Review Questions

2.1 In terms of human participation, what are the three basic categories of work systems?

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

2.2 What is the general characteristic that is common to nearly all pure manual work?

Answer: Moving things.

2.3 What is the one best method principle?

Answer: According to the one best method principle, of all the possible alternative methods that can be used to perform a task, there is one optimal method that minimizes the time and effort required to accomplish it. It is also a safe method that produces a high quality work unit.

2.4 What is meant by the term *normal performance*?

Answer: Normal performance refers to a pace of working that can be maintained throughout an entire work shift (in which periodic rest breaks are allowed) by a properly trained average worker without deleterious short term or long effects on the worker's health or physical well-being.

2.5 What is meant by the term *normal time* for a task?

Answer: The normal time for a task is the time required to accomplish one cycle of the task when working at 100% performance (normal performance).

2.6 What does PFD stand for? What is the purpose of the PFD allowance in determining the standard time for a task?

Answer: PFD stands for personal time, fatigue, and delays. The purpose of the PFD allowance is to provide a small amount of additional time above the normal time to account for losses due to personal time, fatigue (rest breaks), and delays that occur periodically during the work shift.

2.7 What is an irregular work element?

Answer: An irregular work element is an element that is performed less frequently than once per cycle. Examples include changing tools and changing tote pans of parts. Irregular elements do not occur every cycle, so their times are prorated in the regular cycle time.

2.8 Define the meaning of worker efficiency.

Answer: Worker efficiency is the amount of work actually accomplished during a specified period, expressed in terms of standard hours, divided by the number of hours in the shift.

2.9 What is a worker-machine system?

Answer: A worker-machine system is a work system in which the worker operates powered equipment.

2.10 What are the three main categories of powered machinery in worker-machine systems?

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Answer: The three categories listed in the text are (1) portable power tools, (2) mobile powered equipment, and (3) stationary powered machines.

2.11 Define machine tool.

Answer: A machine tool is a stationary power-driven machine that shapes or forms parts. Operations performed by machine tools include machining (e.g., turning, drilling, milling), shearing (e.g., blanking, hole-punching), and squeezing (e.g., forging, extrusion).

2.12 Cycle times in worker-machine systems divide into two categories: (1) machine time depends on operator and (2) machine time is constant and repetitive. Give an example of each category.

Answer: In category (1), an example is a truck driver driving a tractor-trailer. In category (2), an example is a production operation in which the machine operates on semi-automatic cycle.

2.13 What is the difference between an external work element and an internal work element in a worker-machine cycle?

Answer: External work elements are operator elements that are performed sequentially with the machine cycle. Internal work elements are operator elements that are performed simultaneously with the machine cycle.

2.14 What are the factors that affect the workload calculation when determining worker requirements?

Answer: The factors given in the text are worker efficiency and fraction defect rate. The learning curve phenomenon is also mentioned, but it is not included in the workload calculation.

2.15 What does availability mean?

Answer: Availability is a reliability measure that indicates the proportion of the total time that a piece of equipment can be used and is not broken down or being repaired. Availability is the proportion uptime of the equipment.

2.16 What is a machine cluster?

Answer: A machine cluster is defined as a collection of two or more machines producing parts or products with identical cycle times and serviced (usually loaded and unloaded) by one worker.

Problems

Cycle Time Analysis of Manual Work

2.1 If the normal time is 1.30 min for a repetitive task that produces one work unit per cycle, and the company uses a PFD allowance factor of 12%, determine (a) the standard time for the task and (b) how many work units are produced in an 8-hour shift at standard performance.

Solution: (a) T_{std} = 1.30(1 + 0.12) = 1.456 min

(b) Q_{std} = 8(60)/1.456 = 329.7 pc (if rounded, 329 pc)

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2.2 The normal time for a repetitive task that produces two work units per cycle is 3.0 min. The plant uses a PFD allowance factor of 15%. Determine (a) the standard time per piece and (b) how many work units are produced in an 8-hour shift at standard performance.

Solution: (a) T_{std} = 3.0(1 + 0.15) = 3.45 min/cycle
With 2 pc/cycle, T_{std} = 3.45/2 = 1.725 min/pc

(b) Q_{std} = 8(60)/1.725 = 278.3 pc (if rounded, 278 pc)

2.3 The normal time to perform a certain manual work cycle is 3.47 min. In addition, an irregular work element whose normal time is 3.70 min must be performed every 10 cycles. One work unit is produced each cycle. The PFD allowance factor is 14%. Determine (a) the standard time per piece and (b) how many work units are produced during an 8-hour shift at 100% performance, and the worker works exactly 7.018 hr, which corresponds to the 14% allowance factor. (c) If the worker's pace is 120% and he works 7.2 hours during the regular shift, how many units are produced?

