Chapter 13

Direct Time Study

Direct time study, also known as ***stopwatch time study,*** involves the direct and continuous observation of a task using a stopwatch or other timekeeping device to record the time taken to accomplish a task.[1] While observing and recording the time, an appraisal of the worker's performance level is made. These data are then used to compute a standard time for the task, adding an allowance for personal time, fatigue, and delays.

Direct time study was the first work measurement technique to be used, dating back to around 1883 (Historical Note 1.1). It is inextricably connected with the origins of industrial engineering. Computerized techniques have improved the accuracy and application speed of direct time study as well as the database management functions that support it.

The use of direct time study is most appropriate for tasks that involve a repetitive work cycle, at least a portion of which is manual. This kind of work is common in

[1]The Work Measurement and Methods Standards Committee (ANSI Standard Z94.11-1989) defines time study as follows: "A work measurement technique consisting of careful time measurement of the task with a time measuring instrument, adjusted for any observed variation from normal effort or pace and to allow adequate time for such items as foreign elements, unavoidable or machine delays, rest to overcome fatigue, and personal needs. Learning or progress effects may also be considered. If the task is of sufficient length, it is normally broken down into short, relatively homogeneous work elements, each of which is treated separately as well as in combination with the rest."

batch and mass manufacturing. Also, standards for routine office work can often be established using direct time study. Performing a direct time study is time-consuming and is therefore best justified when the job will have a relatively long production run, and/or there will be repeated orders in the future. A limitation of this work measurement technique is that it cannot be used to set a time standard prior to the start of production.

13.1 DIRECT TIME STUDY PROCEDURE

The procedure for determining the standard time for a task using direct time study can be summarized in the following five steps:

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. Evaluate the worker's pace relative to standard performance, a procedure called ***performance rating***. This is used to determine the normal time. Steps 3 and 4 are accomplished simultaneously.
5. Apply an allowance to the normal time to compute the standard time.

Steps 1 and 2 are preliminary steps before actual timing begins, during which the analyst becomes familiar with the task and attempts to improve the work procedure before defining the standard method. In steps 3 and 4, several work cycles are timed, each one performance rated independently. Finally, the values collected in steps 3 and 4 are averaged to determine the normalized time. An appropriate allowance factor for the kind of work involved is then added to compute the standard time for the task. Let us examine each of the steps in more detail.

13.1.1 Define and Document the Standard Method

Before defining and documenting the standard method, a methods engineering study should be undertaken to ensure that the standard method obeys the "one best method" principle—the best method that can be devised under the present economic and technological circumstances. All of the steps in the method should be defined. Any special tools, gauges, or equipment that can improve the task should be designed and included in the method. If there are irregular elements in the work cycle, the frequency with which these elements are to be performed should be stated explicitly. If the labor-management climate in the facility allows, the worker's advice and opinion should be sought in developing the standard method. Once the standard method has been defined, it should be difficult or impossible for the operator to make further improvements.

The standard method should be thoroughly documented. The company should have forms and/or checklists to make certain that all information about the method is included. An example of a methods description form is shown in Figure 13.1. The documentation should enumerate details about the procedure (hand and body motions), tools, equipment and the machine settings used for the equipment (e.g., feeds and speeds

Date	Standard Method Description for Direct Time Study		Page of
Operation	Dept.	Part No.	
Machine	Analyst		

Methods Improvements (check if implemented)	Sketch of Workplace:

Work Element No. and Description with Machine Parameters for Machine Cycles	Freq.	Tools and Gauges

Additional Notes

Figure 13.1 Form for documenting the standard method.

on machine tools), workplace layout, irregular work elements, working conditions, and setup (Section 12.2.2). If there is a work unit associated with the task, then it should also be specified, both its starting and its completed conditions (Section 12.2.3). A videotape (or other video medium) of the standard method can also be made as part of the documentation. This is especially helpful for complex tasks in which details of the method are difficult to explain in writing.

There are several reasons why thorough documentation of the standard method is important:

- *Batch production.* If the task is associated with batch production, then it is likely to be repeated at some time in the future. The time lapse may be significant between the previous batch and the next batch. A different worker may be assigned to perform the task on the next batch. The statement of the standard method provides the worker and the foreman with a complete description of the task and the procedure for doing it, as well as any tooling or equipment needed. This avoids "reinventing the wheel."
- *Methods improvement by the operator.* At some future time, the operator may discover a way to improve the method.[2] A question then arises: Should the methods improvement be incorporated into a new standard method (which would require a change in the standard time), or should the operator be allowed to benefit from the improvement without formally changing the standard method? The typical labor-management contract only allows for retiming the task if it can be demonstrated that a real change in the method has been made. If the operator has indeed made a methods improvement, this can be identified by comparing the method in use with the standard method description.
- *Disputes about the method.* If the operator complains that the standard for the task is too tight, or there is some other reason for a dispute about the standard method, documentation of the standard method can be used to settle the dispute.[3] Perhaps the operator is using a less efficient method than the standard method, or a certain hand tool that should be used in the operation has been neglected. These problems can be addressed by reference to the standard method documentation.
- *Data for standard data system.* Time standards developed by direct time study are sometimes used in standard data systems (Chapter 15). Good documentation of the standard method, especially regarding the work elements and associated normal times, is essential in developing the database for a standard data system.

[2]This possibility seems at odds with the fact that the one best method has already been devised and has been defined as the standard method. However, the intelligence and ingenuity of the worker should not be underestimated. It must be acknowledged that the worker may be able to figure out some motion shortcut or hand tool or other gimmick that reduces the time for the work cycle, even though the work cycle has been subjected to a thorough methods study.

