Chapter 1
INTRODUCTION

REVIEW QUESTIONS

1.1 What is a production system?

Answer: As defined in the text, a production system is a collection of people, equipment, and procedures organized to perform the manufacturing operations of a company.

1.2 Production systems consist of two major components. Name and briefly define them.

Answer: The two major components given in the text are (1) facilities, which consist of the factory, the equipment in the factory, and the way the equipment is organized; and (2) manufacturing support systems, which are the procedures used by the company to manage production and to solve the technical and logistics problems encountered in ordering materials, moving the work through the factory, and ensuring that products meet quality standards. Product design and certain business functions are included among the manufacturing support systems.

1.3 What are manufacturing systems, and how are they distinguished from production systems?

Answer: A manufacturing system is a logical grouping of equipment in the factory and the worker(s) who operate(s) it. Examples include worker-machine systems, production lines, and machine cells. A production system is a larger system that includes a collection of manufacturing systems and the support systems used to manage them. A manufacturing system is a subset of the production system.

1.4 Manufacturing systems are divided into three categories, according to worker participation. Name the three categories.

Answer: The three categories are (1) manual work systems, (2) worker-machine systems, and (3) automated systems.

1.5 What are the four functions included within the scope of manufacturing support systems?

Answer: As identified in the text, the four functions are (1) business functions, (2) product design, (3) manufacturing planning, and (4) manufacturing control.

1.6 Three basic types of automation are defined in the text. What is fixed automation and what are some of its features?

Answer: Fixed automation is a system in which the sequence of processing (or assembly) operations is fixed by the equipment configuration. Each operation in the sequence is usually simple, but the integration and coordination of many such operations in one piece of equipment makes the system complex. Typical features of fixed automation are (1) high initial investment for custom-engineered equipment, (2) high production rates, and (3) relatively inflexible in accommodating product variety.

1.7 What is programmable automation and what are some of its features?

Answer: In programmable automation, the production equipment is designed with the capability to change the sequence of operations to accommodate different part or product configurations. The operation sequence is controlled by a program, which is a set of instructions coded so that they can be read and interpreted by the system. Some of the features of programmable automation are (1) high investment in general purpose equipment, (2) lost production time due to changeovers of physical setup and reprogramming, (3) lower production rates than fixed automation, (4) flexibility to deal with variations and changes in product configuration, and (5) most suitable for batch production.

1.8 What is flexible automation and what are some of its features?

Answer: Flexible automation is an extension of programmable automation. A flexible automated system is capable of producing a variety of parts (or products) with virtually no time lost for changeovers from one part style to the next. There is no lost production time while reprogramming the system and altering the physical setup. Accordingly, the system can produce various mixes and schedules of parts or products instead of requiring that they be made in batches. Features of flexible automation are (1) high investment for a custom-engineered system, (2) continuous production of variable mixtures of products, (3) medium production rates, and (4) flexibility to deal with product design variations

1.9 What is computer-integrated manufacturing?

Answer: As defined in the text, computer-integrated manufacturing (CIM) denotes the pervasive use of computer systems to design the products, plan the production, control the operations, and perform the various information-processing functions needed in a manufacturing firm. True CIM involves integrating all of these functions in one system that operates throughout the enterprise.

1.10 What are some of the reasons why companies automate their operations?

Answer: The reasons give in the text are (1) increase labor productivity, (2) reduce labor cost, (3) mitigate the effects of labor shortages, (4) reduce or eliminate routine manual and clerical tasks, (5) improve worker safety, (6) improve product quality, (7) reduce manufacturing lead time, (8) accomplish processes that cannot be done manually, and (9) avoid the high cost of not automating.

1.11 Identify three situations in which manual labor is preferred over automation.

Answer: The five situations listed in the text are the following: (1) The task is technologically too difficult to automate. (2) Short product life cycle. (3) Customized product. (4) To cope with ups and downs in demand. (5) To reduce risk of product failure.

1.12 Human workers will be needed in factory operations, even in the most highly automated operations. The text identifies at least four types of work for which humans will be needed. Name them.

Answer: The four types of work identified in the text are (1) equipment maintenance, (2) programming and computer operations, (3) engineering project work, and (4) plant management.