Solution: (a) T_{std} = (3.47 + 3.70/10)(1 + 0.14) = 4.378 min

(b) Q_{std} = 8(60)/4.378 = 109.6 pc (if rounded, 109 pc)

(c) T_n = 3.47 + 3.7 = 3.84 min
T_c = 3.84/1.20 = 3.2 min
Daily R_p = 7.2(60)/3.2 = 135 pc

2.4 The normal time to perform a repetitive manual assembly task is 4.25 min. In addition, an irregular work element whose normal time is 1.75 min must be performed every 8 cycles. Two work units are produced each cycle. The PFD allowance factor is 16%. Determine (a) the standard time per piece and (b) how many work units are produced in an 8-hour shift at standard performance. (c) Determine the anticipated amount of time worked and the amount of time lost per 8-hour shift that corresponds to the PFD allowance factor of 16%.

Solution: (a) T_{std} = (4.25 + 1.75/8)(1 + 0.16) = 5.184 min/cycle
With 2 pc/cycle, T_{std} = 5.184/2 = 2.592 min/pc

(b) Q_{std} = 8(60)/2.592 = 185.2 pc (if rounded, 184 pc because it must be an integer multiple of 2)

(c) 8.0 hr = (time worked)(1 + 0.16)
Time worked = 8.0/1.16 = 6.896 hr = 413.8 min
Time lost = 480 – 413.8 – 66.2 min

2.5 The standard time for a manual material-handling work cycle is 2.58 min per piece. The PFD allowance factor used to set the standard was 13%. During a particular 8-hour shift of interest, it is known that the worker lost a total of 53 min due to personal time, rest breaks, and delays. On that same day, the worker completed 214 work units. Determine (a) the number of standard hours accomplished, (b) worker efficiency, and (c) the worker's performance level expressed as a percentage.

Solution: (a) H_{std} = 214(2.58)/60 = 552.12/60 = 9.202 hr

(b) E_w = 9.202/8.0 = 1.15 = 115%

(c) Time worked = 480 – 53 = 427 min

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T_c = (427 min)/(214 pc) = 1.995 min/pc
T_n = 2.58/(1 + 0.13) = 2.283 min/pc
P_w = 2.283/1.995 = 1.144 = 114.4%

2.6 A worker performs a repetitive assembly task at a workbench to assemble products. Each product consists of 25 components. Various hand tools are used in the task. The standard time for the work cycle is 7.45 min, based on using a PFD allowance factor of 15%. If the worker completes 75 product units during an 8-hour shift, determine (a) the number of standard hours accomplished and (b) worker efficiency. (c) If the worker took only one rest break, lasting 13 min, and experienced no other interruptions during the 8 hours of shift time, determine her worker performance.

Solution: (a) H_{std} = 75(7.45)/60 = 558.75/60 = 9.313 hr

(b) E_w = 9.313/8.0 = 1.164 = 116.4%

(c) Time worked = 480 – 13 = 467 min
T_c = (467 min)/(75 pc) = 6.227 min/pc
T_n = 7.45/(1 + 0.15) = 6.478 min/pc
P_w = 6.478/6.227 = 1.040 = 104.0%

Cycle Time Analysis in Worker-Machine Systems

2.7 The normal time of the work cycle in a worker-machine system is 5.39 min. The operator-controlled portion of the cycle is 0.84 min. One work unit is produced each cycle. The machine cycle time is constant. (a) Using a PFD allowance factor of 16% and a machine allowance factor of 30%, determine the standard time for the work cycle. (b) If a worker assigned to this task completes 85 units during an 8-hour shift, what is the worker's efficiency? (c) If it is known that a total of 42 min was lost during the 8-hour clock time due to personal needs and delays, what was the worker's performance on the portion of the cycle he controlled?

