

**EXAMPLE 3.6**

A batch of 50 parts is to be processed through the factory for a particular customer. Raw materials and tooling are supplied by the customer. The total time for processing the parts (including setup and other direct labor) is 100 h. Direct labor cost is $9.00 per hour. The factory overhead rate is 125% and the corporate overhead rate is 160%. Compute the cost of the job.

**Solution:**

1. The direct labor cost for the job is
   \[(100 \text{ h}) \times ($9.00/\text{h}) = $900\]

2. The allocated factory overhead charge, at 125% of direct labor, would be
   \[($900)(1.25) = $1125\]

3. The allocated corporate overhead charge, at 160% of direct labor, would be
   \[($900)(1.60) = $1440\]
Interpretation: (1) The direct labor cost of the job, representing actual cash spent on the customer’s order, is $900.

(2) The total factory cost of the job, including allocated factory overhead, is $900 + $1125 = $2025. To evaluate alternative production methods, at least some of the factory overhead expenses should be included in the cost comparison.

(3) The total cost of the job, including corporate overhead, is $2025 + $1440 = $3465. To price the job for the customer, and to earn a profit over the long run on jobs like this, the price would have to be greater than $3465. For example, if the company uses a 10% markup, the price quoted to the customer would be $(1.10)(3465) = 3811.50$.

Cost of equipment usage

The trouble with overhead rates as we have developed them is that they are based on direct labor cost alone. A machine operator who runs an old, small engine lathe will be costed at the same overhead rate as the operator who runs a modern NC machining center representing a $250,000 investment. Obviously, the time on the automated machine should be valued at a higher rate. If differences between rates of different production machines are not recognized, manufacturing costs will not be accurately measured by the overhead rate structure.

To overcome this difficulty, it is appropriate to divide production costs (excluding raw materials) into two components: direct labor and machine cost. Associated with each will be the applicable factory overhead. These cost components will apply not to the aggregate factory operations but to individual production work centers. A work center would typically be one worker–machine system or a small group of machines plus the labor to operate them.

The direct labor cost consists of the wages paid to operate the work center. The applicable factory overhead allocated to direct labor might include fringe benefits and line supervision. These are factory expense items which are appropriately charged as direct labor overhead.

The machine cost is the capital cost of the machine apportioned over the life of the asset at the appropriate rate of return used by the firm. This provides an annual cost that may be expressed as an hourly rate (or any other time unit) by dividing the annual cost by the number of hours of use per year. The machine overhead rate is based on those factory expenses which are directly applicable to the machine. These would include power for the machine, floor space, maintenance and repair expenses, and so on. In separating the applicable factory overhead items of Table 3.1 between direct labor and machine, some arbitrary judgment must be used.

EXAMPLE 3.7

The determination of an hourly rate for a given work center can best be illustrated by means of an example. Given the following:

direct labor rate = $7.00/h
applicable labor factory overhead rate = 60%
capital investment in machine = $100,000
service life = 8 years
salvage value = zero
applicable machine factory overhead rate = 50%
rate of return used 10%

The machine is operated one 8-h shift per day, 250 days per year. Determine the appropriate hourly cost for this worker-machine system.

**Solution:**

The labor cost per hour is $7.00(1 + 60%) = $11.20/h. The machine cost must first be annualized:

\[ UAC = 100,000(A/P, 10\%, 8) \]
\[ = 100,000(0.18744) = $18,744/yr \]

The number of hours per year is 8 \times 250 = 2000 hr/yr. Dividing the $18,744 by 2000 gives $9.37/h. Applying the 50% overhead rate, the machine cost per hour is $9.37(1 + 50%) = $14.06/h. So the total work center rate = $11.20 + $14.06
\[ = $25.26/h \]

In subsequent chapters there will be problems in which an hourly rate must be applied to a particular automated production system. Example 3.7 illustrates the general method by which this hourly rate is determined.

### 3.3 BREAK-EVEN ANALYSIS

*Break-even analysis* is a method of assessing the effect of changes in production output on costs, revenues, and profits. It is most commonly conceptualized in the form of a break-even chart. To construct the break-even chart, the manufacturing costs are divided into fixed costs and variable costs. The sum of these costs is plotted as a function of production output. To plot the total cost, the variable cost per unit change in output must be determined. Revenues can also be plotted on a break-even chart as a function of production output.

