Review Questions

13.1 Define direct time study.

Answer: Direct time study is the direct and continuous observation of a task using a stopwatch or other timekeeping device to record the time taken to accomplish the task. While observing and recording the time, the worker's performance level is rated. These data are then used to compute a standard time for the task, by adding an allowance for personal time, fatigue, and delays.

13.2 Identify the five steps in the direct time study procedure.

Answer: The five steps are as follows: (1) Define and document the standard method. (2) Divide the task into work elements. (3) Time the work elements to obtain the observed time for the task. (4) Rate the worker's pace to determine the normalized time. Steps 3 and 4 are accomplished simultaneously. (5) Apply allowances to compute the standard time.

13.3 Why is it so important to define and document the standard method as precisely and thoroughly as possible?

Answer: The reasons given in the text (paraphrased) are as follows: (1) to provide work instructions for future batches, (2) to distinguish if the worker has made methods improvements which might justify retiming the task and setting a new standard, (3) as a reference document to settle disputes and complaints by the worker, and (4) to provide data for a standard data system that might be implemented at some future time.

13.4 What is the snapback timing method when using a stopwatch during direct time study?

Answer: In the snapback timing method, the watch is started at the beginning of every work element by snapping it back to zero at the end of the previous element. The reader must note and record the final time for that element as the watch is being zeroed.

13.5 What is the continuous timing method when using a stopwatch during direct time study?

Answer: In the continuous timing method, the watch is zeroed at the beginning of the first cycle and allowed to run continuously throughout the duration of the study. The analyst records the running time on the stopwatch at the end of each respective element. Some analysts adapt the continuous method by zeroing at the beginning of each work cycle, so that the starting time of any given work cycle is always zero.

13.6 Why is performance rating a necessary step in direct time study?

Answer: Performance rating is necessary when the worker is performing the task during the time study at a pace that is different from the organization's definition of standard or 100% performance. Performance rating converts the observed time into the normal time, which is the time that would be required at 100% performance.

13.7 Why is an allowance added to the normal time to compute the standard time?

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Answer: The allowance is added to the normal time in order to account for various reasons why the worker may lose time during the shift. The main reasons for an allowance are personal time, fatigue, and unavoidable delays (PFD).

13.8 What are some of the causes of variability in the observed work element times that occur from cycle to cycle?

Answer: The reasons include (1) variations in hand and body motions, (2) variations in the placement and location of parts and tools used in the cycle, (3) variations in the quality of the starting work units, (4) mistakes by operator (e.g., accidentally dropping the workpart), (5) errors in timing the work elements by the analyst, and (6) variations in worker pace.

13.9 Why is the student t distribution rather than the normal distribution used in the calculation of the number of work cycles to be timed?

Answer: The student t distribution is used in the calculation because the sample size in direct time study is usually smaller than 30, and so the distribution of observed time values is more accurately represented by the student t distribution.

13.10 What is the difference between elemental performance rating and overall performance rating?

Answer: In elemental performance rating, the analyst rates the performance of the worker for each work element. In overall performance rating, the analyst rates the performance of the worker for the entire work cycle.

13.11 What are the characteristics of a well-implemented performance rating system?

Answer: The characteristics include the following: (1) Consistency among tasks. The performance rating system should provide consistent ratings from one task to another. (2) Consistency among analysts. The performance rating for a task should not depend on which time study analyst does the rating. (3) The rating system should be easy to explain by the analyst and simple to understand by the worker. (4) The rating system should be based on a well-defined concept of standard performance. (5) Machine-paced elements should be rated at 100%. (6) The performance rating should be recorded during the observation of the task, not afterward. (7) At the end of the time study observation session, the analyst should inform the worker of the performance rating that was observed.

13.12 What are the advantages of electronic stopwatches compared to mechanical stopwatches?

Answer: The advantages include (1) the digital display is easier to read than the graduated mechanical dial, (2) reading errors are less frequent, (3) lighter weight and generally less susceptible to damage when dropped, (4) more accurate and precise, (5) some electronic watches can be switched back and forth between different time scales, (6) they can be used for either in the continuous timing mode or the snapback mode, and (7) electronic stopwatches are less expensive than mechanical stopwatches.

Problems

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Note: Some of the problems in this set require the use of parameters and equations that are defined in Chapter 2.

Determining Standard Times for Pure Manual Tasks

13.1 The observed average time in a direct time study was 2.40 min for a repetitive work cycle. The worker's performance was rated at 110% on all cycles. The personal time, fatigue, and delay allowance for this work is 12%. Determine (a) the normal time and (b) the standard time for the cycle.

Solution: Normal time T_n = 2.40(1.10) = 2.64 min
Standard time T_{std} = 2.64(1 + 0.12) = 2.957 min

13.2 The observed element times and performance ratings collected in a direct time study are indicated in the table below. The snapback timing method was used. The personal time, fatigue, and delay allowance in the plant is 14%. All elements are regular elements in the work cycle. Determine (a) the normal time and (b) the standard time for the cycle.

Work element	a	b	c	d
Observed time (min)	0.22	0.41	0.30	0.37
Performance rating	90%	120%	100%	90%

Solution: Observed time T_{obs} = 0.22 + 0.41 + 0.30 + 0.37 = 1.30 min
Normal time T_n = 0.22(0.90) + 0.41(1.20) + 0.30(1.0) + 0.37(0.90) = 1.323 min
Standard time T_{std} = 1.323(1 + 0.14) = 1.508 min

13.3 The standard time is to be established for a manual work cycle by direct time study. The observed time for the cycle averaged 4.80 min. The worker's performance was rated at 90% on all cycles observed. After eight cycles, the worker must exchange parts containers, which took 1.60 min, rated at 120%. The PFD allowance for this class of work is 15%. Determine (a) the normal time and (b) the standard time for the cycle. (c) If the worker produces 123 work units during an 8-hour shift, what is the worker's efficiency?

Solution: (a) Normal time T_n = 4.80(0.90) + 1.60(1.20)/8 = 4.32 + 0.24 = 4.56 min

(b) Standard time T_{std} = 4.56(1 + 0.15) = 5.244 min

(c) Standard hours H_{std} = 123(5.244) = 645.0 min = 10.75 hr
Worker efficiency E_w = 10.75/8.0 = 1.344 = 134.4%

13.4 The snapback timing method was used to obtain the average times and performance ratings for work elements in a manual repetitive task. See table below. All elements are worker-controlled. All elements were performance rated at 80%. Element e is an irregular element performed every five cycles. A 15% allowance for personal time, fatigue, and delays is applied to the cycle. Determine (a) the normal time and (b) the standard time for this cycle. If the worker's performance during actual production is 120% on all manual elements for seven actual hours worked on an eight-hour shift, (c) how many units will be produced and (d) what is the worker's efficiency?

Work element	a	b	c	d	e

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Observed time (min)	0.32	0.85	0.48	0.55	1.50

Solution: (a) Normal time T_n = (0.32 + 0.85 + 0.48 + 0.55 + 1.50/5)(0.80)
T_n = 2.50(0.80) = 2.00 min

(b) T_{std} = 2.00(1.15) = 2.30 min

(c) Given P_w = 120% for 7.0 hr on an 8-hour shift
$T_c = T_n/P_w$ = 2.00/1.20 = 1.667 min
Q = 7(60)/1.667 = 252 pc

(d) H_{std} = 252(2.30)/60 = 9.66 hr and E_w = 9.66/8.0 = 1.208 = 120.8%

Comment: The values of worker performance P_w and worker efficiency E_w are so close because the 7.0-hour actually work time is very consistent with the PFD allowance factor of 15%.

13.5 The continuous timing method is used to direct time study a manual task cycle consisting of four elements: a, b, c, and d. Two parts are produced each cycle. Element d is an irregular element performed once every six cycles. All elements were performance rated at 90%. The PFD allowance is 11%. Determine (a) the normalized time for the cycle and (b) the standard time per part. (c) If the worker completes 844 parts in an 8-hour shift during which she works 7 hours and 10 min, what is the worker's efficiency?

Element	a	b	c	d
Observed time (min)	0.35	0.60	0.86	1.46

Solution: (a) T_n = (0.86 + 0.60/6)(0.90) = 0.864 min per cycle

(b) With two parts per cycle, the standard time per part is:
T_{std} = 0.864(1 + 0.11)/2 = 0.4795 = 0.48 min

(c) H_{std} = 844(0.48)/60 = 6.752 hr
E_w = 6.752/8.0 = 0.844 = 84.4%

13.6 The readings in the table below were taken by the snapback timing method of direct time study to produce a certain subassembly. The task was performance rated at 85%. In addition to the above regular elements, an irregular element must be included in the standard: each rack holds 20 mechanism plates and has universal wheels for easy movement. After completing 20 subassemblies, the operator must move the rack (which now holds the subassemblies) to the aisle and then move a new empty rack into position at the workstation. This irregular element was timed at 2.90 min and the operator was performance rated at 80%. The PFD allowance is 15%. Determine (a) the normalized time for the cycle, (b) the standard time, and (c) the number of parts produced by the operator, if he/she works at standard performance for a total of 6 hours and 57 min during the shift.

