2.1 Unit Introduction
Manufacturing changes the geometry, properties, and/or appearance of a given starting material to make parts or products, by applying transformational procedures, such as physical and chemical processes. Manufacturing can also include the joining together of multitudes of parts, in an assembly operation, to create an integrated product. To perform manufacturing we rely on the use of machinery, tools, power and manual labour; and, with the arrangement of the various work tasks to be completed into a sequence, we obtain an ordered manufacturing operation. From an economic perspective, manufacturing may be seen as value-adding procedure, in that—following the application of manufacturing techniques—we transform the inputs to the process into higher-value outputs.

LEARNING ACTIVITY 2.1
Manufacturing, and its associated techniques, has a long and interesting history, tied as it is, to the development of individual societies and human civilization in general. Investigate various facets of the history of manufacturing at http://en.wikipedia.org/wiki/Manufacturing

END LEARNING ACTIVITY 2.1

This unit surveys a number of aspects of manufacturing operations. Firstly, we discuss manufacturing industries and products, and determine the types of manufacturing that can take place. Next, we take an in-depth look at particular manufacturing operations, including processing, assembly, and other factory-related operations that can be performed on the product to be manufactured.
Then we turn to production facilities, and the need for factories to organise these efficiently; here we examine the differences between low, medium, and high production.

Metrics used to measure the relationship between the product and the production system are subsequently discussed, with explanations given of the various metrics used throughout manufacturing. We then turn to an examination of the mathematical models of product performance that can be derived from known or idealised parameters in the production system. Metrics and mathematical models are important for identifying where automation can be applied.

Section 2.2 Unit Learning Objectives

After completing this unit you will be able to:

BULLET LIST
Classify the primary, secondary and tertiary manufacturing industries

Recognise production operations in process and discrete product industries

Define the types of manufactured products that can be produced

Define the difference between processing operations and assembly operations

Determine the ranges of production quantity

Describe product variety in terms of hard product variety, and soft product variety

Determine metrics for a wide range of manufacturing and production processes

ENDLIST

Section 2.3 Manufacturing Industries and Products

The type of manufacturing carried out by a company depends on the kinds of products it makes. Manufacturing industries consists of groups of firms that work together to produce and/or supply goods and/or services. Industries are usually classed as either primary, secondary, or tertiary. Primary industries exploit natural resources—examples include agriculture and mining; secondary industries tend to convert primary industry outputs into products—examples include manufacturers and assemblers; and tertiary industries focus upon the service sector—that is, they supply services usually based upon secondary industry products, or even other tertiary services themselves; examples include insurance, banking, education etc. See Figure 2.1.
Industries are usually classed as either primary, secondary, or tertiary. Primary industries exploit natural resources; secondary industries tend to convert primary industry outputs into products; and tertiary industries focus upon the service sector.

In this unit we focus generally upon the secondary industry, which takes primary industry outputs and creates products by the application of various processes such as machining and assembly. It is possible to distinguish between process industries (that is, those who generally work with primary industry outputs, and convert these raw materials into continuous products—examples include the petro-chemical industry, beverage industry, food industry, and electric-generation industry), and discrete product industries (that is, those who generally work by creating and assembling low-level parts into integrated, high-level products—examples include the automotive industry, the computer industry, the appliance industry, healthcare industry and the suppliers of component parts to these industries).

In the secondary industry, there are process industries and discrete product industries. Discrete product industries work by creating and assembling low-level parts into integrated, high-level products.
Production operations in both industry types may be divided into continuous production and batch production forms. The differences between the two forms are outlined in Table 2.1.

<table>
<thead>
<tr>
<th>Production form</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuous</td>
<td>Occurs when production equipment is used exclusively for given product, with product output uninterrupted. In process industries inputs are likely to be always the same, so the process may be carried-out on a continuous stream of material with no interruptions for change-overs. In discrete product industries continuous production means 100% commitment to producing one type of part or product, with no breaks for product change-overs.</td>
</tr>
<tr>
<td>Batch</td>
<td>Processes finite amounts or quantities (batches) at a time, before being interrupted for product change-over; hence batch product is discontinuous. Used in industries where only finite quantities are required at one time; this can occur in both process and discrete product industries.</td>
</tr>
</tbody>
</table>

Manufactured products may be divided into two major classes: consumer goods and capital goods. Consumer goods are end-customer products such as toys, TVs, entertainment systems, refrigerators, and golf clubs. Capital goods are industrial products that are usually purchased by other companies to aid them in the creation of consumer goods; examples include: machine tools, robotics, handling systems, storage systems, inspection systems, software applications, controllers and computers. Generally a significant amount of capital goods are used in the manufacturing process to create the final output: consumer goods. Thus, the creation of consumer goods is generally reliant on the use of capital goods in the manufacturing process.

