

Methods and movements at the workplace

1. General considerations

In this book we have gradually moved from the wide field of the productivity of industry as a whole to considering in a general way how the productivity of workers and machines can be improved through the use of work study. Still moving from the broader to the more detailed approach, we have also examined procedures of a general nature for improving the effectiveness with which complete sequences of operations are performed and with which material flows through the working area. Turning from materials to workers, we have discussed methods of studying the movements of persons around the working area and the relationships between men or women and machines or workers working together in groups. We have done so following the principle that the broad method of operation must be put right before we attempt improvements in detail.

The time has now come to look at one worker working at a workplace, bench or table and to apply to him or her the principles which have been laid down and the procedures shown in the examples given.

In considering the movements of workers and materials on the larger scale, we have been concerned with the more efficient use of existing plant and machinery (and, where possible, materials) through the elimination of unnecessary idle time, the more effective operation of processes and the more efficient use of the services of labour through the elimination of unnecessary and time-consuming movement within the working area of factory, department or yard.

As our example (Chapter 8) of the trolley operative's need for relaxation shows, the factor of fatigue affects the solution of problems even when we are dealing with areas larger than the individual workplace. But when we come to study individuals at the workplace, the way in which they apply their effort and the amount of fatigue resulting from their manner of working become primary factors affecting their productivity.

Before embarking on a detailed study of an operative doing a job at a single workplace, it is important to make certain that the job is in fact necessary and is being done as it should be done. The questioning technique must be applied as regards:

PURPOSE

To ensure that the job is necessary.

- PLACE**
To ensure that it is being done where it should be done.
- SEQUENCE**
To ensure that it is in its right place in the sequence of operations.
- PERSON**
To ensure that it is being done by the right person.

Once these have been verified and it is certain that the job cannot be eliminated or combined with another operation, it is possible to go on to determine the

- MEANS**
by which the job is being done

and to simplify them as much as is economically justified.

Later in this chapter we shall consider the recording techniques adopted to set out the detailed movements of an individual at his or her workplace in ways which facilitate critical examination and the development of improved methods, in particular the **two-handed process chart**, as well as the **PTS chart** which will be referred to in Part Four of this book. Before doing this, however, it is appropriate to discuss the principles of motion economy and a number of other matters which influence the design of the workplace itself, so as to make it as convenient as possible for the worker to perform his or her job.

2. The principles of motion economy

There are a number of “principles” concerning the economy of movements which have been developed as a result of experience and which form a good basis for the development of improved methods at the workplace. They may be grouped under three headings:

- A. Use of the human body**
- B. Arrangement of the workplace**
- C. Design of tools and equipment**

They are useful in shop and office alike and, although they cannot always be applied, they do form a very good basis for improving the efficiency and reducing the fatigue of manual work. The ideas expounded by Professor Barnes¹ are described here in a somewhat simplified fashion.

A. Use of the human body

When possible:

- (1) The two hands should begin and complete their movements at the same time.
- (2) The two hands should not be idle at the same time except during periods of rest.
- (3) Motions of the arms should be symmetrical and in opposite directions and should be made simultaneously.

¹ See Ralph M. Barnes: *Motion and time study: Design and measurement of work* (New York and London, John Wiley, 7th ed., 1980), Chs. 15-17.

- (4) Hand and body motions should be made at the lowest classification at which it is possible to do the work satisfactorily (see section 3 below).
- (5) Momentum should be employed to help the worker, but should be reduced to a minimum whenever it has to be overcome by muscular effort.
- (6) Continuous curved movements are to be preferred to straight-line motions involving sudden and sharp changes in direction.
- (7) "Ballistic" (i.e. free-swinging) movements are faster, easier and more accurate than restricted or controlled movements.
- (8) Rhythm is essential to the smooth and automatic performance of a repetitive operation. The work should be arranged to permit easy and natural rhythm whenever possible.
- (9) Work should be arranged so that eye movements are confined to a comfortable area, without the need for frequent changes of focus.

