I&ME-471 (Spring 2008)

Homework # 2 Solutions

Chapter 3 Questions:

1. 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.

2. What is production capacity?

Answer: As defined in the text, 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. 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) change the number of work shifts per week S_w or (2) change the number of hours worked per shift H_{sh}.

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

Answer: Utilization is the amount of output of a production facility relative to its capacity. Expressing this as an equation, $U = Q/PC$, where U = utilization, Q = actual output quantity produced during the period of interest, and PC is the production capacity during the same period.

5. 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.

6. What is manufacturing lead time?

Answer: As defined in the text, 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.

7. What is work-in-process?

Answer: As defined in the text, 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.

8. 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.

9. Name five typical factory overhead expenses?

Answer: Table 3.1 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.

10. Name five typical corporate overhead expenses?

Answer: Table 3.2 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.

PROBLEMS

Production Concepts and Mathematical Models

1. 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.

Machine	Setup time (hr.)	Operation time (min.)
1	4	5.0
2	2	3.5
3	8	10.0
4	3	1.9
5	3	4.1
6	4	2.5

Solution: Average T_{su} = (4 + 2 + 8 + 3 + 3 + 4)/6 = 24/6 = 4.0 hr

Average T_c = (5 + 3.5 + 10 + 1.9 + 4.1 + 2.5)/6 = 27/6 = 4.5 min

(a) MLT = 6(4.0 + 100(4.5/60) + 12) = 6(23.5) = **141 hr**

(b) R_p for operation 3: T_p = [8.0 + 100(10/60)]/100 = 24.67/100 = 0.2467 hr/pc R_p = **4.05 pc/hr**

2. Suppose the part in the previous problem is made in very large quantities on a production line in which an automated work handling system is used to transfer parts between machines. Transfer time between stations = 15 s. The total time required to set up the entire line is 150 hours. Assume that the operation times at the individual machines remain the same. Determine (a) manufacturing lead time for a part coming off the line, (b) production rate for operation 3, (c) theoretical production rate for the entire production line?

Solution: (a) MLT = 6(10.25) = 61.5 min for an average part after production has achieved steady state operation.

MLT = 61.5/60 + 150 = **151.025 hr** for first part including setup

(b) T_p for operation 3 = 10.25 min, R_p = 60/10.25 = **5.8536 pc/hr**

(c) Theoretical production rate for line = **5.8536 pc/hr** since station 3 is the bottleneck station on the line.

3. 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) $T_p = (5 + 25 \times 0.1)/25 = 0.30$ hr/pc, $R_p = 3.333$ pc/hr. $PC = 70(18)(3.333)/6 =$ **700 pc/week**

(c) Parts launched per week = 20 x 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 nonoperation time to decrease.

4. Based on the data in the previous problem and your answers to that problem, determine the average level of work-in-process (number of parts-in-process) in the plant.

Solution: $WIP = AU(PC)(MLT) / S_w H_{sh} = \dfrac{(1.0)(0.7143)(700)(105)}{70} =$ **750 pc**

5. A certain job shop specializes in one-of-a-kind orders dealing with parts of medium-to-high complexity. A typical part is processed sequentially through ten machines in batch sizes of one. The shop contains a total of eight conventional machine tools and operates 35 hours per week of production time. The machine tools are interchangeable in the sense that they can be set up for any operation required on any of the parts. Average time values on the part are: machining time per machine = 0.5 hour, work handling time per machine = 0.3 hour, tool change time per machine = 0.2 hour, setup time per machine = 6 hours, and nonoperation time per machine = 12 hours. A new programmable machine has been purchased by the shop that is capable of performing all ten operations in a single setup. The programming of the machine for this part will require 20 hours; however, the programming can be done off-line, without tying up the machine. The setup time will be 10 hours. The total machining time will be reduced to 80% of its previous value due to advanced tool control algorithms; the work handling time will be the same as for one machine; and the total tool change time will be reduced by 50% because it will be accomplished automatically under program control. For the one machine, nonoperation time is expected to be 12 hours. (a) Determine the manufacturing lead time for the traditional method and for the new method. (b) Compute the plant capacity for the following alternatives: (i) a job shop containing the eight traditional machines, and (ii) a job shop containing two of the new programmable machines. Assume the typical jobs are represented by the data given above. (c) Determine the average level of work-in-process for the two alternatives in part (b), if the alternative shops operate at full capacity. (d) Identify which of the ten automation strategies (Section 1.5.2) are represented (or probably represented) by the new machine.

Solution: (a) Present method: $MLT = 10(6 + 1 + 12) =$ **190 hr**.

New method: $MLT = 1(10 + 5.3 + 12) =$ **27.3 hr**.