Element and description	Observed time (min)
1. Pick up mechanism plate from rack and place in fixture.	0.42
2. Assemble motor and fasteners to front side of plate.	0.28

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3. Move to other side of plate.	0.11
4. Assemble two brackets to plate.	0.56
5. Assemble hub mechanism to brackets.	0.33
6. Remove plate from fixture and place in rack.	0.40

Solution: (a) For regular cycle T_{obs} = 0.42 + 0.28 + 0.11 + 0.56 + 0.33 + 0.40 = 2.10 min
For irregular element T_{obs} = 2.90/20 = 0.145 min prorated per cycle
Normal time T_n = 2.10(0.85) + 0.145(0.80) = 1.785 + 0.116 = 1.901 min

(b) Standard time T_{std} = 1.901(1 + 0.15) = 2.186 min

(c) For actual hours worked = 6 hr, 57 min = 6.95 hr
Q = 6.95(60)/1.901 = 219.4 pc rounded down to 219 pc

13.7 The time and performance rating values in the table below were obtained using the snapback timing method on the work elements in a certain manual repetitive task. All elements are worker-controlled. All elements were performance rated at 85%. Element e is an irregular element performed every five cycles. A 15% PFD allowance is applied to the cycle. Determine (a) the normal time and (b) the standard time for this cycle. If the worker's performance during actual production is 125% on all manual elements for seven actual hours worked on an eight-hour shift, (c) how many units will be produced and (d) what is the worker's efficiency?

Work element	a	b	c	d	e
Observed time (min)	0.61	0.42	0.76	0.55	1.10

Solution: (a) T_n = (0.61 + 0.42 + 0.76 + 0.55 + 1.10/5)(0.85) = 2.176 min

(b) T_{std} = 2.176(1 + 0.15) = 2.502 min

(c) Worker performance P_w = 125% for 7.0 hr actually worked in an 8-hour shift
$T_c = T_n/P_w$ = 2.176/1.25 = 1.741 min
Q = 7(60)/1.741 = 241.2 rounded down to 241 pc

(d) H_{std} = 241(2.502)/60 = 10.05 hr, and E_w = 10.05/8.0 = 1.256 = 125.6%

Determining Standard Times for Worker-Machine Tasks

13.8 The snapback timing method was used to obtain average times for work elements in one work cycle. The times are given in the table below. Element d is a machinecontrolled element and the time is constant. Elements a, b, c, e, and f are operatorcontrolled and were performance rated at 80%; however, elements e and f are performed during the machinecontrolled element d. The machine allowance is zero (no extra time is added to the machine cycle), and the PFD allowance is 14%. Determine (a) the normal time for the cycle and (b) the standard time for the cycle.

Element	a	b	c	d	e	f
Observed time (min)	0.24	0.30	0.17	0.76	0.26	0.14

Solution: (a) For elements a, b, and c, T_{obs} = 0.24 + 0.30 + 0.17 = 0.71 min
For elements e and f, T_{obs} = 0.26 + 0.14 = 0.40 min

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$T_n = T_{nw} + \text{Max}\{T_{nwi}(PR), T_m\} = 0.71(0.80) + \text{Max}\{0.40(0.80), 0.76\}$
$T_n = 0.568 + \text{Max}\{0.32, 0.76\} = 1.328$ min

(b) $T_{std} = 0.568(1 + 0.14) + \text{Max}\{0.32(1 + 0.14), 0.76\} = 0.648 + 0.76 = 1.408$ min

13.9 The continuous timing method in direct time study was used to obtain the element times for a worker-machine task as indicated in the table below. Element c is a machinecontrolled element and the time is constant. Elements a, b, d, e, and f are operatorcontrolled and external to the machine cycle, and were performance rated at 80%. If the machine allowance is 25%, and the worker allowance for personal time, fatigue, and delays is 15%, determine (a) the normal time and (b) standard time for the cycle. (c) If the worker completed 360 work units working 7.2 hours on an 8-hour shift, what was the worker's efficiency?

Element	a	b	c	d	e	f
Observed time (min)	0.18	0.30	0.88	1.12	1.55	1.80

Solution: (a) Observed times must be determined for each element: T_e(a) = 0.18 min, T_e(b) = 0.12 min, T_e(c) = 0.58 min, T_e(d) = 0.24 min, T_e(e) = 0.43 min, and T_e(f) = 0.25 min
For elements a, b, d, e, and f, $T_{nw} = (0.18 + 0.12 + 0.24 + 0.43 + 0.25)(0.80) = 0.976$ min
For the cycle, $T_n = 0.976 + 0.58 = 1.556$ min

(b) $T_{std} = 0.976(1 + 0.15) + 0.58(1 + 0.25) = 1.122 + 0.725 = 1.847$ min

(c) $H_{std} = 360(1.847)/60 = 11.08$ hr and $E_w = 11.08/8.0 = 1.385 = 138.5\%$

13.10 A worker-machine cycle is direct time studied using the continuous timing method. One part is produced each cycle. The cycle consists of five elements: a, b, c, d, and e. Elements a, c, d, and e are manual elements, external to machine element b. Every 16 cycles the worker must replace the parts container, which was observed to take 2.0 min during the time study. All worker elements were performance rated at 80%. The PFD allowance is 16%, and the machine allowance = 20%. Determine (a) the normalized time for the cycle, (b) the standard time per part. (c) If the worker completes 220 parts in an 8-hour during which he works 7 hours and 12 min, what is the worker's efficiency?

Element	Description	Cumulative observed time (min)
a	Worker loads machine and starts automatic cycle.	0.25
b	Machine automatic cycle	1.50
c	Worker unloads machine.	1.75
d	Worker files part to size.	2.30
e	Worker deposits part in container.	2.40

Solution: (a) Observed times must be determined for each element: T_e(a) = 0.25 min, T_e(b) = 1.25 min, T_e(c) = 0.25 min, T_e(d) = 0.55 min, and T_e(e) = 0.10 min
For elements a, c, d, and e, $T_{nw} = (0.25 + 0.25 + 0.55 + 0.10 + 2.0/16)(0.80) = 1.02$ min
For the cycle, $T_n = 1.02 + 1.25 = 2.27$ min

(b) $T_{std} = 1.02(1 + 0.16) + 1.25(1 + 0.20) = 1.183 + 1.50 = 2.683$ min

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(c) H_{std} = 220(2.683)/60 = 9.84 hr and E_w = 9.84/8.0 = 1.230 = 123%

13.11 In the preceding problem, a recommendation has been submitted for elements d and e to be performed as internal elements (accomplished simultaneously) with machine element b. The worker would file the part from the previous cycle and deposit it in the container while the current part is being processed in the machine automatic cycle. Performance rating and allowances are the same as in the previous problem. Determine (a) the normal time for the cycle, (b) the standard time per part. (c) If the worker's efficiency is 115% and he works a total of 7 hours and 12 min during an 8-hour shift, how many parts will be produced?

Solution: (a) Observed times must be determined for each element: T_e(a) = 0.25 min, T_e(b) = 1.25 min, T_e(c) = 0.25 min, T_e(d) = 0.55 min, and T_e(e) = 0.10 min
For elements a, c, and irregular element, T_{nw} = (0.25 + 0.25 + 2.0/16)(0.80) = 0.50 min
For the cycle, T_n = 0.50 + Max{(0.55 + 0.10)(0.80), 1.25} = 0.50 + 1.25 = 1.75 min

(b) T_{std} = 0.50(1 + 0.16) + 1.25(1 + 0.20) = 0.58 + 1.50 = 2.08 min

(c) Worker efficiency E_w = 115% for 7.2 hr of an 8-hour shift
Q = 1.15(8)60)/2.08) = 265.4 rounded to 265 pc

13.12 The snapback method was used to time study a worker-machine cycle consisting of three elements: a, b, and c. Elements a and b are worker-controlled and were performance rated at 100% during the time study. Element c is machine-controlled. Elements b and c are performed simultaneously. The PFD allowance = 12% and the machine allowance = 10%. One work piece is produced each cycle. Determine (a) the normal time and (b) standard time for the cycle. (c) If the worker works 7 hours and 10 min during an 8-hour shift, and his performance level is 135%, how many pieces are completed?

Element	a	b	c
Observed time (min)	1.25	0.90	0.80

Solution: (a) T_n = 1.25(1.00) + Max{0.90(1.00), 0.80} = 2.15 min

(b) T_{std} = 1.25(1 + 0.12) + Max{0.90(1 + 0.12), 0.80(1 + 0.10)}
T_{std} = 1.40 + 1.008 = 2.408 min

(c) Worker performance P_w = 135% for 7 hr, 10 min (430 min) of an 8-hour shift
T_c = 1.25/1.35 + Max{0.90/1.35, 0.80} = 0.926 + 0.80 = 1.726 min
Q = 430/1.726 = 249.1 rounded to 249 pc

13.13 The snapback timing method in direct time study was used to obtain the times for a worker-machine task. The recorded times are listed in the table below. Element c is a machinecontrolled element and the time is constant. Elements a, b, and d are operatorcontrolled and were performance rated at 90%. Elements a and b are external to machine-controlled element c. Element d is internal to the machine element. The machine allowance is zero, and the PFD allowance is 13%. Determine (a) the normal time and (b) the standard time for the cycle. The worker's actual time spent working during an 8-hour shift was 7.08 hours, and he produced 420 units of output during this time. Determine (c)

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the worker's performance during the operator-controlled portions of the cycle and (d) the worker's efficiency during this shift.