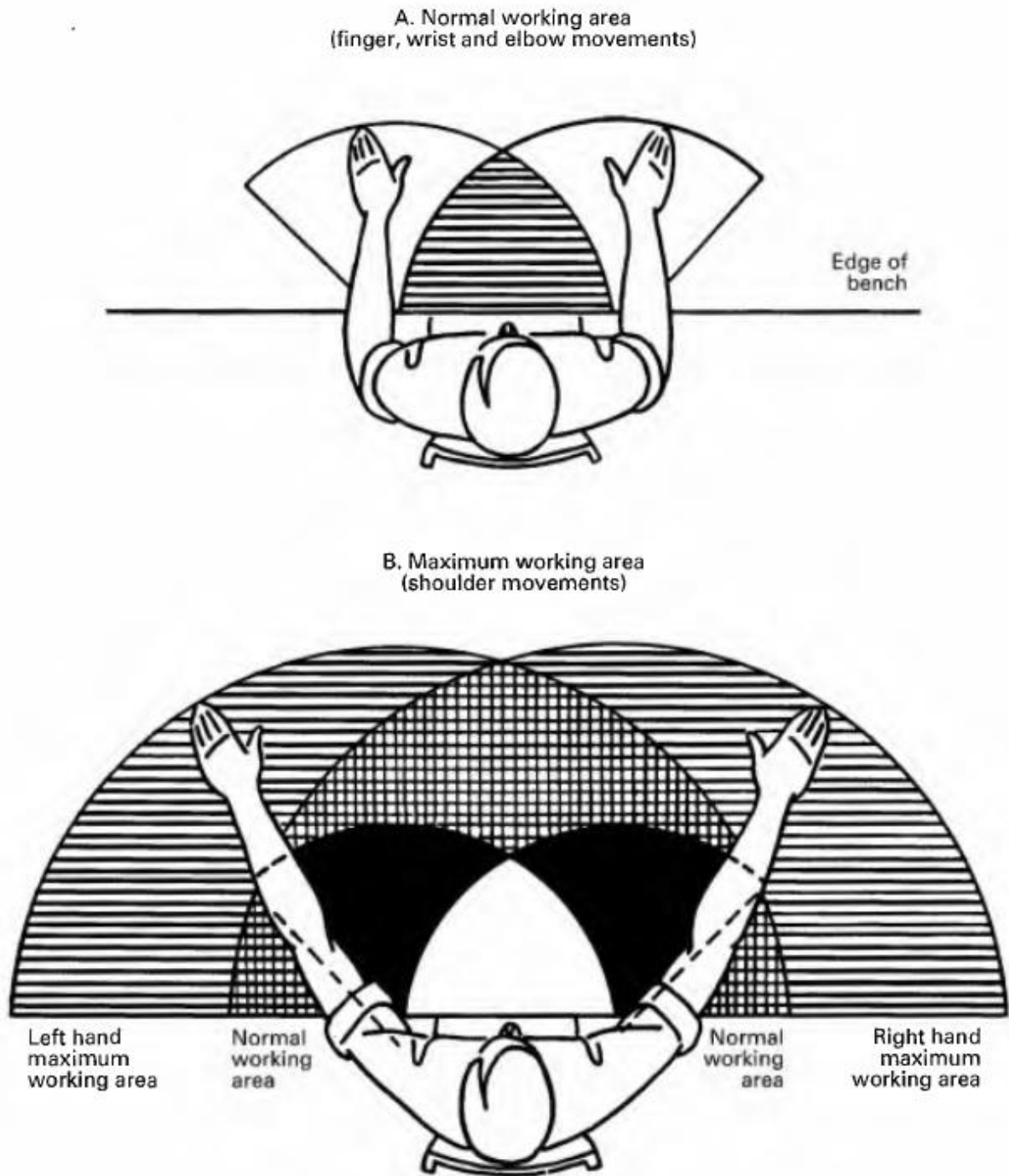
B. Arrangement of the workplace

- (1) Definite and fixed stations should be provided for all tools and materials to permit habit formation.
- (2) Tools and materials should be pre-positioned to reduce searching.
- (3) Gravity feed, bins and containers should be used to deliver the materials as close to the point of use as possible.
- (4) Tools, materials and controls should be located within the maximum working area (see figure 49) and as near to the worker as possible.
- (5) Materials and tools should be arranged to permit the best sequence of motions.
- (6) "Drop deliveries" or ejectors should be used wherever possible, so that the operative does not have to use his or her hands to dispose of the finished work.
- (7) Provision should be made for adequate lighting, and a chair of the type and height to permit good posture should be provided. The height of the workplace and seat should be arranged to allow alternate standing and sitting.
- (8) The colour of the workplace should contrast with that of the work and thus reduce eye fatigue.

C. Design of tools and equipment

- (1) The hands should be relieved of all work of "holding" the workpiece where this can be done by a jig, fixture or foot-operated device.
- (2) Two or more tools should be combined wherever possible.
- (3) Where each finger performs some specific movement, as in typewriting, the load should be distributed in accordance with the inherent capacities of the fingers.
- (4) Handles such as those on cranks and large screwdrivers should be so designed that as much of the surface of the hand as possible can come into contact with the handle. This is especially necessary when considerable force has to be used on the handle.

Figure 49. Normal and maximum working areas



- (5) Levers, crossbars and handwheels should be so placed that the operative can use them with the least change in body position and the greatest “mechanical advantage”.

These “principles”, which reflect those discussed in Chapter 5, can be made the basis of a summary “questionnaire” which will help, when laying out a workplace, to ensure that nothing is overlooked.

Figure 49 shows the normal working area and the storage area on the workbench for the average operative. As far as possible, materials should not be stored in the area directly in front of him or her, as stretching forwards

involves the use of the back muscles, thereby causing fatigue. This has been demonstrated by physiological research.

3. Classification of movements

The fourth “rule” of motion economy in the use of the human body calls for movements to be of the lowest classification possible. This classification is built up on the pivots around which the body members must move, as shown in table 9.

Table 9. Classification of movements

Class	Pivot	Body member(s) moved
1	Knuckle	Finger
2	Wrist	Hand and fingers
3	Elbow	Forearm, hand and fingers
4	Shoulder	Upper arm, forearm, hand and fingers
5	Trunk	Torso, upper arm, forearm, hand and fingers

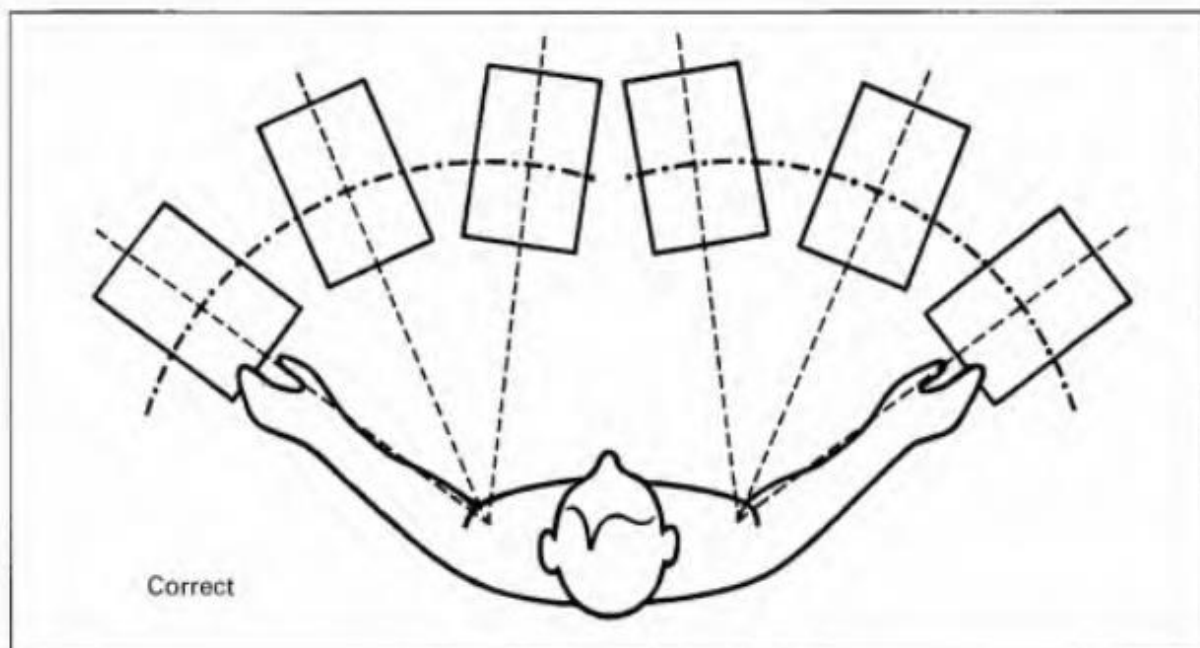
It is obvious that each movement above Class 1 will involve movements of all classes below it. Thus the saving in effort resulting from using the lowest class possible is obvious. If, in laying out the workplace, everything needed is placed within easy reach, this will minimize the class of movement which the work itself requires from the operative.

4. Further notes on workplace layout and simplification of movements

A few general notes on laying out the workplace may be useful.