(b) Present method: For 1 machine, $T_c = (6 + 1)/1 = 7$ hr, $R_c = 1/7 = 0.1429$ pc/hr

For 8 machines, plant capacity PC = (8 machines)(35 hr)(0.1429 pc/hr)/(10 ops/pc) = **4 orders/week**

New method: For each machines, $T_c = (10 + 5.3)/1 = 15.3$ hr, $R_c = 1/15.3 = 0.06536$ pc/hr

For 2 machines, plant capacity PC = (2 machines)(35 hr)(0.06536 pc/hr)/(1 op/pc) = **4.575 orders/week**

(c) Present method: WIP = (4 orders/week)(190 hr/order)/(35 hr/wk) = **21.7 orders**

New method: WIP = (4.575 orders/week)(27.3 hr/order)/(35 hr/wk) = **3.57 orders**

(d) Automation strategies represented: Strategy 2 - combined operations; Strategy 5 - increased flexibility; Strategy 6 - improved material handling; Strategy 8 - process control; Strategy 9 - plant operations control.

Costs of Manufacturing Operations

6. 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 $TC = FC + VC \times Q$. 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.

Solution: (a) $TC = 2{,}000{,}000 + (12 + 0.005Q)Q = 2{,}000{,}000 + 12Q + 0.005Q^2$

$$UC = \frac{TC}{Q} = \frac{2{,}000{,}000}{Q} + 12 + 0.005Q$$

$$\frac{d(UC)}{dQ} = \frac{-2{,}000{,}000}{Q^2} + 0.005 = 0$$

$0.005Q^2 = 2{,}000{,}000$ $\quad Q^2 = 400 \times 10^6$ $\quad Q = 20 \times 10^3 =$ **20,000 pc**

Profit = $250(20{,}000) - (2{,}000{,}000 + 12(20{,}000) + 0.005(20{,}000)^2)$ = **\$760,000/yr**

(b) Profit $\Pi = 250Q - (2{,}000{,}000 + 12Q + 0.005Q^2) = 238Q - 2{,}000{,}000 - 0.005Q^2$

$$\frac{d\Pi}{dQ} = 238 - 2(0.005Q) = 238 - 0.010Q = 0 \qquad Q = 238/0.010 = \textbf{23,800 pc}$$

Profit = $250(23{,}800) - (2{,}000{,}000 + 12(23{,}800) + 0.005(23{,}800)^2)$ = **\$832,200/yr**

7. Costs have been compiled for a certain manufacturing company for the most recent year. The summary is shown in the table below. The company operates two different manufacturing plants, plus a corporate headquarters. Determine (a) the factory overhead rate for each plant, and (b) the corporate overhead rate. The firm will use these rates in the following year.

Expense category	Plant 1	Plant 2	Corporate headquarters
Direct labor	$1,000,000	$1,750,000	
Materials	$3,500,000	$4,000,000	
Factory expense	$1,300,000	$2,300,000	
Corporate expense			$5,000,000

Solution: (a) Plant 1: Factory overhead rate $FOHR_1 = \frac{1{,}300{,}000}{1{,}000{,}000} = 1.30 =$ **130%**

Plant 2: Factory overhead rate $FOHR_2 = \frac{2{,}300{,}000}{1{,}750{,}000} = 1.3143 =$ **131.43%**

(b) Corporate overhead rate $COHR = \frac{5{,}000{,}000}{1{,}000{,}000 + 1{,}750{,}000} = 1.8182 =$ **181.82%**

Chapter 7 Questions:

1. What is numerical control?

Answer: As defined in the text, numerical control (NC) is a form of programmable automation in which the mechanical actions of a machine tool or other equipment are controlled by a program containing coded alphanumeric data.

2. What are the three basic components of an NC system?

Answer: The three components are (1) the part program of instructions, (2) the machine control unit, and (3) the processing equipment (e.g., machine tool) that accomplishes the operation.

3. What is the right-hand rule in NC and where is it used?

Answer: The right-hand rule is used to distinguish positive and negative directions for the rotational axes in NC. Using the right hand with the thumb pointing in the positive linear axis direction ($+x$, $+y$, or $+z$), the fingers of the hand are curled in the positive rotational direction for the a, b, and c axes.

4. What is the difference between point-to-point and continuous path control in a motion control system?

Answer: Point-to-point systems move the worktable to a programmed location without regard for the path taken to get to that location. By contrast, continuous path systems are capable of continuous simultaneous control of two or more axes, thus providing control of the tool trajectory relative to the workpart.

5. What is linear interpolation, and why is it important in NC?

Answer: Linear interpolation is the capability to machine along a straight-line trajectory that may not be parallel to one of the worktable axes. It is important in NC because many workpiece geometries require cuts to be made along straight lines to form straight edges and flat surfaces, and the angles of the lines are not be parallel to one of the axes in the coordinate system.

6. What is the difference between absolute positioning and incremental positioning?

Answer: In absolute positioning, the workhead locations are always defined with respect to the origin of the NC axis system. In incremental positioning, the next workhead position is defined relative to the present location.

7. How is computer numerical control (CNC) distinguished from conventional NC?

Answer: CNC is an NC system whose machine control unit is a dedicated microcomputer rather than a hard-wired controller, as in conventional NC.