Manufactured products may be divided into two major classes: consumer goods such as TVs and capital goods such as robots that are used to create consumer goods in the manufacturing process.

### Keypoint
Manufactured products may be divided into two major classes: consumer goods such as TVs and capital goods such as robots that are used to create consumer goods in the manufacturing process.

### Learning Activity 2.2

PROFESSIONAL TRANSFERABLE SKILLS [CRIT] [PROB] [WCOMM] [NETW]

LEARNING ACTIVITY 2.2
Use the internet or other sources to identify real life companies that exist under the following headings and the products that they produce. Identify companies both in Ireland and abroad:

NUMLIST
Primary, secondary, and tertiary industry
Process industry and discrete product industry
Continuous and batch production, or a combination of both for different products
Capital goods and consumer goods

END LEARNING ACTIVITY 2.2

Section 2.4 Manufacturing Operations

The majority of industry is concerned with discrete products such as microchips, stents or drugs. Factory activities include: processing and assembly operations; material handling and storage; inspection and test; and co-ordination and control. The first three activities are directly connected, with processing/assembly performed directly on the part or product, material handling moving the part from manufacturing location to manufacturing location as necessary, and inspection and test assessing the quality of the part or product at each of these locations.

KEYPOINT
Factory activities for the discrete product industry include: processing and assembly operations; material handling and storage; inspection and test; and co-ordination and control.
END KEYPOINT

Manufacturing processes may be divided into processing operations and assembly operations. A processing operation involves transformation i.e. the input is transformed through the use of certain processes into an output that has a higher value than the input. An assembly operation joins two, or more, inputs to create an output: this is called an assembly or sub-assembly. The two types of operations are further detailed in Table 2.2.

<table>
<thead>
<tr>
<th>Operation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processing</td>
<td>Uses energy to alter a work part’s shape, physical properties or appearance so as to add value to the material undergoing processing. Processing generally uses human energy and machinery and tooling energy to achieve this. General sequence that is followed is thus: 1. input work part into the process; 2. process applied—that is, specific form of energy-application used to transform input; and 3. completed work part exits process as an output. Waste and scrap can also be produced as an</td>
</tr>
</tbody>
</table>
output, as well as defective work parts. More than one type of processing operation may be performed on the work part, thus a sequence of processing operations must be agreed upon.

| Assembly             | Takes two or more separate parts and joins them together to create an assembly or sub-assembly. In turn, sub-assemblies may be joined together later to create more complex assemblies. Components may be connected together in a permanent or semi-permanent fashion. General sequence that is followed is thus: 1. input work parts (2 or more) into the assembly process; 2. joining operation applied to work parts, often in a pre-defined sequence if more than two; and 3. completed assembly exits process as output. Waste and scrap can also be produced as an output, as well as defective assemblies. More than one type of joining operation may be performed on the work parts. |

**KEYPOINT**

Manufacturing processes may be divided into processing operations and assembly operations.

**END KEYPOINT**

Categories of processing operations include: shaping operations; property-enhancing operations; and surface processing operations. For assembly operations, there are two types of joining processes: permanent or semi-permanent. Permanent joining processes include welding, brazing, soldering, and adhesive bonding; mechanical procedures that produce permanent assemblies include riveting, press fitting, and expansion fitting. Semi-permanent joining processes take advantage of mechanical procedures to connect work parts (such as through the use of threaded fasteners—screws, nuts and bolts).

Material handling and storage concerns the transport of materials, work parts, and finished goods between all elements in the production system and between the storage facilities and the production facility. Material handling has acquired a whole set of automation techniques specific to its needs, and to the requirements of the production systems that it serves.