Element	a	b	c	d
Observed time (min)	0.34	0.25	0.68	0.45

Solution: (a) For elements a and b, $T_{nw} = (0.34 + 0.25)(0.90) = 0.531$ min
For the cycle, $T_n = 0.531 + \text{Max}\{0.45(0.90), 0.68\} = 1.211$ min

(b) $T_{std} = 0.531(1 + 0.13) + \text{Max}\{0.45(0.90)(1 + 0.13), 0.68(1 + 0)\} = 1.28$ min

(c) Produced 420 units in 7.08 hr of an 8-hour shift
Machine time = 420(0.68) = 285.6 min
Operator time = 7.08(60) – 285.6 = 424.8 – 285.6 = 139.2 min
Operator cycle time = 139.2/420 = 0.3314 min/cycle
$P_w = T_{nw}/0.3314 = 0.531/0.3314 = 1.602 = 160.2\%$
Alternative method: Operator time at $P_w = 100\% = 420(0.531) = 223$ min
$P_w = 223/139.2 = 1.602 = 160.2\%$

(d) $H_{std} = 420(1.28)/60 = 8.96$ hr, and $E_w = 8.96/8.0 = 1.12 = 112\%$

13.14 The following table lists the average work element times obtained in a direct time study using the snapback timing method. Elements a and b are operatorcontrolled. Element c is a machinecontrolled element and its time is constant. Element d is a workercontrolled irregular element performed every five cycles. Elements a, b and d were performance rated at 80%. The worker is idle during element c, and the machine is idle during elements a, b, and d. One product unit is produced each cycle. To compute the standard, no machine allowance is applied to element c, and a 15% PFD allowance is applied to elements a, b, and d. (a) Determine the standard time for this cycle. (b) If the worker produces 220 units on an 8hour shift during which 7.5 hours were actually worked, what was the worker's efficiency. (c) For the 220 units in (b), what was the worker's performance during the operatorpaced portion of the cycle?

Element	a	b	c	d
Observed time (min)	0.60	0.45	1.50	0.75

Solution: (a) For elements a, b, and d, $T_{nw} = (0.60 + 0.45 + 0.75/5)(0.80) = 0.96$ min
For the cycle, $T_n = 0.96 + 1.50 = 2.46$ min
$T_{std} = 0.96(1 + 0.15) + 1.50 = 1.104 + 1.50 = 2.604$ min

(b) $H_{std} = 220(2.604)/60 = 9.548$ hr and $E_w = 9.548/8.0 = 1.194 = 119.4\%$

(c) Machine time = 220(1.50)/60 = 5.50 hr
Operator time = 7.5 – 5.5 = 2.0 hr = 120 min
Normal time = 220(0.96) = 211.2 min
$P_w = 211.2/120 = 1.76 = 176\%$

13.15 The continuous timing method in direct time study was used to obtain the times for a worker-machine task as indicated in the table below. Element c is a machinecontrolled element and the time is constant. Elements a, b, d, e, and f are operatorcontrolled and were

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performance rated at 95%; they are all external elements performed in sequence with machine element c. The machine allowance is 30%, and the PFD allowance is 15%. Determine (a) the normal time and (b) standard time for the cycle. (c) If the operator works at 100% of standard performance in production and one part is produced each cycle, how many parts are produced if the total time worked during an 8-hour day is 7.25 hours? (d) For the number of parts computed in (c), what is the worker's efficiency for this shift?

Element	a	b	c	d	e	f
Observed time (min)	0.22	0.40	1.08	1.29	1.75	2.10

Solution: (a) Observed times must be determined for each element: T_e(a) = 0.22 min, T_e(b) = 0.18 min, T_e(c) = 0.68 min, T_e(d) = 0.21 min, T_e(e) = 0.46 min, and T_e(f) = 0.35 min
For elements a, b, d, e, and f, $T_{nw} = (0.22 + 0.18 + 0.21 + 0.46 + 0.35)(0.95) = 1.349$ min
For the cycle, $T_n = 1.349 + 0.68 = 2.029$ min

(b) $T_{std} = 1.349(1 + 0.15) + 0.68(1 + 0.30) = 1.551 + 0.884 = 2.435$ min

(c) Worker performance P_w = 100% for 7.25 hr worked during an 8-hour shift
$T_c = 1.349/1.00 + 0.68 = 1.349 + 0.68 = 2.029$ min
$Q = 7.25(60)/2.029 = 214.4$ rounded to 214 pc

(d) $H_{std} = 214(2.435)/60 = 8.685$ hr, and $E_w = 8.685/8.0 = 1.086 = 108.6\%$

Comment: The reason why the worker's efficiency is well above 100% even though his pace is only 100% is because of the 30% machine allowance that is used to compute the standard time.

13.16 The snapback timing method was used to obtain average time and performance rating values for the work elements in a certain repetitive task. The values are given in the table below. Elements a, b, and c are workercontrolled. Element d is a machinecontrolled element and its time is the same each cycle (N.A. means performance rating is not applicable). Element c is performed while the machine is performing its cycle (element d). Element e is a workercontrolled irregular element performed every six cycles. The machine is idle during elements a, b, and e. Four product units are produced each cycle. The machine allowance is zero, and a 15% PFD allowance is applied to the manual portion of the cycle. Determine (a) the normal time and (b) the standard time for this cycle. If the worker's performance during actual production is 140% on all manual elements for seven actual hours worked on an eight-hour shift, (c) how many units will be produced and (d) what is the worker's efficiency?

Work element	a	b	c	d	e
Observed time (min)	0.65	0.50	0.50	0.55	1.14
Performance rating	90%	100%	120%	N.A.	80%

Solution: (a) T_{nw}(a, b) = 0.65(0.90) + 0.50(1.00) = 1.085 min. We must compare worker element c with machine element d. These elements are performed simultaneously. T_n(c) = 0.50(1.20) = 0.60 min vs. Machine element T_m(d) = 0.55 min. The worker element c dominates. Therefore, the normal time is determined as the sum of the normal times for elements a, b, c, and e.

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T_n = 1.085 + 0.60 + 1.14(0.80)/6 = 1.085 + 0.60 + 0.152 = 1.837 min per cycle

(b) T_{std} = (1.085 + 0.152)(1 + 0.15) + Max{0.60(1 + 0.15), 0.55(1 + 0)}
T_{std} = 1.237(1.15) + 0.60(1.15) = 1.443 + 0.69 = 2.113 min per cycle

(c) Worker performance P_w = 140% for 7.0 hr of an 8-hour shift
For elements a, b, and e, T_c = 1.237/1.40 = 0.884 min per cycle
We must again compare elements c and d to determine which one dominates the cycle at the worker pace of 140%. T_c(c) = 0.60/1.40 = 0.429 min vs. T_m(d) = 0.55 min. The cycle time is determined by machine element d.
T_c = 0.884 + 0.55 = 1.434 min per cycle
Number of cycles = 7.0(60)/1.434 = 292.9 rounded to 293 cycles
Q = 293(4 pc/cycle) = 1172 pc

(d) Worker efficiency E_w = 293(2.113/60)/8.0 = 10.32/8.0 = 1.290 = 129%

13.17 The continuous timing method was used to obtain the times for a worker-machine task. Only one cycle was timed. The observed time data are recorded in the table below. Elements a, b, c, and e are worker-controlled elements. Element d is machine controlled. Elements a, b, and e are external to the machine-controlled element, while element c is internal. There are no irregular elements. All worker-controlled elements were performance rated at 80%. The PFD allowance is 15% and the machine allowance is 20%. Determine (a) the normal time and (b) standard time for the cycle. (c) If worker efficiency = 100%, how many units will be produced in one 9-hour shift? (d) If the actual time worked during the shift was 7.56 hours, and the worker performance = 120%, how many units would be produced?

Worker element (min)	a (0.65)	b (1.80)	c (4.25)	e (5.45)
Machine element (min)			d (4.00)	

Solution: Observed times must be determined for each element: T_e(a) = 0.65 min, T_e(b) = 1.15 min, T_e(c) = 2.45 min, T_e(d) = 2.20 min, and T_e(e) = 1.20 min
Compare normal time of worker element c with machine element d.
For element c, T_n = 2.45(0.80) = 1.96 min
For element d, T_m = 2.20 min. Element d dominates.
For the cycle, T_n = (0.65 + 1.15 + 1.20)(0.80) + 2.20 = 2.40 + 2.20 = 4.60 min

(b) T_{std} = 2.40(1 + 0.15) + 2.20(1 + 0.20) = 2.76 + 2.64 = 5.40 min

(c) Worker efficiency E_w = 100% for a 9-hour shift
Q = 9(60)/5.4 = 100 pc

(d) Worker performance P_w = 120% for 7.56 hr
T_c = 2.40/1.20 + 2.20 = 4.20 min
Q = 7.56(60)/4.20 = 108 pc

13.18 The continuous stopwatch timing method was used to obtain the observed times for a worker-machine task. Only one cycle was timed. The data are recorded in the table below. The times listed indicate the stopwatch reading at the end of the element. Elements a, b,

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and d are worker-controlled elements. Element c is machine controlled. Elements a and d are external to the machine-controlled element, while element b is internal. Every four cycles, there is an irregular worker element that takes 1.32 min rated at 100% performance. For determining the standard time, the PFD allowance is 15% and the machine allowance is 30%. Determine (a) the normal time and (b) standard time for the cycle. (c) If worker efficiency = 100%, how many units will be produced in one 8-hour shift? (d) If the actual time worked during the shift was 6.86 hours, and the worker performance = 125%, how many units would be produced?