Solution: Machine time per cycle T_m = 5.39 – 0.84 = 4.55 min
T_{std} = 0.84(1 + 0.16) + 4.55(1 + 0.30) = 6.889 min

(b) H_{std} = 85(6.889)/60 = 585.6/60 = 9.76 hr
E_w = 9.76/8.0 = 1.22 = 122%

(c) Time worked = 480 – 42 = 438 min
Total machine time = 85(4.55) = 386.75 min
Total operator time = 438 – 386.75 = 51.25 min
Total operator time at normal pace = 85(0.84) = 71.4 min
P_w = 71.4/51.25 = 1.393 = 139.3%

2.8 A worker is responsible for loading and unloading a production machine. The load/unload elements in the repetitive work cycle have a normal time of only 24 sec, and the machine cycle time is 2.83 min. One part is produced each cycle. Every sixth cycle, the operator must replace the tote pans of parts, which takes 2.40 min (normal time). For setting the standard time, the PFD allowance factor is 15%, and the machine allowance factor is 15%. Determine the standard time under the following alternative assumptions: (a) the irregular element is performed as an external element and (b) the irregular element is performed as

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an internal element. (c) Determine the corresponding standard daily production quantities (8-hour shift) for each of these time standards.

Solution: (a) T_{nw} = 0.40 + 2.4/6 = 0.80 min
T_{std} = 0.80(1 + 0.15) + 2.83(1 + 0.15) = 4.175 min

(b) Irregular element occurs once every 6th cycle.
For 5 cycles, T_{std} = 0.4(1 + 0.15) + 2.83(1 + 0.15) = 3.715 min
For the 6th cycle, T_{std} = 0.4(1 + 0.15) + Max{2.40(1 + 0.15), 2.83(1 + 0.15)} = 3.715 min
Since these values are the same, T_{std} = 3.715 min. If the two values would have been different, then a weighted average should be used to determine the standard time for the cycle.

(c) For (a), Q_{std} = 8(60)/4.175 = 115 pc
For (b), Q_{std} = 8(60)/3.715 = 129 pc

2.9 The work cycle in a worker-machine system consists of (1) external manual work elements with a total normal time of 0.42 min, (2) a machine cycle with machine time of 1.12 min, and (3) internal manual elements with a total normal time of 1.04 min. (a) Determine the standard time for the cycle, using a PFD allowance factor of 15%, and a machine allowance factor of 30%. (b) How many work units are produced daily (8-hour shift) at standard performance?

Solution: (a) T_{std} = 0.42(1.15) + Max{1.04(1.15), 1.12(1.30)} = 1.939 min

(b) Q_{std} = 8(60)/1.939 = 247.6 pc (if rounded, 247 pc)

2.10 Solve the previous problem but assume that the machine allowance factor is 0%.

Solution: (a) T_{std} = 0.42(1.15) + Max{1.04(1.15), 1.12(1.0)} = 1.679 min

(b) Q_{std} = 8(60)/1.679 = 285.9 pc (if rounded, 286 pc)

2.11 The normal time for a work cycle in a worker-machine system is 6.27 min. For setting the standard time, the PFD allowance factor is 12%, and the machine allowance factor is 25%. The work cycle includes manual elements totaling a normal time of 5.92 min, all but 0.65 min of which are performed as internal elements. Determine (a) the standard time for the cycle and (b) the daily output at standard performance. (c) During an 8-hour shift, the worker lost 39 min due to personal time, rest breaks, and delays, and she produced 72 pieces. What was the worker's pace on the operator-controlled portion of the shift?

Solution: (a) Machine time per cycle T_m = 6.27 – 0.65 = 5.62 min
Internal normal time T_{nwi} = 5.92 – 0.65 = 5.27 min
T_{std} = 0.65(1.12) + Max{5.27(1.12), 5.62(1.25)} = 0.728 + 7.025 = 7.753 min

(b) Q_{std} = 8(60)/7.753 = 61.9 pc (if rounded, 62 pc)

(c) Time worked = 480 – 39 = 441 min
Given that Q = 72 pc, then total machine time = 72(5.62) = 404.64 min
Total worker-controlled time = 441 – 404.64 = 36.36 min
Given T_{nw} = 0.65 min, total worker-controlled time at normal pace = 72(0.65) = 46.8 min
P_w = 46.8/36.36 = 1.287 = 128.7%

2.12 Solve the previous problem but assume the machine allowance factor is 0%.

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Solution: (a) Machine time per cycle T_m = 6.27 – 0.65 = 5.62 min
Internal normal time T_{nwi} = 5.92 – 0.65 = 5.27 min
T_{std} = 0.65(1.12) + Max{5.27(1.12), 5.62(1.0)} = 0.728 + 5.902 = 6.630 min