Inspection and testing, quality control activities, are used to determine whether the products that are being manufactured are meeting established specifications for design and quality. Inspection takes existing produced-work-parts and tests their specifications against design parameters; for example, the assessment of a machine part to see if its specifications are within the tolerances set-out in the design plan.

Co-ordination and control includes overall administration of plant level activities, and the regulation and management of individual processing and assembly operations.

**PROFESSIONAL TRANSFERABLE SKILLS [CRIT] [PROB] [WCOMM]**

**LEARNING ACTIVITY 2.3**

Use the internet or a company with which you are familiar, and write a short report on particular factory activities. Use the parameters supplied above i.e.
processing and assembly operations, material handling and storage, inspection and test, and co-ordination and control.

**END LEARNING ACTIVITY 2.3**

**Section 2.5 Production Facilities**

To achieve efficiency, production facilities must be arranged so as to serve the mission of each plant. The main factor that determines this mission, and hence the arrangement of the production facilities, is product type, whereby different types of products to be manufactured require different arrangements of the production facilities. The quantity of parts or product we wish to produce has a significant influence on production equipment arrangement. Production quantity refers to the number of units of a given part or product produced on an annual basis. Three ranges can be calculated based upon production quantity, Q. Low production (Q = 1 to 100 units) e.g. aircraft or ships; medium production (Q = 100 to 10,000 units) e.g. buses or stents; and high production (Q = 10,000 to millions of units produced) e.g. cars or paper clips. Depending on product-type these arbitrary boundaries between production quantities may shift.

**KEYPOINT**
Production quantity, Q, refers to the number of units of a given part or product produced annually and can be low, medium or high.

**END KEYPOINT**

At this stage product variety, P, becomes important. Some factories may produce more than one product, so they may be forced—owing to the fact that resources are being shared across products—to produce in low, or medium volumes. Product variety (P) refers to the number of different product designs or types that are produced in a plant. Product type refers to differences in geometries, shapes and sizes between products. Thus, when the number of product types made in a factory is high, there is a corresponding likelihood that product variety is high also; and there is also the likelihood that production quantity (Q) is low, as there is an inverse correlation between product variety and production quantity.

**KEYPOINT**
Product variety refers to the different product designs or types that are produced in a plant. Product type refers to differences in geometries, shapes, sizes and even colours between products.

**END KEYPOINT**

Product variety may be further broken-down to include some dimension that assesses the extent of the difference in design parameters. Hard product variety depicts two products with substantial design differences—for example, the difference between a car and a TV; soft product variety, on the other hand, depicts two products with substantial commonality across designs—for example,
the commonality between a car and a truck. Soft product variety implies that there is a certain commonality between the parts produced for two or more designs, hence there is likely to be much similarity in the parts produced across the same product families. This affects the production quantities that can be reached, as similar processes may be used to produce parts from different families, thus cutting change-over times, processing costs and so on.

**KEYPOINT**
Product variety may be hard or soft. Hard product variety depicts two products with substantial design differences; soft product variety, depicts two products with substantial commonality across designs.

**END KEYPOINT**

The three production quantity (Q) ranges can be used to illustrate the three sorts of production facilities; these are depicted in more detail in Table 2.3.

<table>
<thead>
<tr>
<th>Range</th>
<th>Description</th>
</tr>
</thead>
</table>
workstations are arranged in one long line, or series of line segments, often powered by a conveyor system to move parts from one workstation to the next. The assembly line is a typical example; this, when dedicated to just one product, is called a single-model production line. Mixed-model production lines are similar, but they let soft product variants in product design through the production system.

PROFESSIONAL TRANSFERABLE SKILLS [CRIT] [PROB] [WCOMM]
LEARNING ACTIVITY 2.4
Use the internet or companies with which you are familiar, and write a short report on product quantity and variety. Name the company and its products. Differentiate between Irish and international companies. In your report provide details on the following issues:

BULLETLIST
How many different products (P) does the firm produce?
What is the typical production quantity (Q) for each of the products?
What product variety (hard or soft) does the firm experience?
What production techniques does the firm favour?
ENDLIST
END LEARNING ACTIVITY 2.4