[3]A "tight" standard means that the standard time is too short, making it difficult or impossible to accomplish the task within the time standard. A "loose" standard is one in which the time is relatively long, making it easy to achieve a high worker efficiency.

13.1.2 Divide the Task into Work Elements

Any task can be divided into work elements. A ***work element*** is a series of motion activities that are logically grouped together because they have a unified purpose in the task. The description of the standard method can be organized into work elements suitable for use in direct time study. Indeed, the most natural way to describe the standard method is often as a list of work elements. Some practical guidelines for defining work elements in direct time study are presented in Table 13.1. An important reason for defining the

TABLE 13.1 Guidelines for Defining the Work Elements in Direct Time Study

Guideline	Explanation and Examples
Each work element should consist of a logical group of motion elements.	The work element should have a unified purpose, such as reaching for an object and moving it to a new location (e.g., reach, grasp, move, and place). There would be no purpose in separating the reach from the move motions since they both involve the same object.
Beginning point of one element should be end point of preceding element.	There should be no gap between one element and the next in the task sequence. Otherwise, the time of the gap is omitted from the recorded total time.
Each element should have a readily identifiable end point.	A readily identifiable end point can be easily detected during the study. It can often be anticipated to allow reading of the watch more conveniently. An audible sound, such as the actuation of a pneumatic device, provides a readily identifiable end point.
Work elements should not be too long.	If a work element is very long (i.e., several minutes), it should probably be divided into multiple elements that are timed separately. Machine semiautomatic cycle time is an exception. Some machine cycles can take several minutes and should be identified as one element.
Work elements should not be too short.	A practical lower limit in direct time study is around 3 sec. Below this, reading accuracy may suffer. If a video camera is used for timing purposes, shorter elements may be possible.
Irregular work elements should be identified and distinguished from regular elements.	Irregular elements are work elements that do not occur every cycle. The frequency with which they should be performed must be noted. The time(s) for the irregular element(s) are prorated across the regular work cycle when the standard time is computed.
Manual elements should be separated from machine elements.	Manual elements depend on the operator's performance (pace) and therefore vary over time. Machine elements are generally constant values that depend on machine settings. Once the settings are established, the actuation time shows no perceptible variation.
Internal elements should be separated from external elements.	Internal elements are performed by the operator during the machine cycle. In most cases, they do not affect the overall work cycle time. External elements are performed outside of the machine cycle. They contribute to the overall work cycle time.

Source: Adapted from guidelines in [13] and other sources.

work elements is that the worker may exhibit different performance levels on different elements. Accordingly, these performance levels are rated and recorded separately by the time study analyst.

13.1.3 Time the Work Elements

Once the work elements have been defined, the analyst is ready to collect data. The time data are usually recorded on a time study form, similar to the one shown in Figure 13.2. Space is provided for a listing of the work elements, which can be referenced to the more complete standard method documentation. Each element should be timed over several cycles to obtain a reliable average, and the form is designed for recording multiple cycles of the task. The appropriate number of cycles can be determined using the statistical techniques described in Section 13.2. For the convenience of the analyst, the time study form is usually held in a special clipboard that also holds the stopwatch used in the study.

There are several pieces of equipment that can be used to record the times for the work cycles. We describe the products in Section 13.4. The traditional instrument in direct time study is the stopwatch, which is usually calibrated in decimal minutes. There are two principal methods for using a stopwatch in direct time study: (1) snapback timing method and (2) continuous timing method. 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 therefore note and record the final time for that element just as the watch is being zeroed. (Most stopwatches, especially electronic watches, have features that facilitate this reading.) 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 prefer to 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. This facilitates cycle-to-cycle comparisons during the study.

There are two advantages to the snapback method: (1) the analyst can readily see how the element times vary from one cycle to the next, and (2) no subtraction is necessary, as in the continuous timing method, to obtain individual element times. The advantages of the continuous method include the following: (1) when the clock is continuously running, elements are not as easily omitted by mistake, (2) regular and irregular elements can be more readily distinguished, and (3) not as much manipulation of the stopwatch is required as in the snapback method.

13.1.4 Rate the Worker's Performance

While observing and recording the time data, the analyst must simultaneously observe the performance of the worker and rate this performance relative to the definition of standard performance used by the organization. Other terms for performance include pace, speed, effort, and tempo. Standard performance is given a rating of 100%. A performance rating greater than 100% means that the worker's performance is better than standard (which results in a shorter observed work cycle time), and less than 100% means poorer performance than standard (and a longer observed time).

Date	Direct Time Study Observation Form			Page of
Operation		Dept.		Part No.
Machine				Tooling
Worker				Worker No.
Analyst	Start Time		Finish Time	Elapsed Time

Work Elements, Machine Settings, and Observations				Cycle No. (regular elements)										
Element Number and Description	Feed	Speed		1	2	3	4	5	6	7	8	9	10	Avg T_n
1			T_{obs}											
			PR											
			T_n											
2			T_{obs}											
			PR											
			T_n											
3			T_{obs}											
			PR											
			T_n											
4			T_{obs}											
			PR											
			T_n											
5			T_{obs}											
			PR											
			T_n											
6			T_{obs}											
			PR											
			T_n											
7			T_{obs}											
			PR											
			T_n											
8			T_{obs}											
			PR											
			T_n											
Normal time = Sum of T_n (regular work elements)														

Irregular Element and Description	Freq	T_0	T_f	PR	T_n	Calculation of Standard Time T_{std}	
A						Sum of T_n (regular work elements)	
B						Sum of freq x T_n (irregular elements)	
C						Total T_n per cycle	
D						PFD allowance A_{pfd}	
E						Standard time $T_{std} = T_n(1 + A_{pfd})$	
Additional Notes							

Figure 13.2 Direct time study form.

