Chapter 3

Manual Work

3 Introduction

There are three categories of **work systems**:

1. **Manual work system**, where the worker performs one or more tasks without the aid of power tools.
2. **Worker-machine system**, where the worker operates power tools.
3. **Automated work system**, where the process is performed without the direct participation of the human worker.

A work unit is an object that is processed by the work system. It can be a workpiece being machined (production work), material being moved (logistics work), a customer in a store (service work), or a product being designed (knowledge work).

3.1 Manual Work Systems

A **manual work system** is a system where human workers perform tasks without the assistance of machinery or automation. These tasks can range from simple repetitive actions to complex manual operations that require significant skill and dexterity. This can occur with or without hand tools. When hand tools are used, the power to operate them is derived from the strength and stamina of a human worker. Other human faculties may be required, such as hand-eye coordination and mental effort. A general characteristic that is common to nearly all pure manual work is to move things.

Examples of **pure manual work** include:

1. A material handler manually moving cartons in a warehouse.
2. An assembly worker putting together parts to create a finished product.
3. Creating products by hand, such as pottery or woodworking.
4. An office worker filing documents.
5. Manually inspecting products for defects or quality standards.
6. Manually packing products into containers or boxes.

Examples of **manual work with hand tools** include:

1. A machinist filing a part.
2. An assembly worker using a screwdriver.
3. A painter using a paintbrush to paint door trim.
4. A QC inspector uses a micrometer to measure a shaft diameter.
5. A material handling worker using a dolly to move furniture.
6. An office worker writing with a pen.

3.2 Worker Performance

Worker performance is defined as the pace or relative speed of working. As worker performance increases, cycle time decreases. From the employer's viewpoint, it is desirable for worker performance to be high.

Performance Rating (PR) = performance rating of the worker's pace as observed by a trained time study analyst, usually recorded as a percentage during the observation but applied as a decimal fraction in the normal time, Tn, equation.

As shown in Figure 3.1 below,

Faster pace than standard: PR > 100%, takes less time than normal
Standard Performance: PR = 100%
Slower pace than standard: PR < 100%, takes more time than normal

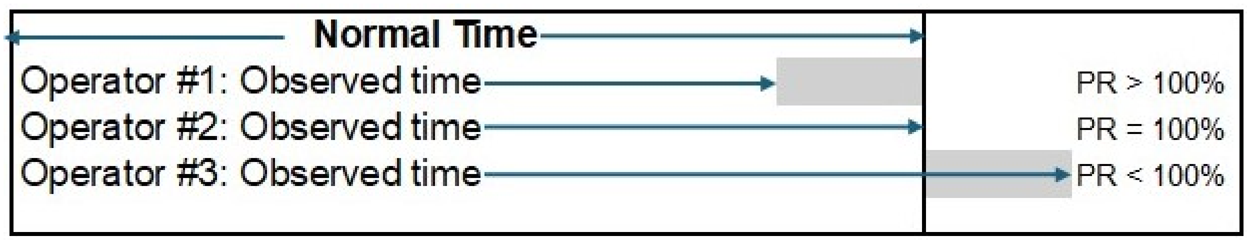

Figure 3.1. Performance rating examples.

Example 1. Performance Ratings

Say, normal time = Tn = 6.5 sec

Solution:

$$When\ PR = 120\%, T_c = \frac{T_n}{PR} = \frac{6.5\ sec}{1.2} = 5.417\ \text{sec} => faster\ pace\ than\ standard$$

$$When\ PR = 100\%, T_c = \frac{T_n}{PR} = \frac{6.5\ sec}{1.0} = 6.5\ \text{sec} => standard\ pace$$

$$When\ PR = 90\%, T_c = \frac{T_n}{PR} = \frac{6.5\ sec}{0.90} = 7.222\ \text{sec} => slower\ pace\ than\ standard$$

Some reasons for variation in cycle times include the following:

