Time Study and Work Measurement

Part III

Chapters:

12. Introduction to Work Measurement
13. Direct Time Study
14. Predetermined Motion Time Systems
15. Standard Data Systems
16. Work Sampling
17. Computerized Work Measurement and Standard Maintenance
18. Economic Justification and Applications of Time Standards
19. Learning Curves

Introduction to Work Measurement

Chapter 12

Sections:

1. Time Standards and How They Are Determined
2. Prerequisites for Valid Time Standards
3. Allowances in Time Standards
4. Accuracy, Precision, and Speed of Application in Work Measurement

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Time Is Important

- Most workers are paid for their time on the job
- The labor content (cost of labor time) is often a major factor in the total cost of a product or service
- For any organization, it is important to know how much time will be required to accomplish a given amount of work

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Some Definitions

- **Work measurement** – evaluation of a task in terms of the time that should be allowed by an average worker to perform the task
  - 4 techniques
  - Focus on human work
  - Standard time (allowed time) – amount of time that should be allowed for an average worker to process one work unit using the standard method and working at normal pace
  - Includes allowance
- **Time study**

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Some Definitions

- **Work measurement**
- **Time study** – all the ways in which time is analyzed in work situations
  - Broader term
  - Focus on machine times
- How much time it should take to accomplish a given task
- Both terms (work measurement and time study) can be used interchangeably

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When Are Time Standards Beneficial?

Characteristics of industrial situations in which time standards would be beneficial

- Low productivity: significant opportunities for improvement
- Repeat orders: once the time standard is set for the first, it can be used for successive ones
- Long production runs: reduced average cost of work measurement
- Repetitive work cycles: work measurement can be justified more readily
- Short cycle times: requires less time to set standards

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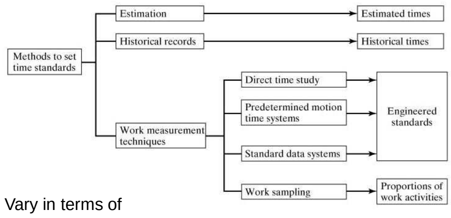
Functions of Time Standards

- They define a "fair day's work"
- They provide a means to convert workload into staffing and equipment needs
- They allow alternative methods to be compared objectively
- They provide a basis for wage incentives and evaluation of worker performance
- They provide time data for:
  - Production planning and scheduling
  - Cost estimating
  - Material requirements planning

Methods to Determine Time Standards



- Vary in terms of
  - accuracy and reliability of the values derived from the method
  - amount of time required to apply the corresponding method

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Methods to Determine Time Standards

- Estimation
  - Judgment of a person who is familiar with the job
    - Subjective
    - Least accurate method
- Historical records
  - Records on the actual times and production quantities for previous identical or similar job orders - "Time card"s
    - Average time per part
    - Improvement over estimates
    - Limitation: No indication of efficiency measures
- Work measurement techniques
  - Time consuming
  - More accurate than estimation and historical records

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Work Measurement Techniques

1. Direct time study (DTS)
2. Predetermined motion time system (PMTS)
3. Standard data systems (SDS)
   - These 3 are known as engineered standards
   - Some effort has been made to determine the best method to accomplish a given task
4. Work sampling
   - Determine proportions of time spent in work activities using randomized observations

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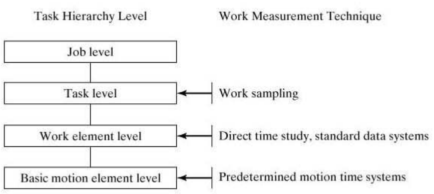
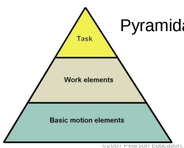
Task Hierarchy & Work Measurement





Pyramidal Structure of Work

Work measurement techniques measure work at different levels of this hierarchy

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Direct Time Study

- Direct observation of a task using a stopwatch to record the time taken to accomplish a task.
- The task is usually divided into work elements and each work element is timed seperately.
- During the observation, the analyst evaluates the worker's pace - performance rating
- Normal time

$$T_n = T_{obs}(PR)$$

where T_n= normal time, min; T_{obs}=observed time, min; PR=performance rating of the worker's pace

