CHAPTER 53

Time Standards*

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1. WHY DETERMINE TIME/JOB? 1392
- 1.1. Cost Allocation 1392
- 1.2. Production and Inventory Control 1392
- 1.3. Evaluation of Alternatives 1392
- 1.4. Acceptable Day's Work 1392
- 1.5. Incentive Pay 1392

2. ESTABLISHING TIME STANDARDS 1392
- 2.1. Nonengineered (Type 2) Estimates 1392
  - 2.1.1. Historical Records 1392
  - 2.1.2. Ask Expert 1393
  - 2.1.3. Time Logs 1393
  - 2.1.4. Work (Occurrence) Sampling 1393
- 2.2. Engineering (Type 1) Estimates 1393
  - 2.2.1. Stopwatch Time Study 1393
  - 2.2.2. Standard Data 1393

3. ADJUSTMENTS TO TIME: ALLOWANCES 1394
- 3.1. Three Levels of Time 1394
- 3.2. Personal Allowances 1394
- 3.3. Fatigue Allowances 1394
  - 3.3.1. Physical: Physical Fatigue 1395
  - 3.3.2. Physical: Short Cycle 1395
  - 3.3.3. Physical: Static Load (Body Posture) 1395
  - 3.3.4. Physical: Restrictive Clothing 1395
  - 3.3.5. Mental: Concentration/Anxiety 1395
  - 3.3.6. Mental: Monotony 1395
  - 3.3.7. Environmental: Climate 1395
  - 3.3.8. Environmental: Dust, Dirt, and Fumes 1395
  - 3.3.9. Environmental: Noise and Vibration 1398
  - 3.3.10. Environmental: Eye Strain 1398
  - 3.3.11. Overview of Fatigue Allowances 1398
- 3.4. Delay Allowances 1398

4. ADJUSTMENTS TO TIME: LEARNING 1400
- 4.1. Learning 1400
  - 4.1.1. Individual Learning 1400
  - 4.1.2. Organization Learning (Manufacturing Progress) 1400
  - 4.1.3. Quantifying Improvement 1400
  - 4.1.4. Typical Rates for Organization Progress 1404
  - 4.1.5. Typical Values for Learning 1405
  - 4.1.6. Example Applications of Learning 1405

5. DOCUMENTING, USING, AND MAINTAINING STANDARDS 1406
- 5.1. Documenting Standards 1406
- 5.2. Using Standards 1406
  - 5.2.1. Reports 1406
  - 5.2.2. Consequences of Not Making Standard 1406
- 5.3. Maintaining Standards (Auditing) 1407

REFERENCES 1407

* This chapter is a concise version of the material in Konz and Johnson (2000).

Handbook of Industrial Engineering: Technology and Operations Management, Third Edition.
Edited by Gavriel Salvendy

1. WHY DETERMINE TIME/JOB?

It is useful to know the direct labor cost/unit, especially when the job is repetitive. Five typical applications are:

1. Cost allocation
2. Production and inventory control
3. Evaluation of alternatives
4. Acceptable day's work
5. Incentive pay

1.1. Cost Allocation

To determine cost/unit, you need the direct material cost, the direct labor cost, and various miscellaneous costs (called overhead or burden). Direct labor cost is (direct labor time)(wage cost/hr). So you need to determine how long the job takes. But, in addition, overhead costs usually are allocated as a percentage of direct labor (e.g., overhead is 300% of direct labor cost). So again you need direct labor time. Without good estimates of the cost of production to compare vs. selling price, you don't know your profit/unit (it may even be negative!). The goal is to improve and control costs through better information.

1.2. Production and Inventory Control

Without time/unit, you can not schedule or staff (i.e., use management information systems). How many people should be assigned to the job? When should production start in order to make the due date and thus avoid stockouts?

1.3. Evaluation of Alternatives

Without time/unit, you can not compare alternatives. Should a mechanic repair a part or replace it with a new one? Is it worthwhile to use a robot that takes 10 seconds to do a task?

1.4. Acceptable Day's Work

Sam picked 1600 items from the warehouse today—is that good or bad? Supervisors would like to be able to compare actual performance to expected performance. Many applications of standards to repetitive work have shown improvement in output of 30% or more when measured daywork systems are installed in place of nonengineered standards. Output increases about 10% more when a group incentive payment is used and 20% more when an individual incentive is used.

1.5. Incentive Pay

A minority of firms use the pay-by-results (the carrot) approach. If you produce 1% more, you get paid 1% more. This works for the firm because even though direct labor cost/unit stays constant, overhead costs do not increase and thus total cost/unit decreases.

2. ESTABLISHING TIME STANDARDS

There are two basic strategies: nonengineered (subjective) standards (''did take'' times) and engineered (objective) standards (''should take'' times). The techniques to use depend upon the cost of obtaining the information and the benefits of using the information.

2.1. Nonengineered (Type 2) Estimates

''Quick and dirty'' information can be obtained at low cost. But using ''dirty'' information increases the risk of errors in decisions. Since nonengineered standards are not preceded by methods or quality analysis, they are ''did take'' times, not ''should take'' times.

There are four approaches: historical records, ask expert, time logs, and work (occurrence) sampling.

2.1.1. Historical Records

Standards from historical records tend to be very ''dirty'' (although cheap). For example, in the warehouse, how many cases can be picked per hour? From shipping records, determine the number of cases shipped in January, February, and March. From personnel, determine the number of employees in shipping in each month. Divide total cases/total hours to get cases/hr. Ignore changes in product output, product mix, absenteeism, delays, and so on.

2.1.2. Ask Expert

Here you ask a knowledgeable expert how long a job will take. For example, ask the maintenance supervisor how long it will take to paint a room. Ask the sales supervisor how many customers can be contacted per week. A serious problem is that the expert may have an interest in the answer. For example, a "hungry" maintenance supervisor wants work for his group and so quotes a shorter painting time; a sales supervisor may be able to hire more staff (and thus increase her prestige and power) by giving a low estimate of customers/sales representative.

2.1.3. Time Logs

It may be that a job is "cost plus" and so the only problem is how many hours to charge to a customer. For example, an engineer might write down, for Monday, 4.0 hr for project A, 2.5 hr for B, and 3.5 hr for C. Obviously there are many potential errors here (especially if work is done on project D, for which there no longer is any budget).