Break-even analysis can be used for either of two main purposes:

1. *Profit analysis*. In this case the break-even chart shows the effect of changes in output on costs and revenues. This gives a picture of how profits (or losses) will vary for different output levels. The break-even point is the output level at which total costs
equal revenues and the profit is zero. An example of a break-even chart used for profit analysis is shown in Figure 3.2.

2. Production method cost comparison. In this case the break-even chart shows the effect of changes in output level on the costs of two (or more) different methods of production. The break-even point for this chart is the output level at which the costs for the two production methods are equal. (When more than two production methods are plotted on the same chart, there will be a break-even point for each pair of production methods.) Figure 3.3 shows a break-even chart used for production method cost comparison.

We will illustrate the two types of break-even analysis by means of two examples.

EXAMPLE 3.8

This example illustrates the use of a break-even chart for profit analysis. A manually operated production machine costs $66,063. It will have a service life of 7 years with an anticipated salvage value of $5000 at the end of its life. The machine will be used to produce one type of part at a rate of 20 units/h. The annual cost to maintain the machine is $2000. A machine overhead rate of 15% is applicable to capital cost and maintenance. Labor to run the machine costs $10.00/h and the applicable overhead rate is 30%. Determine the profit break-even point if the value added is $1.00/unit and the rate-of-return criterion is 20%.

![Profit break-even chart (see Example 3.8).](image-url)
Solution:

Let Q be the annual level. Variable cost is labor cost, including applicable overhead, divided by production rate.

\[
\frac{\$10.00/h(1 + 30\%)}{20 \text{ pieces/h}} = \$0.65/\text{unit}
\]

The variable cost as a function of Q is 0.65Q.

The annual fixed cost is figured on the machine investment plus the maintenance. First, ignoring overhead, we have

\[
\text{UAC} = 66,063(A/P, 20\%, 7) + 2000 - 5000(A/F, 20\%, 7)
\]
\[
= 19,939
\]

Adding the 15% overhead, the fixed cost = $22,930.

The sum of the fixed and variable costs provides the total cost equation as a function of Q:

\[
\text{total cost} = 22,930 + 0.65Q
\]

Revenues as a function of Q are the product of value added per unit multiplied by Q. Revenues = $1.00Q. This is plotted in Figure 3.2. The break-even point occurs where the revenue line intersects the total cost line. To calculate the break-even point, the following equation can be set up:

\[
\text{profit} = 1.00Q - 22,930 - 0.65Q = 0
\]
Break-Even Analysis

\[ 1.00Q = 22,930 + 0.65Q \]
\[ 0.35Q = 22,930 \]
\[ Q = 65,514 \text{ units/yr} \]

At a production rate of 20 units/h this would require \( \frac{65,514}{20} = 3276 \text{ h/yr} \).

**EXAMPLE 3.9**

This example illustrates the cost break-even analysis. Suppose that an alternative to the manually operated production machine of Example 3.8 is available. The alternative is an automated machine, costing \$125,000, but capable of a production rate of 50 units/h. Its service life is 5 years with no salvage value at the end of that time. Annual maintenance will cost \$5000. One-third of one operator costing \$12.00/h will be required to run the machine. The overhead rates and rate of return used in Example 3.8 are applicable. Determine the break-even point for the automated and manual methods of production.

**Solution:**

Variable cost for the automated machine is

\[ \frac{($12.00/h)(1/3)(1 + 30\%)}{50 \text{ pieces/h}} = 0.104/\text{unit} \]

Fixed cost is the capital cost plus maintenance, with machine overhead added.

\[ [125,000(A/P, 20\%, 5) + 5000](1 + 15\%) = 53,820 \]

Total cost is variable cost plus fixed cost:

\[ \text{total cost} = 53,820 + 0.104Q \]

The total cost functions for the two production methods are plotted in Figure 3.3. The break-even point is represented by the intersection point for the two methods. Setting the two total cost equations equal yields

\[ 53,820 + 0.104Q = 22,930 + 0.65Q \]
\[ 53,820 - 22,930 = 0.65Q - 0.104Q \]
\[ 30,890 = 0.546Q \]
\[ Q = 56,575 \text{ units/yr} \]

For the manual method, this corresponds to 2829 h of production per year, and for the automated method this quantity would require 1131.5 h of operation per year.