- Differences in the speed and efficiency of workers from one cycle to the next
- Machine issues, such as breakdowns, wear and tear, or operational inconsistencies
- Variations in the quality of raw materials or components
- Different methods or techniques used by workers
- Changes in the work environment, such as temperature, humidity, and lighting
- More complex products or assemblies may naturally require more time to complete
- Differences in batch sizes or the frequency of batch changes, particularly in batch processing systems
- Delays or variability in the supply of materials or components
- Unexpected interruptions, such as equipment malfunctions, power outages, or unplanned maintenance
- Variations due to human error, absenteeism, or differences in individual worker pace and attention
- The learning curve effect

3.3 Normal Performance and Normal Time

Normal performance is a pace of working that can be maintained by a properly trained average worker throughout an entire work shift without deleterious short-term or long-term effects on the worker's health or physical well-being. The work shift is usually 8 hours, during which periodic rest breaks are allowed. Normal performance = 100% performance. A common benchmark of normal performance is walking at 3 miles per hour.

Normal time is defined as the time required to complete a task under normal working conditions, without allowances for delays or interruptions. The actual time to perform the cycle depends on the worker's pace.

$$T_n = T_{obs}(PR) = T_c(PR) \tag{3.1}$$

where Tn = normal time, min/pc; $Tobs$ = observed time, min/pc; Tc = cycle time, min/pc; and PR = performance rating, or worker pace.

The cycle time is calculated as

$$T_c = \frac{T_n}{PR} \tag{3.2}$$

where *Tc* = cycle time, *Tn* = normal time, and *PR* = worker performance rating, or pace.

Example 2. Normal Time

If the observed time for a task is 8.25 minutes and the performance rating is 1.1 (110%), what is the normal time?

Solution:

$$T_n = T_c(PR) = 8.25\ min/pc(1.10) = 9.075\ min/pc$$

Example 3. Cycle Time for Repetitive Work

If a worker assembles a product in 5 minutes and performs quality checks in 2 minutes, both at a normal pace, the cycle time is:

Solution:

$$T_{obs}(PR) = T_c(PR) = (5\ \mathrm{min} + 2\ \mathrm{min})(1.00) = 7.0\ min/pc$$

Example 4. Cycle Time for Nonrepetitive Work

If a worker completes a one-time setup in 10 minutes and then performs a 20-minute assembly task, both at a normal pace, the cycle time is:

Solution:

$$T_{obs}(PR) = T_c(PR) = (10\ \mathrm{min} + 20\ \mathrm{min})(1.00) = 30.0\ min/pc$$

3.4 Standard Performance and Standard Time

Standard Performance is the same as normal performance but acknowledges that periodic rest breaks must be taken by the worker. Periodic rest breaks are allowed during the work shift. Federal law requires the employer to pay the worker during these breaks. Other interruptions and delays also occur during the shift.

PFD Allowance is used to account for delays due to:

- Personal time (P)
  - Restroom breaks, water fountain breaks
- Fatigue (F)
  - Rest breaks are intended to deal with fatigue
- Delays (D)
  - Interruptions, equipment breakdowns

Standard Time is defined as the normal time, but with an allowance added in to account for losses due to personal time, fatigue, and delays. The standard time is defined in Equation 3.4 as follows:

$$T_{std} = T_n(1 + A_{pfd}) \tag{3.3}$$

Where *Tstd* = standard time, min/pc; *Tn* = normal time, min/pc; and *Apfd* = allowance for personal time, fatigue, and delays.

Example 5. Standard Time

If the normal time is 8.8 minutes and the allowance factor is 15%, what is the standard time per unit?

Solution:

$$T_{std} = T_n\left(1 + A_{pfd}\right) = 8.8\,min/pc(1 + .015) = 10.125\,min/pc$$

Example 6. Lost Time due to an Allowance Factor

If the standard time is 17.28 minutes and the allowance factor is 20%, what is the lost time?