The observed time is subsequently multiplied by the performance rating to obtain the ***normal time*** (other names include ***normalized time*** and ***base time***) for the element or cycle. The calculation is summarized in the following equation:

$$T_n = T_{obs}(PR) \tag{13.1}$$

where T_n = normal time, min; T_{obs} = observed time, min; and PR = performance rating, usually expressed as a percentage but used in the equation as a decimal fraction. The symbols T_n and T_{obs} can be used to represent individual work elements or the entire work cycle, depending on how the data are taken and recorded.

Performance rating is the most difficult and controversial step in direct time study. The reason is that it requires the judgment of the analyst to assess the value of PR. The analyst's judgment of standard performance may differ from that of the worker who is being observed. It is in the worker's interest and advantage to be rated at a high performance level during the study, because that will mean that the normal time and ultimately the standard time for the task will be longer (resulting in a looser standard). Thus, it will be easier for the worker to achieve a higher efficiency level as the job continues. This is especially important to the worker if he or she is paid on a wage incentive plan (Chapter 30). We consider performance rating and the issues surrounding it in Section 13.3.

13.1.5 Apply Allowance to Compute Standard Time

To obtain the standard time for the task, a PFD allowance is added to the normal time, as calculated in the following equation:

$$T_{std} = T_n(1 + A_{pfd}) \tag{13.2}$$

where T_{std} = standard time, min; T_n = normal time, min; and A_{pfd} = allowance factor for personal time, fatigue, and delays. This is often expressed as a percentage but used as a decimal fraction in our equation. Allowances are discussed in Section 12.3. The function of the allowance factor is to inflate the value of the standard time relative to the normal time in order to account for the various reasons why the operator loses time during the work shift. The allowance factor represents an average for the type of work, equipment, and conditions under which the operator works. Some days the worker may lose more time, other days less time, than what is provided by the allowance factor. In the long run it is intended to average out to a realistic value.

Example 13.1 Determining a Standard Time for Pure Manual Work

A direct time study was taken on a manual work cycle using the snapback timing method. The regular work cycle consisted of three elements, identified as a, b, and c in the following table. Element d is an irregular element performed every 5 cycles. Observed times and performance ratings of the elements are also given. Determine (a) the normal time and (b) the standard time for the work cycle, using an allowance factor of 15%.

Work Element	a	b	c	d
Observed time	0.56 min	0.25 min	0.50 min	1.10 min
Performance rating	100%	80%	110%	100%

Solution **(a)** The normal time for the cycle is obtained by multiplying the observed element times by their respective performance ratings and summing. In the case of element d, this normal time is prorated over 5 cycles.

$$T_n = 0.56(1.00) + 0.25(0.80) + 0.50(1.10) + 1.10(1.00)/5$$
$$= 0.56 + 0.20 + 0.55 + 0.22 = 1.53 \text{ min}$$

(b) The standard time is computed by adding the allowance.

$$T_{std} = 1.53(1 + 0.15) = 1.76 \text{ min.}$$

If the task includes a machine cycle, then company policy may provide for a machine allowance factor (Section 12.3.2) to be included in the standard time computation. The standard time equation becomes

$$T_{std} = T_{nw}(1+A_{pfd})+T_m(1+A_m) \tag{13.3}$$

where T_{nw} = normal time of the worker external elements, min; T_m = machine cycle time, min; A_m = machine allowance factor; and the other terms have the same meanings as before. If the company does not include a separate machine allowance, then $A_m = 0$ in the equation, or it uses the regular allowance A_{pfd}. Equation (13.3) assumes that there are no internal elements in the cycle. If the work cycle includes internal elements, then it must be determined whether the sum of the worker internal elements or the machine cycle time is larger in order to determine the normal time and the standard time.

Example 13.2 Determining a Standard Time for a Task That Includes a Machine Cycle

The snapback timing method was used in a direct time study of a task that includes a machine cycle. Elements a, b, c, and d are performed by the operator, and element m is a machine semi-automatic cycle. Element b is an internal element performed simultaneously with element m, and element d is an irregular element performed once every 15 cycles. Observed times and performance ratings are given in the table below. The PFD allowance factor is 15%, and the machine allowance is 20%. Determine (a) the normal time and (b) the standard time for the work cycle.

Worker element	a	b	c	d
Observed time, manual	0.22 min	0.65 min	0.47 min	0.75 min
Performance rating	100%	80%	100%	100%
Machine element		m		
Observed time, machine	(idle)	1.56 min	(idle)	(idle)

Solution **(a)** The normal time must take account of which element, b or m, has the larger value. Also, element d must be prorated across 15 cycles.

$$T_n = 0.22(1.00) + \text{Max}\{0.65(0.80), 1.56\} + 0.47(1.00) + 0.75(1.00)/15$$
$$= 0.22 + 1.56 + 0.47 + 0.05 = 2.30 \text{ min}$$

(b) The same comparison between elements b and m must be made in computing the standard time.

$$T_{std} = (0.22 + 0.47 + 0.05)(1 + 0.15)$$
$$+ \text{Max}\{0.52(1 + 0.15), 1.56(1 + 0.20)\}$$
$$= 0.85 + 1.87 = 2.72 \text{ min}$$

13.2 NUMBER OF WORK CYCLES TO BE TIMED

One of the practical issues in taking a time study is determining how many work cycles should be timed. The reason this issue arises is that there is statistical variation in the times of respective elements from one work cycle to the next. Direct time study involves a sampling procedure, and the objective is to determine a value for the population work element time as accurately as is possible and practical. As we increase the sample size, we expect the accuracy of the estimate to improve. On the other hand, increasing the sample size also increases the cost of taking the time study. It seems reasonable to try to find a balance between these competing factors.