2.1.4. Work (Occurrence) Sampling

This technique is described in more detail in Chapter 54. It is especially useful when a variety of jobs are done intermittently (e.g., as in maintenance or office work). Assume that during a three-week period a maintainer spends 30% of the time doing carpentry, 40% painting, and 30% miscellaneous; this means 120 hr $\times$ 0.4 = 48 hr for painting. During the three-week period, 10,000 ft^2 of wall were painted or 10,000/48 = 208 ft^2/hr. Note that the work method used, work rate, delays, production schedule, and so on are not questioned.

2.2. Engineering (Type 1) Estimates

Engineered estimates of time must be preceded by a methods and quality analysis; the result is a "should take" time, not a "did take" time. MIL-STD-1567A requires for all individual type 1 standards (assuming the basic standards system is in place):

1. Documentation that the method was analyzed before time was determined
2. A record of the method or standard practice followed when the time standard was developed
3. A record of rating (if time study was used)
4. A record of the observed times (if time study) or predetermined time values were used
5. A record of the computations of standard time, including allowances

You would not expect a time standard established in 1960 to be valid today; things are different now, we think. But what differs? Thus, step 2 (record of method followed) is essential information for maintaining standards.

There are two basic ways of determining time/job: stopwatch time study and standard data.

2.2.1. Stopwatch Time Study

Stopwatch time study, which is described in detail in Chapter 54, requires an operator to do the operation; thus it cannot be done ahead of production. In general, it requires the operator to do the operation over and over rather than doing different tasks intermittently (such as might be done in office or maintenance work). Before the timing is done, the method must be analyzed.

In repetitive work, where detailed methods analysis is desired, a videotape of the task can be made; the analyst can study the tape instead of a live operator.

Because of learning, do not do time studies on operators who are early on the learning curve. If the study must be done early, label it temporary and restudy it in, say 30 days.

2.2.2. Standard Data

Standard data can be at the micro level or the macro level (see Chapter 54). In this approach, the analyst visualizes what the job entails (a danger is that the analyst may not think of some of the steps [elements] needed to complete the job). After determining the method, the analyst uses a table or formula to determine the amount of time for each element. The database elements are expressed in normal time (i.e., rating is included), so no additional rating is required. Then normal time is increased with allowances to obtain standard time.

Compared with time study, the standard data method has three advantages: (1) cost of determining a standard is low (assuming you have a database with standard times); (2) consistency is high because everyone using the database should get the same times; and (3) ahead-of-production standards are helpful in many planning activities. But among these three roses are two thorns: (1) you may not have the money to build the database (the databases are built from stopwatch studies and predetermined times); and (2) the analyst must imagine the work method; even experienced analysts may overlook some details or low-frequency elements.

3. ADJUSTMENTS TO TIME: ALLOWANCES

3.1. Three Levels of Time

Time is reported at three levels:

1. *Observed time:* The raw (unadjusted) time taken by the worker. It does not have any rating, allowance or learning adjustment.
2. *Normal time:*

$$\text{Normal time} = (\text{observed time})(\text{rating})$$

   The observer estimates the pace of the worker in relation to normal pace. Normal time is the time an experienced operator takes when working at a 100% pace. See Chapter 54 for more details.
3. *Standard time:* For allowances expressed as a percent of shift time:

$$\text{Standard time} = \text{normal time}/(1 - \text{allowances})$$

   For allowances expressed as a percent of work time:

$$\text{Standard time} = \text{normal time } (1 + \text{allowances})$$

   It is a policy decision by the firm whether to give allowances as a percent of shift or work time. Normal time needs to be increased from standard time by personal, fatigue, and delay allowances.

3.2. Personal Allowances

Personal allowances are given for such things as blowing your nose, going to the toilet, getting a drink of water, smoking, and so on. They do not vary with the task but are the same for all tasks in the firm. There is no scientific or engineering basis for the percent to give. Values of 5% (24 minutes in a 480-minute day) seem to be typical.

Most firms have standardized break periods (coffee breaks)—for example, 10 minutes in the first part of the shift and the same in the second part. It is not clear whether most firms consider this time as part of the personal allowance or in addition to it.

The midshift meal break (lunch) is another question. This 20–60-minute break obviously permits the worker to attend to personal needs and recover from fatigue. Yet lunch usually is not considered as part of allowances—even if the lunch period is paid.

Some firms give an additional break if work is over 8 hours. For example, if a shift is over 10 hours, there is an additional break of 10 minutes after the 9th hour.

In addition, some firms give an additional allowance to all workers for cleanup (either of the person or the machine), putting on and taking off of protective clothing, or travel. In mines, the travel allowance is called portal-to-portal pay; pay begins when the worker crosses the mine portal, even though the worker will not arrive at the working surface until some time later.

3.3. Fatigue Allowances

The rationale of fatigue allowances is to compensate the person for the time lost due to fatigue. In contrast to personal allowances, which are given to everyone, fatigue allowances are given only for cause—for fatigue. No fatigue? Then no fatigue allowance!

Another challenge is the concept of machine time. With the increasing capabilities of servomechanisms and computers, many machines operate semiautomatically (operator is required only to load/unload the machine) or automatically (machine loads, processes, and unloads). During the machine time of the work cycle, the operator may be able to drink coffee (personal allowance) or talk to the supervisor (delay allowance) or recover from fatigue. Thus, as a general principle, give a fatigue allowance only for the portion of the work cycle outside the machine time.

The following will discuss the fatigue allowances developed by the International Labor Organization (ILO 1992). They were supplied by a British consulting firm. Use of the ILO values is complex. Remembering that fatigue allowances are given for work time only (not machine time), sum the applicable fatigue allowance points. Then, using Table 1, convert points to percent time. For a more detailed discussion of allowances, see Konz and Johnson (2000, chap. 32).

The fatigue factors are grouped into three categories: physical, mental, and environmental.

3.3.1. Physical: Physical Fatigue

Table 2 shows how the ILO makes a distinction among carrying loads, lifting loads, and force applied. In the NIOSH lifting guideline, the lift origin and destination, frequency of move, angle, and container are considered as well as load.

3.3.2. Physical: Short Cycle

Table 3 gives the fatigue allowance to allow time for the muscles to recover.

3.3.3. Physical: Static Load (Body Posture)

Table 4 gives the allowance for poor posture.

3.3.4. Physical: Restrictive Clothing

Table 5 gives the allowance for restrictive clothing.

3.3.5. Mental: Concentration/Anxiety

Table 6 gives the allowance for concentration/anxiety.