1.13 What is the USA Principle? What does each of the letters stand for?

Answer: The USA Principle is a common sense approach to automation and process improvement projects. U means "understand the existing process," S stands for "simplify the process," and A stands for "automate the process."

1.14 The text lists ten strategies for automation and process improvement. Identify five of these strategies.

Answer: The ten strategies listed in the text are (1) specialization of operations, (2) combined operations, (3) simultaneous operations, (4) integration of operations, (5) increased flexibility, (6) improved material handling and storage, (7) on-line inspection, (8) process control and optimization, (9) plant operations control, and (10) computer-integrated manufacturing (CIM).

1.15 What is an automation migration strategy?

Answer: As defined in the text, an automation migration strategy is a formalized plan for evolving the manufacturing systems used to produce new products as demand grows.

1.16 What are the three phases of a typical automation migration strategy?

Answer: As defined in the text, the three typical phases are the following: Phase 1: Manual production using single-station manned cells operating independently. Phase 2: Automated production using single-station automated cells operating independently. Phase 3: Automated integrated production using a multi-station automated system with serial operations and automated transfer of work units between stations.

Chapter 2
MANUFACTURING OPERATIONS

REVIEW QUESTIONS

2.1 What is manufacturing?

Answer: Two definitions are given in the text. The technological definition is the following: Manufacturing is the application of physical and chemical processes to alter the geometry, properties, and/or appearance of a given starting material to make parts or products. Manufacturing also includes the joining of multiple parts to make assembled products. The economic definition is the following: Manufacturing is the transformation of materials into items of greater value by means of one or more processing and/or assembly operations.

2.2 What are the three basic industry categories?

Answer: The three basic industry categories are (1) primary industries, which are those that cultivate and exploit natural resources, such as agriculture and mining; (2) secondary industries, which convert the outputs of the primary industries into products; they include manufacturing, construction, and power generation; and (3) tertiary industries, which constitute the service sector of the economy; examples include banking, retail, transportation, education, government.

2.3 What is the difference between consumer goods and capital goods?

Answer: Consumer goods are products that are purchased directly by consumers, such as cars, personal computers, TVs, tires, toys, and tennis rackets. Capital goods are products purchased by other companies to produce goods and supply services. Examples include commercial aircraft, mainframe computers, machine tools, railroad equipment, and construction machinery.

2.4 What is the difference between a processing operation and an assembly operation?

Answer: A processing operation transforms a work material from one state of completion to a more advanced state that is closer to the final desired part or product. It adds value by changing the geometry, properties, or appearance of the starting material. An assembly operation joins two or more components to create a new entity, called an assembly, subassembly, or some other term that refers to the joining process.

2.5 Name the four categories of part-shaping operations, based on the state of the starting work material.

Answer: The four categories are (1) solidification processes, (2) particulate processing, (3) deformation processes, and (4) material removal processes.

2.6 Assembly operations can be classified as permanent joining methods and mechanical assembly. What are the four types of permanent joining methods?

Answer: The joining processes are (1) welding, (2) brazing, (3) soldering, and (4) adhesive bonding.

2.7 What is the difference between hard product variety and soft product variety?

Answer: Hard product variety is when the products differ substantially. In an assembled product, hard variety is characterized by a low proportion of common parts among the products; in many cases, there are no common parts. Soft product variety is when there are only small differences between products. There is a high proportion of common parts among assembled products whose variety is soft.

2.8 What type of production does a job shop perform?

Answer: Low production of specialized and customized products. The products are typically complex, such as experimental aircraft and special machinery.

2.9 Flow line production is associated with which one of the following layout types: (a) cellular layout, (b) fixed-position layout, (c) process layout, or (d) product layout?

Answer: (d) Product layout.

2.10 What is the difference between a single-model production line and a mixed-model production line?

Answer: A single-model production line makes products that are all identical. A mixed-model production line makes products that have model variations characterized as soft product variety.

2.11 What is meant by the term *technological processing capability*?

Answer: Technological processing capability of a plant (or company) is its available set of manufacturing processes. It includes not only the physical processes, but also the expertise possessed by plant personnel in these processing technologies.

PROBLEMS

Answers to problems labeled **(A)** are listed in the Appendix at the back of the book.