Solution:

$$Lost\ time = 17.28\,min \times 0.15 = 2.592\,min$$

3.5 Irregular Work Elements

Irregular work elements are elements that occur infrequently or irregularly during a process. Irregular elements are prorated into the regular cycle according to their frequency.

Examples:

- Changing a tool like a blade on a utility knife
- Exchanging tote pans of parts
- Swapping out a full pallet for an empty pallet
- Changing a tool or machine setup that occurs once per shift

If a work cycle includes an irregular work element, defined as a work element that occurs with a frequency of less than once per cycle (i.e., it occurs once every *x* number of cycles rather than once per cycle), then the standard time is computed as:

$$T_{std} = \left(T_n + \frac{T_{nwi}}{\#\ cycles}\right)\left(1 + A_{pfd}\right) \qquad (3.4)$$

where *Tstd* = standard time, min/pc; *Tn* = normal time, min/pc; *Tnwi* = normal time for irregular work element, min/pc; and *Apfd* = allowance for personal time, fatigue, and delays.

Example 7. Standard Time with Irregular Work Element

The normal time to perform a certain manual work cycle is 4.25 min. In addition, an irregular work element whose normal time is 3.5 min must be performed every 20 cycles. One work unit is produced each cycle. The PFD allowance factor is 12%. The worker's pace is 105%. (a) Determine the standard time per unit. (b) What is the cycle time?

Solution:

(a)

$$T_{std} = \left(T_n + \frac{T_{nwi}}{\#\ cycles}\right)\left(1 + A_{pfd}\right) = \left(4.25\ min/cycle + \frac{3.50\ min}{20\ cycles}\right)(1 + 0.15)$$

$$= 5.089\ min/pc$$

(b)

$$T_c = \frac{T_n}{PR} = \frac{4.25\ min/cycle}{1.05} = 4.048\ min/pc$$

3.6 Standard Hours, Standard Quantity, and Worker Efficiency

Standard hours indicate the amount of work accomplished by the worker in each time period (i.e., 8-hour shift, 40-hour week), given in units of time. In short, standard hours are equivalent to the quantity produced multiplied by the standard time per unit, as shown in Eq. 3.5.

$$H_{std} = QT_{std} \tag{3.5}$$

where *Hstd* = standard hours achieved, *Q* = quantity produced; and *Tstd* = standard time, min/pc.

Standard output, or standard quantity, is represented by the number of shift hours divided by the standard time per unit, as shown in Eq. 3.6.

$$Q_{std} = \frac{H_{sh}}{T_{std}} \tag{3.6}$$

where *Qstd* = quantity expected to be produced per time period; *Hsh* = number of shift hours; and *Tstd* = standard time, min/pc.

Worker efficiency is equal to the amount of work accomplished during the shift given as a proportion of the shift hours, as shown in Eq. 3.7.

$$E_w = \frac{H_{std}}{H_{sh}} \tag{3.7}$$

where *Ew* = worker efficiency, %; *Hstd* = standard hours achieved; and *Hsh* = number of shift hours.

Example 8. Standard Hours and Worker Efficiency

A worker performs a repetitive assembly task on a table to assemble products. Each product consists of 8 components. Various hand tools are used in the assembly process. The standard time for the work cycle is 5.25 min, based on a PFD allowance factor of 12%. If the worker completes 110 product units during an 8-hour shift, determine (a) the number of standard hours achieved, (b) worker efficiency, (c) standard quantity, and (d) If the worker took only one 15-min rest break, and had no other interruptions during the shift, determine her worker pace.