There is inherent variability in any human activity, and performing manual work is a human activity. Work element times vary from cycle to cycle because of the following reasons:

- Variations in hand and body motions
- Variations in the placement and location of parts and tools used in the cycle
- Variations in the quality of the starting work units (e.g., a plastic molded part with flash that must be trimmed)
- Mistakes by operator (e.g., operator accidentally drops the work part)
- Errors in timing the work elements by the analyst
- Variations in worker pace

All of these variations are manifested in the work element times recorded for the cycle. Performance rating is supposed to compensate for the last item, variations in worker pace. However, because performance rating requires judgment by the analyst, that also introduces error and variation.

For analysis purposes, we assume that the observed work element times are normally distributed about the true value of the work element time. For practical purposes, we identify the longest work element in the cycle, or the most critical element (the one in whose accuracy we are most interested), as the element to focus on. Let us call this element time T_e. Our objective is to be able to identify the true value of T_e within a certain confidence interval. For example, we might state that we want to be 95% confident that the true value of T_e lies within $\pm 10\%$ of the observed average value of the element time. Let us identify the average value simply as $\bar{x}$. This is illustrated in Figure 13.3, which shows the distribution of observed time values taken during the time study.

The area under the normal curve between $\pm 10\%$ of $\bar{x}$ represents the probability that the true value of element time T_e lies within $\pm 10\%$ of $\bar{x}$. The general statement of the confidence interval can be expressed as follows:

$$\Pr\left(T_e \text{ lies within } \bar{x} \pm z_{\alpha/2}\frac{\sigma}{\sqrt{n}} \right) = (1-\alpha) \tag{13.4}$$

where $z_{\alpha/2}$ = standard normal variate, σ = standard deviation of the population element time, n = sample size, and $(1-\alpha)$ = confidence level. The term $z_{\alpha/2}\frac{\sigma}{\sqrt{n}}$ is made equal to our desired interval size (e.g., $\pm 10\%$ of $\bar{x}$), and we solve for the value of n, the number of work cycles to time.

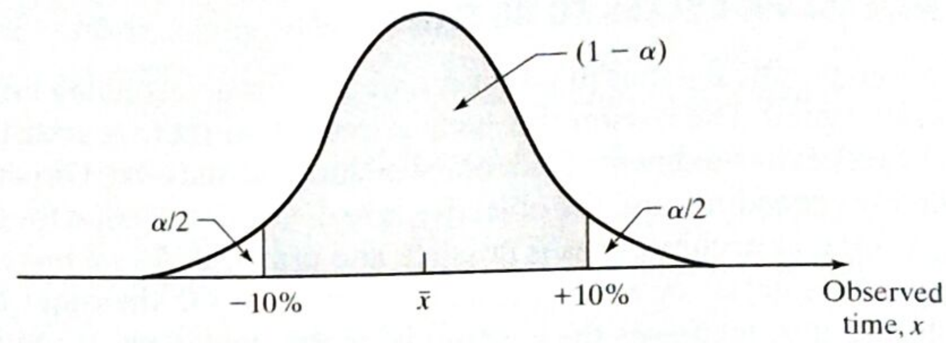

Figure 13.3 Distribution of observed element times in a direct time study.

There are two difficulties with the preceding analysis: (1) we do not know the population standard deviation σ and (2) the sample size n that we are usually dealing with is relatively small. The standard deviation must be estimated from the sample itself, just as the mean $\bar{x}$ must be determined from the sample. The value of the sample standard deviation is given by

$$s = \sqrt{\frac{\Sigma(x-\bar{x})^2}{n-1}} \tag{13.5}$$

where s = sample standard deviation, x = individual values of the observed times collected during the study, and the other terms have previously been defined. Because the sample size n is usually small (e.g., less than 30), the sample values are distributed according to the student t rather than the normal distribution.

Taking these adjustments into account, we can make the following confidence interval statement to replace equation (13.4):

$$\Pr\left(T_e \text{ lies within } \bar{x} \pm t_{\alpha/2}\frac{s}{\sqrt{n}}\right) = (1-\alpha) \tag{13.6}$$

Our objective is to find the value of sample size n that will satisfy our specification of α and interval size for the values of $\bar{x}$ and s that have been determined from the data collected. Let us express the interval size in more general terms:

$$\text{Interval size} = \bar{x} \pm k\bar{x}$$

where k = a proportion that specifies the interval size (e.g., k = 10% or 0.10). We will set that equal to $\bar{x} \pm t_{\alpha/2}\frac{s}{\sqrt{n}}$, from which the following can be established:

$$k\bar{x} = t_{\alpha/2}\frac{s}{\sqrt{n}} \tag{13.7}$$

Rearranging and solving for n, we have

$$n = \left(\frac{t_{\alpha/2}s}{k\bar{x}}\right)^2 \tag{13.8}$$

where values of $t_{\alpha/2}$ can be found in the appendix to this book.

Example 13.3 Determining the Number of Work Cycles to Be Timed

A time study analyst has collected 10 readings on a particular work element of interest and would like to consider how many more cycles to time. Based on the sample, the mean time for the element is $\bar{x} = 0.40$ min and the sample standard deviation $s = 0.07$ min. At a 95% confidence level, how many cycles should be timed to ensure the actual element time is within $\pm 10\%$ of the mean?