2.1 **(A)** A manufacturing plant produces three product lines in one of its plants: A, B, and C. Each product line has multiple models: 3 models within product line A, 5 models within B, and 7 within C. Average annual production quantities of model A is 400 units, 800 units for model B, and 500 units for model C. Determine the number of (a) different product models and (b) total quantity of products produced annually in this plant.

Solution: (a) The total number of different product models produced is
$P = 3 + 5 + 7 =$ **15 different models**

(b) The total production quantity of all products made in the factory is
$Q_f = 3(400) + 5(800) + 7(500) = 1200 + 4000 + 3500 =$ **8700 units** annually

2.2 Consider product line A in preceding Problem 2.1. Its three models have an average of 46 components each, and the average number of operations needed to produce each component is 3.5. All components are made in the same plant. Determine the total number of (a) components produced and (b) operations performed in the plant annually.

Solution: (a) The total number of components produced is given by Eq. (2.7).
$n_{pf} = PQn_p = 3(400)(46) =$ **55,200 components**

(b) The total number of operations performed annually in the plant is given by Eq. (2.9).
$n_{of} = PQn_pn_o = 3(400)(46)(3.5) =$ **193,200 operations**

2.3 A company produces two products in one of its plants: A and B. Annual production of Product A is 3600 units and of Product B is 2500 units. Product A has 47 components and Product B has 52 components. For Product A, 40% of the components are made in the plant, while 60% are purchased parts. For Product B, 30% of the components are made in the plant, while 70% are purchased. For these two products taken together, what is the total number of (a) components made in the plant and (b) components purchased?

Solution: (a) The total number of components produced in the plant can be determined using Eq. (2.3), adjusting it for the proportions of each part made in the factory: n_{pf} = 3600(47)(0.40) + 2500(52)(0.30) = 67,680 + 39,000 = **106,680 parts made in plant**

(b) Let n_{pp} = the total number of parts purchased: n_{pp} = 3600(47)(0.60) + 2500(52)(0.70) = 101,520 + 91,000 = **192,520 purchased parts**

2.4 **(A)** A product line has two models: X and Y. Model X consists of 4 components: a, b, c, and d. The number of processing operations required to produce these four components are 2, 3, 4, and 5, respectively. Model Y consists of 3 components: e, f, and g. The number of processing operations required to produce these three components are, 6, 7, and 8 respectively. The annual quantity of Model X is 1000 units and of Model Y is 1500 units. Determine the total number of (a) components and (b) processing operations associated with these two models.

Solution: (a) The total number of components can be determined using Eq. (2.3): n_{pf} = 1000(4) + 1500(3) = 4000 + 4500 = **8500 components**

Alternatively, Eq. (2.7) can be used, first computing the average values for Q and n_p using Eqs. (2.6) and (2.8).
Q = (1000 + 1500)/2 = 1250 units
n_p = (1000(4) + 1500(3))/(2 × 1250) = 3.4 components per unit product
n_{pf} = 2(1250)(3.4) = 8500 components

(b) The total number of processing operations can be determined using Eq. (2.4): n_{of} = 1000(2 + 3 + 4 + 5) + 1500(6 + 7 + 8) = 1000(14) + 1500(21) = **45,500 operations**

Alternatively, Eq. (2.9) can be used, first computing the average values for n_p and n_o using Eqs. (2.8) and (2.10).
The value of n_p was calculated above: n_p = 3.4 components per unit product
n_o = (1000(2 + 3 + 4 + 5) + 1500(6 + 7 + 8))/3.4 = 5.353 operations per component
n_{of} = 2(1250)(3.4)(5.353) = 45,500 operations

2.5 The ABC Company is planning a new product line and a new plant to produce the parts for the line. The product line will include 8 different models. Annual production of each model is expected to be 900 units. Each product will be assembled of 180 components. All processing of parts will be accomplished in the new plant. On average, 6 processing operations are required to produce each component, and each operation takes an average of 1.0 min (including 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. The plant operates one shift. Determine the number of (a) components, (b) processing operations, and (c) workers that will be needed to accomplish the processing operations if each worker works 2000 hr/yr.