- (1) If similar work is being done by each hand, there should be a separate supply of materials or parts for each hand.
- (2) If the eyes are used to select material, as far as possible the material should be kept in an area where the eyes can locate it without there being any need to turn the head.
- (3) Use semi-circular arrangements in preference to circular arrangements (see figure 50).
- (4) Design the workplace using ergonomic principles. In a sitting position a recommended posture is shown in figure 51.
- (5) The nature and the shape of the material influence its position in the layout. Use various bins such as those shown in figure 52 to accommodate material.

Figure 50. Semi-circular and circular working arrangement



This is a correct and better arrangement than a circular arrangement

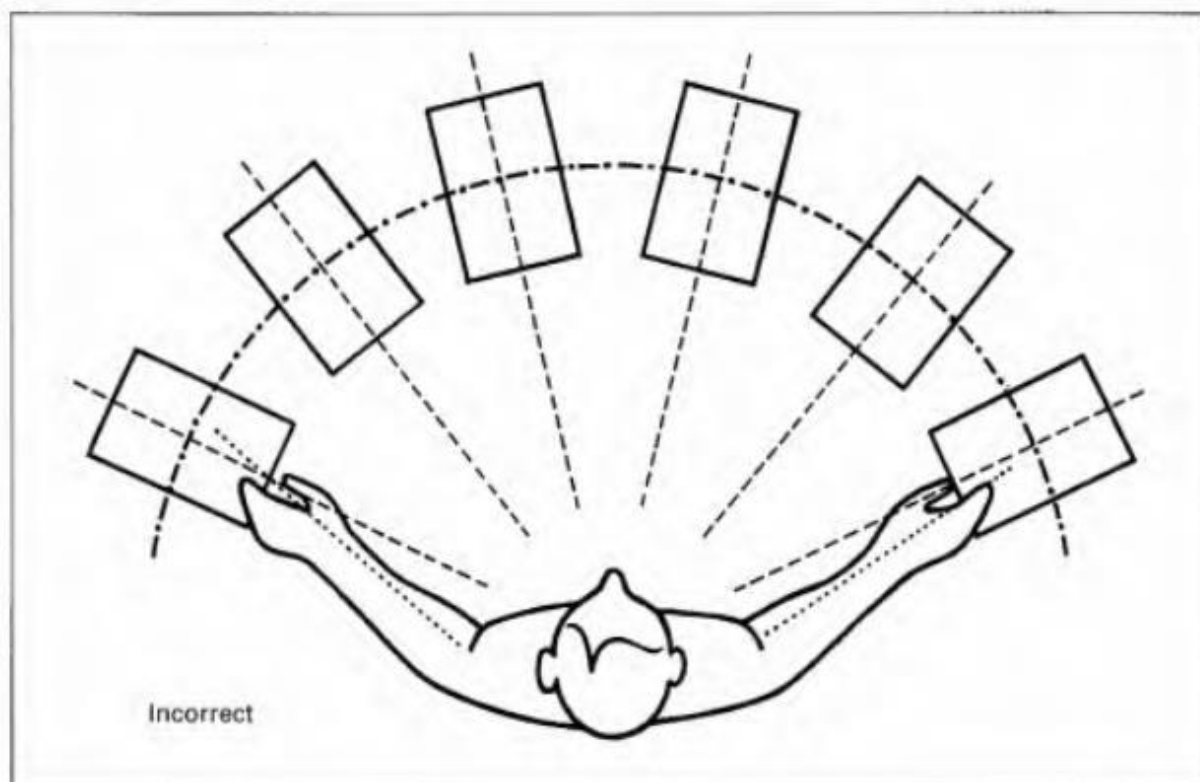
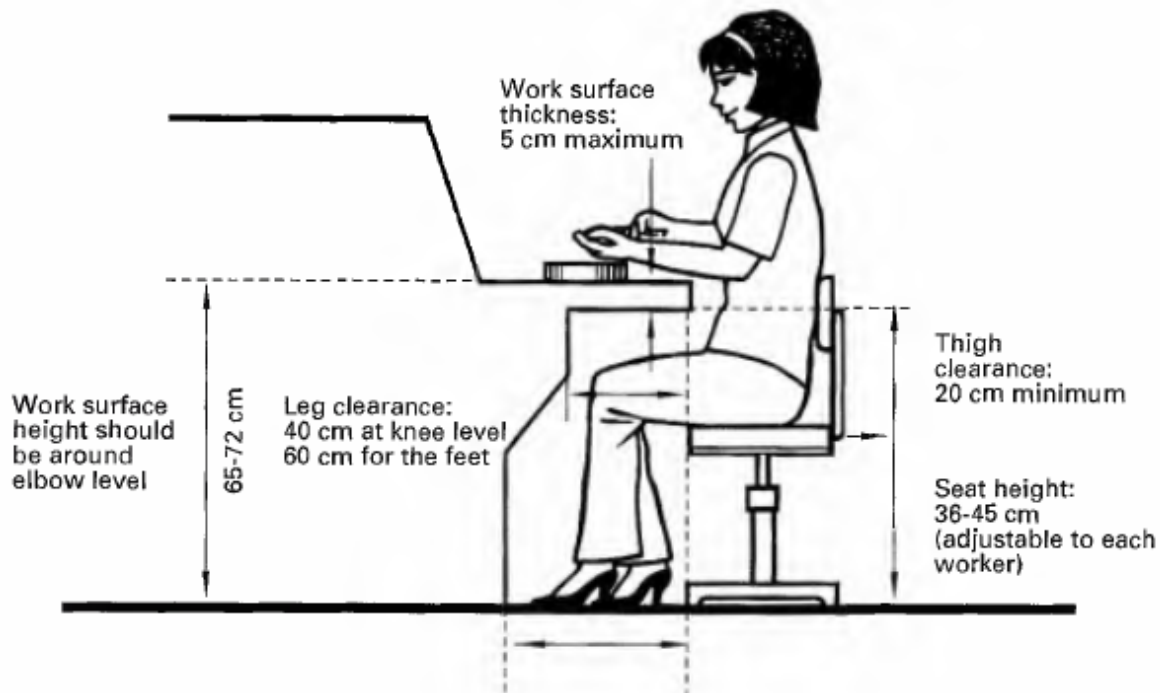