- Standard time

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

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Predetermined Motion Time Systems

- A database of normal times of basic motion elements (therbligs) such as reach, grasp, move etc.
- Conditions under which the motion elements (work variables) are performed are important.
- Example: normal time for TL
  - Distance moved
  - Weight of the object being moved
- The analyst list all of the basic motion elements that comprise the task; then normal times for basic motion elements are summed up to obtain the normal time for the task
- Advantages:
  - No need for performance rating
  - Can be applied before production starts

Standard Data Systems

- A compilation of normal time values for work elements used in the tasks performed in facility
- Used to establish time standards for tasks composed of work elements similar to those in the database
- Source of data: direct time study, PMTS, work sampling, historical data
- Effect of work variables should be included
  - Tables
  - Charts
  - Mathematical equations

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Work Sampling

- A random sampling technique to estimate the proportions of time spent in different activities
- Identify activities clearly. Example: machine setup, production, idleness
- Multiple subjects (entities) can be included
- Observations
  - Random: minimize bias
  - Large in number: to achieve statistical accuracy
- Objectives:
  - Setting time standards: Statistical estimation error is high ☹
  - Estimating resource utilization (different from other techniques) ☺
  - Determining allowance factors (different from other techniques) ☺

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Cycle Time Variations

- Once the method has been standardized, the actual time to perform the task is a variable because of:
  - Differences in worker performance
  - Mistakes, failures and errors
  - Variations in starting work units
  - Variations in hand and body motions
  - Extra elements not performed every cycle
  - Differences among workers
  - The learning curve phenomenon

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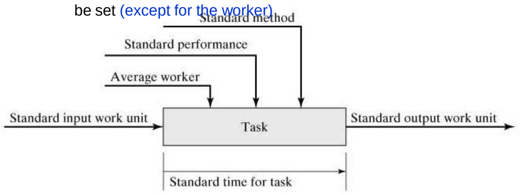
Prerequisites for Valid Time Standards

Time to perform a task depends on

- •worker (gender, strength etc.),
- •worker's pace,
- •method used,
- •work unit

Factors that must be standardized before a time standard can be set (except for the worker)



Average (Standard) Worker

- A worker who
  - is representative of the persons who usually perform tasks similar to the task being measured.
    - if the work is performed mostly by men (women), then the average worker is male (female)
  - have learned the task, practiced and proficient at it
  - is capable of performing the task consistently throughout the shift

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Standard Method

- Determining the optimum method for processing a work unit
- "One best method": the safest, quickest, most productive, and least stressful to the worker
- Must include all of the details on how the task is performed, including:
  - Procedure - hand and body motions
  - Tools
  - Equipment
  - Workplace layout (what are the locations of the parts, tools)
  - Irregular work
  - Working conditions (is the work performed outside or inside)
  - Setup

Standard Work Units

- The time needed to process the work unit depends on its starting condition
  - Therefore this condition must be specified by engineering documents
  - If the actual condition deviates from the specification, then extra time may be required to accomplish the task
- Exactly what changes are made in the work unit by the task?
- What is the final state of the completed work unit?
- Service work: more difficult to define

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Measurement

- A procedure in which an unknown quantity is compared to a known standard, using an accepted and consistent system of units
- Important attributes of a measurement system:
  - Accuracy
  - Precision
  - Speed of response
- Work measurement is a measurement process

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Accuracy and Precision

- Accuracy
  - Degree to which the measured value agrees with the true value of the quality of interest
  - Freedom from systematic errors, which are positive or negative deviations from the true value that are consistent from measurement to measurement
- Precision
  - Repeatability of the measurement system
  - High precision means random errors are small, where errors are assumed to follow a normal distribution
  - Plus or minus three standard deviations often used as a benchmark: $[\mu-3\sigma,\mu-3\sigma]$