Worker element	Description of worker element	Time (min)	Perform. rating	Machine element	Description of machine element	Time (min)
a	Acquire workpart from tray, cut to size, and load into machine	1.24	100%	(idle)		
b	Enter machine settings for next cycle	4.24	120%	c	Automatic cycle controlled by machine settings entered in previous cycle	4.54
d	Unload machine and place part on conveyor	5.09	80%	(idle)		

Solution: Observed times must be determined for each element: T_e(a) = 1.24 min, T_e(b) = 3.00 min, T_e(c) = 3.30 min, and T_e(d) = 0.55 min
Compare normal time of worker element b with machine element c
For element b, T_n = 3.00(1.20) = 3.60 min
For element c, T_m = 3.30 min. Element b dominates
For the cycle, T_n = 1.24(1.00) + 3.60 + 0.55(0.80) + 1.32(1.00)/4
T_n = 1.24 + 3.60 + 0.44 + 0.33 = 5.61 min

(b) T_{std} = (1.24 + 0.44 + 0.33)(1 + 0.15) + Max{3.60(1 + 0.15), 3.30(1 + 1.30)}
T_{std} = 2.31 + Max{4.14, 4.29} = 2.31 + 4.29 = 6.60 min

(c) Worker efficiency E_w = 100% for an 8-hour shift
Q = 8(60)/6.60 = 72.7 rounded to 73 pc

(d) Worker performance P_w = 125% for 6.86 hr
Compare worker element b at 125% and machine element c:
For element b, T_c(b) = 3.60/1.25 = 2.88 min
For element c, T_m(c) = 3.30 min. Element c dominates
T_c = (1.24 + 0.44 + 0.33)/1.25 + 3.30 = 1.61 + 3.30 = 4.91 min
Q = 6.86(60)/4.91 = 83 9 rounded to 84 pc

13.19 The snapback timing method in direct time study was used to obtain the times for a worker-machine task. The recorded times are listed in the table below. Element d is a machinecontrolled element and the time is constant. Elements a, b, c, e, and f are operatorcontrolled and were performance rated at 90%. Element f is an irregular element, performed every five cycles. The operator-controlled elements are all external to machine -controlled element d. The machine allowance is zero, and the PFD allowance is 13%. Determine (a) the normalized time for the cycle and (b) the standard time for the cycle. The worker's actual time spent working during an 8-hour shift was 7.08 hours, and he produced 400 units of output during this time. Determine (c) the worker's performance during the operator-controlled portions of the cycle and (d) the worker's efficiency during this shift.

Element	a	b	c	d	e	f
Observed time (min)	0.14	0.25	0.18	0.45	0.20	0.62

Solution: (a) T_n = (0.14 + 0.25 + 0.18 + 0.20 + 0.62/5)(0.90) + 0.45

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T_n = = 0.805 + 0.45 = 1.255 min

(b) T_{std} = 0.805(1 + 0.13) + 0.45(1 + 0) = 0.91 + 0.45 = 1.36 min

(c) Given Q = 400 pc during 7.08 hr of an 8-hour shift
Machine time during shift = 400(0.45) = 180 min
Worker time during shift = 7.08(60) – 180 = 244.8 min
Cycle time for worker portion of cycle T_c = 244.8/400 = 0.612 min
P_w = 0.805/0.612 = 1.315 = 131.5%

(d) Worker efficiency E_w = 400(1.36/60)/8.0 = 1.133 = 113.3%

13.20 For a worker-machine task, the continuous timing method was used to obtain the times indicated in the table below. Element c is a machinecontrolled element and the time is constant. Elements a, b, d, and e are operatorcontrolled and were performance rated at 100%; however, element d is performed simultaneously with element c. The machine allowance is 16%, and the PFD allowance is 16%. Determine (a) the normal time and (b) standard time for the cycle. (c) If the operator works at 140% of standard performance in production and two parts are produced each cycle, how many parts are produced if the total time worked during an 8-hour day is 7.4 hours? (d) For the number of parts computed in (c), what is the worker's efficiency for this shift?

Element	a	b	c	d	e
Observed time (min)	0.30	0.65	1.65	1.90	2.50

Solution: (a) Observed times must be determined for each element: T_e(a) = 0.30 min, T_e(b) = 0.35 min, T_e(c) = 1.00 min, T_e(d) = 1.90 – 0.65 = 1.25 min, and T_e(e) = 0.60 min
Because worker element d is significantly longer than machine element c, the normal time for the cycle is the sum of the normal times of elements a, b, d, and e.
T_n = (0.30 + 0.35 + 1.25 + 0.60)(1.00) = 2.5 min

(b) T_{std} = 2.5(1 + 0.16) = 2.90 min for the cycle

(c) Worker performance P_w = 140% for 7.4 hr worked during an 8-hour shift. We must check to determine whether worker element d performed at 140% performance is less than the machine element c. Cycle time for worker element d is T_c(d) = 1.25/1.40 = 0.893 min, which is less than T_m(c) = 1.00 min. Therefore, the overall cycle time is determined as worker elements a, b, and e plus machine element c.
T_c(a, b, e) = 0.30 + 0.35 + 0.60 = 1.25 min
For the work cycle, T_c = 1.25/1.40 + 1.00 = 1.893 min for two parts per cycle
Number of cycles = (7.4)(60)/1.893 = 234.6 rounded to 235 cycles
Number of parts Q = 2(235) = 470 pc

(d) H_{std} = 235(2.90)/60 = 11.36 hr, and E_w = 11.36/8.0 = 1.420 = 142%

13.21 For a certain repetitive task, the snapback timing method was used to obtain the average work element times and performance ratings listed in the table below. Elements a, b, and c are workercontrolled. Element d is a machinecontrolled element and its time is the same each cycle (N.A. means performance rating is not applicable). Element c is performed

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while the machine is performing its cycle (element d). Element e is a workercontrolled irregular element performed every five cycles. The machine is idle during elements a, b, and e. One part is produced each cycle. The machine allowance is 15%, and a 15% PFD allowance is applied to the manual portion of the cycle. Determine (a) the normal time and (b) the standard time for this cycle. If the worker's performance during actual production is 130% on all manual elements for 7.3 actual hours worked on an eight hour shift, (c) how many units will be produced and (d) what is the worker's efficiency?

Work element	a	b	c	d	e
Observed time (min)	0.47	0.58	0.70	0.75	2.10
Performance rating	90%	80%	110%	N.A.	85%

Solution: Compare manual element c with machine element d
For element c, T_n(c) = 0.70(1.10) = 0.77 min
For element d, T_m(d) = 0.75 min. Element c dominates.
T_n = 0.47(0.90) + 0.58(0.80) + 0.77 + 2.10(0.85)/5
T_n = 0.423 + 0.464 + 0.77 + 0.357 = 2.014 min

(b) T_{std} = (0.423 + 0.464 + 0.357)(1 + 0.15) + Max{0.77(1 + 0.15), 0.75(1 + 0.15}
T_{std} = 1.244(1.15) + 0.8855 = 2.316 min

(c) Worker performance P_w = 130% during 7.3 hr actual working during an 8-hour shift
Compare worker element c at 130% with machine element d.
For element c, T_c(c) = 0.77/1.30 = 0.592 min
For element d, T_m(d) = 0.75 min. Element d dominates.
For the cycle, T_c = 1.244/1.30 + 0.75 = 1.707 min
Q = 7.3(60)/1.707 = 256.6 rounded to 257 pc

(d) E_w = 257(2.316/60)/8.0 = 1.240 = 124%

13.22 The work element times for a repetitive work cycle are listed in the table below, as determined in a direct time study using the snapback timing method. Elements a and b are operatorcontrolled. Element c is a machinecontrolled element and its time is constant. Element d is a workercontrolled irregular element performed every ten cycles. Elements a and b were performance rated at 90%, and element d was performance rated at 75%. The worker is idle during element c, and the machine is idle during elements a, b, and d. One product unit is produced each cycle. No special allowance is added to the machine cycle time (element c), but a 15% allowance factor is applied to the total cycle time. (a) Determine the standard time for this cycle. If the worker produced 190 units on an 8hour shift during which 7 hours are actually worked, (b) what was the worker's efficiency, and (c) what was his performance during the operatorpaced portion of the cycle?