Solution:

(a) $H_{std} = QT_{std} = 110\ pc\left(5.25\frac{min}{pc}\right)\left(\frac{hr}{60\ min}\right) = 9.625\ hr$

(b) $Q_{std} = \frac{H_{sh}}{T_{std}} = \frac{8\ hr}{5.25\ min/pc}\left(\frac{60\ min}{hr}\right) = 91.4\ pc$

(c) $E_w = \frac{H_{std}}{H_{sh}} = \frac{9.625\ hr}{8\ hr} = 1.20 \times 100 = 120\%$

Alternatively,

$$E_w = \frac{Actual\ qty\ produced}{Expected\ qty\ to\ be\ produced} = \frac{110\ pc}{91.4\ pc} = 1.20 \times 100 = 120\%$$

(d) $Actual\ time\ worked = 480\ min - 15\ min = 465\ min$

$$T_c = \frac{465\ min}{110\ pc} = 4.227\ min/pc$$

$$T_n = \frac{5.25\ min}{(1 + 0.12)} = 4.6875\ min/pc$$

$$PR = \frac{T_n}{T_c} = \frac{4.6875\ min/pc}{4.227\ min/pc} = 1.109 \times 100 = 110.9\%$$

3.7 Foreign Work Elements

Foreign work elements are tasks that are not part of the standard work process and can include disruptions or unplanned activities.

Examples:

- Responding to an unexpected machine breakdown
- Responding to an urgent request from a supervisor
- Responding to an anomaly in the process

3.8 Worker-Machine Systems

In a ***worker-machine system***, tasks are shared between a human worker and a machine or equipment. Worker-machine systems will be discussed in the following classifications: (1) types of powered machinery in the system, (2) numbers of workers and machines in the system, and (3) level of operator attention required to run the machinery.

Examples:

- Construction worker operating a front-end loader for excavation at a construction site
- Truck driver driving an 18-wheeler on an interstate highway
- Forklift driver operating a forklift to transport unit loads in the plant
- Clerical worker entering data into a PC

Powered machinery can be classified into three categories, as illustrated in Figure 3.2.

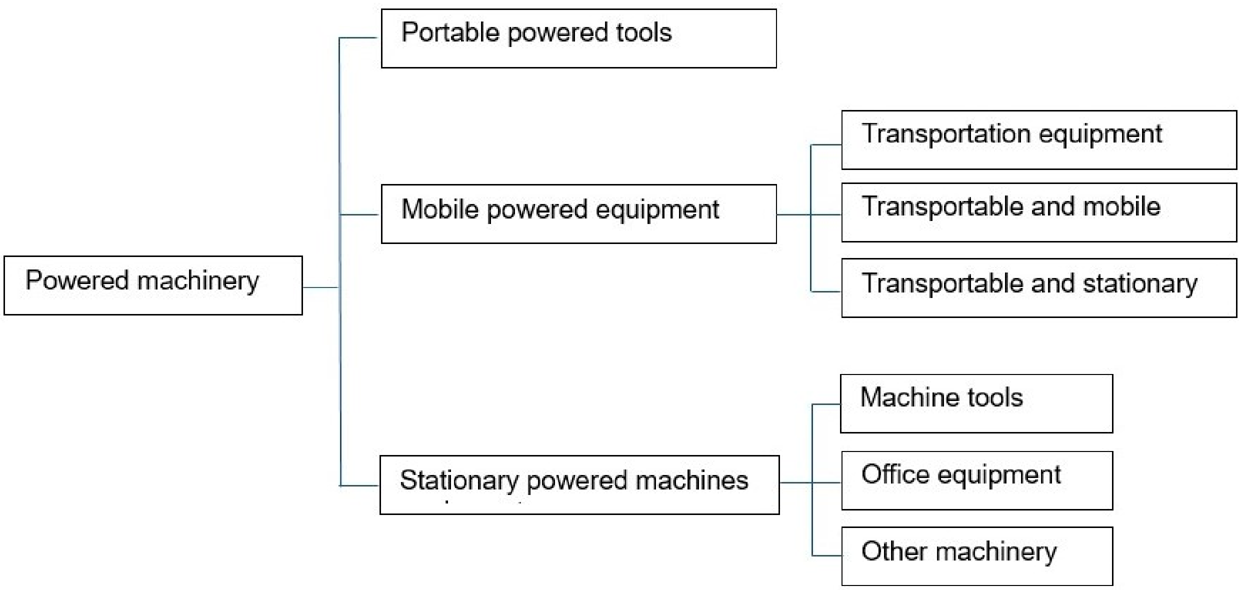

Figure 3.2. Different classifications of powered machinery in worker-machine systems.