3.3.6. Mental: Monotony

Table 7 gives the allowance for monotony. In the author's opinion, allowances for monotony, boredom, lack of a feeling of accomplishment, and the like are questionable. These factors are unlikely to cause fatigue and thus increase time/cycle. These factors primarily reflect unpleasantness and thus should be reflected in the wage rate/hr rather than the time/unit.

3.3.7. Environmental: Climate

Table 8 gives the allowance for climate.

3.3.8. Environmental: Dust, Dirt, and Fumes

Table 9 gives the allowance for dust, dirt and fumes.

TABLE 1 Conversion from Points Allowance to Percent Allowance for ILO

Points	0	1	2	3	4	5	6	7	8	9
0	10	10	10	10	10	10	10	11	11	11
10	11	11	11	11	11	12	12	12	12	12
20	13	13	13	13	14	14	14	14	15	15
30	15	16	16	16	17	17	17	18	18	18
40	19	19	20	20	21	21	22	22	23	23
50	24	24	25	26	26	27	27	28	28	29
60	30	30	31	32	32	33	34	34	35	36
70	37	37	38	39	40	40	41	42	43	44
80	45	46	47	48	48	49	50	51	52	53
90	54	55	56	57	58	59	60	61	62	63
100	64	65	66	68	69	70	71	72	73	74
110	75	77	78	79	80	82	83	84	85	87
120	88	89	91	92	93	95	96	97	99	100
130	101	103	105	106	107	109	110	112	113	115
140	116	118	119	121	122	123	125	126	128	130

From International Labour Office, *Introduction to Work Study,* 4th (Rev.) Ed., pp. 491–498. Copyright © International Labour Organization 1992.

The second column (0) gives the 10s, and the remaining columns give the units. Thus, 30 points (0 column) = 15%; 31 points (1 column) = 16%; 34 points = 17%. The percent allowance is for manual work time (not machine time) and includes 5% personal time for coffee breaks.

TABLE 2 Carrying, Lifting, and Body Force Allowances

Weight or Force, kg	Push Points	Carry Points	Lift Points
1	0	0	0
2	5	5	10
3	8	9	15
4	10	13	18
5	12	15	21
6	14	17	23
7	15	20	26
8	17	21	29
9	19	24	32
10	20	26	34
11	21	29	37
12	23	31	40
13	25	33	44
14	26	34	46
15	27	36	50
16	28	39	50
17	30	40	53
18	32	42	56
19	33	44	58
20	34	46	60

From International Labour Office, *Introduction to Work Study,* 4th (Rev.) Ed., pp. 491–498.

The ILO tables go to 64 kg. Push includes foot pedal push and carry on the back. Carry includes hand carry and swinging arm movements. Weight is averaged over time. A 15 kg load lifted for 33% of a cycle is 5 kg.

TABLE 3 Short-Cycle Allowances

Points	Cycle Time, min
1	0.16–0.17
2	0.15
3	0.13–0.14
4	0.12
5	0.10–0.11
6	0.08–0.09
7	0.07
8	0.06
9	0.05
10	Less than 0.05

From International Labour Office, *Introduction to Work Study,* 4th (Rev.) Ed., pp. 491–498.

TABLE 4 Posture Allowances

Points	Activity
0	Sitting easily
2	Sitting awkwardly or mixed sitting and standing
4	Standing or walking freely
5	Ascending or descending stairs, unladen
6	Standing with a load; walking with a load
8	Climbing up or down ladders; some bending, lifting, stretching, or throwing
10	Awkward lifting; shoveling ballast to container
12	Constant bending, lifting, stretching, or throwing
16	Coal mining with pickaxes; lying in low seam

From International Labour Office, *Introduction to Work Study,* 4th (Rev.) Ed., pp. 491–498.

TABLE 5 Restrictive Clothing Allowances

Points	Clothing
1	Thin rubber (surgeon's) gloves
2	Household rubber gloves; rubber boots
3	Grinder's goggles
5	Industrial rubber or leather gloves
8	Face mask (e.g., for paint spraying)
15	Asbestos suit or tarpaulin coat
20	Restrictive protective clothing and respirator

ILO (1979) considers clothing weight in relation to effort and movement. Also consider whether it affects ventilation and breathing.

From International Labour Office, *Introduction to Work Study,* 4th (Rev.) Ed., pp. 491–498. Copyright © International Labour Organization 1992.

TABLE 6 Concentration/Anxiety Allowances

Allowance Points	Degree
0	Routine, simple assembly; shoveling ballast
1	Routine packing, washing vehicles, wheeling trolley down clear gangway
2	Feed press tool (hand clear of press); topping up battery
3	Painting walls
4	Assembling small and simple batches (performed without much thinking); sewing machine work (automatically guided)
5	Assembling warehouse orders by trolley; simple inspection
6	Load/unload press tool; hand feed into machine; spraypainting metalwork
7	Adding up figures; inspecting detailed components
8	Buffing and polishing
10	Guiding work by hand on sewing machine; packing assorted chocolates (memorizing patterns and selecting accordingly); assembly work too complex to become automatic; welding parts held in jig
15	Driving a bus in heavy traffic or fog; marking out in detail with high accuracy

From International Labour Office, *Introduction to Work Study,* 4th (Rev.) Ed., pp. 491–498. Copyright © International Labour Organization 1992.

ILO (1979) considers what would happen if the operator were to relax attention, responsibility, need for exact timing, and accuracy or precision required.

TABLE 7 Monotony Allowances

Allowance Points	Degree
0	Two people on jobbing work
3	Cleaning own shoes for 0.5 hr on one's own
5	Operator on repetitive work; operator working alone on nonrepetitive work
6	Routine inspection
8	Adding similar columns of figures
11	One operator working alone on highly repetitive work

From International Labour Office, *Introduction to Work Study,* 4th (Rev.) Ed., pp. 491–498. Copyright © International Labour Organization 1992.

ILO (1979) considers the degree of mental stimulation and whether there is companionship, competitive spirit, music, and so on.

TABLE 8 Climate Allowances

Points for Temperature/Humidity			
	Temperature, °C		
Humidity, %	Up to 24	24–32	Over 32
Up to 75	0	6–9	12–16
76–85	1–3	8–12	15–26
Over 85	4–6	12–17	20–36

Points	Wet
0	Normal factory operations
1	Outdoor workers (e.g., postman)
2	Working continuously in the damp
4	Rubbing down walls with wet pumice block
5	Continuous handling of wet articles
10	Laundry washhouse, wet work, steamy, floor running with water, hands wet

Points	Ventilation
0	Offices; factories with office-type conditions
1	Workshop with reasonable ventilation but some drafts
3	Drafty workshops
14	Working in sewer

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ILO (1979) considers temperature/humidity, wet, and ventilation. For temperature/humidity, use the average environmental temperature. For wet, consider the cumulative effect over a long period. For ventilation, consider quality/freshness of air and its circulation by air conditioning or natural movement.