Work element	a	b	c	d
Observed time (min)	0.75	0.30	1.62	1.05

Solution: (a) T_n = (0.75 + 0.30)(0.90) + 1.62 + 1.05(0.75)/10 = 2.644 min
T_{std} = 2.644(1 + 0.15) = 3.04 min

(b) Quantity produced Q = 190 pc in 7.0 hr of actual working during 8-hour shift

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E_w = 190(3.04/60)/8.0 = 1.203 = 120.3%

(c) Machine time during shift = 190(1.62) = 307.8 min
Work time during shift = 420 – 307.8 = 112.2 min
Actual worker-paced cycle time per unit 112.2/190 = 0.591 min
Normal time for worker portion of cycle T_{nw} = 2.644 – 1.62 = 1.024 min
Worker performance during worker-paced portion of shift = 1.024/0.591 = 1.733 = 173.3%

Number of Cycles

13.23 Seven cycles have been observed during a direct time study. The mean for the largest element time = 0.85 min, and the corresponding sample standard deviation s = 0.15 min, which was also the largest. If the analyst wants to be 95% confident that the mean of the sample was within ±10% of the true mean, how many more observations should be taken?

Solution: For *dof*= 6 degrees of freedom and α = 0.05, t = 2.447
$n = (2.447 \text{ x } 0.15)/(0.10 \text{ x } 0.85)^2 = 4.318^2$ = 18.65 rounded to 19 total observations
We need 19 – 7 = 12 more observations.

13.24 A total of 9 cycles have been observed during a time study. The mean for the largest element time = 0.80 min, and the corresponding sample standard deviation s = 0.15 min, which was also the largest. If the analyst wants to be 95% confident that the mean of the sample was within ±0.10 min of the true mean, how many more observations should be taken?

Solution: For *dof*= 8 degrees of freedom and α = 0.05, t = 2.306

Given that $k\bar{x}$ = 0.10 min
$n = (2.306 \text{ x } 0.15)/(0.10)^2 = 3.459^2$ = 11.96 rounded to 12 total observations
We need 12 – 9 = 3 more observations.

13.25 A total of 6 cycles have been observed in a direct time study. The mean for the largest element time = 0.82 min, and the corresponding sample standard deviation s = 0.11 min, which was also the largest. If the analyst wants to be 95% confident that the mean of the sample was within ±0.10 min of the true mean, how many more observations should be taken?

Solution: For *dof*= 5 degrees of freedom and α = 0.05, t = 2.571

Given that $k\bar{x}$ = 0.10 min
$n = (2.571 \text{ x } 0.11)/(0.10)^2 = 2.828^2$ = 7.998 rounded to 8 total observations
We need 8 – 6 = 2 more observations.

13.26 Ten cycles have been observed during a direct time study. The mean time for the longest element was 0.65 min, and the standard deviation calculated on the same data was 0.10 min. If the analyst wants to be 95% confident that the mean of the sample was within ±8% of the true mean, how many more observations should be taken?

Solution: For *dof*= 9 degrees of freedom and α = 0.05, t = 2.262
$n = (2.262 \text{ x } 0.10)/(0.08 \text{ x } 0.65)^2 = 4.35^2$ = 18.9 rounded to 19 total observations

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We need 19 – 10 = 9 more observations.

13.27 Six cycles have been observed during direct time study. The mean time for the longest element was 0.82 min, and the standard deviation calculated on the same data was 0.13 min. If the analyst wants to be 90% confident that the mean of the sample was within ±0.06 min of the true mean, how many more observations should be taken?

Solution: For *dof*= 5 degrees of freedom and $\alpha = 0.10$, $t = 2.015$

Given that $k\bar{x}$ = 0.06 min
$n = (2.015 \text{ x } 0.13)/(0.06)^2 = 4.366^2 = 19.06$ rounded to 20 total observations
We need 20 – 6 = 14 more observations.

13.28 Six cycles have been observed during a direct time study. The mean for the largest element time = 1.00 min, and the corresponding sample standard deviation $s = 0.10$ min. (a) Based on these data, what is the 90% confidence interval on the 1.0 min element time? (b) If the analyst wants to be 90% confident that the mean of the sample was within ±10% of the true mean, how many more observations should be taken?

Solution: (a) For *dof*= 5 degrees of freedom and $\alpha = 0.10$, $t = 2.015$

Given that $k\bar{x}$ = 0.10 min
Confidence interval CI = $1.0 \pm 2.015(0.10)/6^{0.5} = 1.0 \pm 0.08226$
The range is 0.9177 to 1.0823

(b) Same confidence level and *dof*, so $t = 2.015$
$n = (2.015 \text{ x } 0.10)/(0.10 \text{ x } 1.0)^2 = 2.015^2 = 4.06$ rounded to 5 total observations
We already have 6 observations, so no more observations of the cycle are required.

13.29 A total of 9 cycles have been observed during a direct time study. The mean for the largest element time = 1.30 min, and the corresponding sample standard deviation $s = 0.20$ min. (a) Based on these data, what is the 95% confidence interval on the 1.30 min element time? (b) If the analyst wants to be 98% confident that the mean of the sample was within ±5% of the true mean, how many more observations should be taken?

Solution: (a) For *dof*= 8 degrees of freedom and $\alpha = 0.05$, $t = 2.306$

Given that $k\bar{x}$ = 0.20 min
Confidence interval CI = $1.30 \pm 2.306(0.20)/9^{0.5} = 1.30 \pm 0.154$
The range is 1.146 to 1.454

(b) For *dof*= 8 degrees of freedom and $\alpha = 0.02$, $t = 2.896$
$n = (2.896 \text{ x } 0.20)/(0.05 \text{ x } 1.30)^2 = 8.91^2 = 79.4$ rounded to 80 total observations
We need 80 – 9 = 71 more observations.

Performance Rating

13.30 One of the traditional definitions of standard performance is a person walking at 3.0 miles per hour. Given this, what is the performance rating of a longdistance runner who breaks the four-minute mile?

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Solution: Given the standard performance of 3.0 miles/hr, the standard time to complete 1.0 mile = 60/3.0 = 20 min. The performance of a runner who completes a mile in 4.0 min P_w = 20/4 = 5.00 = 500%

Alternative solution: The runner's speed = 1 mi/4 min = 0.25 mi/min x 60 = 15 mi/hr
Compared to standard performance of 3.0 mi/hr, P_w = 15/3 = 5.00 = 500%

Comment: Although this performance level is much greater than we would ever expect of a worker performing a task, two facts stand out: (1) The 500% performance only lasts for 4.0 minutes. No runner could maintain such a pace for an entire 8-hour period. (2) A runner who is able to run a 4-minute mile is a very unusual person - many standard deviations from the average person in terms of running ability.

13.31 In 1982, the winner of the Boston Marathon was A. Salazar, whose time was 2 hours, 23 min and 3.2 sec. The marathon race covers 26 miles and 385 yards. Given that one of the traditional definitions of standard performance is a person walking at 3.0 miles per hour, what was Salazar's performance rating in the race.

Solution: The time of 2 hours, 23 min and 3.2 sec = 2.3842 hr
The distance of 26 miles, 385 yards = 26.2188 mi
Salazar's average speed v = 26.2188/2.3842 = 10.997 mi/hr
Compared to standard performance of 3.0 mi/hr, P_w = 10.997/3.0 = 3.666 = 366.6%

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Review Questions

16.1 Define work sampling.

Answer: Work sampling is a statistical technique for determining the proportions of time spent by subjects (e.g., workers, machines) in various defined categories of activity (e.g., setting up a machine, producing parts, idle).

16.2 What are the characteristics of work situations for which work sampling is most suited?

Answer: The characteristics given in the text are (1) there is enough time available to perform the study because of the substantial period of time required to complete a work sampling study, (2) multiple subjects are feasible, (3) long cycle times of the jobs covered, and (4) the work is not highly repetitive; instead, the jobs usually consist of various tasks rather than a single repetitive task.

16.3 What are some of the common applications of work sampling?

Answer: The common applications listed in the text are determining (1) how the time of a machine is allocated among setup, production, downtime, and other activities, (2) how workers spend their time among various categories of activity (or non-activity), (3) allowances for time standards, (4) average unit time per work unit, if work units are processed in the work activity, and (5) time standards.

16.4 What is a biased estimate in work sampling?

Answer: A biased estimate is one that differs from the true value, either because the estimating method is somehow flawed or the variable being estimated is influenced by the act of observing it. In work sampling, this can occur if the subject workers know that the work sampling observer is about to observe them, and they alter their work activity to make themselves look productive.

16.5 On what kinds of jobs or tasks is work sampling an appropriate technique for setting time standards?

Answer: Work sampling is most appropriate for setting time standards on indirect labor activities, clerical office work, and similar work situations in which the units of work may be common, but there is inherent variability in the tasks required to process them.

16.6 What is meant by the term sampling stratification?

Answer: Sampling stratification means that the total number of observations is divided into a specified number of time periods (e.g., days, half-days, hours) so that there are an equal number of samples taken in each period. Stratification means that instead of randomizing the observation times throughout the entire period of the study, we make a certain number of observation rounds each day.