Solution: We have $10 - 1 = 9$ degrees of freedom in the t distribution, so the value of $t_{\alpha/2}$ at the 95% confidence level ($\alpha/2 = 0.025$) is 2.262. Using equation (13.8), we obtain

$$n = \left(\frac{2.262(0.07)}{0.10(0.40)}\right)^2 = 15.7$$

This should be rounded up to 16 cycles total. Since 10 cycles have already been timed, the analyst needs data from 6 more work cycles. ■

The time study analyst may wish to turn the problem around; that is, to determine the size of the confidence interval at a certain desired confidence level, given that the observed times have already been recorded for a completed time study. This can be done using equation (13.8) but rearranging to solve for k.

Notwithstanding the preceding statistical approach, the problem of determining how many work cycles should be timed often boils down to the practical issue of how much time can we afford to spend doing the time study. Certain observations are germane here:

- The statistical accuracy of the time data increases when more observations are taken. The equations tell us that. If the task being studied is an important one in the factory operations, then more time should be spent on the time study to ensure the highest possible accuracy of the standard. More time should be spent studying high production operations than low production operations.
- Shorter work cycles allow more cycles to be timed during the study. For work cycles under 1 minute, 30 or more cycles are practical. For longer work cycles, fewer cycles can be included. For work cycles of 30 minutes, it may only be practical to observe six work cycles (which is 3 hours or more of time study observation).
- It is a judgment call by the time study department as to the appropriate number of work cycles to be timed. The judgment attempts to balance the desire for statistical accuracy against the cost of the time study.

13.3 PERFORMANCE RATING

Performance rating, also called ***performance leveling***, is the step in direct time study in which the analyst observes the worker's performance and records a value representing that performance relative to the analyst's concept of standard performance. A number of different performance rating methods have been proposed over the years, but the simplest and most common method is based on speed or pace.[4] It is sometimes referred to as speed rating. The other methods are rarely used today.

As its name indicates, ***speed rating*** involves rating the operator's pace of working relative to the concept of standard performance. A rating greater than 100% means that the worker is working faster than standard pace, and less than 100% means the worker is slower than standard. Pace is the only factor that is rated. However, pace depends on the type of work involved. To rate the operator's pace, the analyst must use judgment that is based on previous training and experience in rating similar work. An analyst who is experienced in machine shop time studies would find this experience of limited value if suddenly faced with the job of conducting time studies in a garment factory. The concept of standard performance is different for different kinds of work. Standard performance for a highly repetitive manual assembly task in which the cycle time is 1 minute should be defined differently than standard performance in a design prototype modeling shop in which the worker must apply technical skill and artistic talent to the job. And within a given category of work, some tasks are more difficult than others. Accordingly, the analyst must observe two aspects of the work scene during performance rating: (1) the degree of difficulty of the task and what 100% pace would be for that task, and (2) the subject worker's pace relative to the concept of 100% pace.

Let us examine these two aspects of performance using one of our accepted definitions of standard performance, walking at 3 miles/hr (4.83 km/hr). This is a 20-minute mile. The more complete definition is walking at 3 miles/hr on level flat ground, using 27-inch steps.[5] Also, it is assumed that the walker carries no load. If any of these conditions are not satisfied (i.e., level ground, 27-inch steps, no load), then it represents a change in the degree of difficulty, and so the definition of 100% performance might need adjusting. For example, walking uphill on a 3% slope might have a standard pace of only 2.5 miles/hr. But if the conditions of the definition are satisfied, so that standard performance is 3 miles/hr, then an individual's walking speed can be measured to assess his or her performance rating relative to this standard. In fact, walking is a situation where we can very precisely determine performance level if we assume that performance level is directly proportional to the speed of the walker. For example, suppose the walker is able to complete 1 mile in 18 min (0.30 hr) instead of 20. This is a speed of 3.33 miles/hr (1 mile ÷ 0.3 hr). Compared to 3.0 miles/hr, the performance level is 111%. We do not necessarily know that the walker's performance was a constant 111% (3.33 miles/hr) throughout the entire mile, but we know that on average it was 111%.

Unfortunately, very few work situations lend themselves to such a precise measurement of performance. Thus, performance rating comes down to a matter of the analyst judging the worker's pace relative to his or her concept of standard performance for the type of work involved. Direct time study is not the only instance where judgment is used to rate people. There are many areas of human activity in which judgments are used by experts to decide the relative performance of subjects, and the expert's judgments are readily accepted. Table 13.2 presents a list of activities in which judges rate the

[4]For the interested reader, the other performance rating methods are described in [14].
[5]This definition was apparently proposed by Ralph Presgrave, one of the early workers in time and motion study.

TABLE 13.2 Activities in Which Trained and Experienced Judges Rate the Contestants

Human Activities That Are Judged	Other Activities That Are Judged
Figure skating	Dog shows
Diving events	Farm shows
Gymnastics	Gourmet food contests
Bodybuilding contests	Art contests
Beauty contests	High school science fair contests
Umpire calling balls and strikes behind home plate in a baseball game	Grading of (college) freshman English essays

contestants, often reducing the judgment to a numerical score. Just as in these other areas, time study analysts must be trained and become practiced in performance rating. Training is accomplished through the use of training films (videotapes) that show scenes of workers performing various kinds of industrial tasks at a variety of performance levels. The workers' pace in these scenes have been performance rated by experts, so that a trainee can judge each scene and compare his or her ratings with those of the experts. On-the-job practice is obtained by accompanying experienced analysts during actual time studies.

Depending on the type of work and length of the work cycle, the analyst must decide whether to rate the performance of individual elements (called ***elemental rating***) or to rate the entire cycle (***overall rating***). If the work cycle is relatively short (e.g., less than a minute) and the work content is similar throughout the cycle, then convenience may favor rating the entire cycle. If the cycle is longer and involves different kinds of work elements, on which the operator exhibits different pace levels, then elemental rating is more appropriate.