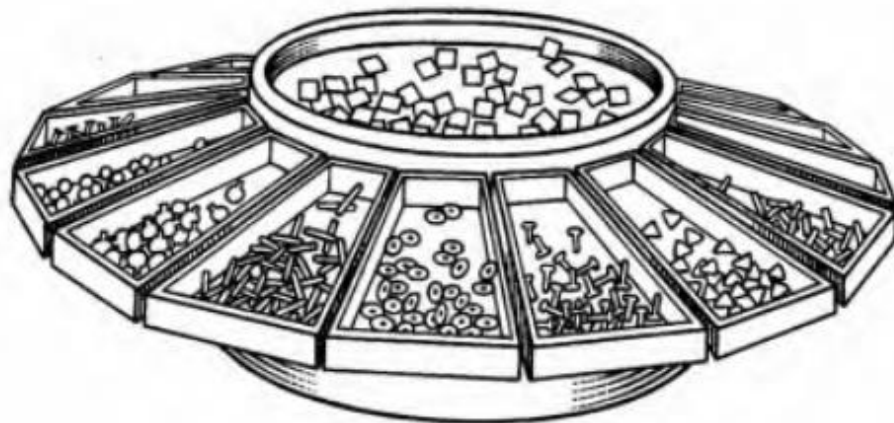
Figure 51. Recommended dimensions for seated tasks



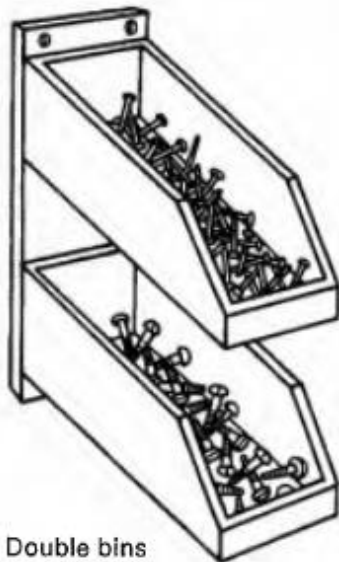
Source: Thurman et al., op. cit., figure 54.

- (6) Hand tools should be picked up with the least possible disturbance to the rhythm and symmetry of movements. As far as possible the operator should be able to pick up or put down a tool as the hand moves from one part of the work to the next, without making a special journey. Natural movements are curved, not straight; tools should be placed on the arc of movements, but clear of the path of movement of any material which has to be slid along the surface of the bench.
- (7) Tools should be easy to pick up and replace; as far as possible they should have an automatic return, or the location of the next piece of material to be moved should allow the tool to be returned as the hand travels to pick it up.
- (8) Finished work should be:
 - (a) dropped down a hole or a chute;
 - (b) dropped through a chute when the hand is starting the first motion of the next cycle;
 - (c) put in a container placed so that hand movements are kept to a minimum;
 - (d) if the operation is an intermediate one, placed in a container in such a way that the next operative can pick it up easily.
- (9) Always look into the possibility of using pedals or knee-operated levers for locking or indexing devices on fixtures or devices for disposing of finished work.

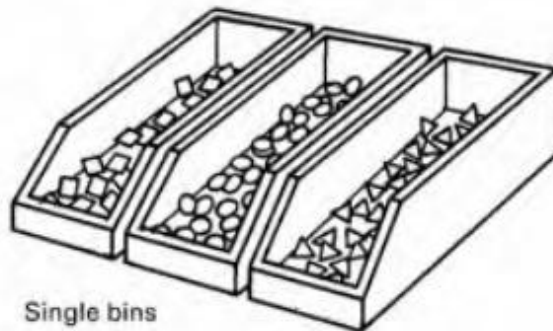
Figure 52. Various bins and motion-economy devices



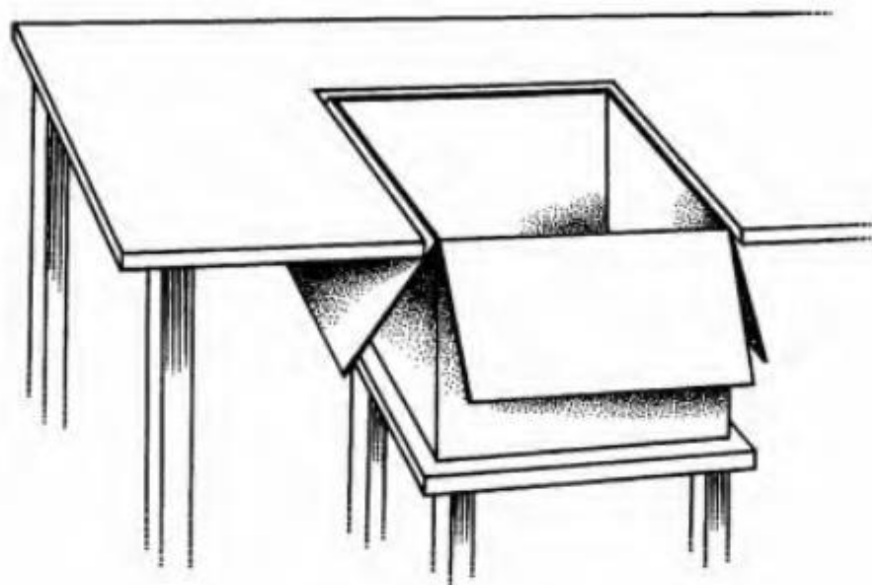
Rotating bin



Double bins



Single bins



Depression in a table to hold flaps of a carton for packaging operation

Figure 53. An example of a workstation layout



Source: Adapted from Thurman et al., op. cit., figure 53.

An example of a workstation layout

Let us now look at a typical workstation with the principles of motion economy and the notes in the previous section in mind.

Figure 53 shows a typical example of the layout of a workstation for the assembly of electrical equipment. Certain points will be noticed at once:

- (1) A fixture has been provided for holding the workpiece, leaving both the operative's hands free for assembly work. The use of one hand purely for holding the part being worked on should **always** be avoided, except for operations so short that a fixture would not be justified.
- (2) The necessary tools are suspended in front of the operative so that he or she has to make only a very short and easy movement to grasp them and bring them to the work. They are, however, clear of the surface of the table and of the work. The hammer and wire-cutter are within easy reach, so that the operative can pick them up without searching. They are placed to one side of the trays of parts, so that they do not get in the way.
- (3) All the small parts are close to the operative, well within the "maximum working area". Each part has a definite location, and the trays are designed with "scoop" fronts for easy withdrawal, parts being drawn forward with the tips of the fingers and grasped as they come over the rounded edge. They are arranged for symmetrical movements of the arms, so that parts which are assembled simultaneously are picked up from trays

in the same relative position to the operative, on either side of him or her. It will be noted that the trays come almost in front of the operative, but this is not very important in this case as the length of reach is not excessive and will not involve much play of the shoulder and back muscles.

5. Notes on the design of jigs, tools and fixtures

A jig holds parts in an exact position and guides the tool that works on them

A fixture is a less accurate device for holding parts which would otherwise have to be held in one hand while the other worked on them

The designer's object in providing jigs and fixtures is primarily accuracy in machining or assembly. Often, opening and closing them or positioning the workpiece calls for more movements on the part of the operative than are strictly necessary. For example, a spanner may have to be used to tighten a nut when a wing nut would be more suitable; or the top of the jig may have to be lifted off when the part might be slid in.