16.7 What are some of the advantages of work sampling? Name three.

Answer: Advantages given in the text are the following: (1) Activities that are impractical or too costly to measure by continuous observation can be measured using work sampling.

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(2) Multiple subjects can be included in a single work sampling study. (3) It usually requires less time and lower cost to perform a work sampling study than to acquire the same information through direct continuous observation. (4) In work sampling, observations are taken over a long period of time, thus reducing the risk of short-time aberrations in the work routine of the subjects. (5) Training requirements to perform a work sampling study are generally less than for direct time study or predetermined motion time systems. (6) Performing a work sampling study tends to be less tiresome and tedious on the observer than continuous observation. (7) Being a subject in a work sampling study tends to be less awkward than direct observation, since the observations are made quickly at random times rather than over a long continuous period.

16.8 What are some of the disadvantages and limitations of work sampling? Name three.

Answer: Disadvantages and limitations given in the text are the following: (1) For setting time standards, work sampling is not as accurate as other work measurement techniques, such as DTS and PMTS. (2) Work sampling is usually not practical for studying a single subject. (3) If the subjects in a work sampling study are separated geographically by significant distances, the observer may spend too much time walking between them. In addition, it may allow workers at the beginning of the observer's tour to alert workers at the end of the tour that the observer is coming, with the possible risk that they would adjust their activities and bias the results of the study. (4) Work sampling provides less detailed information about the work elements of a task than direct time study or predetermined time systems. (5) Since work sampling is usually performed on multiple subjects, it tends to average their activities; thus, differences in each individual's activities may be missed by the study. (6) Because work sampling is based on statistical theory, workers and their supervisors may not understand the technique as readily as they understand direct time study. (7) A work sampling study does not normally include detailed documentation of the methods used by the workers. (8) As in so many fields of study, the behavior of the subject may be influenced by the act of observing him or her. If this occurs in work sampling, the results of the study can become biased, perhaps leading to incorrect conclusions and inappropriate recommendations.

Problems

16.1 For the data in Example 16.1, determine a 90% confidence interval for the proportion of time spent running production, category (2).

Solution: $\hat{\sigma}_p = \sqrt{\dfrac{0.60(0.40)}{500}} = 0.0219$

For 90% confidence interval, $z_{\alpha/2} = 1.65$

$\hat{p} - z_{\alpha/2}\hat{\sigma}_p = 0.60 - 1.65(0.0219) = 0.60 - 0.0361 = 0.5639$

$\hat{p} + z_{\alpha/2}\hat{\sigma}_p = 0.60 + 1.65(0.0219) = 0.60 + 0.0361 = 0.6361$

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16.2 The allowance factor for personal time, fatigue, and delay (PF&D) is to be determined in the machine shop area. If it is estimated that the proportion of time per day is spent in these three categories (personal time, fatigue, and delay are grouped together to obtain one proportion) is 0.12, determine how many observations would be required to be 95% confident that the estimated proportion is within ±0.02 of the true proportion?

Solution: For 95% confidence interval, $z_{\alpha/2}$ = 1.96; and interval value c = 0.02
$n = (1.96)^2(0.12)(0.88)/(0.02)^2$ = 1014.2 rounded to 1015 observations

16.3 This problem uses the context and data from Examples 16.1 and 16.3 in the text. After taking 684 observations (as computed in Example 16.3), the observed proportion was found to be $\hat{p}$ = 0.15 (as in Example 16.1), instead of 0.20 as the foreman had originally estimated. Recompute the number of observations required for this new proportion, and if the value is less than 684, determine (a) the new confidence level that is obtained from 684 observations and (b) the new value of *c*, the half-width of the confidence interval at the original confidence level of 95%.

Solution: For $\hat{p}$ = 0.15, $n = (0.15)(0.85)/(0.0153)^2$ = 545 observations. Since this is fewer than the original 684 observations obtained in Example 16.3 for $\hat{p}$ = 0.20, then either (a) the confidence level is higher for the original half-width value of c = 0.03, or (b) the half-width value of c is less than the original value at the confidence level of 95%.

(a) For $\hat{p}$ = 0.15, $\hat{\sigma}_p = \sqrt{\dfrac{0.15(0.85)}{684}}$ = 0.01365

We know that $c = z_{\alpha/2}\,\hat{\sigma}_p$. Given the c = 0.03 and $\hat{\sigma}_p$ = 0.01365, we can compute that $z_{\alpha/2}$ = 0.03/0.01365 = 2.20. The corresponding confidence level in the normal probability distribution is 97.2%.

(b) At the original confidence level of 95%, $z_{\alpha/2}$ = 1.96. Given this value and $\hat{\sigma}_p$ = 0.01365, we compute the new value of c to be 1.96(0.01365) = 0.0268. Thus, at the 95% confidence level we can state that the true value of p is within ±0.0268 of 0.15.

16.4 The foreman in the welding department wanted to know what value of allowance to use for a particular section of the shop. A work sampling study was authorized. Only two activity categories were considered: (1) welding and other productive work, and (2) personal time, rest breaks, and delays. Over a fourweek period (40 hours/week), 125 observations were made at random times. Each observation captured the category of activity of each of eight welders in the shop section of interest. Results indicated that category 2 constituted 33% of the total observations. (a) Define the limits of a 96% confidence interval for activity 2. (b) If a total of 725 work units were produced during the 4 weeks, and all category 1 activity was devoted to producing these units, what was the average time spent on each unit?

Solution: With 8 welders and 125 observations of each welder, the total number of observations n = 125(8) = 1000 observations.

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For the 96% confidence level, $z_{\alpha/2}$ = 2.05.

$\hat{\sigma}_p = \sqrt{\dfrac{0.33(0.67)}{1000}}$ = 0.01487

$\hat{p}_2 - z_{\alpha/2}\,\hat{\sigma}_p$ = 0.33 – 2.05(0.01487) = 0.33 – 0.0305 = 0.2995

$\hat{p}_2 + z_{\alpha/2}\,\hat{\sigma}_p$ = 0.33 + 2.05(0.01487) = 0.33 + 0.0305 = 0.3605

(b) Given Q = 725 work units

$\hat{p}_1$ = 1 – 0.33 = 0.67

Total time TT = (4 weeks)(40 hr/week)(8 welders) = 1280 hr

T_c = 0.67(1280)/725 = 1.183 hr/work unit

16.5 A work sampling study was performed during a three-hour final exam to determine the proportion of time that students spend using a calculator. There were 70 students taking the exam. A total of five observations were taken of each student at random times during the three hours. Of the total observations taken, 77 of the observations found the students using their calculators. (a) Form a 90% confidence interval on the proportion of time students spend using their calculators during an exam. (b) How many observations must be taken for the analyst to be 95% confident that the estimate of proportion of time a student uses a calculator is within ±3% of the true proportion?

Solution: (a) For the 90% confidence level, $z_{\alpha/2}$ = 1.65

Total number of observations n = 5(70) = 350 observations

$\hat{p}$ = 77/350 = 0.22

$\hat{\sigma}_p = \sqrt{\dfrac{0.22(0.78)}{350}}$ = 0.02214

$\hat{p}_2 - z_{\alpha/2}\,\hat{\sigma}_p$ = 0.22 – 1.65(0.02214) = 0.22 – 0.0365 = 0.1835

$\hat{p}_2 + z_{\alpha/2}\,\hat{\sigma}_p$ = 0.22 + 1.65(0.02214) = 0.22 + 0.0365 = 0.2565

(b) For the 95% confidence level, $z_{\alpha/2}$ = 1.96

We know that $c = z_{\alpha/2}\,\hat{\sigma}_p$. Given c = 0.03, we can compute that $\hat{\sigma}_p$ = 0.03/1.96 = 0.0153. Thus, $n = 0.22(0.78)/(0.0153)^2$ = 732.5 rounded to 733 observations

16.6 The Chief IE in the production department wanted to know what value of PFD allowance to use for a particular section of the shop. A work sampling study was authorized. Only three activity categories were considered: (1) production work, (2) personal time, rest breaks, and delays, and (3) other activities. Over a fourweek period (40 hours/week), 100 observations were made at random times. Each observation captured the category of activity of each of 22 production workers in the department. Results indicated that category 2 constituted 19% of the total observations. (a) Define the limits of a 95% confidence

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interval for activity 2. (b) If a total of 522 work units were produced during the 4 weeks, and the 1540 observations in category 1 activity were all devoted to producing these units, what was the average time spent on each unit?

Solution: With 22 workers and 100 observations of each worker, the total number of observations n = 100(22) = 2,200 observations.