Operator selection can influence the performance rating procedure. The pace observed by the analyst depends to some extent on the worker's skill, experience, exertion level, and attitude toward time study. If there is more than one worker performing the same task that is to be time studied, then it is in the analyst's interest to select a skilled worker who is familiar with the job (has had time to learn the task) and who accepts time study as a necessary management tool. Such workers are usually willing to cooperate with the time study analyst, even to the extent that they will attempt to work at a pace consistent with the company's definition of standard performance, thus relieving the analyst of being forced to attach a rating that is significantly different from 100%. It has been found that when the subject performs at a pace that is within about 15% of standard, the resulting standard time value is much more likely to be fair and accurate and accepted by the worker. If the subject's performance during observation deviates significantly from standard, not only does this make life more difficult for the analyst, it increases the likelihood that the standard will not be an accurate measure of the task.

Potential difficulties are encountered in performance rating because a potential conflict of interest exists between the subject worker and the time study analyst. It is always in the worker's interest for the performance rating to be high due to its effect on the computation of standard time. Notwithstanding the difficulties, we can identify the following characteristics of a well-implemented performance rating system:

- *Consistency among tasks.* The performance rating system should provide consistent ratings from one task to another. A worker who is able to perform at 125% efficiency on one task should be able to achieve the same efficiency level on any other task. The performance rating used to establish the normal time is a key factor in obtaining this consistency among tasks.
- *Consistency among analysts.* The performance rating for a task should not depend on which time study analyst does the rating. Consistency within a group of time study analysts can be measured using the deviations of individual *PR* values about the group average. Niebel and Freivalds indicate that a deviation of ±5% is considered adequate [14]. Proper initial training and periodic refresher training for the analysts in a company should provide this level of consistency.
- *Easily understood.* The rating system should be easy to explain by the analyst and simple to understand by the worker.
- *Related to standard performance.* The company should have a well-defined concept of standard performance. To the extent possible, this concept should be documented for reference by workers. Time study analysts should apply this definition when performance rating a task.
- *Machine-paced elements rated at 100%.* The operator has no control over machine-paced elements and therefore deserves no performance rating for these elements. Any adjustment for machine-cycle elements should be done using a machine allowance when computing the standard time.
- *Performance rating recorded during observation of task.* The performance should not be rated and recorded afterward.
- *Worker notification.* At the conclusion of the time study observation session, the analyst should inform the worker of the performance rating that was observed. This sets a proper tone for the relationship between the two people. It puts pressure on the analyst to be as fair as possible in the rating process, and it allows the worker to express agreement or disagreement with the rating.

13.4 TIME STUDY EQUIPMENT

In direct time study, the analyst directly observes the task as a worker performs it. The equipment used by the analyst ranges from simple to sophisticated. In our coverage we divide the range into three categories: (1) traditional time study using a stopwatch, (2) video camera to record the observation on tape, and (3) computerized time study techniques. The computerized techniques are covered in Chapter 17.

13.4.1 Stopwatch Time Study

The traditional equipment used in direct time study consists of a stopwatch and a time study form on which to record the times during observation. There are alternatives to the stopwatch, such as a wristwatch or wall clock, but the proper professional instrument

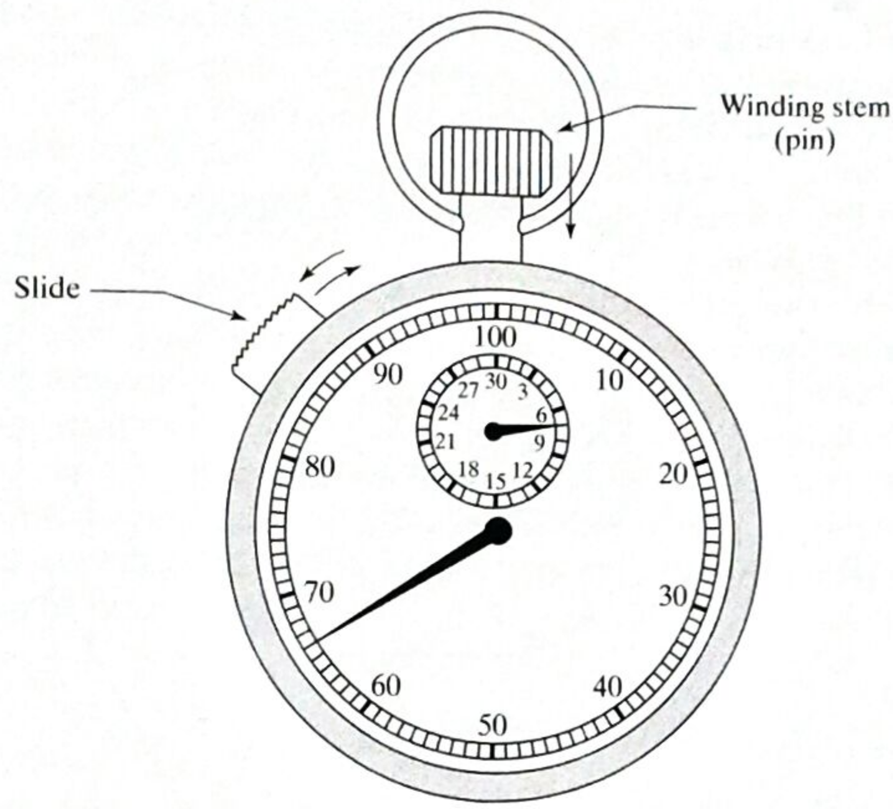

Figure 13.4 Mechanical stopwatch calibrated in decimal minutes (0.01 min) on the large dial. The small dial reads up to 30 minutes. Depressing the pin (also used as the winding stem) zeros the watch. The slide is used to start and stop the timing of individual work elements.

is a stopwatch. The time study form is usually held on a clipboard, which is designed to hold the stopwatch as well. Following the observation, the collected time data are analyzed and a time standard is calculated for the task.