Section 2.6 Product/Production Relationships

We saw earlier that a production facility can have a variety of products (P) and that each product can be produced in a particular quantity (Q). In most manufacturing facilities both of these variables can be difficult to compute i.e. what is the total quantity of products produced for all of the varieties. Production quantity, can be measured as follows:

\[ Q_f = \sum_{j=1}^{P} Q_j \]

where \( Q_f \) is production quantity (\( f \) refers to factory); \( Q_j \) annual quantity of style \( j \); \( P \) is product variety; and \( j \) is product or part style. For product variety we can determine the total number of product models, thus:

\[ P = \sum_{j=1}^{P_1} P_{2j} \]
where $P$ is product variety; $P_1$ is the number of distinct product lines produced by the factory (in other words, hard product variety); $P_2$ is the number of models in a product line (in other words, soft product variety); and $j$ is product or part style.

**Example 2.1**

Figure 2.2 illustrates sticky notes. There are eight product lines, thus $P_1 = 8$. Within each product line there are different colours or models e.g. $P_2$ for the ‘pastel’ family = 4. The total number of unique styles, $P$, is given by:

$$P = \sum_{j=1}^{P_1} P_{2j} = 1 + 5 + 4 + 5 + 5 + 5 + 5 + 4 = 34$$

![Sticky Notes](image-url)

Figure 2.2: Hard and soft product Varieties

**KEYPOINT**

Production quantity $(Q)$ and Product variety $(P)$ are key determinants in how factories are designed.

**END KEYPOINT**

Another variable in the determination of the design of a factory is product complexity i.e. some products such as pencils are very simple whereas products such as cars are very complex. Product complexity contains both quantitative and qualitative aspects which makes it a difficult metric to define. In terms of quantitative measures, we can define it on a basic level by examining the number of components it contains; or by examining the number of processing steps required to manufacture the product. The more parts there are, the more
complex the product; similarly, the more processing steps required, and the more potential processing operations that can be performed on the part, the more complex the product. A clutch pencil for example has 10 parts whereas a car has 20,000 parts. Regarding processing, a washer has one processing step (i.e. stamping) whereas a car engine has 50 steps (i.e. casting, boring, drilling, etc.)

We can determine the total number of parts manufactured by the plant per year \( (n_{pf}) \) as follows:

\[
n_{pf} = \sum_{j=1}^{P} Q_{j} n_{pj}
\]

where \( n_{pf} \) is the total number of parts made in the factory per year; \( P \) is product variety; \( j \) is product or part style; \( Q_{j} \) is the annual quantity of product style \( j \); and \( n_{pj} \) is the number of parts in product \( j \). Alternatively, part complexity can also be assessed by examining the total number of processing operations performed by the plant \( (n_{of}) \), as follows:

\[
n_{of} = \sum_{j=1}^{P} Q_{j} \sum_{k=1}^{n_{pj}} n_{ojk}
\]

where \( n_{of} \) is the total number of operation cycles performed in the factory; \( P \) is product variety; \( j \) is product or part style; \( Q_{j} \) is the annual quantity of product style \( j \); \( n_{pj} \) is the number of parts in product \( j \); and \( n_{ojk} \) is the number of processing operations for each part \( k \).

**KEYPOINT**

Product complexity can be determined by examining the number of components or by examining the number of processing steps required to manufacture the product.

**END KEYPOINT**

**Example 2.2**

The ABC Company is planning a new product line and will build a new plant to manufacture the parts for a new product line. The product line will include 50 different models. Annual production of each model is expected to be 1000 units. Each product will be assembled of 400 components. All processing of parts will be accomplished in one factory. There are an average of 6 processing steps required to produce each component, and each processing step takes 1.0 minute (includes an allowance for setup time and part handling). All processing operations are performed at workstations, each of which includes a production machine and a human worker. If each workstation requires a floor space of 250
m², and the factory operates one shift (2000 hr/yr), determine (a) how many production operations, (b) how much floorspace, and (c) how many workers will be required in the plant.