Solution: (a) Number of components produced in the plant:
$n_{pf} = PQn_p =$ 8(900)(180) = **1,296,000 components**

(b) Number of operations performed in the plant:
$n_{of} = PQn_pn_o$ = 8(900)(180)(6) = **7,776,000 operations** in the plant per year

(c) Total operation time $TT = n_{of}T_p$, where T_p = time for one processing operation.
TT = 7,776,000(1.0) = 7,776,000 min = 129,600 hr of processing time

At 2000 hours/yr per worker, number of workers w = 129,600/2000 = 64.8 workers
This should be rounded up to **65 workers**.

2.6 The XYZ Company is planning a new product line and a new factory to produce the parts and assembly the final products. The product line will include 10 different models. Annual production of each model is expected to be 1000 units. Each product will be assembled of 300 components, but 65% of these will be purchased parts (not made in the new factory). There are an average of 8 processing operations required to produce each component, and each processing step takes 30 sec (including an allowance for setup time and part handling). Each final unit of product takes 48 min to assemble. All processing operations are performed at work cells that include a production machine and a human worker. Products are assembled at single workstations consisting of one worker each plus assembly fixtures and tooling. Each work cell and each workstation require 25 m^2 of floor space and an additional allowance of 45% must be added to the total production area for aisles, work-in-process storage, shipping and receiving, rest rooms, and other utility space. The factory will operate one shift (the day shift, 2000 hr/yr). Determine (a) how many processing and assembly operations, (b) how many workers (direct labor only), and (c) how much total floor space will be required in the plant.

Solution: (a) The number of products is $Q_f = PQ$ = 10(1000) = 10,000 products/yr
Therefore, the number of final assembly operations = **10,000 asby ops/yr**
Total number of parts n_{pf} = 10(1000)(300) = 3,000,000 components, but 65% of these are purchased, so the number made in the plant will be 0.35(3,000,000) = 1,050,000
Number of processing operations n_{of} = 1,050,000(8) = **8,400,000 proc ops/yr**

(b) Total processing time $TT_p = n_{of}T_p$, where T_p = time for one processing operation.
TT_p = 8,400,000(0.50) = 4,200,000 min = 70,000 hr/yr
Total assembly time $TT_a = QT_a$, where T_a = assembly time for each product.
TT_a = 10,000(48) = 480,000 min/yr = 8000 hr/yr
Number of workers w = (70,000 + 8000)/2000 = **39 workers**

(c) With 1 worker per workstation for processing operations and 1 worker per assembly workstation, $n = w$ = 39 workstations.
Total floor space $TA = nA_w(1 + AL)$, where A_w = area of each work cell or workstation, and AL = allowance for aisles, storage, etc.
TA = 39(25)(1 + 0.45) = **1413.75 m^2** (~15,217 ft^2)

2.7 Suppose the company in Problem 2.6 were to operate two shifts (a day shift and an evening shift, a total of 4000 hr/yr) instead of one shift to accomplish the processing operations. The assembly of the product would still be accomplished on the day shift. Determine (a) how many processing and assembly operations, (b) how many workers on each shift (direct labor only), and (c) how much total floor space will be required in the plant.

Solution: (a) Number of final assembly operations PQ = 10(1000) = **10,000 asby ops/yr**
Total number of parts n_{pf} = 10(1000)(300) = 3,000,000 components, but 65% of these are purchased, so the number made in the plant will be 0.35(3,000,000) = 1,050,000
Number of processing operations n_{of} = 1,050,000(8) = **8,400,000 proc ops/yr**

(b) Total processing time $TT_p = n_{of}T_p$, where T_p = time for one processing operation.
TT_p = 8,400,000(0.50 min) = 4,200,000 min = 70,000 hr/yr total for two shifts
TT_p = 70,000/2 = 35,000 hr/yr total for each shift
Number of processing operation workers per shift w_p = 35,000/2000 = 17.5 rounded up to 18 parts production workers per shift

Total assembly time $TT_a = QT_a$, where T_a = assembly time for each product.
TT_a = 10,000(48) = 480,000 min/yr = 8000 hr/yr
Number of assembly workers w_a = 8000/2000 = 4 assembly workers
Number of workers on day shift w = 18 + 4 = **22 workers**
Number of workers on evening shift w = **18 workers**

(c) The floor space must be based on the number of day shift operations, which includes processing and assembly operations.
Total floor space $TA = nA_w(1 + AL)$, where A_w = area of each work cell or workstation, and AL = allowance for aisles, etc.
TA = 22(25)(1 + 0.45) = **797.5 m^2** (~8584 ft^2)
Comment: This is a savings in floor space of ~44% compared to the one-shift operation in the previous problem.