3.8.1 Types of Powered Equipment

1. ***Portable power tools*** are light enough in weight that they can be carried by the worker from one location to another and manipulated by hand. Common power sources are electric, pneumatic, gasoline, and battery-packs.
    a. Portable power drills, chain saws, electric hedge trimmers, string trimmers, lawn edgers
2. ***Mobile powered equipment*** can be divided into three categories: (1) transportation equipment, (2) transportable and mobile during operation, and (3) transportable and stationary during operation. They are generally large, heavy pieces of equipment and cannot be classified as powered hand tools.
    a. ***Transportation equipment*** includes vehicles and is designed to carry materials or people.

b. ***Transportable and mobile equipment*** consists of equipment that can move under its own power but can also be moved by transportation equipment (i.e., tractor and flatbed). This type of equipment includes backhoes, forklift trucks, electric power generator at a construction site, portable welding unit, etc.
c. ***Stationary powered equipment*** stands on the floor or ground or sit on a desktop or countertop and cannot be moved while they are operating, and they are normally not moved between operations. Examples include many types of industrial machinery, and office equipment such as cash registers, computers, telephones, photocopiers, etc.

3.8.2 Numbers of Workers and Machines

Another means of classifying worker-machine systems is determining whether one or more workers and one or more machines is required to complete a job. There are four categories of worker-machine systems, as described in Table 3.1.

Table 3.1. Classification of Worker-Machine Systems according to number of machines and workers.

	One Machine	Multiple Machines
One worker	One worker-one machine.	One worker-multiple machines.
	Examples: (1) A worker loading and unloading parts in a machine, (2) A forklift operator driving a forklift.	**Example:** A worker tending several production machines in a U-shaped work cell.
Multiple workers	Multiple workers-one machine.	Multiple workers-multiple machines.
	Examples: (1) A work crew on a ship or airplane, (2) A construction crew building a new stadium.	**Examples:** (1) A maintenance crew responding to machine breakdowns within a factory, (2) A road emergency crew responding to vehicle breakdowns on the interstate.

3.8.3 Level of Operator Attention

Another way to distinguish between worker-machine systems is by the level of attention required by the worker(s), as described in Table 3.2.

Table 3.2. Levels of operator attention in worker-machine systems.

Category	Description	Examples
Full-time attention	Worker is engaged 100% of the time in operating the equipment.	(1) Worker on an assembly line, (2) Truck driver driving an 18-wheeler on the interstate

Part-time attention during each work cycle	Worker is engaged < 100% of the time in operating the equipment.	(1) Worker loading and unloading parts in a machine each cycle, (2) Worker processing work units on a semi-automatic machine.
Part-time attention with regular servicing	Worker services machine at regular intervals that are > one work cycle.	(1) A material handler swapping full pallets of 500 units with empty pallets at a work center, (2) A crane operator moving goods, when needed, at a construction site.
Periodic attention with random servicing	Worker services machine at random intervals that average > one work cycle.	(1) A maintenance worker servicing machine breakdowns that occur at random times, (2) Firefighters responding to alarms that occur at random times.

3.9 Cycle Time Analysis

Cycle time analysis includes two categories of worker-machine systems:

- Systems in which the machine time depends on operator control
    - Mechanic using a pneumatic wrench to tighten lug nuts on a wheel
    - Carpenter using a circular saw to cut lumber
- Systems in which machine time is constant and independent of operator control
    - Metal stamping process
    - Robotic spot-welding process

3.10 Cycle Times with No Overlap Between the Worker and Machine

If there is no overlap in work elements between the worker and the machine, then the normal time for the cycle is the sum of their respective normal times:

$$T_n = T_{nw} + T_m \qquad (3.5)$$

where *Tnw* = normal time of the worker, min; *Tm* = machine cycle time (assumed constant).