Solution:
This problem neglects the effect of assembly time.
(a) \( n_{op} = PQn_pn_o = 50(1000)(400)(6) = 120,000,000 \) operations in the factory per year.
(c) Total operation time = \( (120 \times 10^6 \text{ ops})(1\text{ min.}/(60 \text{ min.}/\text{hr})) = 2,000,000 \text{ hr/yr} \).
At 2000 hours/yr per worker, \( w = 1000 \) workers.
(b) Number of workstations \( n = w = 1000 \). Total floorspace = \( (1000 \text{ stations})(250 \text{ m}^2/\text{station}) = 250,000 \text{ m}^2 \)

LEARNING ACTIVITY 2.5
The XYZ Company is planning to introduce a new product line and will build a new factory to produce the parts and assemble the final products for the product line. The new product line will include 100 different models. Annual production of each model is expected to be 1000 units. Each product will be assembled of 600 components. All processing of parts and assembly of products will be accomplished in one factory. There are an average of 10 processing steps required to produce each component, and each processing step takes 30 sec.
(includes an allowance for setup time and part handling). Each final unit of product takes 3.0 hours to assemble. All processing operations are performed at work cells that each includes a production machine and a human worker.
Products are assembled on single workstations consisting of two workers each. If each work cell and each workstation require 200 m², and the factory operates one shift (2000 hr/yr), determine: (a) how many production operations, (b) how much floorspace, and (c) how many workers will be required in the plant.

END LEARNING ACTIVITY 2.5

Section 2.7 Metrics of Production

Manufacturing companies use metrics to measure and manage their production systems. Later we will see how automation can be used to improve these metrics. Metrics may be developed and applied to the system, and upon feedback of metric data, various administrative decisions can be made to improve the system. In this section we look at some key measures that can, with relative ease, be captured from an operational production system.

Production rate is defined as the number of work units completed per hour. It can be calculated for batch production, job-shop production, and mass production typologies. In order to determine the production rate, the time a work unit spends being processed or assembled—that is, its cycle time—must be calculated first. This is done as follows:

\[
T_c = T_o + T_h + T_{th}
\]
where $T_c$ is the cycle time; $T_o$ is the time of the actual processing or assembly operation; $T_h$ is the handling time; and $T_{th}$ is the tool handling time.

Using cycle time we can then examine the time required to process a work batch, which is used in both batch and job-shop production typologies; this is calculated as:

$$T_b = T_{su} + QT_c$$

where $T_b$ is the batch processing time; $T_{su}$ is the set-up time to prepare for the batch; $Q$ is the batch quantity; and $T_c$ is the cycle time for each unit.

Figure 2.3: Batch of units where each individual part takes time, $T_c$ to process.

From this we can quickly calculate the average production time per unit ($T_p$), thus:

$$T_p = \frac{T_b}{Q}$$

where terms are as before. Hence the average production rate per hour for batch and job-shop production is:

$$R_p = \frac{60}{T_p}$$

where $R_p$ is the hourly production rate; and $T_p$ is the average production time per minute.
For mass production scenarios where batches are extremely large, the setup time become negligible and the production rate tends to reach the cycle rate of any one machine in the production line, so for all practical purposes we define it thus:

\[ R_p \rightarrow R_C = \frac{60}{T_p} \]

Figure 2.4: Injection molding has high production rate, \( R_p \).

**KEYPOINT**
Production rate tells us the number of work units a production system can complete in a given time frame (e.g. per hour).

**END KEYPOINT**

We can also determine production capacity, which is defined as the maximum rate of output that a production facility (or production line, work centre, or group of work centres) is able to produce under a given set of assumed operating conditions. Its general parameters for measurement are as follows:

\[ PC = nS_w H_{sh} R_p \]

where \( PC \) is production capacity; \( n \) is the number of machines or work centres in the facility; \( S_w \) is the number of work shifts per week; \( H_{sh} \) is the number of hours a work centre operates per shift; and \( R_p \) is the average production rate.

This equation changes, however, when we consider the number of operations required in its processing sequence. If we examine the possibility of altering the
number of processing operations \((n_0)\) that the work part undergoes—with the requirement for additional set-ups on each machine—then we have:

\[
PC = \frac{nS_w H_{sh} R_p}{n_0}
\]

where the terms are as before, and \(n_0\) is the number of distinct operations through which work units are passed.