For the 95% confidence level, $z_{\alpha/2}$ = 1.96

$\hat{\sigma}_p = \sqrt{\frac{0.21(0.81)}{2200}}$ = 0.00836

$\hat{p}_2 - z_{\alpha/2}\,\hat{\sigma}_p$ = 0.19 – 1.96(0.00836) = 0.19 – 0.0164 = 0.1736

$\hat{p}_2 + z_{\alpha/2}\,\hat{\sigma}_p$ = 0.19 + 1.96(0.00836) = 0.19 + 0.0164 = 0.2064

(b) Given Q = 522 work units

$\hat{p}_1$ = 1540/2200 = 0.70

Total time TT = (4 weeks)(40 hr/week)(22 workers) = 3520 hr

T_c = 0.70(3520)/522 = 4.72 hr/work unit

16.7 A work sampling study is to be performed on an insurance office staff consisting of 15 persons to see how much time they spend processing claims. The duration of the study is 20 days, eight hours per day. Processing claims is only one of the activities done by the staff members. The office manager estimates that the proportion of time processing claims = 0.20. (a) At the 95 percent confidence level, how many observations are required if the upper and lower confidence limits are 0.16 and 0.24? (b) Regardless of your answer to (a), a total of 1200 observations were taken, and staff members were processing claims in 300 of those observations. Construct a 98 percent confidence interval for the true proportion of time processing claims. (c) Records for the period of the study indicate that 335 claims were processed. Estimate the average time per claim processed? (d) Determine a standard for processing claims, but express the standard in terms of the number of claims processed per day (8 hours) per person. Assume a 100% performance rating and that no allowance factor is to be included in the standard.

Solution: (a) For 95% confidence interval, $z_{\alpha/2}$ = 1.96; and interval value c = 0.04

$n = (1.96)^2(0.20)(0.80)/(0.04)^2$ = 384.2 rounded to 385 observations

(b) Given n = 1,200 observations, $\hat{p}$ = 300/1200 = 0.25

For 98% confidence interval, $z_{\alpha/2}$ = 2.33

$\hat{\sigma}_p = \sqrt{\frac{0.25(0.75)}{1200}}$ = 0.0125

$\hat{p}_2 - z_{\alpha/2}\,\hat{\sigma}_p$ = 0.25 – 2.33(0.0125) = 0.25 – 0.0291 = 0.2209

$\hat{p}_2 + z_{\alpha/2}\,\hat{\sigma}_p$ = 0.25 + 2.33(0.0125) = 0.25 + 0.0291 = 0.2791

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(c) Given Q = 335 work units
Total time TT = (20 days)(8 hr/day)(15 workers) = 2400 hr
T_c = 0.25(2400)/335 = 1.79 hr/claim

(d) Standard rate for claims processed = (8 hr)/(1.79 hr/claim) = 4.5 claims per day

16.8 A work sampling study is to be performed on an office pool consisting of 10 persons to see how much time they spend on the telephone. The duration of the study is to be 22 days, seven hours per day. All calls are local. Using the phone is only one of the activities that members of the pool accomplish. The supervisor estimates that 25% of the time of the workers is spent on the phone. (a) At the 95% confidence level, how many observations are required if the lower and upper limits on the confidence interval are 0.20 and 0.30. (b) Regardless of your answer to (a), suppose that 200 observations were taken on each of the ten workers (2000 observations total), and members of the office pool were using the telephone in 590 of these observations. Construct a 95% confidence interval for the true proportion of time on the telephone. (c) Phone records indicate that 3894 phone calls (incoming and outgoing) were made during the observation period. Estimate the average time per phone call.

Solution: (a) For 95% confidence interval, $z_{\alpha/2}$ = 1.96; and interval value c = 0.05
$n = (1.96)^2(0.25)(0.75)/(0.05)^2$ = 288.1 rounded to 289 observations

(b) Given n = 2,000 observations, $\hat{p}$ = 590/2000 = 0.295

$$\hat{\sigma}_p = \sqrt{\frac{0.295(0.705)}{2000}} = 0.0102$$

$\hat{p}_2 - z_{\alpha/2}\,\hat{\sigma}_p$ = 0.295 – 1.96(0.0102) = 0.295 – 0.020 = 0.275

$\hat{p}_2 + z_{\alpha/2}\,\hat{\sigma}_p$ = 0.295 + 1.96(0.0102) = 0.295 + 0.020 = 0.315

(c) Given Q = 3894 calls
Total time TT = (22 days)(7 hr/day)(10 workers) = 1540 hr
T_c = 0.295(1540)/3894 = 0.1167 hr/call = 7.0 min/call

16.9 The shop foreman has estimated that the proportion of time the machines in her department are idle is a mere 10%. On the basis of this estimate, a work sampling study is to be performed. (a) If we want a 95% confidence level that the true value of the proportion idle time is within ±2.5% of this 10% (that is, the confidence interval runs from 7.5% to 12.5%), how many observations must be taken? (b) Suppose after the study is taken with the number of observations from part (a), the proportion of observations is actually 15% rather than 10%. What is the range of the 95% confidence interval in this case? (c) How many more observations need to be taken to achieve a confidence interval of 15% ±2.5%?

Solution: (a) For 95% confidence interval, $z_{\alpha/2}$ = 1.96; and interval value c = 0.025
$n = (1.96)^2(0.10)(0.90)/(0.025)^2$ = 553.2 rounded to 554 observations

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(b) Actual $\hat{p} = 0.15$

$$\hat{\sigma}_p = \sqrt{\frac{0.15(0.85)}{554}} = 0.0152$$

$\hat{p}_2 - z_{\alpha/2}\,\hat{\sigma}_p = 0.15 - 1.96(0.0152) = 0.15 - 0.0298 = 0.1202$

$\hat{p}_2 + z_{\alpha/2}\,\hat{\sigma}_p = 0.15 + 1.96(0.0152) = 0.15 + 0.0298 = 0.1798$

(c) $n = (1.96)^2(0.15)(0.85)/(0.025)^2 = 783.7$ rounded to 784 observations
We need 784 – 554 = 230 more observations

16.10 A work sampling study has been performed on a women's college sorority to determine how much time the women spend at their desks reading homework assignments. The sorority consists of 30 women. The duration of the study was 4 weeks, 7 days per week, between the hours of 7:00 a.m. and 11:00 p.m. each day. It is assumed that no reading was done before 7:00 a.m. or after 11:00 p.m., since the sorority members observe a very strict work ethic code. Five observations were taken at random times each day, and each observation included all 30 women. Out of all the observations, a total of 1344 observations found the women reading homework assignments at their desks. (a) Construct a 95% confidence interval for the true proportion of time spent reading homework assignments. (b) What is the average time per day that each woman spends reading homework assignments? (c) If the women in the sorority collectively completed a total of 513 reading assignments during the observation period, how many hours did each assignment take, on average?

Solution: (a) Number of observations n = (30 subjects)(28 days)(5 obs/day) = 4200 obs.

$\hat{p}_1 = 1344/4200 = 0.32$

For 95% confidence interval, $z_{\alpha/2} = 1.96$

$$\hat{\sigma}_p = \sqrt{\frac{0.32(0.68)}{4200}} = 0.0072$$

$\hat{p}_2 - z_{\alpha/2}\,\hat{\sigma}_p = 0.32 - 1.96(0.0072) = 0.32 - 0.0141 = 0.3059$

$\hat{p}_2 + z_{\alpha/2}\,\hat{\sigma}_p = 0.32 + 1.96(0.0072) = 0.32 + 0.0141 = 0.3341$

(b) Total time TT = (28 days)(16 hr/day)(30 students) = 13,440 hr
Number of student days = (30 students)(28 days) = 840 student days
Hours per day per student = 0.32(13,440)/840 = 5.12 hr/day per student

(c) Given Q = 513 reading assignments
Time per assignment = 0.32(13,440)/513 = 8.38 hr/assignment

16.11 A work sampling study is to be performed on the art department in a publishing company. The department consists of 22 artists who work at computer graphics workstations developing line drawings based on authors' rough sketches. The duration of the study is 15

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days, seven hours per day. Line drawings are the main activity performed by the artists, but not the only activity. The supervisor of the department estimates that the proportion of time spent making line drawings is 75% of each artist's day. (a) At the 95% confidence level, how many observations are required if the lower and upper confidence limits are 0.72 and 0.78, respectively. (b) Regardless of your answer in preceding part (a), a total of 1000 observations were actually taken, and artists were making line drawings in 680 of those observations. Construct a 97.5% confidence interval for the true proportion of time making line drawings. (c) Records for the period of the study indicate that 5,240 line drawings were completed. Estimate the average time per line drawing? (d) Determine the standard time for one line drawing, given that the average performance rating for the artists was observed to be 90%, and the allowance for personal time, fatigue, and delays is 15%.