To determine the standard time for the cycle, a machine allowance is sometimes added to the machine time. Hence, we have

$$T_{std} = T_{nw}\left(1 + A_{pfd}\right) + T_m(1 + A_m) \qquad (3.6)$$

where *Tnw* = normal time of the worker, min; *Tm* = constant time for the machine, min; *Apfd* = allowance factor for the worker, *Am* = allowance factor for the machine. The allowance factors are expressed as decimal numbers in the formula.

Whereas some companies use a machine allowance factor, such as $A_m = 30\%$, which helps workers achieve higher worker efficiencies, companies that use a machine allowance factor of $A_m = 0\%$ reason that the worker is idle during this portion of the work cycle and, therefore, does not expend any extra effort while idle. Still, some companies prefer to set the A_m value equal to the A_{pfd} value.

Example 9. Worker-Machine System with No Overlap

A wage incentive plan pays workers a daily wage at a rate of $20.00/hr multiplied by the number of hours worked during the shift. One worker-machine task in the plant includes worker-paced elements totaling a normal time of 1.25 minutes and machine-paced elements with a time of 2.00 minutes. The PFD allowance is 15%. Determine the standard time for the task given that Am = 25%.

Solution:

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

$$= 1.25\ min/pc(1 + 0.15) + 2.00\ min/pc(1 + 0.25)$$

$$= 1.438\ min/pc + 2.50\ min/pc$$

$$= 3.938\ min/pc$$

Example 10. Worker-Machine System with Overlap

A worker’s task time is 15.5 minutes, which overlaps with a machine task time of 20 minutes. The PFD allowance is 12%. Determine the standard time for the task given that Am = 10%.

Solution:

$$T_{std} = max\left[T_{nw}\left(1 + A_{pfd}\right), T_m(1 + A_m)\right]$$

$$= max[15.5\ min/pc(1 + 0.12), 20.0\ min/pc(1 + 0.10)]$$

$$= max[17.36\ min/pc, 22.00\ min/pc]$$

$$= 22.00\ min/pc$$

3.11 Cycle Time vs. Production Rate

Production rate, or rate of production, refers to the number of units produced per given time period or the time it takes to produce one unit. Typically, the production rate is expressed as the number of units produced per hour, although it can be expressed as the number of units per minute. Cycle time, Tc, and the production rate, Rp, have an ***inverse*** relationship. That is,

Example 11. Cycle Time/Production Rate Inverse Relationship

If Tc = 6 sec/unit, then what is the production rate?

Solution:

$$R_p = \frac{1}{T_c} = \frac{1}{6\ sec/pc} = \frac{1\ pc}{6\ sec} \times \frac{60\ sec}{min} \times \frac{60\ min}{hr} = 600\ pc/hr$$

Conversely,

If Rp = 600 pc/hr, then what is the cycle time?

Solution:

$$T_c = \frac{1}{R_p} = \frac{1}{600\ pc/hr} = \frac{1\ hr}{600\ pc} = \frac{60\ min}{hr} = \frac{60\ sec}{min} = 6\ sec/unit$$

3.12 Summary

Work measurement metrics are crucial in a manual work production environment as they provide the basis for assessing efficiency, productivity, and overall performance. The detailed descriptions and examples in this chapter illustrate a comprehensive understanding of the various work systems, time measurements, and efficiency calculations in industrial engineering. In a manual work production environment, these work measurement metrics provide the foundation for optimizing operations, enhancing worker productivity, and maintaining competitive production standards.

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References

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[2] Groover, M.P. *Work Systems and the Methods, Measurement, and Management of Work*, Upper Saddle River, NJ: Pearson Prentice Hall, 2007.