**KEYPOINT**
Production capacity determines the maximum rate of output of a production facility.

**END KEYPOINT**

Utilisation and availability equations can also be determined. Utilisation compares the actual plant production against its potential plant capacity. Utilisation of a production facility is given by:

\[
U = \frac{Q}{PC}
\]

where \(U\) is the utilisation of the facility; \(Q\) is the total production quantity produced by the facility during a given time period; and \(PC\) is the production capacity over the same period.

Availability examines the machine time differences between failures and repairs; it is given thus:

\[
A = MTBF - \frac{MTTR}{MTBF}
\]

where \(A\) is availability; \(MTBF\) is mean time between failures; and \(MTTR\) is mean time to repair.

**Example 2.3**
The mean time between failure for a certain production machine is 250 hours, and the mean time to repair is 6 hours. Determine the availability of the machine.

Solution: Availability \(A = \frac{(250 - 6)}{250} = 0.976 = 97.6\%

**KEYPOINT**
Utilisation compares the actual plant production against its capacity. Availability measures the reliability of production system equipment.

END KEYPOINT

Manufacturing lead time (MLT) and work-in-process (WIP) can both be determined for a particular production facility. MLT is the total time required to process a certain part or product through the plant; it includes all lost time owing to production equipment failures, delays, rework, storage time, etc. MLT is calculated as follows:

$$MLT_j = \sum_{i=1}^{n_o} (T_{suji} + Q_j T_{cji} + T_{noji})$$

where $MLT_j$ is the manufacturing lead time for part or product $j$, $T_{suji}$ is the set-up time for operation $i$, $Q_j$ is the quantity of part or product $j$ in the batch being processed; $T_{cji}$ is the operation cycle time for operation $i$, $T_{noji}$ is the non-operation time associated with operation $i$, $n_o$ is the number of operations through which the work must pass; and $j$ is the part or product.

WIP assesses the quantity of parts or products in the factory that are undergoing processes, or waiting to be processed. Work-in-process is calculated thus:

$$WIP = \frac{A(U)(PC)(MLT)}{S_w H_{sh}}$$

where $WIP$ is work-in-process; $A$ is availability; $U$ is utilisation; $PC$ is the production capacity of the facility; $MLT$ is the manufacturing lead time; $S_w$ is the number of shifts per week; and $H_{sh}$ is the hours per shift.
KEYPOINT
Manufacturing Lead Time is the total time required to process a certain part or product through the plant. Work-In-Process assesses the quantity of parts or products in the factory that are undergoing processes, or waiting to be processed.
END KEYPOINT

Example 2.4
The average part produced in a certain batch manufacturing plant must be processed sequentially through six machines on average. Twenty (20) new batches of parts are launched each week. Average operation time = 6 min., average setup time = 5 hours, average batch size = 25 parts, and average nonoperation time per batch = 10 hr/machine. There are 18 machines in the plant working in parallel. Each of the machines can be set up for any type of job processed in the plant. The plant operates an average of 70 production hours per week. Scrap rate is negligible. Determine (a) manufacturing lead time for an average part, (b) plant capacity, (c) plant utilization. (d) How would you expect the nonoperation time to be affected by the plant utilization?

Solution:
(a) $MLT = 6(5 + 25(0.1) + 10) = 105$ hr
(b) $Tp = (5 + 25 \times 0.1)/25 = 0.30$ hr/pc, $Rp = 3.333$ pc/hr.
$PC = 70(18)(3.333)/6 = 700$ pc/week
(c) Parts launched per week = $20 \times 25 = 500$ pc/week. Utilization $U = 500/700 = 0.7143 = 71.43\%$
(d) As utilization increases towards 100%, we would expect the nonoperation time to increase. When the workload in the shop grows, the shop becomes
busier, but it usually takes longer to get the jobs out. As utilization decreases, we would expect the non-operation time to decrease.

LEARNING ACTIVITY 2.6
A certain part is routed through six machines in a batch production plant. The setup and operation times for each machine are given in the table below. The batch size is 100 and the average non-operation time per machine is 12 hours. Determine (a) manufacturing lead time and (b) production rate for operation 3.