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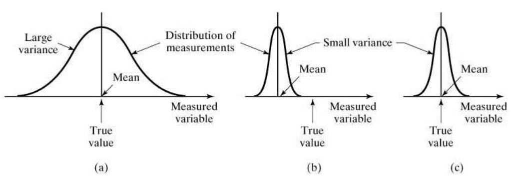
Measurement Accuracy vs. Precision



High accuracy
Low precision

Low accuracy
High precision

High accuracy
High precision

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Accuracy in Work Measurement

- Accuracy is concerned with closeness to the true value
  - But what is the true value of a task time?
- Measurement is a procedure in which an unknown quantity is compared with a known standard
  - But the known standard in work measurement is the definition of standard performance used by the company
  - The standard is not based on time

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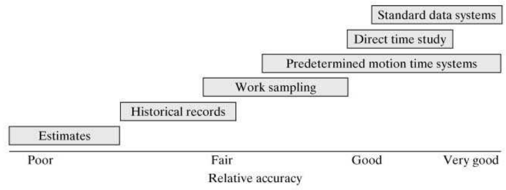
Precision in Work Measurement

- Precision is concerned with the expected variability within a single time study
- Precision of a time standard is determined at a certain reliability or confidence level
  - For example, the standard time for a task is 4.00 min, and we are 95% confident that the actual time is within 5% of that time
  - 95 out of 100 time studies performed on the task, the resulting standard time values lie between 3.80 min and 4.20 min
- Related term: Consistency – concerned with variations in standard time values among different time study analysts

Relative Accuracy of Time Standards



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Application Speed Ratio

- Speed of response – the lag between the time when the measuring device is applied and when the measured value is available to the user
- how much time is required to determine the time standard for a given task
  - Varies for different work measurement techniques
- In work measurement speed of response is application speed ratio.
- Application speed ratio = ratio of the time required to set the standard divided by the value of the time standard itself
  - Typical values = 100 to 250
  - Application speed ratio=100: It takes 100 min of analyst time to determine a 1 min-time standard.

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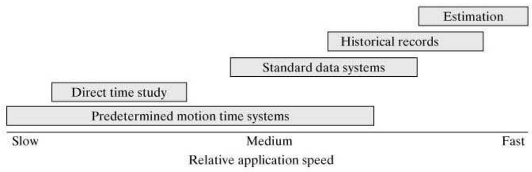
Relative Application Speed



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Computerized Work Measurement

- Facilitates collection of data
- Performs routine computations
- Organizes time standards files and databases
- Retrieves data in predetermined motion time systems and standard data systems
- Assists in the preparation of the documentation
  - Methods descriptions
  - Reports

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Worker Performance

- Average (Standard) Worker ????
- Defined as the pace (tempo) or relative speed with which the worker does the task.
- As worker performance increases, cycle time decreases
- From the employer's viewpoint, it is desirable for worker performance to be high
- What is a reasonable performance/pace to expect from a worker in accomplishing a given task?

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Normal Performance (pace)

- A pace of working that can be maintained by a properly trained average worker throughout an entire work shift without harmful 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
  - Faster pace > 100%, slower pace < 100%
- Common benchmark of normal performance:
  - Walking at 3 mi/hr (~4.83 km/hr)
  - Dealing four hands of cards from a 52 card deck in exactly 30 sec

Normal Time

- The time to complete a task when working at normal performance
- Actual time to perform the cycle depends on worker performance

$$T_n = T_c \times P_w$$

where

T_c = actual cycle time,

T_n = normal time,

P_w = worker performance or pace

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Example 2.2: Normal Performance

- Given: A man walks in the early morning for health and fitness. His usual route is 1.85 miles. The benchmark of normal performance = 3 mi/hr.
- Determine:

  (a) how long the route would take at normal performance

  (b) the man's performance when he completes the route in 30 min.