(b) Q_{std} = 8(60)/6.63 = 72.4 pc (if rounded, 72 pc)

(c) Time worked = 480 – 39 = 441 min
Given that Q = 72 pc, then total machine time = 72(5.62) = 404.64 min
Total worker-controlled time = 441 – 404.64 = 36.36 min
Given T_{nw} = 0.65 min, total worker-controlled time at normal pace = 72(0.65) = 46.8 min
P_w = 46.8/36.36 = 1.287 = 128.7%

Determining Worker and Machine Requirements

2.13 A total of 1000 units of a certain product must be completed by the end of the current week. It is now late Monday afternoon, so only four days (8-hour shifts) are left. The standard time for producing each unit of the product (all manual operations) is 11.65 min. How many workers will be required to complete this production order if it is assumed that worker efficiency will be 115%?

Solution: Workload WL = 1000(11.65)/1.15 = 10,130.4 min = 168.84 hr
Available time AT = 4(8.0) = 32 hr/worker
w = 168.84/32 = 5.28 rounded up to 6 workers

2.14 Future production requirements in the turret lathe department must be satisfied through the acquisition of several new machines and the hiring of new operators, the exact number to be determined. There are three new parts that will be produced. Part A has annual quantities of 20,000 units; part B, 32,000 units; and part C, 47,000 units. Corresponding standard times for these parts are 7.3 min, 4.9 min, and 8.4 min, respectively. The department will operate one 8-hour shift for 250 days/yr. The machines are expected to be 98% reliable, and the anticipated scrap rate is 4%. Worker efficiency is expected to be 100%. How many new turret lathes and operators are required to meet these production requirements?

Solution: WL = (20,000 x 7.3 + 32,000 x 4.9 + 47,000 x 8.4)/(1 – 0.04)
WL = (146,000 + 156,800 + 394,800)/0.96 = 726,667 min = 12,111 hr
AT = 8(250)(0.98) = 1960 hr/yr
$n = w$ = 12,111/1960 = 6.16 rounded up to 7 workers and 7 lathes

2.15 A new stamping plant must supply an automotive final assembly plant with stampings, and the number of new stamping presses must be determined. Each press will be operated by one worker. The plant will operate one 8-hour shift per day, five days per week, 50 weeks per year. The plant must produce a total of 20,000,000 stampings annually. However, 400 different stamping designs are required, in batch sizes of 5000 each, so each batch will be produced 10 times per year to minimize build-up of inventory. Each stamping takes 6 sec on average to produce. Scrap rate averages 2% in this type of production. Before each batch, the press must be set up, with a standard time per setup of 3.0 hours. Presses are 95% reliable (availability = 95%) during production and 100% reliable during setup. Worker efficiency is expected to be 100%. How many new stamping presses and operators will be required?

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Solution: Number of setups = 20,000,000/5,000 = 4,000 setups/yr
Setup workload WL_{su} = 4,000(3.0) = 12,000 hr/yr
Cycle time T_c = 6 sec = 0.1 min
Production workload WL_p = 20,000,000(0.1)/0.98(60) = 34,013.6 hr/yr
Available time for setup AT_{su} = 2,000(1.0) = 2,000 hr/yr per press
Available time for production AT_p = 2000(0.95) = 1900 hr/yr
$n = w$ = 34,013.6/1,900 + 12,000/2,000 = 17.9 + 6 = 23.9 rounded up to 24 presses and 24 operators

2.16 Solve the previous problem, except the plant will operate two 8-hour shifts instead of one. (a) How much money would be saved if each press has an investment and installation cost of $250,000. (b) If each worker's wage rate is $15.00/hr, how much money would be saved by operating two 8-hour shifts per day rather than one 8-hour shift?