Cooperation between the work study person and the jig and tool designers, in industries where they are employed (principally the engineering industry), should start in the early stages of designing, and tool designers should be among the first people to take appreciation courses in method study. Some points worth noting are:

- (1) Clamps should be as simple to operate as possible and should not have to be screwed unless this is essential for accuracy of positioning. If two clamps are required, they should be designed for use by the right and left hands at the same time.
- (2) The jig should be designed so that both hands can load parts into it with a minimum of obstruction. There should be no obstruction between the point of entry and the point from which the material is obtained.
- (3) The action of unclamping a jig should at the same time eject the part, so that additional movements are not required to take the part out of the jig.
- (4) Where possible on small assembly work, fixtures for a part which does not require both hands to work on it at once should be made to take two parts, with sufficient space between them to allow both hands to work easily.
- (5) In some cases jigs are made to take several small parts. It will save loading time if several parts can be clamped in position as quickly as one.
- (6) The work study person should not ignore machine jigs and fixtures such as milling jigs. A great deal of time and power is often wasted on milling machines owing to the fact that parts are milled one at a time, when it may be quite feasible to mill two or more at once.

- (7) If spring-loaded disappearing pins are used to position components, attention should be paid to their strength of construction. Unless the design is robust, such devices tend to function well for a while but then have to be repaired or redesigned.
- (8) In introducing a component into a jig it is important to ensure that the operative should be able to see what he or she is doing at all stages; this should be checked before any design is accepted.

6. Machine controls and displays of dials

Until recently, machinery and plant of all kinds were designed with very little thought being given to the convenience of the operative. In short cycle work especially, the manipulation of the controls (changing speeds on a capstan lathe, for example) often involved awkward movements. There is not much that the user can do about the controls of a machine after having bought it; but he or she **can** draw the attention of the makers to inconvenient controls so that they can make improvements in later models. There is evidence, however, that machinery makers generally are becoming more conscious of this problem. In the few companies that make their own machinery or plant, the work study department should be called in at the earliest possible stage of the design process, to give assistance and advice.

Physiologists and psychologists have given some thought to the arrangement of dials with a view to minimizing the fatigue to people who have to watch them. The arrangement of the control panels for chemical processes and similar types of process is often made at the works installing them, and the work study person should be consulted when this is done.

The growing awareness of the importance of arranging machine controls and workplaces so that they are convenient for the people who have to do the work has led in recent years to the development of a new field of scientific study which is concerned entirely with such matters. This is **ergonomics**,² the study of the relationship between a worker and the environment in which he or she works, particularly the application of anatomical, physiological and psychological knowledge to the resulting problems. Ergonomists have carried out many experiments to decide on matters such as the best layout for machine controls, the best dimensions for seats and worktops, the most convenient pedal pressures, and so on, and this is often incorporated in the designs of new machines and equipment.

7. The two-handed process chart

The study of the work of an operative at the bench starts, as does method study over the wider field, with a process chart. In this case the chart used is the fifth of the charts indicating process sequence (table 8), the one known as the **two-handed process chart**.

² See Ch. 5.

The two-handed process chart is a process chart in which the activities of a worker's hands (or limbs) are recorded in their relationship to one another

The two-handed process chart is a specialized form of process chart because it shows the two hands (and sometimes the feet) of the operative moving or static in relation to one another, usually in relation to a time scale. One advantage of incorporating a time scale in the chart form is that the symbols for what the two hands are doing at any given moment are brought opposite each other.

The two-handed process chart is generally used for repetitive operations, when one complete cycle of the work is to be recorded. Recording is carried out in more detail than is normal on flow process charts. What may be shown as a single operation on a flow process chart may be broken down into a number of elemental activities which together make up the operation. The two-handed process chart generally employs the same symbols as the other process charts; however, because of the greater detail covered, the symbols are accorded slightly different meanings:

- *OPERATION* Is used for the activities of grasp, position, use, release, etc., of a tool, component or material.
- ⇒ *TRANSPORT* Is used to represent the movement of the hand (or limb) to or from the work, a tool or material.
- D *DELAY* Is used to denote time during which the hand or limb being charted is idle (although the others may be in use).
- ▽ *HOLD* The term **storage** is not used in connection with the two-handed process chart. Instead, the symbol is redesignated as **hold** and is used to represent the activity of holding the work, a tool or material — that is, when the hand being charted is holding something.

The symbol for **inspection** is not much used because the hand movements when an operative is inspecting an article (holding it and examining it visually or gauging it) may be classified as “operations” on the two-handed chart. It may, however, sometimes be useful to employ the “inspection” symbol to draw attention to the examination of a piece.³

The very act of making the chart enables the work study specialist to gain an intimate knowledge of the details of the job, and the chart itself enables him or her to study each element of the job by itself and in relation to other elements. From this study ideas for improvements are developed. These ideas should be written down in chart form when they occur, just as in all other process charting. It may be that different ways of simplifying the work can be

³ Some authorities feel that the standard process-chart symbols are not entirely suitable for recording hand and body movements and have adopted variants, such as:

O: Operation; TL: Transport loaded; TE: Transport empty; H: Hold; R: Rest.

found; if they are all charted, they can be compared easily. The best method is generally that which requires the fewest movements.

The two-handed process chart can be applied to a great variety of assembly, machining and clerical jobs. In assembly operations, tight fits and awkward positioning present certain problems. In the assembly of small parts with close fits, "positioning" should be shown as a separate movement ("Operation") apart from the actual movement of assembly (e.g. fitting a screwdriver in the head of a small screw). Attention can thus be focused on it and, if it is shown against a time scale, its relative importance can be assessed. Major savings can be made if the number of such positionings can be reduced.

Notes on compiling two-handed process charts

The chart form should include:

- spaces at the top for the usual information;
- adequate space for a sketch of the layout of the workplace (corresponding to the flow diagram used in association with the flow process chart), or a sketch of jigs, etc.;
- spaces for the movements of right and left hands;
- space for a summary of movements and analysis of idle time;

Examples are given in the following pages.

Some points on compiling charts are worth mentioning:

- (1) Study the operation cycle a few times before starting to record.
- (2) Chart **one** hand at a time.
- (3) Do not record more than a few symbols at a time.
- (4) The action of picking up or grasping a fresh part at the beginning of a cycle of work is a good point at which to start the record. Start with the hand that handles the part first or the hand that does the most work. The exact point of starting is not really important, as the complete cycle will eventually come round to it again, but the point chosen must be definite. Add in the second column the kinds of work done by the other hand.
- (5) Only record actions on the same level **when they occur at the same moment**.
- (6) Actions which occur **in sequence** must be recorded on the chart at different horizontal levels. Check the chart for the time relation of the hands.
- (7) Care must be taken to list **everything** the operative does and to avoid combining operations and transports or positionings, unless they actually occur at the same time.