Just to complete the example, let us compute the profit break-even point for the automated method given that the value added per unit is \$1.00.

\[ \text{profit} = 1.00Q - 53,820 - 0.104Q = 0 \]
\begin{align*}
1.00Q &= 53,820 + 0.104Q \\
0.896Q &= 53,820 \\
Q &= 60,067 \text{ units/yr}
\end{align*}

This would require 1201.3 h of operation per year.

### 3.4 UNIT COST OF PRODUCTION

In Examples 3.8 and 3.9, one of the complications in the problems was the difference in production rates for the two alternatives. The automated method outproduced the manual method, which is often the case in comparing automation against manual production. To help decide between the alternatives, it is often useful to determine the unit cost of production for the two (or more) methods under consideration.

The unit cost for a certain operation is the total cost of production divided by the number of units produced. The total cost of production includes both fixed and variable costs. Accordingly, because of the fixed portion of the cost of production, the unit cost will vary as a function of annual output $Q$. As the annual output increases, the unit cost decreases. Using the manual production method from Example 3.8 to illustrate, dividing the total cost equation by the quantity $Q$, we get the unit cost equation, which we will symbolize by $C_{pc}$ (cost per piece):

$$C_{pc} = \frac{22,930 + 0.65Q}{Q} = 0.65 + \frac{22,930}{Q}$$

Similarly, the unit production cost for the automated method of Example 3.9 is given by

$$C_{pc} = 0.104 + \frac{53,820}{Q}$$

The two relationships are plotted as a function of $Q$ in Figure 3.4. Note that the unit costs are equal at the previously determined break-even point of Example 3.9 (56,575 units per year).

In subsequent chapters we will sometimes use the unit cost as a measure of performance for a production system. The reader should recall that these unit costs are calculated under assumed conditions of annual cost and production rate. As indicated in Figure 3.4, the actual cost per unit of production is strongly dependent on the level of annual output.

One other observation about Examples 3.8 and 3.9 is that the total cost equations for the two alternatives ignore certain practical realities that might influence how the production methods are implemented. For both methods, the number of hours of operation were calculated at the various break-even points. In the case of the manual method, the number of annual hours of operation at the profit break-even point = 3276 h. This is
greater than the number of hours normally worked by one person per year (40/week × 50 weeks/yr = 2000 h/yr). Will the extra hours be achieved by using two machines, or by using two shifts on one machine, or by working overtime by one production worker? In each instance, there are additional costs which are not included in the total cost equation. If two machines are used, the capital cost (fixed cost) is doubled. If two shifts are used, the worker on the second shift will probably be paid at a higher rate, and there will be other additional costs if the plant does not normally operate a second shift. If overtime is used to achieve the 3276 annual hours of operation, the cost will increase, as the overtime rate is higher (typically time-and-a-half) than the regular shift rate. Problem 3.12 requires the reader to determine the total cost equation and unit cost equation for the three alternatives described here.

In the case of the automated production machine, the number of hours of annual operation to reach the profit break-even point is 1201.3 h, well under 2000 h/yr. If the company operates the machine at that point or only slightly above, it will be running below capacity and the utilization will be low. In this case, the company might want to consider ways of increasing demand for the product in order to raise the machine utilization.
These complicating factors must be considered when alternative production methods are compared in a real-life industrial setting.

3.5 COST OF MANUFACTURING LEAD TIME AND WORK-IN-PROCESS

One of the considerations that is often overlooked in an automation proposal is the effect that the automated method will have on manufacturing lead time and in-process inventory. Automation will often result in dramatic reductions in both of these factors by comparison to previous conventional manufacturing methods. In this section we present a method for evaluating the cost of these factors, based on concepts suggested by Meyer [3].

Our definition in Chapter 2 indicated that production typically consists of a series of separate manufacturing steps or operations. An operation time is required for each step, and that time has an associated cost. There is also a time between each operation, at least for most manufacturing situations, which we have referred to as the nonoperation time. The nonoperation time includes material handling, inspection, and storage. There is also a cost associated with the nonoperation time. These times and costs for a given part can be illustrated graphically as shown in Figure 3.5. At time $t = 0$, the cost of the part is simply its material cost $C_m$. The cost of each processing step on the part will be the production time multiplied by the rate for the machine and labor. The production time $T_p$ is determined from Eq. (2.5) and accounts for both setup time and operation

![Cost](image)

**FIGURE 3.5** Cost of product or part as a function of time in the factory. As operations are completed, value and cost are added to the product.