Solution: (a) Number of setups = 20,000,000/5,000 = 4,000 setups/yr
Setup workload WL_{su} = 4,000(3.0) = 12,000 hr/yr
Cycle time T_c = 6 sec = 0.1 min
Production workload WL_p = 20,000,000(0.1)/0.98(60) = 34,013.6 hr/yr
Available time for setup AT_{su} = 4,000(1.0) = 4,000 hr/yr per press
Available time for production AT_p = 4,000(0.95) = 3,800 hr/yr per press
n = 34,013.6/3,800 + 12,000/4,000 = 8.95 + 3 = 11.95 rounded up to 12 presses
Savings from 24 – 12 presses at $250,000 = $3,000,000

(b) Workers are limited to 2,000 hr/yr
w = 34,013.6/1,900 + 12,000/2,000 = 17.9 + 6 = 23.9 rounded up to 24 operators (12 operators per shift). Since the number of workers remains the same as in a one-shift operation, there would be no significant change in labor cost. In fact, the cost might be greater because operators on the evening shift are often paid at a slightly higher rate (called a "shift differential").

2.17 Specialized processing equipment is required for a new type of integrated circuit to be produced by an electronics manufacturing company. The process is used on silicon wafers. The standard time for this process is 10.6 min per wafer. Scrap rate is 15%. A total of 125,000 wafers will be processed each year. The process will be operated 24 hours per day, 365 days per year. Data provided by the manufacturer of the processing equipment indicate that the availability is 93%. Each machine is operated by one worker, and worker efficiency is 100%. No setups are required for the machine. How many pieces of processing equipment will be needed to satisfy production requirements?

Solution: Workload WL = 125,000(10.6)/60(1 – 0.15) = 25,980.4 hr/yr
Available time AT = 365(24)(0.93) = 8,146.8 hr/yr per equipment piece
n = 25,980.4/8,146.8 = 3.19 rounded up to 4 pieces of processing equipment

2.18 The standard time to produce a certain part in a worker-machine system is 9.0 min. A rush order has been received to supply 1000 units of the part within five working days (40 hours). How many worker-machine systems must be diverted from other production to satisfy this order? Each machine must be set up at the beginning of production of parts for the order, and the setup time per machine is 5.0 hours. Fraction defect rate is 5%, and worker efficiency is

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100%. Availability is expected to be 98% during setup and production. How many machines and machine operators are required during the week?

Solution: Production workload WL_p = 1,000(9.0)/60(1 – 0.05) = 157.9 hr/wk
Setup workload WL_{su} = 5.0 n
Total workload WL = 157.9 + 5.0 n
Available time (production and setup) AT = 40(0.98) = 39.2 hr/wk per machine
n = (157.9 + 5.0 n)/39.2
39.2 n = 157.9 + 5.0 n
34.2 n = 157.9
n = 4.62 rounded up to 5 machines and 5 operators

2.19 A small company that specializes in converting pickup trucks into rear-cabin vehicles has just received a long-term contract and must expand. Heretofore, the conversion jobs were customized and performed in a garage. Now a larger building must be occupied, and the operations must be managed more like a production plant. Three models will be produced: A, B, and C. Annual quantities for the three models are as follows: A, 700; B, 400; and C, 250. Conversion times are as follows: A, 20 hr; B, 30 hr; and C, 40 hr. Defect rates are as follows: A, 11%; B, 7%; and C, 8%. Work teams of three workers each will accomplish the conversions. Each work team will require a space of 350 ft^2 in the plant. Reliability (availability) and worker efficiency of the work teams are expected to be 95% and 90%, respectively. Although the defect rates are given, no truck is permitted to leave the plant with any quality defects. Accordingly, all of the defects must be corrected, and the average time to correct the defect is 25% of the initial conversion time. The same work teams will accomplish this rework. (a) If the plant is run as a one-shift (2000 hr/yr) operation, how many work teams will be required? (b) If the total floor space in the building must include additional space for aisles and offices and the allowance that is added to the working space is 30%, what is the total area of the building?

Solution: (a) AT = 2000(0.95)(0.90) = 1,710 hr/yr
Production workload WL_{prod} = 700(20) + 400(30) + 250(40) = 36,000 hr/yr
Defect correction workload WL_{cor} = 700(0.11)(20)(0.25) + 400(0.07)(30)(0.25) + 250(0.08)(40)(0.25) = 795 hr/yr
Total workload WL = 36,000 + 795 = 36,795 hr/yr
n = 36,795/1710 = 21.5 rounded up to 22 work teams

(b) Plant area TA = 22(350)(1 + 0.30) = 10,010 ft^2

2.20 It has just been learned that a Boeing 747 transporting garments made in China crashed in the Pacific Ocean during its flight to Los Angeles. Although the crew was saved, all cargo was lost, including 3000 garments that must be delivered in one week. The garment company must produce the order at its Los Angeles plant to satisfy delivery obligations. The number of workers must be determined and workspace must be allocated in the plant for this emergency job. Standard time to produce one garment is 6.50 min. The garments are then 100% inspected at a standard time of 0.75 min per unit. The scrap rate in production is 7%. However, all defective garments can be corrected through rework. Standard time for rework is 5.0 min per unit reworked. It is not necessary to reinspect the garments after rework. Worker efficiency is 120% during production and 100% during inspection and rework. The same production workers do the rework, but inspectors are a different job class. How many

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workers and how many inspectors are required to produce the required batch of 3000 garments in the regular 40-hour work week?