<table>
<thead>
<tr>
<th>Machine</th>
<th>Setup time (hr.)</th>
<th>Operation time (min.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4</td>
<td>5.0</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>3.5</td>
</tr>
<tr>
<td>3</td>
<td>8</td>
<td>10.0</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>1.9</td>
</tr>
<tr>
<td>5</td>
<td>3</td>
<td>4.1</td>
</tr>
<tr>
<td>6</td>
<td>4</td>
<td>2.5</td>
</tr>
</tbody>
</table>

END LEARNING ACTIVITY 2.6

Section 2.8 Manufacturing Costs
Manufacturing costs must be taken into consideration when deciding whether to use automation or not. There are two types of manufacturing costs: fixed costs—which remain at a constant level regardless of production output; and variable costs—which vary in proportion to the level of production output. Examples of fixed costs are insurance, taxes, and capital investments in equipment, facilities etc. Examples of variable costs include direct labour, raw materials, and electrical power for equipment.
The sum of fixed costs and variable costs gives the total costs incurred by the manufacturing facility:

$$TC = FC + VC(Q)$$

where $TC$ is the total annual cost; $FC$ is the fixed annual cost; $VC$ is the variable annual cost; and $Q$ is the annual quantity produced.

Manufacturing costs are used to compare investment alternatives between manual and automated methods. Manual methods usually have low fixed costs ($FC$) and high variable costs ($VC$). Automated methods typically have high fixed costs and low variable costs. Figure 2.7 illustrates a break even analysis that compares a manual method with an automated method. A break even point exists where if production quantity ($Q$) were below this point then the manual
method should be chosen. Above this point, the automated method should be chosen.

![Cost Benefit Analysis](image)

**Figure 2.7: Cost Benefit Analysis**

**Example 2.5**

The break-even point is to be determined for two production methods, one a manual method and the other automated. The manual method requires two workers at €9.00/hr each. Together, they produce at a rate of 36 units/hr. The automated method has an initial cost of €125,000, a 4-year service life, no salvage value, and annual maintenance costs = €3000. No labour (except for maintenance) is required to operate the machine, but the power required to run the machine is 50 kW (when running). Cost of electric power is €0.05/kWh. If the production rate for the automated machine is 100 units/hr, determine the break-even point for the two methods, using a rate of return = 25%. The solution requires familiarity with the Uniform Annual Cost (UAC) method of determining an annual amount payable (A) on a principle sum (P).

**Solution:**

Manual method: variable cost = (2 workers)($9.00/hr)/(36 pc/hr) = $0.50/pc

Total cost as a function of Q is TC = 0.50 Q assuming no fixed costs.

Automated method: \( (A/P, 25\%, 4) = \frac{0.25(1 + 0.25)^4}{(1 + 0.25)^4 - 1} = 0.4234 \)

UAC = 125,000(A/P, 25%, 4) + 3000 = 125,000(0.4234) + 3000 = €55,930/yr

Variable cost = \( \frac{50 \text{kWh/hr} \times 0.05 \text{€/kWh}}{100 \text{pc/hr}} = 0.025/\text{pc} \)

Total cost as a function of Q = 55,930 + 0.025 Q

Break even point: 0.50 Q = 55,930 + 0.025 Q, 0.475Q = 55,930, Q = 117,747 pc/yr
Hours of operation per year: Manual: \( H = \frac{117,747 \text{ pc/yr}}{36 \text{ pc/hr}} = 3270.76 \text{ hr/yr} \).

Comment: This would require two shifts.

Automated: \( H = \frac{117,747 \text{ pc/yr}}{100 \text{ pc/hr}} = 1177.47 \text{ hr/yr} \).

Comment: Plenty of additional capacity in one shift beyond the break-even point.

**LEARNING ACTIVITY 2.7**

Theoretically, any given production plant has an optimum output level. Suppose a certain production plant has annual fixed costs \( FC = €2,000,000 \). Variable cost \( VC \) is functionally related to annual output \( Q \) in a manner that can be described by the function \( VC = €12 + €0.005Q \). Total annual cost is given by \( TC = FC + VC \cdot Q \). The unit sales price for one production unit \( P = €250 \). (a) Determine the value of \( Q \) that minimizes unit cost \( UC \), where \( UC = TC/Q \); and compute the annual profit earned by the plant at this quantity. (b) Determine the value of \( Q \) that maximizes the annual profit earned by the plant; and compute the annual profit earned by the plant at this quantity.