Chapter 3

MANUFACTURING METRICS

REVIEW QUESTIONS

3.1 What is the cycle time in a manufacturing operation?

Answer: As defined in the text, the cycle time T_c is the time that one work unit spends being processed or assembled. It is the time between when one work unit begins processing (or assembly) and when the next unit begins.

3.2 What is a bottleneck station?

Answer: The bottleneck station is the slowest workstation in a production line, and therefore it limits the pace of the entire line.

3.3 What is production capacity?

Answer: Production capacity is the maximum rate of output that a production facility (or production line, work center, or group of work centers) is able to produce under a given set of assumed operating conditions.

3.4 How can plant capacity be increased or decreased in the short term?

Answer: As listed in the text, the two ways that plant capacity can be increased or decreased in the short term are (1) add workers, (2) change the number of work shifts per week S_w, and (3) change the number of hours worked per shift H_{sh}.

3.5 How can plant capacity be increased or decreased in the intermediate or long term?

Answer: As listed in the text, the two ways that plant capacity can be increased or decreased in the intermediate or long term are (1) increase or decrease the number of work centers in the plant or (2) increase the production rate of the work centers by making methods improvements or using more productive processing technologies.

3.6 What is utilization in a manufacturing plant? Provide a definition.

Answer: Utilization is the proportion of time that a productive resource (e.g., a work center) is used relative to the time available under the definition of capacity. Expressing this as an equation,

$$U_i = \sum_j f_{ij}$$

where U_i = utilization of machine i, and f_{ij} = the fraction of time during the available hours that machine i is processing part style j. An overall utilization for the plant is determined by averaging the U_i values over the number of work centers:

$$U = \frac{\sum_{i=1}^{n} \sum_j f_{ij}}{n} = \frac{\sum_j U_i}{n}$$

3.7 What is availability and how is it defined?

Answer: Availability is a reliability metric that indicates the proportion of time that a piece of equipment is up and working properly. It is defined as follows:

$$A = (MTBF - MTTR)/MTBF$$

where A = availability, $MTBF$ = mean time between failures, and $MTTR$ = mean time to repair.

3.8 What is manufacturing lead time?

Answer: Manufacturing lead time is the total time required to process a given part or product through the plant, including any lost time due to delays, time spent in storage, reliability problems, and so on.

3.9 What is work-in-process?

Answer: Work-in-process (WIP) is the quantity of parts or products currently located in the factory that are either being processed or are between processing operations. WIP is inventory that is in the state of being transformed from raw material to finished product.

3.10 How are fixed costs distinguished from variable costs in manufacturing?

Answer: Fixed costs remain constant for any level of production output. Examples include the cost of the factory building and production equipment, insurance, and property taxes. Variable costs vary in proportion to the level of production output. As output increases, variable costs increase. Examples include direct labor, raw materials, and electric power to operate the production equipment.

3.11 Name five typical factory overhead expenses?

Answer: Table 3.2 in the text lists the following examples of factory overhead expenses: plant supervision, applicable taxes, factory depreciation, line foremen, insurance, equipment depreciation, maintenance, heat and air conditioning, fringe benefits, custodial services, light, material handling, security personnel, power for machinery, shipping and receiving, tool crib attendant, payroll services, and clerical support.

3.12 Name five typical corporate overhead expenses?

Answer: Table 3.3 in the text lists the following examples of corporate overhead expenses: corporate executives, engineering, applicable taxes, sales and marketing, research and development, cost of office space, accounting department, support personnel, security personnel, finance department, insurance, heat and air conditioning, legal counsel, fringe benefits, and lighting.

3.13 Why should factory overhead expenses be separated from corporate overhead expenses?

Answer: A manufacturing company may operate more than one factory, and each factory has its own overhead expenses that are different from the expenses at other factories. On the other hand corporate overhead expenses are applied to all factories operated by the company. Also, in matters of analyzing costs, corporate overhead would simply inflate the operating costs so they should not be included in the cost analyses, but at least some of the factory overhead costs should be included. In pricing decisions, both factory and corporate expenses must be included.

3.14 What is the capital recovery factor in cost analysis?