Solution: Production workload WL_p = 3,000(6.5)/1.20 = 16,250 min = 270.83 hr
Rework workload WL_{rw} = 3,000(0.07)(5.0)/1.00 = 1050 min = 17.5 hr
Inspection workload WL_{insp} = 3,000(0.75)/1.00 = 2,250 min = 37.5 hr
Available time AT = 40 hr/worker
For production and rework, w = (270.83 + 17.5)/40 = 7.21 rounded up to 8 workers
For inspection, w = 37.5/40 = 0.94 rounded up to one inspector

2.21 In the previous problem, suppose it turns out that only five workers are available to accomplish the production and rework, and because they must work overtime, worker efficiency will be reduced to 110% in production and 90% in rework. If they work 6 days/wk for one week, how many hours per day must they work to produce the 3000 garments?

Solution: Production workload WL_p = 3,000(6.5)/1.10 = 17,727.3 min = 295.46 hr
Rework workload WL_{rw} = 3,000(0.07)(5.0)/0.90 = 1166.7 min = 19.45 hr
Total workload (production and rework) WL = 295.46 + 19.45 = 314.9 hr
AT = (6 days)(H_{sh}) per worker
Total available time for 5 workers = 5(6 days)(H_{sh}) = 30 H_{sh}
30 H_{sh} = 314.9
H_{sh} = 314.9/30 = 10.497 hr/day for all workers

Machine Clusters

2.22 The CNC grinding section has a large number of machines devoted to grinding of shafts for the automotive industry. The machine cycle takes 3.6 min to grind the shaft. At the end of this cycle, an operator must be present to unload and load parts, which takes 40 sec. (a) Determine how many grinding machines the worker can service if it takes 20 sec to walk between the machines and no machine idle time is allowed. (b) How many seconds during the work cycle is the worker idle? (c) What is the hourly production rate of this machine cluster?

Solution: (a) n = (3.6 + 0.667)/(0.667 + 0.333) = 4.267 rounded down to 4 machines to avoid machine idle time

(b) Machine cycle time = 3.6 + 0.667 = 4.267 min
Worker time per machine = 0.667 + 0.333 = 1.00 min
Worker idle time = 4.267 – 4.00 = 0.267 min = 16 sec

(c) Given T_c = 4.267 min and 4 machines, R_p = 4(60)/4.267 = 56.25 pc/hr

2.23 The screw machine department has a large number of machines devoted to the production of a certain component that is in high demand for the personal computer industry. The semiautomatic cycle for this component is 4.2 min per piece. At the end of the machining cycle, an operator must unload the finished part and load raw stock for the next part. This servicing time takes 21 sec and the walking time between machines is estimated at 24 sec. (a) Determine how many screw machines one worker can service if no idle machine time is allowed. (b) How many seconds during the work cycle is the worker idle? (c) What is the hourly production rate of this machine cluster if one part is produced per machine each cycle?

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Solution: (a) n = (4.2 + 0.35)/(0.35 + 0.40) = 6.07 rounded down to 6 machines to avoid machine idle time

(b) Machine cycle time = 4.2 + 0.35 = 4.55 min
Worker time per machine = 0.35 + 0.40 = 0.75 min
Worker idle time = 4.55 – 6(0.75) = 0.05 min = 3 sec

(c) Given T_c = 4.55 min and 6 machines, R_p = 6(60)/4.55 = 79.12 pc/hr

2.24 A worker is currently responsible for tending two machines in a certain production cell. The service time per machine is 0.35 min and the time to walk between machines is 0.15 min. The machine automatic cycle time is 1.90 min. If the worker's hourly rate is $12/hr and the hourly rate for each machine is $18/hr, determine (a) the current hourly rate for the cell, and (b) the current cost per unit of product, given that two units are produced by each machine during each machine cycle. (c) What is the percentage of idle time of the worker? (d) What is the optimum number of machines that should be used in the cell, if minimum cost per unit of product is the decision criterion?