*END LEARNING ACTIVITY 2.7*

**Section 2.9 Unit Review**

**BULLETLIST**

Manufacturing industries consist of groups of firms that work together to produce and/or supply goods and/or services. Industries are usually classed as either primary, secondary, or tertiary.

In the secondary industry, there are process industries and discrete product industries. Process industries work with primary industry outputs, and convert raw materials into forms suitable for industrial work; discrete product industries work by creating and assembling low-level parts into integrated, high-level products.

Production operations in process and discrete product industry types may be divided into continuous production and batch production forms. Batch production occurs in discontinuous industries where product change-over is frequent, and where finite amounts or quantities are all that is needed.

Manufactured products may be divided into two major classes: consumer goods and capital goods. The creation of consumer goods for end-users is generally reliant on the use of capital goods in the manufacturing process.

Factory activities for the discrete product industry include the following: processing and assembly operations; material handling and storage; inspection and test; and co-ordination and control.
Manufacturing processes may be divided into processing operations and assembly operations. Material handling and storage concerns the transport of materials, work parts, and finished goods between all elements in the production system. Inspection and testing are quality control activities that are used to determine whether the products that are being manufactured are meeting established specifications for design and quality. Co-ordination and control includes overall administration of plant level activities, and the regulation and management of individual processing and assembly operations.

Production quantity refers to the number of units of a given part or product produced. Product variety refers to the different product designs or types that are produced. Production quantity and Product variety are key determinants in how products are manufactured.

Production rate tells us the number of work units a production system can complete per hour.

Production capacity determines the maximum rate of output of a production facility.

Utilisation compares the actual plant production against its potential with regard to its capacity. Availability measures the reliability of production system equipment.

Manufacturing Lead Time is the total time required to process a certain part or product through the plant; it includes all lost time owing to production equipment failures, delays, rework, storage time, etc. Work-In-Process assesses the quantity of parts or products in the factory that are undergoing processes, or waiting to be processed.

Manufacturing costs must be taken into consideration when deciding whether to use automation or not. There are two types of manufacturing costs: fixed costs, and variable costs. The sum of fixed costs and variable costs gives the total costs incurred by the manufacturing facility.

**Section 2.10 Self-Assessment Questions**

What are the constituent components of manufacturing industries? What classification do manufacturing industries hold?

What production operations occur in process and discrete product industries?
What are the types of manufactured products that may be produced by industry?

Define the difference between processing operations and assembly operations.

What are the ranges of production quantity? How is this related to production plants themselves?

What are the types of product variety that may be defined?

What metrics may be used for measuring production quantity and product variety?

Specify four metrics that may be used to meet a wide range of manufacturing and production requirements.

**Section 2.11 Answers to Self-Assessment Questions**

Manufacturing industries consist of groups of firms that work together to produce and/or supply goods and/or services. Industries are usually classed as either primary, secondary, or tertiary. Manufacturing industries are secondary industries.

Continuous production and batch production are the types of production that occur in process and discrete product industries. Continuous production occurs when production equipment is used exclusively for a given product, with product output uninterrupted. Batch production occurs in discontinuous industries where product change-over is frequent, and where finite amounts or quantities are all that is needed.

Manufactured products may be divided into two major classes: consumer goods and capital goods. The creation of consumer goods for end-users is generally reliant on the use of capital goods in the manufacturing process.

Processing operations use energy to alter a work part’s shape, physical properties or appearance so as to add value to the material undergoing processing. Processing operations include shaping operations, property-enhancing operations, and surface processing operations. Assembly operations join work parts together using either permanent or semi-permanent joining methods.

Production quantity refers to the number of units of a given part or product produced on an annual basis; three ranges can be calculated based upon production quantity: low production, medium production, and high production.
Production plants can be classified according to the production ranges they produce as per this categorisation.

Product variety refers to the different product designs or types that are produced in a plant. It may be broken-down into two types: hard product variety, which depicts two products with substantial design differences; and soft product variety, which depicts two products with substantial commonality across designs.

The metrics used for measuring production quantity and product variety are: the total quantity of all parts or products made in the factory, and the total number of product models.

Four metrics that may be used to meet a wide range of manufacturing and production requirements are: production rate, production capacity, manufacturing lead time, and manufacturing costs.
END LIST