Example of a two-handed process chart: Cutting glass tubes

This very simple example describes how a two-handed process chart was constructed for cutting off short lengths of glass tube with the aid of a jig. This is illustrated on the form; the operations involved are self-explanatory (figure 54).

Figure 54. Two-handed process chart: Cutting glass tubes (original method)

Two-handed process chart									
Chart No. 1		Sheet No. 1 of 1		Workplace layout					
Drawing and part: <i>Glass tube 3 mm dia., 1 metre original length</i>									
Operation: <i>Cut to lengths of 1.5 cm</i>									
Location: <i>General shop</i>									
Operative:									
Charted by		Date:							
Left-hand description	○	▷	▷	▽	○	▷	▷	▽	Right-hand description
<i>Holds tube</i>									<i>Picks up file</i>
<i>To jig</i>									<i>Holds file</i>
<i>Inserts tube to jig</i>									<i>File to tube</i>
<i>Presses to end</i>									<i>Holds file</i>
<i>Holds tube</i>									<i>Notches tube with file</i>
<i>Withdraws tube slightly</i>									<i>Holds file</i>
<i>Rotates tube 120°/180°</i>									<i>Holds file</i>
<i>Pushes to end jig</i>									<i>Moves file to tube</i>
<i>Holds tube</i>									<i>Notches tube</i>
<i>Withdraws tube</i>									<i>Places file on table</i>
<i>Moves tube to R. H.</i>									<i>Moves to tube</i>
<i>Bends tube to break</i>									<i>Bends tube</i>
<i>Holds tube</i>									<i>Releases cut piece</i>
<i>Changes grasp on tube</i>									<i>To file</i>
Summary									
Method	Present		Proposed						
	L. H.	R. H.	L. H.	R. H.					
<i>Operations</i>	8	5							
<i>Transports</i>	2	5							
<i>Delays</i>	-	-							
<i>Holds</i>	4	4							
<i>Inspections</i>	-	-							
Totals	14	14							

RECORD

In the original method the tube was pressed to the stop at the end of the jig, marked with the file and then eased back for notching. It was then taken out of the jig for breaking. The chart goes into great detail in recording the movements of the hands, because in short cycle work of this kind fractions of seconds, when added together, may represent a large proportion of the total time needed for the job.

EXAMINE critically

An examination of the details of the original method, using the questioning technique, at once raises certain points. (It is not considered necessary to go through the questions in sequence at this stage in the book: it is assumed that the reader will always do so.)

- (1) Why is it necessary to hold the tube in the jig?
- (2) Why cannot the tube be notched while it is being rotated instead of the right hand having to wait?
- (3) Why does the tube have to be taken out of the jig to break it?
- (4) Why pick up and put down the file at the end of each cycle? Can it not be held?

A study of the sketch will make the answers to the first three questions plain.

- (1) The tube will always have to be held because the length supported by the jig is short compared with the total length of the tube.
- (2) There is no reason why the tube cannot be rotated and notched at the same time.
- (3) The tube has to be taken out of the jig to be broken because, if the tube were broken by bending against the face of the jig, the short end would then have to be picked out — an awkward operation if very little were sticking out. If a jig were so designed that the short end would fall out when broken, it would not then be necessary to withdraw the tube.

The answer to the fourth question is also obvious.

- (4) Both hands are needed to break the tube using the old method. This might not be necessary if a new jig could be devised.

DEVELOP the new method

Once these questions have been asked and answered, it is fairly easy to find a satisfactory solution to the problem. Figure 55 shows one possible solution. It will be seen that, in redesigning the jig, the study person has arranged it in such a way that the notch is cut on the right-hand side of the supporting pieces, so that the short end will break away when given a sharp tap and it will no longer be necessary to withdraw the tube and use both hands to break off the end. The number of operations and movements has been reduced from 28 to six, as a result of which an increase in productivity of 133 per cent was expected. In fact this was exceeded, because the job is now more satisfactory following the elimination of irritating work such as “position tube in jig”. The new method can be carried out without looking closely at the work, so that workers can be trained more easily and become less fatigued.

Figure 55. Two-handed process chart: Cutting glass tubes (improved method)

Two-handed process chart									
Chart No. 2		Sheet No. 1 of 1		Workplace layout					
Drawing and part: <i>Glass tube 3 mm dia., 1 metre original length</i>									
Operation: <i>Cut to lengths of 1.5 cm</i>									
Location: <i>General shop</i>									
Operative:									
Charted by		Date:							
Left-hand description	○	▷	▷	▽	○	▷	▷	▽	Right-hand description
<i>Pushes tube to stop</i>									<i>Holds file</i>
<i>Rotates tube</i>									<i>Notches with file</i>
<i>Holds tube</i>									<i>Taps with file: end drops to box</i>
Summary									
Method	Present		Proposed						
	L. H.	R. H.	L. H.	R. H.					
<i>Operations</i>	8	5	2	2					
<i>Transports</i>	2	5	-	-					
<i>Delays</i>	-	-	-	-					
<i>Holds</i>	4	4	1	1					
<i>Inspections</i>	-	-	-	-					
Totals	14	14	3	3					

General remarks on work measurement

1. Definition

In Chapter 3 it was said that work study consists of two complementary techniques — method study and work measurement. In that chapter both were defined; before we go on to discuss work measurement it is worthwhile repeating the definition of that technique given there.

Work measurement is the application of techniques designed to establish the time for a qualified worker to carry out a task at a defined rate of working

We shall have occasion to examine several features of this carefully thought-out definition in more detail in later chapters. For instance, the reader will have noted the references to “a qualified worker”, and to “a defined rate of working”. We need not concern ourselves with the exact meaning of these terms for the moment. It is worth noting, however, that the term “work measurement”, which we have referred to hitherto as a technique, is really a term used to describe a family of techniques, any one of which can be used to measure work, rather than a single technique by itself. The principal techniques which are classed as work measurement techniques are listed in section 5 of this chapter.

2. The purpose of work measurement

In Chapter 2 we discussed the way in which the total time of manufacture of an article was increased by undesirable features of the product itself, by a poorly designed process and by ineffective time added in the course of production and by actions due to the human element. All these factors tended to reduce the productivity of the enterprise.

We also discussed the management techniques by which these factors could be eliminated or, at any rate, reduced. Method study has been shown to be one of the principal techniques by which the work involved in the product or

It is thus clear that work measurement provides the basic information necessary for all the activities of organizing and controlling the work of an enterprise in which the time element plays a part. Its uses in connection with these activities will be more clearly seen when we have shown how the standard time is obtained.