Stopwatches can be classified as mechanical or electronic. ***Mechanical stopwatches*** have the familiar round face with one or more rotating hands, as shown in Figure 13.4. They are designed to be held in the time study clipboard or the palm of one's hand so the fingers can actuate the pin and slide at the top. Mechanical stopwatches are not a recent development. They have been used for time study since the late 1800s. Modern stopwatches for time study are typically graduated in one of three time measurement scales: (1) decimal minutes, shown in Figure 13.4, (2) decimal hours, and (3) TMUs (Time Measurement Units); 1 TMU = 0.00001 hr or 0.036 sec). The reason for having different scales is that different organizations have adopted different units to express their time standards. Decimal minute watches seem to be the most common, decimal hours less common, and TMUs are sometimes used because they are usually the time units in certain predetermined motion time systems (Chapter 14).

Electronic stopwatches (Figure 13.5) provide a digital display of the time; otherwise their operating features are similar to those of mechanical watches. They have largely replaced mechanical stopwatches in time study for several compelling reasons. Because they display a digital readout, they are easier to read than the graduated mechanical dial, especially if the mechanical hand is moving. Because they are easier to read, reading errors occur less frequently. They are lighter in weight and generally less

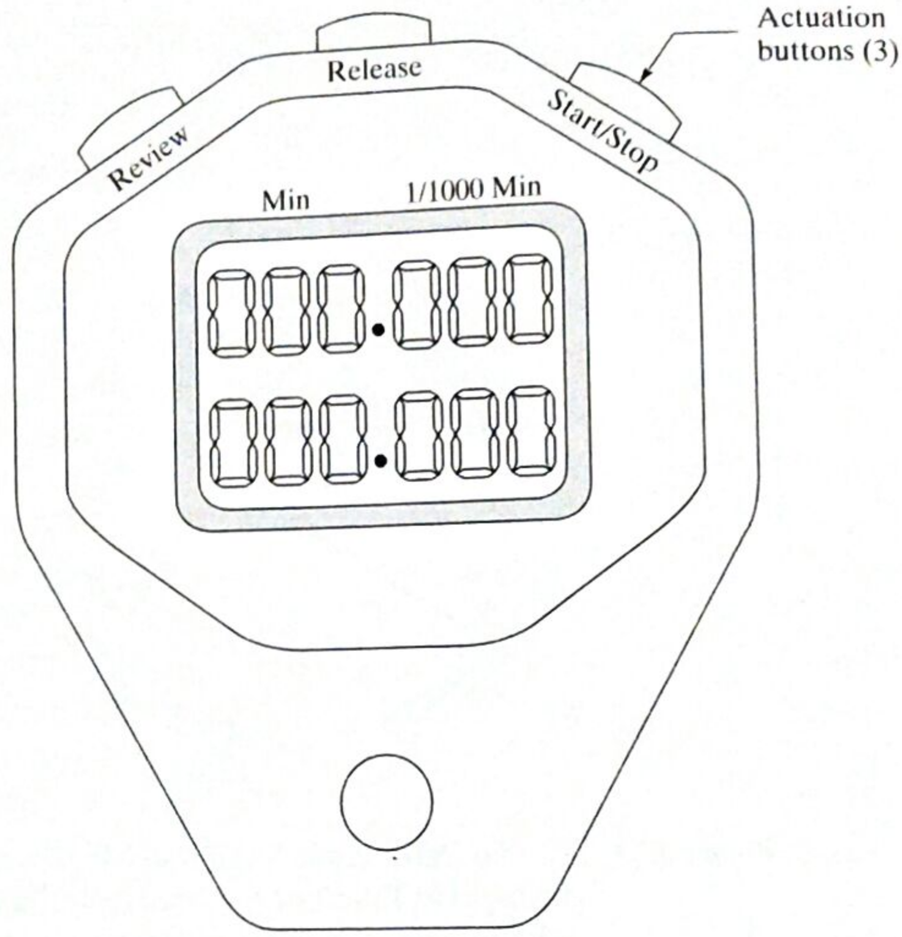

Figure 13.5 Electronic stopwatch with LED read-out, that can be used for continuous or snapback timing methods.

susceptible to damage when dropped or otherwise abused. Electronic watches are also more accurate and precise, which allows them to be used to read shorter work elements more conveniently. Some electronic watches can be switched back and forth between different time scales, unlike their mechanical counterparts. They can be used for either the continuous timing mode or the snapback mode. Finally, electronic stopwatches are less expensive than mechanical stopwatches.

The direct time study observation form (Figure 13.2) provides space for the analyst to record the observed times and the performance rating of the operator. Either the continuous timing method or the snapback method can be used. Observed times for multiple work cycles can be entered on the form.

13.4.2 Video Cameras

Video cameras have become a familiar piece of electronic equipment not only to consumers but to time study analysts as well. They are useful in direct time study because they provide a complete visual and audio record of the method used by the worker. The method is captured in much greater detail than the analyst can observe with the naked eye or is willing to include in any written documentation of the method. The tape also provides an accurate record of the times taken by each work element (accurate to 1/30 sec based on a frame-to-frame frequency of 30 Hz in the United States, or 1/25 sec based on 25 Hz in Europe). The tape can be subsequently played and replayed (in slow motion if desired) analyze the method, perhaps uncovering possible improvements in the task. Work element times can be analyzed for cycle-to-cycle variations. Operator performance can be rated in a much more relaxed and objective setting than what is possible in the shop floor environment. And finally, a standard time can be determined for the task from the tape.