3.3.9. Environmental: Noise and Vibration

Table 10 gives the allowance for noise and vibration.

3.3.10. Environmental: Eye Strain

Table 11 gives the allowance for eye strain.

3.3.11. Overview of Fatigue Allowances

In general, the fatigue allowances seem to have inadequate range. In addition, note from Table 1 that points are not converted one for one to percent. A person with 0 points for fatigue gets a 10% fatigue allowance. A person with 30 points gets a 15% fatigue allowance—an increase of only 5%.

In addition, neither the length of the workday nor the number of days/week is specified. Presumably it is 8 hr/day and 5 days/week. The author does not recommend changing the allowance for working a shorter or longer time period. Any adjustment should be in the discipline level (see Section 5.2.2).

3.4. Delay Allowances

Delay allowances should vary with the task but not the operator. They compensate for machine breakdowns, interrupted material flow, conversations with supervisors, machine maintenance and cleaning, and so on. If the delay is long (e.g., 30 minutes), the operator clocks out (records the start and stop time of the delay on a form) and works on something else during the clocked-out time. Delays usually permit the operator to take some personal time and reduce fatigue; that is, they also serve as personal allowances and fatigue allowances.

How do you set a delay allowance? One possibility is to record the delays during a work sampling study or time study. For example, if there were 4 minutes of delay during 100 minutes of time study, then 4% could be used for the delay allowance.

Errors in delay allowances can occur from poor sampling or changing conditions.

To obtain a valid sample of delays, the sample must represent the total shift, not just the middle of the shift. That is, the delays must be observed at the start and stop of the shift and just before and after lunch and coffee breaks, in addition to the middle of the shift. Also observe delays on the second and third shifts.

TABLE 9 Dust, Dirt, and Fumes Allowances

Points	Dust
0	Office, normal light assembly, press shop
1	Grinding or buffing with good extraction
2	Sawing wood
4	Emptying ashes
6	Finishing weld
10	Running coke from hoppers into skips or trucks
11	Unloading cement
12	Demolishing building
Points	**Dirt**
0	Office work, normal assembly operations
1	Office duplicators
2	Dustman (garbage collector)
4	Stripping internal combustion engine
5	Working under old motor vehicle
7	Unloading bags of cement
10	Coal miner; chimneysweep with brushes
Points	**Fumes**
0	Lathe tuning with coolants
1	Emulsion paint, gas cutting, soldering with resin
5	Motor vehicle exhaust in small commercial garage
6	Cellulose painting
10	Molder procuring metal and filling mold

From International Labour Office, *Introduction to Work Study,* 4th (Rev.) Ed., pp. 491–498.

For dust, consider both volume and nature of the dust. The dirt allowance covers ''washing time'' where this is paid for (e.g., 3 min for washing). Do not allow both time and points. For fumes, consider the nature and concentration; whether toxic or injurious to the health; irritating to eyes, nose, throat, or skin; odor.

TABLE 10 Noise and Vibration Allowances

Points	Noise Category
0	Working in a quiet office, no distracting noise; light assembly work
1	Work in a city office with continual traffic noise outside
2	Light machine shop; office or assembly shop where noise is a distraction
4	Woodworking machine shop
5	Operating steam hammer in forge
9	Riveting in a shipyard
10	Road drilling
Points	**Vibration Category**
1	Shoveling light materials
2	Power sewing machine; power press or guillotine if operator is holding the material; cross-cut sawing
4	Shoveling ballast; portable power drill operated by one hand
6	Pickaxing
8	Power drill (2 hands)
15	Road drill on concrete

From International Labour Office, *Introduction to Work Study,* 4th (Rev.) Ed., pp. 491–498.

ILO (1979) considers whether the noise affects concentration, is a steady hum or a background noise, is regular or occurs unexpectedly, is irritating or soothing. Consider the impact of the vibration on the body, limbs, or hands and the addition to mental effort as a result, or to a series of jars or shocks.

TABLE 11 Eye Strain Allowances

Points	Eye Strain Category
0	Normal factory work
2	Inspection of easily visible faults; sorting distinctively colored articles by color; factory work in poor lighting
4	Intermittent inspection for detailed faults; grading apples
8	Reading a newspaper in a bus
10	Continuous visual inspection (cloth from a loom)
14	Engraving using an eyeglass

From International Labour Office, *Introduction to Work Study,* 4th (Rev.) Ed., pp. 491–498. Copyright © International Labour Organization 1992.

ILO (1979) considers the lighting conditions, glare, flicker, illumination, color, and closeness of work and for how long strain is endured.

Conditions change over time. A reasonable procedure is to give delay allowances an expiration date, for example, two years after being set. After two years, they must be redetermined.

4. ADJUSTMENTS TO TIME: LEARNING

4.1. Learning

Failure to adjust standard time for learning is the primary cause of incorrect times. Learning occurs both in the individual and in the organization.

4.1.1. Individual Learning

Individual learning is improvement in time/unit even though neither the product design nor the tools and equipment change. The improvement is due to better eye–hand coordination, fewer mistakes, and reduced decision time.

4.1.2. Organization Learning (Manufacturing Progress)

This is improvement with changing product design, changing tools and equipment, and changing work methods; it also includes individual learning. Often it is called manufacturing progress.

Consider the server Maureen serving breakfast. During the individual learning period, she learned where the coffeepot and cups were, the prices of each product, and so on. The amount of time she took declined to a plateau. Then management set a policy to serve coffee in cups without saucers and furnish cream in sealed, one-serving containers so the container need not be carried upright. These changes in product design reduced time for the task. Other possible changes might include a coffeepot at each end of the counter. A different coffeepot might have a better handle so less care is needed to prevent burns. The organization might decide to have the server leave the bill when the last food item is served. Organization progress comes from three factors: operator learning with existing technology, new technology, and substitution of capital for labor.

Point 1 was just discussed. Examples of new technology are the subsurface bulblike nose on the front of tankers (which increased tanker speed at very low cost) and solid-state electronics. Moore's law states that the number of transistors on a given chip size (roughly a gauge of chip performance) doubles every 1.5–2 years. Some example numbers are 3,500 transistors/chip in 1972, 134,000 in 1982, 3,100,000 in 1993, and 7,500,000 in 1997.