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Example 2.2: Solution

(a) At 3 mi/hr, time = 1.85 mi / 3 mi/hr
= 0.6167 hr = 37 min

(b) Rearranging equation, $P_w = T_n / T_c$
P_w = 37 min / 30 min = 1.233 = 123.3 %

or an alternative approach in (b):
Using v = 1.85 mi / 0.5 hr = 3.7 mi/hr
P_w = 3.7 mi/hr / 3.0 mi/hr = 1.233

- If worker performance > 100%, then the time required to complete the cycle will be less than normal time.
- If worker performance < 100%, then the time required to complete the cycle will be greater than normal time.

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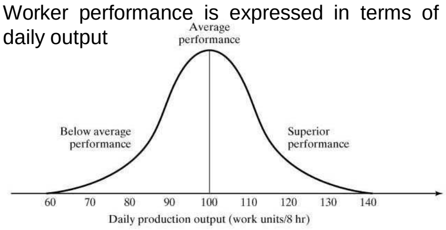
Distribution of Worker Performance

Variations among workers →performance variations

Worker performance is expressed in terms of daily output



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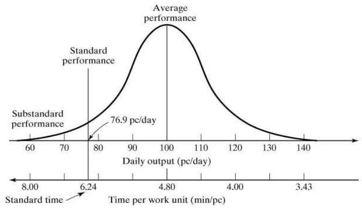
How a Normal Time is Defined

Distribution of worker performance, indicating how normal time is defined so that it can be readily achieved by most workers



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More on Normal Performance

- Normal performance is commonly defined to be a pace that can be readily attained by the majority of workers
- Companies want most workers to be able to achieve the normal performance easily.
  - A typical policy is to define standard performance so that an average worker is able to work at a pace that is 130% of that pace
    - Thus, most workers are able to easily achieve normal performance

Standard Time

- Same as normal time, but acknowledges that periodic rest breaks must be taken by the worker
- Periodic rest breaks are allowed during the work shift
  - Lunch breaks (yemek molası-1/2 or 1 hour)
    - usually not counted as part of work shifts
  - Shorter rest breaks (çay molası-15 mins)
    - usually counted as part of work shifts
- Other interruptions (allowances)

Rest Breaks in a Work Shift

- A typical work shift is 8 hours (8:00 A.M. to 5:00 P.M. with one hour lunch break)
  - In Turkey work time is defined as 45 hours a week (so 8:00 A.M. to 6:00 P.M. with one hour lunch break, provided that workers work for 5 days)
- The shift usually includes one rest break in the morning and another in the afternoon.
- The employers allows these breaks, because they know that the overall productivity of a worker is higher if rest breaks are allowed.
  - In Turkey the rest periods are not included in daily work hours in which employers are paid for.

Allowances in Time Standards

- Normal time is adjusted by an allowance factor A_{pfd} to obtain the standard time
- Purpose of allowance factor is to compensate for lost time due to work interruptions and other reasons
- Standard time:

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

where pfd = personal time, fatigue, and delays

Reasons for Lost Time at Work (Allowances)

Work-related interruptions

- Machine breakdowns
- Waiting for materials or parts
- Receiving instructions from foreman
- Talking to co-workers about work-related matters
- Rest breaks for fatigue
- Cleaning up at end of shift

Non-work-related interruptions

- Personal needs (e.g., restroom breaks)
- Talking to co-workers about matters unrelated to work
- Lunch break (not included in A_{pfd})
- Smoke break
- Beverage break
- Personal telephone call

PFD Allowance

- Personal time
  - Rest room breaks, phone calls, water fountain stops, cigarette breaks (5% typical)
  - For example: A larger value will be approporiate if the work environment is hot
- Fatigue
  - Rest allowance to overcome fatigue due to work-related stresses and conditions (5% or more)- refer to Chapter 23
  - For example: If the work is physiologically very demanding, then relaxation time should be allowed periodically for the body to recover (in this case use 20% allowance)
- Delays

PFD Allowance

- Personal time
- Fatigue
- Delays
  - Random, unavoidable interruptions
  - Machine breakdowns, foreman instructions (5% typical)
  - Usually management is responsible for these delays.
  - Sudden urge for a cigarette break? Is it personal or delay?
  - Do you know how to measure allowances?