4. The basic procedure

In section 3 of Chapter 3 we described the basic steps of work study, embracing both method study and work measurement. We shall now isolate those steps which are necessary for the systematic carrying out of work measurement. These steps are:

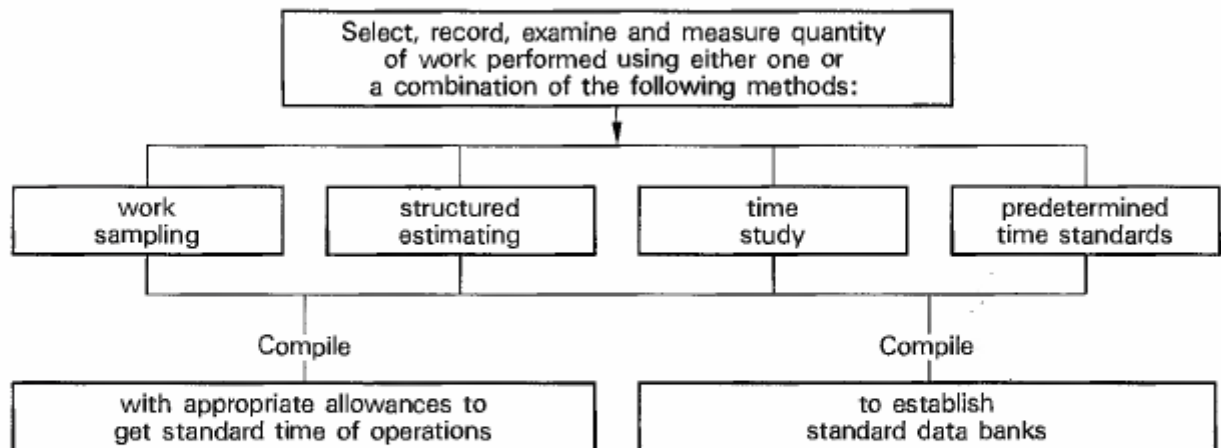
- SELECT* the work to be studied.
- RECORD* all the relevant data relating to the circumstances in which the work is being done, the methods and the elements of activity in them.
- EXAMINE* the recorded data and the detailed breakdown critically to ensure that the most effective method and motions are being used and that unproductive and foreign elements are separated from productive elements.
- MEASURE* the quantity of work involved in each element, in terms of time, using the appropriate work measurement technique.
- COMPILE* the standard time for the operation, which in the case of stop-watch time study will include time allowances to cover relaxation, personal needs, etc.
- DEFINE* precisely the series of activities and method of operation for which the time has been compiled and issue the time as standard for the activities and methods specified.

It will be necessary to take the full range of steps listed above only if a time is to be published as a standard. When work measurement is being used only as a tool of investigation of ineffective time before or during a method study, or to compare the effectiveness of alternative methods, only the first four steps are likely to be needed.

5. The techniques of work measurement

The following are the principal techniques by which work measurement is carried out (figure 87):

Figure 87. Work measurement



- work sampling;
- structured estimating;
- time study;
- predetermined time standards (PTS);
- standard data.

In the next few chapters we shall describe each of these techniques in some detail.

Work sampling and structured estimating

Work sampling is a method of finding the percentage occurrence of a certain activity by statistical sampling and random observations

1. The need for work sampling

Work sampling (also known as “activity sampling”, “ratio-delay study”, “random observation method”, “snap-reading method” and “observation ratio study”) is, as the name implies, a sampling technique. Let us first see why such a technique is needed.

In order to obtain a complete and accurate picture of the productive time and idle time of the machines in a specific production area, it would be necessary to observe continuously all the machines in that area and to record when and why any of the machines were stopped. It would of course be quite impossible to do this unless a large number of workers spent the whole of their time on this task alone — an unrealistic proposition.

If it were possible to note at a glance the state of every machine in a factory at a given moment, however, it might be found that, say, 80 per cent of the machines were working and 20 per cent were stopped. If this action was repeated 20 or more times at different times of the day and if each time the proportion of machines working was always 80 per cent, it would be possible to say with some confidence that at any one time there were always 80 per cent of the machines working.

As it is not generally possible to do this either, the next best method has to be adopted; that of making tours of the factory at random intervals, noting which machines are working and which are stopped, and noting the cause of each stoppage. This is the basis of the **work sampling** technique. When the sample size is large enough and the observations made are indeed at random, there is quite a high probability that these observations will reflect the real situation, plus or minus a certain margin of error.

2. A few words about sampling

Unlike the costly and impractical method of continuous observation, sampling is mainly based on **probability**. Probability has been defined as “the extent to which an event is likely to occur”. A simple and often-mentioned example that illustrates the point is that of tossing a coin. When we toss a coin there are two possibilities: that it will come down “heads”, or that it will come down “tails”. The law of probability says that we are likely to have 50 heads and 50 tails in every 100 tosses of the coin. Note that we use the term “likely to have”. In fact, we might have a score of 55-45, say, or 48-52, or some other ratio. But it has been proved that the law becomes increasingly accurate as the number of tosses increase. In other words, the greater the number of tosses, the more chance we have of arriving at a ratio of 50 heads to 50 tails. This suggests that the larger the size of the sample, the more accurate or representative it becomes with respect to the original “population”, or group of items under consideration.

We can therefore visualize a scale where, at one end, we can have the complete accuracy achieved by continuous observation and, at the other end, very doubtful results derived from a few observations only. The size of the sample is therefore important, and we can express our confidence in whether or not the sample is representative by using a certain **confidence level**.

3. Establishing confidence levels

Let us go back to our previous example and toss five coins at a time, and then record the number of times we have heads and the number of times we have tails for each toss of these five coins. Let us then repeat this operation 100 times. The results could be presented as in table 11, or graphically as in figure 88.

If we considerably increase the number of tosses and in each case toss a large number of coins at a time, we can obtain a smoother curve, such as that shown in figure 89.