Use of two coffee pots by Maureen is an example of substituting capital for labor. Another example is the use of the computer in the office, permitting automation of many office functions. The ratio of capital/labor also can be improved by economies of scale. This occurs when equipment with twice the capacity costs less than twice as much. Then capital cost/unit is reduced and fewer work hours are needed/unit of output.

4.1.3. Quantifying Improvement

"Practice makes perfect" has been known for a long time. Wright (1936) took a key step when he published manufacturing progress curves for the aircraft industry. Wright made two major contributions. First, he quantified the amount of manufacturing progress for a specific product. The equation was of the form Cost = a (number of airplanes)^b; (see Figure 1). But the second step was probably even more important: he made the data a straight line (by putting the curve in the axis!) (see Figure 2). That is, the data is on a log–log scale.

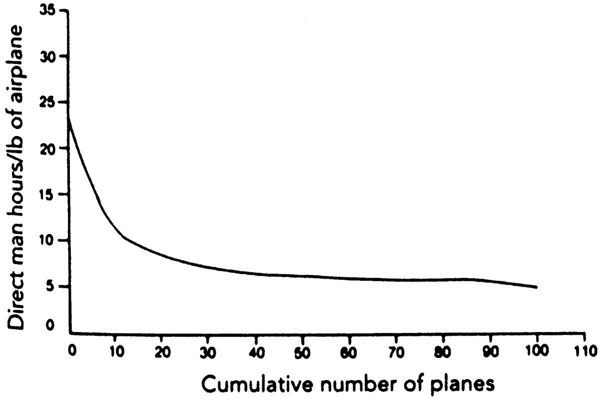

Figure 1 Practice Makes Perfect. As more and more units are produced, the fixed cost is divided by more and more units, so fixed cost/unit declines. In addition, variable cost/unit declines because fewer mistakes are made, less time is spent looking up instructions, better tooling is used, and so on. The variable cost data usually can be fitted with an equation of the form $y = ax^b$. (From *Work Design: Industrial Ergonomics,* 5th Ed., by S. Konz and S. Johnson. Copyright © 2000 by Holcomb Hathaway, Pub., Scottsdale, AZ. Reprinted with permission.)

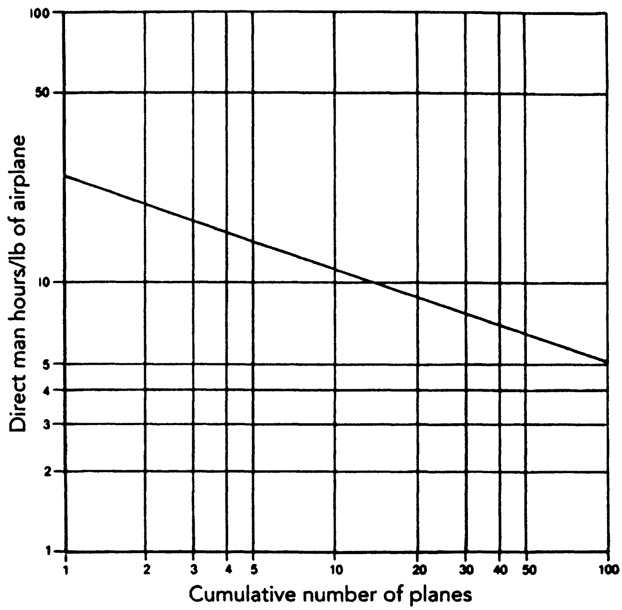

Figure 2 Log–Log Scale. Supervisors like straight lines. Plotting $y = ax^b$ on log–log paper gives a straight line. The key piece of information supervisors desire is the rate of improvement—the slope of the line. The convention is to refer to reduction with doubled quantities. If quantity $x_1 = 8$, the quantity $x_2 = 16$. Then if cost at x_1 is $y_1 = 100$ and cost at x_2 is $y_2 = 80$, this is an 80% curve. (From *Work Design: Industrial Ergonomics,* 5th Ed., by S. Konz and S. Johnson. Copyright © 2000 by Holcomb Hathaway, Pub., Scottsdale, AZ. Reprinted with permission.)

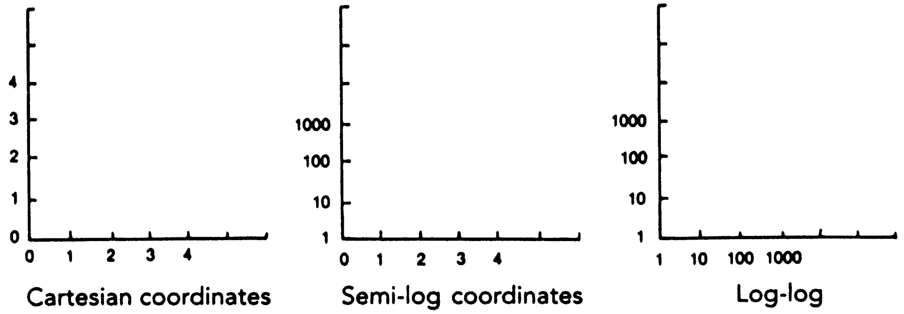

Figure 3 Cartesian Coordinates, Semi-Log Coordinates, and Log–Log Coordinates. Cartesian coordinates have equal distances for equal numerical differences; that is, the linear difference from 1 to 3 is the same as from 8 to 10. On a log scale, the same distance represents a constant *ratio*; that is, the distance from 2 to 4 is the same as from 30 to 60 or 1000 to 2000. Semi-log paper has one axis Cartesian and one axis log. Log–log (double log) paper has a log scale on both axes. (From *Work Design: Industrial Ergonomics,* 5th Ed., by S. Konz and S. Johnson. Copyright © 2000 by Holcomb Hathaway, Pub., Scottsdale, AZ. Reprinted with permission.)