Normal time vs Standard time

- Normal time: Time it takes to perform a task under the normal (standard) (100%) performance
- Normal time does not include allowances for time losses
- Standard time: Normal time + allowance
  Normal time$(1 + A_{pfd})$

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

T_{std} = standard time, T_n = normal time, A_{pfd} = PFD allowance factor

Standard Hours and Worker Efficiency

- Two (three) common measures of worker productivity used in industry
  - Standard hours – represents the amount of work actually accomplished during a given period (shift, week)
  - Quantity of work units (in terms of time) produced

$$H_{std} = Q\, T_{std}$$

where
H_{std} =standard hours accomplished, hr
Q = quantity of work units completed during the period, pc
T_{std} =standard time per work unit, hr/pc

Standard Hours and Worker Efficiency

- Two (three) common measures of worker productivity used in industry
  - Worker efficiency – work accomplished during the shift expressed as a proportion of shift hours

$$E_w = H_{std} / H_{sh}$$

where
H_{std} =standard hours accomplished, hr
E_w =worker efficiency, normally expressed as a percentage, hr
H_{sh} =number of shift hours, hr

Irregular Work Elements

- Elements that are performed with a frequency of less than once per cycle
- Examples:
  - Changing a tool
  - Exchanging parts when containers become full
- Irregular elements are prorated into the regular cycle according to their frequency

Example 2.3: Determining Standard Time and Standard Output

- Given: The normal time to perform the regular work cycle is 3.23 min. In addition, an irregular work element with a normal time = 1.25 min is performed every 5 cycles. The PFD allowance factor is 15%.
- Determine
  (a) the standard time
  (b) the number of work units produced during an 8-hr shift if the worker's pace is consistent with standard performance.

Example 2.3: Solution

(a) Normal time T_n = 3.23 + 1.25/5
= 3.48 min

Standard time T_{std} = 3.48 (1 + 0.15)
= 4.00 min

(b) Number of work units produced during an 8-hr shift

Q_{std} = 8.0(60)/4.00 = 120 work units

- Normal time of a task involves normal times for regular and irregular work elements

Example 2.6: Standard hours and worker efficiency

- Given: The worker performance of 125% in the previous example.
- T_{sd}=4.00 min. The worker produces 150 work units during an 8-hour shift.
- Determine:
  (a) number of standard hours produced
  (b) worker efficiency
- Solution:
  (a) H_{std}=150(4 min)=600 min= 10.0 hr
  ($H_{std} = Q\ T_{std}$)
  (b) E_w = 10hr / 8 hr =125 %
  ($E_w = H_{std} / H_{sh}$)

Example 2.6: Standard hours and worker efficiency (skip)

- Note that worker efficiency is found to be equal to the worker performance (rate).
- What are the reasons for that?
  - The number of hours actually worked is consistent with 15% allowance factor.
  - The entire work cycle consists of manual labor.
    - So, worker efficiency=worker performance (rate)

More on Worker Efficiency

- Worker efficiency is commonly used to evaluate workers in industry.
- In many incentive wage payment plans, the worker's earnings are based on
  - worker's efficiency, E_w,
    or
  - the number of standard hours accomplished, H_{std}.
- Either one of these two measures can be derived from the other one. Thus, they are equivalent.