8. What are four advantages of numerical control when properly applied in machine tool operations?

Answer: The text lists the following 11 advantages: (1) nonproductive time is reduced, (2) greater accuracy and repeatability, (3) lower scrap rates, (4) inspection requirements are reduced, (5) more-complex part geometries are possible, (6) engineering changes can be accommodated more gracefully, (7) simpler fixtures are needed, (8) shorter manufacturing lead times, (9) reduced parts inventory, (10) less floor space required due to fewer machines, and (11) operator skill requirements are reduced.

9. What are three disadvantages of implementing NC technology?

Answer: Four disadvantages are identified in the text: (1) higher investment cost because NC machines are more expensive than conventional machine tools, (2) higher maintenance effort due to greater technological sophistication of NC, (3) part programming is required, and (4) equipment utilization must be high to justify the higher investment, and this might mean additional work shifts are required in the machine shop.

10. What is manual data input of the NC part program?

Answer: Manual data input is when the machine operator manually enters the part program data and motion commands directly into the MCU prior to running the job.

PROBLEMS

NC Applications

1. A machinable grade of aluminum is to be milled on an NC machine with a 20 mm diameter four-tooth end milling cutter. Cutting speed = 120 m/min and feed = 0.008 mm/tooth. Convert these values to rev/min and mm/rev, respectively.

Solution: $N = \dfrac{120\text{m / min}}{20\pi(10^{-3})\text{m / rev}}$ = **1909.9 rev/min**

Feed in mm/rev = (4 teeth/rev)(0.08 mm/tooth) = **0.32 mm/rev**

2. A turning operation is to be performed on an NC lathe. Cutting speed = 2.5 m/s, feed = 0.2 mm/rev, and depth = 4.0 mm. Workpiece diameter = 100 mm and its length = 400 mm. Determine (a) rotational speed of the workbar, (b) feed rate, (c) metal removal rate, and (d) time to travel from one end of the part to the other.

Solution: (a) $N = \dfrac{2.5(60)\text{m / min.}}{100\pi(10^{-3})\text{m / rev.}}$ = **477.5 rev/min**

(b) f_r = 477.5 rev/min(0.2 mm/rev) = **95.5 mm/min**

(c) R_{MR} = vfd = 2.5 m/s(10^3)(.2 mm)(4.0 mm) = **2000 mm^3/s**

(d) T_m = 400/95.5 = **4.188 min**

3. A numerical control drill press drills four 10.0 mm diameter holes at four locations on a flat aluminum plate in a production work cycle. Although the plate is only 12 mm thick, the drill must travel a full 20 mm vertically at each hole location to allow for clearance above the plate and breakthrough of the drill on the underside of the plate. Cutting conditions: speed = 0.4 m/s and feed = 0.10 mm/rev. Hole locations are indicated in the following table:

Hole number	x-coordinate (mm)	y-coordinate (mm)
1	25.0	25.0
2	25.0	100.0
3	100.0	100.0
4	100.0	25.0

The drill starts out at point (0,0) and returns to the same position after the work cycle is completed. Travel rate of the table in moving from one coordinate position to another is 500 mm/min. Owing to effects of acceleration and deceleration, and time required for the control system to achieve final positioning, a time loss of 3 s is experienced at each stopping position of the table. Assume that all moves are made so as to minimize the total cycle time. If loading and unloading the plate take 20 s (total handling time), determine the time required for the work cycle.

Solution: Drilling operations: $N = \frac{0.4(60)}{10\pi(10^{-3})} = 763.9$ rev/min

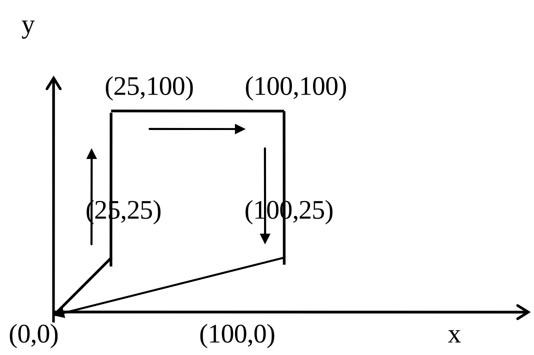
$f_r = Nf = 763.9(0.10) = 76.39$ mm/min

For each hole, $T_m = 20/76.39 = 0.262$ min

Assume retraction of dril at each hole takes an equal time. Total time/hole = 0.524 min

For four holes, $T_m = 4(0.524) = 2.096$ min

Workpart and axis system with assumed tool path shown in accompanying drawing:



Total distance traveled between positions = $\sqrt{25^2 + 25^2} + 75 + 75 + 75 + \sqrt{25^2 + 100^2} = 363.43$ mm

Time to move between positions = $\frac{363.43}{500} + \frac{5(3)}{60} = 0.977$ min

Cycle time = $T_h + T_m$ + move time = 20/60 + 2.096 + 0.977 = **3.406 min**