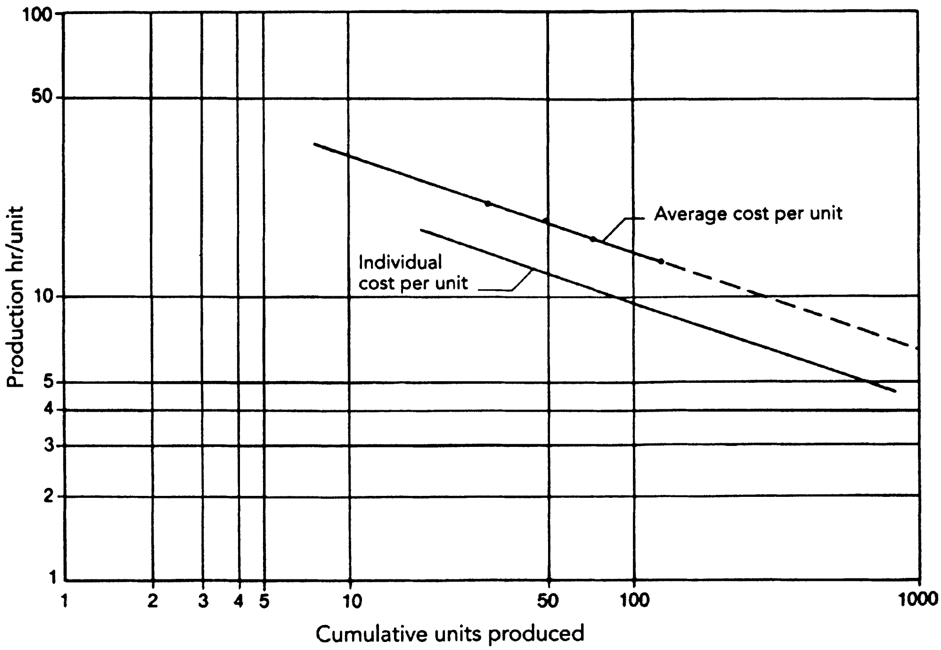

Figure 4 Average Cost/Unit from Table 12. Table 12 gives a 79% curve. Cost/unit is the cost of the *n*th unit; average cost/unit is the sum of the unit costs/*n*. Cost/unit can be estimated by multiplying average cost/unit by the factor from Table 12. The average cost of the first 20 units is estimated as 25.9 from the fitted line; the cost of the 20th unit is 25.9(0.658) = 17.0 hr. (From *Work Design: Industrial Ergonomics,* 5th Ed., by S. Konz and S. Johnson. Copyright © 2000 by Holcomb Hathaway, Pub., Scottsdale, AZ. Reprinted with permission.)

TABLE 12 Factors for Various Improvement Curves

Improvement Curve, % Between Doubled Quantities	Learning Factor, *b*, For Curve $y = ax^b$	Multiplier to Determine Unit Cost if Average Cost Is Known	Multiplier to Determine Average Cost if Unit Cost Is Known
70	−0.515	0.485	2.06
72	−0.474	0.524	1.91
74	−0.434	0.565	1.77
76	−0.396	0.606	1.65
78	−0.358	0.641	1.56
80	−0.322	0.676	1.48
82	−0.286	0.709	1.41
84	−0.252	0.746	1.34
85	−0.234	0.763	1.31
86	−0.218	0.781	1.28
88	−0.184	0.813	1.23
90	−0.152	0.847	1.18
92	−0.120	0.877	1.14
94	−0.089	0.909	1.10
95	−0.074	0.926	1.08
96	−0.059	0.943	1.06
98	−0.029	0.971	1.03

The multipliers in columns 3 and 4 are large-quantity approximations. For example, for a 90% curve, the table value in column 4 is 1.18. A more precise value at a quantity of 10 = 1.07, at 50 = 1.13, and at 100 = 1.17. A more precise value for an 85% curve at a quantity of 100 = 1.29; a more precise value for a 95% curve at a quantity of 100 = 1.077.

TABLE 13 Time and Completed Units as They Might Be Reported for a Product

Month	Units Completed (Pass Final Inspection)	Month's Direct Labor Hours Charged To Project	Cumulative Units Completed	Cumulative Work Hours Charged to Project	Average Work hr/unit
March	14	410	14	410	29.3
April	9	191	23	601	26.1
May	16	244	39	845	21.7
June	21	284	60	1129	18.8
June	24	238	84	1367	16.3
August	43	401	127	1708	13.4

On a log scale, the physical distance between doubled quantities is constant (i.e., 8 to 16 is the same distance as 16 to 32 or 25 to 50) (see Figure 4). Wright gave the new cost as a percent of the original cost when the production quantity had doubled. If cost at unit 10 was 100 hr and cost at unit 20 was 85 hr, then this was an 85/100 = 85% curve. Since the curve was a straight line, it was easy to calculate the cost of the 15th or the 50th unit. If you wish to solve the $Y = ax^b$ equation instead of using a graph (calculators are much better now than in 1935), see Table 12.

For example, assume the time for a (i.e., cycle 1)= 10 min and there is a 90% curve (i.e., $b = -0.152$), then the time for the 50th unit is: $Y = 10\ (50)^{-0.152} = 10/(50)^{0.152} = 5.52$ min.

Table 13 shows how data might be obtained for fitting a curve. During the month of March, various people wrote down on charge slips a total of 410 hours against this project charge number.

The average work hours/unit during March then becomes 29.3. The average x-coordinate is (1 + 14)/2 = 7.5. Because the curve shape is changing so rapidly in the early units, some authors recommend plotting the first lot at the 1/3 point[(1 + 14)/3] and points for all subsequent lots at the midpoint.

During April, 9 units passed final inspection and 191 hours were charged against the project. Cumulative hours of 601 divided by cumulative completed output of 23 gives average hr/unit of 26.1. The 26.1 is plotted at (15 + 23)/2 = 19. As you can see from the example data, there are many possible errors in the data, so a curve more complex than a straight line on log–log paper is not justified. Figure 4 shows the resulting curve.

Although average cost/unit is what is usually used, you may wish to calculate cost at a specific unit. Conversely, the data may be for specific units and you may want average cost. Table 12 gives the multiplier for various slopes. The multipliers are based on the fact that the average cost curve and the unit cost curve are parallel after an initial transient. Initial transient usually is 20 units, although it could be as few as 3. The multiplier for a 79% slope is (0.641 + 0.676)/2 = 0.658. Thus, if we wish to estimate the cost of the 20th unit, it is (24.9 hr)(0.658) = 16.4 hr.

Cost/unit is especially useful in scheduling. For example, if 50 units are scheduled for September, then work-hr/unit (for a 79% curve) at unit 127 = (13.4)(0.656) = 8.8 and at unit 177 = 7.8. Therefore between 390 and 440 hours should be scheduled.

Looking at Figure 4, you can see that the extrapolated line predicts cost/unit at 200 to be 11.4 hr, at 500 to be 8.3, and at 1,000 to be 6.6. If we add more cycles on the paper, the line eventually reaches a cost of zero at cumulative production of 200,000 units. Can cost go to zero? Can a tree grow to the sky? No.