Cycle Time Analysis

- Two categories of worker-machine systems in terms of cycle time analysis
- Cases:
  1. Systems in which the machine time depends on operator control
     - A typist typing a list of names on a typewriter
     - Carpenter using power saw to cut lumber
     - A construction worker operating a backhoe
     - Cycle time analysis is same as for manual work cycle
  2. Systems in which machine time is constant and independent of operator control
     - Operator loading semi-automatic production machine
     - Our focus is on this 2nd type
     - Two types:

Case 2.a: Cycle Times with No Overlap Between Worker and Machine

- Worker elements and machine elements are sequential
- There is no overlap in work elements between the worker and the machine
  - While worker is busy, machine is idle
  - While machine is busy, worker is idle
- *Worker's work elements are external*
- Normal time for cycle
  $T_n = T_{nw} + T_m$,
  where
  T_{nw} = Normal time for the worker-controlled portion of the cycle time, min
  T_m = Machine cycle time (assumed to be constant)

Case 2.a: Cycle Times with No Overlap Between Worker and Machine

- Standard time for cycle

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

  where

  T_{nw} = Normal time for the, min

  T_m = Machine cycle time (constant)

  A_m = Machine allowance factor

- A_m=30%: Workers love that since efficiencies are overestimated
- A_m=0%: Workers hate that since efficiencies are overestimated
- $A_m = A_{pfd}$

Case 2.b: Internal Work Elements

- Some worker elements are performed while machine is working
  - Internal work elements performed simultaneously with machine cycle
  - External work elements performed sequentially with machine cycle
- Desirable to design the work cycle with internal rather than external work elements
- If it is possible, include operator work elements that are performed while machine is running.

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Normal Time and Standard Time

- Normal time

  $T_n = T_{nw} + \text{Max}\{T_{nwi}, T_m\}$

- Standard time

  $T_{std} = T_{nw} (1 + A_{pfd}) + \text{Max}\{T_{nwi}(1 + A_{pfd}), T_m(1 + A_m)\}$

- Actual cycle time (skip)

  $T_c = T_{nw} / P_w + \text{Max}\{T_{nwi}/P_w, T_m\}$

where

T_{nw} = normal time for the worker's external elements, min

T_{nwi} = normal time for the worker's internal elements, min

T_m = machine cycle time, min

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Example 2.10: Internal vs external work elements in cycle time analysis

Seq.	Work Element Description	Worker Time (min)	Machine Time (min)
1	Worker walks to tote pan containing raw stock	0.13	(idle)
2	Worker picks up raw workpart and transports to machine	0.23	(idle)
3	Worker loads part into machine and engages machine semiautomatic cycle	0.12	(idle)
4	Machine semiautomatic cycle	(idle)	0.75
5	Worker unloads finished part from machine	0.10	(idle)
6	Worker transports finished part and deposits into tote pan	0.15	(idle)
Total		0.73	0.75

T_c=0.73+0.75=1.48 min

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Example 2.10: Internal vs external work elements in cycle time analysis

Seq.	Work Element Description	Worker Time (min)	Machine Time (min)
1	Worker unloads finished part from machine	0.10	(idle)
2	Worker loads part into machine and engages semiautomatic machine cycle	0.12	(idle)
3	Machine semiautomatic cycle	(idle)	0.75
4	Worker transports finished part and deposits it into tote pan, walks to tote pan containing raw stock, and picks up raw workpart and transports it to machine. (This element is internal to the machine semiautomatic cycle.)	0.15+ 0.13+ 0.23= 0.51	(operating)
Total		0.73	0.75

T_c=0.10+0.12+0.75=0.97 min

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Example 2.10: Internal vs external work elements in cycle time analysis

- The cycle time is reduced from 1.48 min to 0.97 min.
- % cycle time reduction=$(CT_{current}-CT_{improved})/CT_{current}$

  =(1.48-0.97)/1.48=%34
- $R_{current}$=1/1.48 min=0.68 units per min
- $R_{improved}$=1/0.97 min=1.03 units per min
- % increase in $R=(R_{improved}-R_{current})/R_{current}$

  =(1.03-0.68)/0.68=%53
- %decrease in $R=(R_{current}-R_{improved})/R_{current}$

  =(0.68-1.03)/0.68=−%53

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Other Types of Allowances

- There are other reasons for adding allowances, which are not as common as PFD allowances. They are applied in addition to A_{pfd}
- Contingency Allowance
  - Additional allowance due to a problem with the task (e.g., raw material problem) - not greater than 5%
  - Temporary basis – after solving the underlying problem, it will disappear
- Policy allowance: They are based on company policy
  - Machine allowance (set by company policy as a part of the wage incentives.)
  - Training allowance – for teaching new workers
  - Learning allowance – learning a new task