Later, if a dispute arises about the standard time, the method, or the performance rating, the tape can be viewed to help settle the dispute, perhaps avoiding a formal grievance. If the operator wants to watch his own work performance, perhaps to decide whether he agrees with the rating, this can be accommodated. The tape can be used for training purposes for new time study analysts. The videotape provides an objective and accurate record of the worker performing the task using the method for which the time standard was determined.

Video cameras can be used for a variety of work situations in motion and time study: short repetitive work cycles, long cycles with variable elements, worker-machine systems, crews of workers, and several workers working independently but captured in the field of vision of the camera.[6]

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REVIEW QUESTIONS

13.1 Define direct time study.

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

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

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

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

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

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

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

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?

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

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

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

PROBLEMS

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 (PFD) allowance for this work is 12%. Determine (a) the normal time and (b) the standard time for the cycle.

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 PFD 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

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, (b) the standard time for the cycle, and (c) the worker's efficiency if the worker produces 123 work units during an 8-hour shift.

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 and 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 7 actual hours worked on an 8-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)	0.32	0.85	0.48	0.55	1.50

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, (b) the standard time per part, (c) the worker's efficiency if the worker completes 844 parts in an 8-hour shift during which she works 7 hours and 10 min.

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

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 or she works at standard performance for a total of 6 hr 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
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

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 and 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 7 actual hours worked on an 8-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

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 machine-controlled element and the time is constant. Elements *a*, *b*, *c*, *e*, and *f* are operator-controlled and were performance rated at 80%; however, elements *e* and *f* are performed during the machine-controlled 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

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 machine-controlled element and the time is constant. Elements *a*, *b*, *d*, *e*, and *f* are operator-controlled and external to the machine cycle, and they were performance rated at 80%. If the machine allowance is 25%, and the worker PFD allowance is 15%, determine (a) the normal time, (b) the standard time for the cycle, and (c) the worker's efficiency if the worker completes 360 work units working 7.2 hr on an 8-hour shift.

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

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 is 20%. Determine (a) the normalized time for the cycle, (b) the standard time per part, and (c) the worker's efficiency if the worker completes 220 parts in an 8-hour shift during which he or she works 7 hr and 12 min.

Element	Description	Cumulative Observed Time (min)
a	Worker loads machine and starts automatic cycle.	0.25
b	Machine is engaged in 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

ms

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, and (c) the number of parts that will be produced if the worker's efficiency is 115% and he works a total of 7 hr and 12 min during an 8-hour shift.

13.12 The snapback method was used to time study a worker-machine cycle consisting of 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 is 12% and the machine allowance is 10%. One work piece is produced each cycle. Determine (a) the normal time, (b) the standard time for the cycle. (c) the number of pieces completed if the worker works 7 hr and 10 min during an 8-hour shift, and his performance level is 135%.

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

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 machine-controlled element and the time is constant. Elements a, b, and d are operator-controlled 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) 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

13.14 The table below lists the average work element times obtained in a direct time study using the snapback timing method. Elements a and b are operator-controlled. Element c is a machine-controlled element and its time is constant. Element d is a worker-controlled 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 8-hour 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 operator-paced portion of the cycle?

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

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 machine-controlled element and the time is constant. Elements *a*, *b*, *d*, *e*, and *f* are operator-controlled and were 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

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 worker-controlled. Element *d* is a machine-controlled 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 worker-controlled 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 7 actual hours worked on an 8-hour shift, determine (c) how many units will be produced and (d) what the worker's efficiency will be.

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

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 is 100%, how many units will be produced in one 9-hour shift? (d) If the actual time worked during the shift is 7.56 hours, and the worker performance is 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)	

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*, 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 is 100%, how many units will be produced in one 8-hour shift? (d) If the actual time worked during the shift is 6.86 hours, and the worker performance is 125%, how many units will be produced?

Worker Element	Description of Worker Element	Time (min)	Performance 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)		

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 machine-controlled element and the time is constant. Elements *a*, *b*, *c*, *e*, and *f* are operator-controlled 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

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 machine-controlled element and the time is constant. Elements *a*, *b*, *d*, and *e* are operator-controlled and were performance rated at 100%; however, element *d* is performed during the machine-controlled 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

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 worker-controlled. Element *d* is a machine-controlled 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 worker-controlled irregular element performed every six 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 8-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

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 operator-controlled. Element *c* is a machine-controlled element and its time is constant. Element *d* is a worker-controlled irregular element performed every 10 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 8-hour shift during which 7 hours are actually worked, (b) what was the worker's efficiency, and (c) what was his performance during the operator-paced portion of the cycle?

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

umber of Cycles

13.23 Seven cycles have been observed during a direct time study. The mean for the largest element time is 0.85 min, and the corresponding sample standard deviation *s* is 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% of the true mean, how many more observations should be taken?

13.24 Nine cycles have been observed during a time study. The mean for the largest element time is 0.80 min, and the corresponding sample standard deviation *s* is 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?

13.25 Six cycles have been observed in a direct time study. The mean for the largest element time is 0.82 min, and the corresponding sample standard deviation *s* is 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?

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?

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?

13.28 Six cycles have been observed during a direct time study. The mean for the largest element time is 1.00 min, and the corresponding sample standard deviation s is 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?

13.29 A total of 9 cycles has been observed during a direct time study. The mean for the largest element time is 1.30 min, and the corresponding sample standard deviation s is 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?

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 long-distance runner who breaks the four-minute mile?

13.31 In 1982, the winner of the Boston Marathon was Alberto Salazar, whose time was 2 hr, 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?