The log–log plot increases understanding of improvement, but it also deceives. Note that cost/unit for unit 20 was 24.9 hr. When output was doubled to 40 units, cost dropped to 19.7; doubling to 80 dropped cost to 15.5; doubling to 160 dropped cost to 12.1; doubling to 320 dropped cost to 9.6; doubling to 640 dropped cost to 7.6. Now consider the improvement for each doubling. For the first doubling from 20 to 40 units, cost dropped 5.20 hr or 0.260 hr/unit of extra experience. For the next doubling from 40 to 80, cost dropped 4.2 hr or 0.105 hr/unit of extra experience. For the doubling from 320 to 640, cost dropped 2.0 hr or 0.006 hr/unit of extra experience. In summary, the more experience, the more difficult it is to show additional improvement.

Yet the figures would predict zero cost at 200,000 units, and products just aren't made in zero time. One explanation is that total output of the product, in its present design, is stopped before 200,000 units are produced. In other words, if we no longer produce Model T's and start to produce Model A's, we start on a new improvement curve at zero experience. A second explanation is that the effect of improvement in hours is masked by changes in labor wages/hr. The Model T Ford had a manufacturing progress rate of 86%. In 1910, when 12,300 Model T Fords had been built, the price was $950. When it went out of production in 1926 after a cumulative output of 15,000,000, the price was $270; $200 in constant prices plus inflation of $70.

The third explanation is that straight lines on log–log paper are not perfect fits over large ranges of cycles. If output is going to go to 1,000,000 cumulative units over a 10-year period, you really shouldn't expect to predict the cost of the 1,000,000th unit (which will be built 10 years from the start) from the data of the first 6 months. There is too much change in economic conditions, managers, unions, technology and other factors. Anyone who expects the future to be perfectly predicted by a formula has not yet lost money in the stock market.

4.1.4. Typical Values for Organization Progress

The rate of improvement depends on the amount that can be learned. The more that can be learned, the more will be learned. The amount that can be learned depends upon two factors: (1) amount of previous experience with the product and (2) extent of mechanization. Table 14 gives manufacturing progress as a function of the manual/machine ratio. Allemang (1977) estimates percent progress from

TABLE 14 Prediction of Manufacturing Progress

Percent of Task Time		
Manual	Machine	Manufacturing Progress, %
25	75	90
50	50	85
75	25	80

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product design stability, a product characteristics table (complexity, accessability, close tolerances, test specifications, and delicate parts), parts shortage, and operator learning.

Konz and Johnson (2000) have two detailed tables giving about 75 manufacturing progress rates reported in the literature.

4.1.5. Typical Values for Learning

Assume learning has two components: (1) cognitive learning and (2) motor learning (Dar-El et al. 1995a, b). Cognitive learning has a greater improvement (say 70% curve), while motor learning is slower (say 90% curve). For a task with both types, initially the cognitive dominates and then the motor learning dominates. Use values of 70% for ''pure cognitive,'' 72.5% for ''high cognitive,'' 77.5% for ''more cognitive than motor,'' 82.5% for ''more motor than cognitive,'' and 90% for ''pure motor.'' Konz and Johnson (2000) give a table of 43 tasks for which learning curves have been reported.

The improvement takes place through reduction of fumbles and delays rather than greater movement speed. Stationary motions such as position and grasp improve the most while reach and move improve little. It is reduced information-processing time rather than faster hand speed that affects the reduction.

The range of times and the minimum time of elements show little change with practice. The reduction is due to a shift in the distribution of times; the shorter times are achieved more often and the slower times less often—''going slowly less often'' (Salvendy and Seymour 1973).

The initial time for a cognitive task might be 13–15 times the standard time; the initial time for a manual task might be 2.5 times the standard time.

4.1.6. Example Applications of Learning

Table 15 shows the effect of learning/manufacturing progress on time standards. The fact that labor hr/unit declines as output increases makes computations using the applications of standard time more complicated. Ah, for the simple life!

4.1.6.1. Cost Allocation Knowing what your costs are is especially important if you have a make–buy decision or are bidding on new contracts. If a component is used on more than one product (standardization), it can progress much faster on the curve since its sales come from multiple sources. Manufacturing progress also means that standard costs quickly become obsolete.

Note that small lots (say due to a customer emergency) can have very high costs. For example, if a standard lot size is 100 and labor cost is 1 hr/unit and there is a 95% curve, a lot of 6 would have a labor cost about 23% higher (1.23 hr/unit). Consider charging more for special orders!

4.1.6.2. Scheduling Knowing how many people are needed and when is obviously an important decision. Also, learning/manufacturing progress calculations will emphasize the penalties of small lots.

4.1.6.3. Evaluation of Alternatives When alternatives are being compared, a pilot project might be run. Data might be obtained for 50–100 cycles. Note that the times after the pilot study should be substantially shorter due to learning. In addition, the learning/manufacturing progress rate for alternatives A and B might differ so that what initially is best will not be best in the long run.

TABLE 15 Demonstration of the Learning Effect on Time Standards

Learning Curve, %	Time/Unit at			Percent of Standard at		
	2X	4X	32X	2X	4X	32X
98	0.98	0.96	0.90	102	104	111
95	0.95	0.90	0.77	105	111	129
90	0.90	0.81	0.59	111	124	169
85	0.85	0.72	0.44	118	138	225

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Even a small learning rate can have a major effect on performance. X = experience level of the operator when time study was taken, for example, 50, 100, or 500 cycles. The table gives time/unit based on a time standard of 1.0 min/unit; therefore, if actual time standard were 5.0 min/unit, then time/unit at 98% and 2X would be 0.98 (5.0) = 4.9.

4.1.6.4. Acceptable Day's Work Assume a time standard y is set at an experience level x. Assume further, for ease of understanding, that $y = 1.0$ min and $x = 100$ units. A time study technician, Bill, made a time study of the first 100 units produced by Sally, calculated the average time, and then left. Sally continued working. Let's assume a 95% rate is appropriate. Sally completes the 200th piece shortly before lunch and the 400th by the end of the shift. The average time/unit for the first day is about 0.9 min (111% of standard). The second day, Sally completes the 800th unit early in the afternoon. She will complete the 3200th unit by the end of the week. The average time of 0.77 min/unit during the week yields 129% of standard!