Solution: (a) Current hourly rate = $12.00 + 2($18.00) = $48.00/hr

(b) T_c = 0.35 + 1.9 = 2.25 min
Hourly production rate for the cluster (2 machines, 2 parts/cycle for each machine):
R_p = 2(2)(60)/2.25 = 106.67 pc/hr
C_{pc} = $48.00/106.67 = $0.45/pc

(c) Idle time for worker = 2.25 – 2(0.35 + 0.15) = 2.25 – 1.00 = 1.25 min
Percent idle time = 1.25/2.25 = 0.555 = 55.5%

(d) n = (1.9 + 0.35)/(0.35 + 0.15) = 2.25/0.50 = 4.5 machines
C_L = $12/hr = $0.20/min, C_m = $18/hr = $0.30/min
For n_1 = 4 machines, C_{pc} = {0.20(2.25) + 4(0.30)(2.25)}/4(2) = $0.394/pc
For n_2 = 5 machines, C_{pc} = {0.20(5)(0.50) + 5(0.30)(5)(0.50)}/5(2) = $0.425/pc
Optimum number of machines is n_1 = 4 machines.

2.25 In a worker-machine cell, the appropriate number of production machines to assign to the worker is to be determined. Let n = the number of machines. Each production machine is identical and has an automatic processing time T_m = 4.0 min to produce one piece. Servicing time T_s = 12 sec for each machine. The full cycle time for each machine in the cell is $T_c = T_s + T_m$. The walk time (repositioning time) for the worker is given by $T_r = 5 + 3n$, where T_r is in seconds. T_r increases with n because the distance between machines increases with more machines. (a) Determine the maximum number of machines in the cell if no machine idle time is allowed. For your answer, compute (b) the cycle time, (c) the worker idle time expressed as a percentage of the cycle time, and (d) the production rate of the machine cluster.

Solution: (a) $T_c = T_m + T_s$ = 4.0(60) + 12 = 252 sec
Worker time per machine = $T_s + T_r = 12 + 5 + 3n = 17 + 3n$
$n = 252/(17 + 3n)$
$n(17 + 3n) = 252$
$17n + 3n^2 = 252$
Setting this up to use the quadratic equation, $3n^2 + 17n - 252 = 0$

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$n = \dfrac{-17 \pm \sqrt{17^2 - 4(3)(-252)}}{2(3)}$ = -2.83 ± 9.59 = 6.76 or –12.42

For no machine idle time, n = 6 machines

(b) T_c = 252 sec = 4.2 min

(c) Worker idle time = 252 – 6(17 + 3(6)) = 252 – 210 = 42 sec per cycle
Percent idle time = 42/252 = 0.167 = 16.7%

2.26 The injection-molding department contains a large number of molding machines, all of which are automated. They can run continuously for multiple molding cycles without the attention of a human operator by allowing the molded parts to fall into tote pans beneath the machines. However, the tote pans must be periodically emptied by a worker who must attend the machine to perform this task. Each machine can run continuously for approximately 20 min between tote pan changes. A time of 2.0 min is allowed for a worker to tend a given machine. The time to walk between machines increases with the number of machines tended by a worker. In measurements by the time study department, the walking time between two machines in close proximity is about 15 sec. This walking time increases by 15 sec for each new machine added to the worker's tour. Determine (a) how many injection-molding machines one worker can service if no idle machine time is allowed, and (b) how many seconds during the work cycle the worker is idle?

Solution: (a) $T_c = T_m + T_s$ = 20 + 2 = 22 min
Worker time per machine = $T_s + T_r$ = 2.0 + 0.25n
n = 22/(2 + 0.25n)
n(2 + 0.25n) = 22
2n + 0.25n^2 = 22
Setting this up to use the quadratic equation, 0.25n^2 + 2n – 22 = 0
Multiply both sides by 4 to obtain: n^2 + 8n – 88 = 0

$n = \dfrac{8 \pm \sqrt{64 - 4(1)(-88)}}{2}$ = -4 ± 10.2 = 6.2 or –14.2

For no machine idle time, n = 6 machines

(b) Worker idle time = 22 – 6(2 + 0.25(6)) = 22 – 21 = 1.0 min = 60 sec per cycle

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