Contingency Allowances

Problem area	Problems and examples
Materials or parts	Starting materials or parts are out of specification, and extra time is needed to correct the nonconformance (e.g., oversized casting that requires an extra machining pass or slower feed rate).
Process	Manufacturing process is not in statistical control (Section 10.2), and additional time is required to inspect every piece rather than inspect on a sampling basis.
Equipment	Equipment is malfunctioning or breaking down more frequently than what is provided by the unavoidable delay factor, and additional time is needed to compensate the worker to make adjustments, lubricate the machine more frequently, or other extra task(s) not included in the standard time.

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Policy Allowances

- To cover special work situations that are usually associated with a wage incentive system.
- Example: Machine allowance – provides an opportunity of the worker to maintain a high rate of earnings even though (s)he has control over only a portion of the cycle.

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

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Other types of policy allowances

- **Training allowances:** for workers whose responsibilities include teaching other workers
- **Learning allowances:** for workers who are learning a new job, or new employees
- Worker would be reluctant to train others or to learn new jobs unless some form of compensation were provided to cover the losses because of training.
- If a wage incentive plan is not used, there is no reason to have policy allowances.

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Example 2.8: Effect of machine allowance on standard time

- Given: The work cycle consists of several manual work elements (operator controlled) and one machine element performed under semiautomatic control. The manual work elements: a normal time of 1 min and the semiautomatic machine cycle time is 2 min. A_{pfd}=15%.
- Determine: the standard time using
  (a) A_m=0,
  (b) A_m=30%.

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Example 2.8: Solution

- The normal time for the work cycle: T_n=1.0+2.0=3.0 min

(a) T_{std}=1.0(1+0.15)+2.0=3.15 min
($T_{std} = T_{nw}\,(1 + A_{pfd}) + T_m\,(1 + A_m)$)

Workers ☹

(b) T_{std}=1.0(1+0.15)+2.0(1+0.30) =3.75 min
($T_{std} = T_{nw}\,(1 + A_{pfd}) + T_m\,(1 + A_m)$)

Workers ☺

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Example 2.9: Effect of machine allowance on worker efficiency

- Given: Standard times in the previous example (Example 2.8).
- Determine: The worker efficiencies if 150 units are produced in an 8-hour shift.
- Solution:
  (a) H_{std}=150(3.15)=472.5min=7.875hr ☹
  ($H_{std} = Q\ T_{std}$)
  E_w=7.875/8.0=0.984=98.4% ☹
  ($E_w = H_{std} / H_{sh}$)

  (b) H_{std}=150(3.75)=562.5min=9.375hr ☺
  ($H_{std} = Q\ T_{std}$)
  E_w=9.375/8.0=1.172=117.2% ☺
  ($E_w = H_{std} / H_{sh}$)

Example: Use of machine allowance in a wage incentive plan

Given: A wage incentive plan pays workers a daily wage at a rate of $15/hr multiplied by the number of standard hours accomplished during the shift. T_{nw} =1 min, T_m =3 min, A_{pfd} =15%. Workers' work elements are external.

Determine the standard time for

a) A_m=0, ☹

b) A_m=30%. ☺

c) What does a worker earn for the day under each A_m (policy!) if (s)he produces 115 parts a day?

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Example Solution

a) T_{std} = 1 (1 + .15) + 3 (1 + 0)=4.15 min

b) T_{std} = 1 (1 + .15) + 3 (1 + 0.30)=5.05 min

c) H_{std} under

  a) H_{std}=115(4.15)/60=7.95 hr ☹

  b) H_{std}=115(5.05)/60=9.68 hr ☺

  The worker is paid under

  a) 15(7.95)=$119.25 ☹

  b) 15(9.68)=$145.19 ☺

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