Solution: (a) For 95% confidence interval, $z_{\alpha/2}$ = 1.96; and interval value c = 0.03
$n = (1.96)^2(0.75)(0.25)/(0.03)^2 = 800.3$ rounded to 801 observations

(b) Actual $\hat{p}$ = 680/1000 = 0.68

For 97.5% confidence interval, $z_{\alpha/2}$ = 2.24

$$\hat{\sigma}_p = \sqrt{\frac{0.68(0.32)}{1000}} = 0.0148$$

$$\hat{p}_2 - z_{\alpha/2}\,\hat{\sigma}_p = 0.68 - 2.24(0.0148) = 0.68 - 0.0331 = 0.647$$

$$\hat{p}_2 + z_{\alpha/2}\,\hat{\sigma}_p = 0.68 + 2.24(0.0148) = 0.68 + 0.0331 = 0.713$$

(c) Given Q = 5,240 drawings
Total time TT = (15 days)(7 hr/day)(22 artists) = 2,310 hr
Average time per drawing = 0.68(2,310)/5,240 = 0.2998 hr = 17.99 min

(d) Standard time per drawing T_{std} = 17.99(0.90)(1 + 0.15) = 18.62 min

16.12 A work sampling study was performed on the day-shift maintenance department in a power generating station. The day-shift consists of four repair persons, each of whom works independently to repair equipment when it breaks down. A total of 800 observations (200 observations per repair person) were taken during a fourweek period (160 total hours of station operation). The observations were classified into one of the following categories: (1) maintenance person repairing equipment, or (2) maintenance person idle. There were a total of 432 observations in category 1. It is known that 83 equipment repairs were made during the 4 weeks. (a) How many more observations would be required, if any, to be 90% confident that the true proportion of category 1 activity is within ± 0.03 of the proportion indicated by the observations? Also, determine: (b) average time it takes a repair person to repair a piece of broken-down equipment, and (c) how many hours of idle time per week is experienced by each repair person, on average.

Solution: (a) For 90% confidence interval, $z_{\alpha/2}$ = 1.65; and interval value c = 0.03

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Actual $\hat{p}$ = 432/800 = 0.54
$n = (1.65)^2(0.54)(0.46)/(0.03)^2 = 751.4$ rounded to 752 observations
No more observations are required.

(b) Given Q = 83 equipment repairs
Total time TT = (160 hr/worker)(4 repair workers) = 640 hr
Average time per repair = 0.54(640)/83 = 4.164 hr

(c) Hours of idle time per repair worker per week = 0.46(40) = 18.4 hr/wk per worker

16.13 A work sampling study was performed on 12 assembly workers in a small electronics final assembly plant. Various products are made in small lot sizes, and it would not be cost effective to direct time study every job. However, the jobs can be distinguished on the basis of the size of the starting printed circuit board (PCB), and it is believed that work sampling might provide estimates of the average time per board size. There are three different PCB sizes: A (large), B (medium), and C (small). The study was carried out over a five-week period (25 8-hour days or 200 working hours). Observations were taken at random times four times each day for 25 days, for a planned total of 1200 observations (4 x 25 x 12). However, due to worker absences, 60 observations were omitted (15 worker-day absences). Results of the study are presented in the table below. (a) What is the mean assembly time per product unit for each of the three PCB sizes? (b) For the C size PCB assembly, construct a 96% confidence interval about the mean assembly time per product.

Category of activity	A assembly	B assembly	C assembly	Miscellaneous
Number of observations	228	285	456	171
Number of units completed	610	1127	3025	(none)

Solution: (a) Total number of observations n = 1,200 – 60 = 1,140 observations

$\hat{p}_A$ = 228/1,140 = 0.20

$\hat{p}_B$ = 285/1,140 = 0.25

$\hat{p}_C$ = 456/1,140 = 0.40

Total time TT = (12 workers)(200 hr/worker) – (15 worker-days absent)(8 hr/day)
TT = 2,400 – 120 = 2,280 hr
T_A = 0.20(2,280)/610 = 0.7475 hr = 44.85 min
T_B = 0.25(2,280)/1,127 = 0.5058 hr = 30.35 min
T_C = 0.40(2,280)/3,025 = 0.3015 hr = 18.09 min

(b) For 96% confidence interval, $z_{\alpha/2}$ = 2.054

$$\hat{\sigma}_p = \sqrt{\frac{0.40(0.60)}{1140}} = 0.0145$$

$\hat{p}_2 - z_{\alpha/2}\,\hat{\sigma}_p$ = 0.40– 2.054(0.0145) = 0.40 – 0.0298 = 0.3702

$\hat{p}_2 + z_{\alpha/2}\,\hat{\sigma}_p$ = 0.40+ 2.054(0.0145) = 0.40 + 0.0298 = 0.4298

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Converting these fractions into assembly time values
Lower time value = 18.09(0.3702/0.40) = 16.74 min
Upper time value = 18.09(0.4298/0.40) = 19.44 min

16.14 A work sampling study was performed on four account executives in a stockbroker's office. Virtually all sales in the office are made through telephone solicitations. A total of 500 observations were made over a period of one week (seven hours per day, five days per week). The categories of activity and number of observations per category were as follows: (1) telephone calls, 164; (2) filing and sorting, 150; (3) reading and research, 101; (4) personal and nonproductive time, 85. Total sales during this period were $525,000, on which the office earned a commission of 4.0%. (a) Construct a 97% confidence interval on the proportion of time on the telephone during the one-week period? (b) Estimate how many hours were spent on the phone by the four account executives during this period? (c) The office is considering hiring a clerk at $800/week to do the filing and sorting (category 2). This would reduce the time taken by the account executives on these activities by seven hours per day. It is anticipated that all of these extra seven hours would be spent on phone calls to increase sales. If sales level (in dollars) has been found to be proportional to time on the telephone, will the increase in commissions pay for the clerk? Compute the estimated net increase or decrease in weekly revenues from hiring the clerk.

Solution: (a) Proportion of time on the phone

$\hat{p}_1$ = 164/500 = 0.328

For 97% confidence interval, $z_{\alpha/2}$ = 2.17

$\hat{\sigma}_p = \sqrt{\frac{0.328(0.672)}{500}}$ = 0.021

$\hat{p}_1 - z_{\alpha/2}\,\hat{\sigma}_p$ = 0.328– 2.17(0.021) = 0.328 – 0.0456 = 0.2824

$\hat{p}_1 + z_{\alpha/2}\,\hat{\sigma}_p$ = 0.328+ 2.17(0.021) = 0.328 + 0.0456 = 0.3736

(b) Hours on the phone of 4 account executives = 4(5 days)(7 hr/day)(0.328) = 45.92 hr

(c) Consider how much time is spent in category 2 by account executives.

$\hat{p}_2$ = 150/500 = 0.30
Total hours of 4 account executives in category 2 = 4(7)(0.30) = 8.4 hr/day
The newly hired clerk would spend 7 hr/day performing filing and sorting for the account executives.
Commissions per week = $525,000(0.04) = $21,000/wk
Sales commissions per hour = 21,000/45.92 = $457.32/hr
Increase in commissions for 7 hours = 7(457.32) = $3,201.24
Increase in commissions per week = 5($3,201.24) = $16,006/wk
With the clerk costing $800/wk, the net weekly increase = 16,006 – 800 = $15,206

16.15 A work sampling study was performed on 15 social workers in a county government office. The social workers handle three types of cases: A, single parents; B, foster parents;

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and C, juvenile delinquents. The purpose of the work sampling study was to determine estimates of the average time per case for each case type. In addition to the three case types, two additional activity categories were included in the study: D, traveling between cases; and E, other (miscellaneous) activities. The study was carried out over a five-week period (25 8-hour days or 200 working hours). Observations were taken at random times four times each day for 25 days, for a planned total of 1500 observations (4 x 25 x 15). Each social worker was provided with a cell phone so they could be contacted if they were not in the office building. Because of worker absences, 72 observations were omitted (18 worker-days of absences). Results of the study are presented in the table below. (a) What is the mean time per case for each of the three case types? (b) What is the average travel time spent on a case? (c) For the C type cases, construct a 92.5% confidence interval about the mean case time.

Category of activity	A cases	B cases	C cases	D Transport	E Other
Number of observations	314	272	350	388	104
Number of cases completed	439	725	273	(none)	(none)

Solution: (a) Total number of observations n = 1,500 – 72 = 1,428 obs

$\hat{p}_A$ = 314/1,428 = 0.2199

$\hat{p}_B$ = 272/1,428 = 0.1905

$\hat{p}_C$ = 350/1,428 = 0.2451

Total time TT = (15 workers)(200 hr/worker) – (18 worker-days absent)(8 hr/day)
TT = 3,000 – 144 = 2,856 hr
T_A = 0.2199(2,856)/439 = 1.43 hr
T_B = 0.1905(2,856)/725 = 0.75 hr
T_C = 0.2451(2,856)/273 = 2.56 hr

(b) $\hat{p}_D$ = 388/1,428 = 0.2717
Total time spent driving (category D) = 0.2717(2,856) = 776 hr
Total number of cases = 439 + 725 + 273 = 1,437
Average time spent driving per case = 776/1,437 = 0.54 hr

(c) For 92.5% confidence interval, $z_{\alpha/2}$ = 1.78

$$\hat{\sigma}_p = \sqrt{\frac{0.2451(0.7549)}{1428}} = 0.0114$$

$\hat{p}_1 - z_{\alpha/2}\hat{\sigma}_p$ = 0.2451– 1.78(0.0114) = 0.2451 – 0.0203 = 0.2248

$\hat{p}_1 + z_{\alpha/2}\hat{\sigma}_p$ = 0.2451+ 1.78(0.0114) = 0.2451 + 0.0203 = 0.2654

Converting these fractions into assembly time values
Lower time value = 2.56(0.2248/0.2451) = 2.35 hr
Upper time value = 2.56(0.2654/0.2451) = 2.77 hr

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