Point. If none of the operators in your plant ever turns in a time that improves as they gain experience, do you have stupid operators or stupid supervisors?

Next point. The magnitude of the learning effect dwarfs potential errors in rating. You might be off 5% or 10% in rating but this effect is trivial compared versus the errors in using a time standard without considering learning/mfg. progress.

Third point. Any time standard that does not consider learning/manufacturing progress will become less and less accurate with the passage of time.

Final point. Since learning and manufacturing progress are occurring, output and number of work hours should not both be constant. Either the same number of people should produce more or fewer people can produce a constant output.

5. DOCUMENTING, USING, AND MAINTAINING STANDARDS

5.1. Documenting Standards

Standards are part of a goal-setting system, and control is essential to any goal-setting system.

The more detailed the data, the more detailed the possible analysis; you can always consolidate data after they is gathered, but you can't break the data down if they are consolidated before they are gathered. Computerization permits detailed recording and thus analysis of downtime, machine breakdown, setup time, and so on. With bar coding of parts and computer terminals at workstations, it is feasible to record times for each individual part. For example, for product Y, operator 24 completed operation 7 on part 1 at 10:05, part 2 at 10.08, and so on. More commonly, however, you would just record that for product Y, operator 24 started operation 7 at 10:00 and completed the 25 units at 11:50. Least useful would be recording, for product Y, that all operations on 25 units were completed on Tuesday. Companies tend to develop elaborate codes for types of downtime, quality problems, and so on. Be careful about downtime reporting: it is easy to abuse.

5.2. Using Standards

5.2.1. Reports

Variance is the difference between standard performance and actual performance. Generally, attention is focused on large negative variances so that impediments to productivity can be corrected. Performance should be fed back to both workers and management at least weekly. Daily reports highlight delays and production problems; monthly reports smooth the fluctuations and show long-term trends.

5.2.2. Consequences of Not Making Standard

If the standard is used to determine an acceptable day's work or pay incentive wages, the question arises, What if a person doesn't produce at a standard rate?

For a typical low-task standard such as methods time measurement (MTM), over 99% of the population should be able to achieve standard, especially after allowances are added. The relevant question is not what workers are able to do but what they actually do.

Comparisons of performance vs. standard should be over a longer time period (such as a week) rather than a short period (such as a day).

The first possibility to consider is learning. As noted above, for cognitive work, the first cycle time may be as much as 13 times MTM standard and, for motor work, 2.5 times MTM standard. If a new operator's performance is plotted vs. the typical learning curve for that job, you can see whether the operator is making satisfactory progress. For example, Jane might be expected to achieve 50% of standard the first week, 80% the second week, 90% the third week, 95% the fourth week, and 100% the fifth week. Lack of satisfactory progress implies a need for training (i.e., the operator may not be using a good method).

If Jane is a permanent, experienced worker, the below-standard performance could be considered "excused" or "nonexcused." Excused failure is for temporary situations—bad parts from the supplier, back injuries, pregnancy for females, and so forth. For example, "Employees returning to work from Worker's Compensation due to a loss-of-time accident in excess of 30 days will be given consideration based upon the medical circumstances of each individual case."

Nonexcused performances are those for which the worker is considered capable of achieving the standard but did not make it.

Table 16 shows some example penalties. Most firms have a ''forget'' feature; for example, one month of acceptable performance drops you down a step. The use of an established discipline procedure allows workers to self-select themselves for a job. The firm can have only minimal preemployment screening and thus not be subject to discrimination charges.

Standards are based on an eight-hour day, but people work longer and shorter shifts. Because most standards tend to be loose, people can pace themselves and output/hr tends to be constant over the shift. I do not recommend changing the standard for shifts other than eight hours.

The level at which discipline takes place is negotiable between the firm and the union. For example, it might be 95% of standard—that is, as long as workers perform above 95% of standard, they are considered satisfactory. However, this tends to get overall performance slightly higher—say 98%. The best long-range strategy probably is to set discipline at 100% of standard. Anything less will give a long-term loss in production, especially if a measured daywork system is used instead of incentives.

Firms can use several strategies to improve the group's performance and reduce output restrictions. Basically, they allow the employees as well as the firm to benefit from output over 100%.

The primary technique is to give money for output over 100%. A 1% increase in pay for a 1% increase in output is the prevalent system.

Another alternative is to give the worker time off for output over 100%. For example, allow individuals to ''bank'' weekly hours earned over 100%. Most people will soon run up a positive balance to use as ''insurance.'' This can be combined with a plan in which all hours in the bank over (say) 20 hr are given as scheduled paid time off. This tends to drop absenteeism because workers can use the paid time off for personal reasons.

5.3. Maintaining Standards (Auditing)

A standard can *restrict* productivity if it has not been updated because workers will produce only to the obsolete standard and not to their capabilities.

What to audit? To keep the work-measurement system up to date, accurate, and useful, MIL-STD-1567A says the audit should determine (1) the validity of the prescribed coverage, (2) the percentage of type I and II coverage, (3) use of labor standards, (4) accuracy of reporting, (5) attainment of goals, and (6) results of corrective actions regarding variance analysis.

How often to audit? Auditing should be on a periodic schedule. A good procedure is to set an expiration date on each standard at the time it is set; MIL-STD-1567 says annually. A rule of thumb is to have it expire at 24 months if the application is <50 hr/year, at 12 months if between 50 and 600 hr/year, and at 6 months if over 600 hr/year. Then, when the standard expires, and if it is still an active job, an audit is made. If it is not active, the standard will be converted from permanent to temporary. Then, if the job is resumed, the temporary can be used for a short period (e.g., 30 days) until a new permanent standard is set. An advantage of a known expiration date is that if a standard is audited (and perhaps tightened), the operator will not feel picked on.

If the resources for auditing are not sufficient for doing all the audits required, use the Pareto principle. Audit the ''mighty few'' and don't audit the ''insignificant many.'' However, when the standard on one of the insignificant many passes the expiration date, convert the permanent standard to temporary.

TABLE 16 Example Discipline Levels for Not Producing Enough

Step	Description
0	Normal operator, acceptable performance
1	Oral warning
2	Oral warning; detailed review of method with supervisor or trainer
3	Written warning; additional training
4	Written warning; some loss of pay
5	Written warning; larger loss of pay
6	Discharge from job

From *Work Design: Industrial Ergonomics,* 5th Ed., by S. Konz and S. Johnson.

A published set of rules ensures that everyone is treated fairly. Most organizations have a similar set of rules for tardiness and absenteeism.

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