Figure 88. Proportional distribution of “heads” and “tails” (100 tosses of five coins at a time)

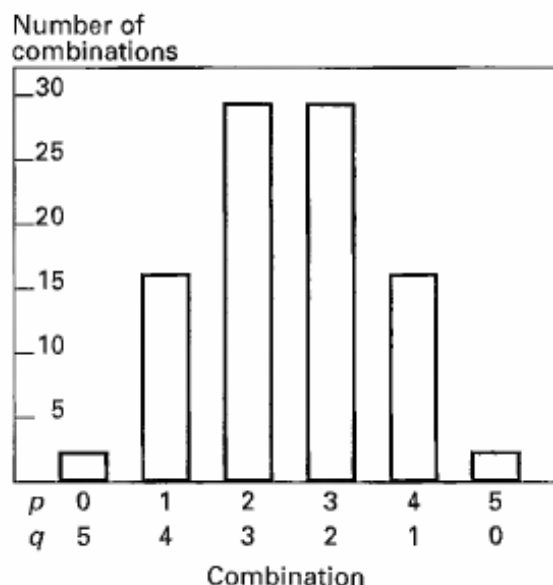
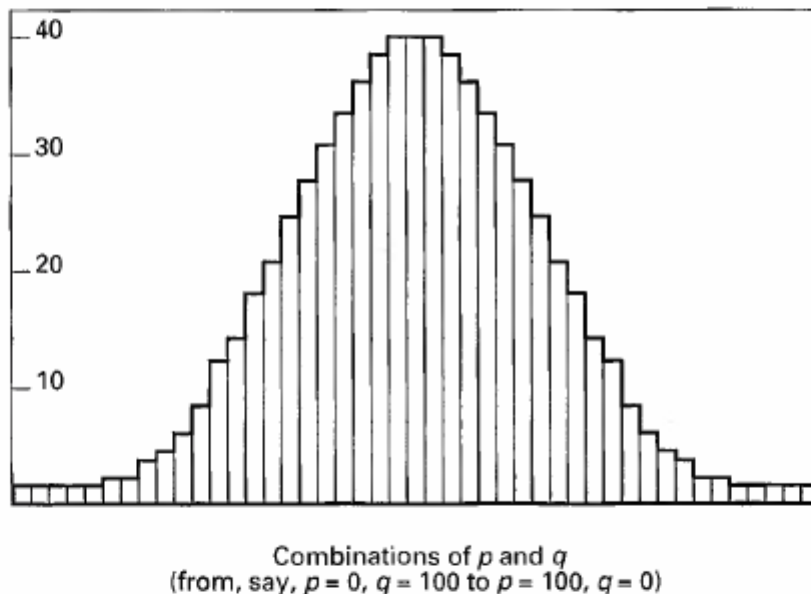


Table 11. Proportional distribution of "heads" and "tails" (100 tosses of five coins at a time)

Combination		No. of combinations
Heads (p)	Tails (q)	
5	0	3
4	1	17
3	2	30
2	3	30
1	4	17
0	5	3
		100

Figure 89. Distribution curve showing probabilities of combinations when large samples are used

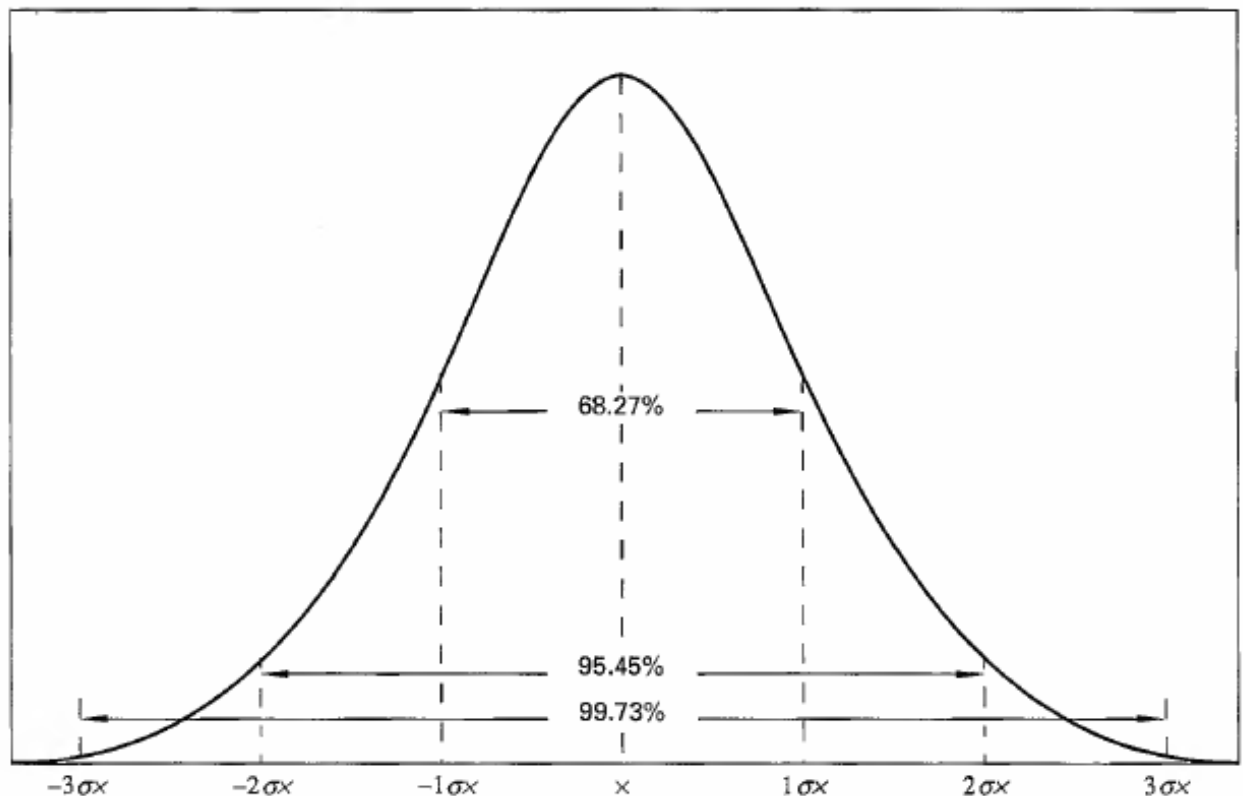


This curve, called the **curve of normal distribution**, may also be depicted as in figure 90. Basically, this curve tells us that, in the majority of cases, the tendency is for the number of heads to equal the number of tails in any one series of tosses (when $p = q$ the number of tosses is a maximum). In few cases, however, is p markedly different from q due to mere chance.

Curves of normal distribution may be of many shapes. They may be flatter, or more rounded. To describe these curves we use two attributes: \bar{x} , which is the average or measure of central dispersion; and σ , which is the deviation from the average, referred to as standard deviation. Since in this case we are dealing with a proportion, we use σp to denote the standard error of the proportion.

The area under the curve of normal distribution can be calculated. In figure 90 one σp on both sides of \bar{x} gives an area of 68.27 per cent of the total area; two σp on both sides of \bar{x} gives an area of 95.45 per cent and three σp on both sides of \bar{x} gives an area of 99.73 per cent. We can put this in another way and say that, provided that we are not biased in our random sampling, 95.45 per

Figure 90. Curve of normal distribution



cent of all our observations will fall within $\bar{x} \pm 2 \sigma$ and 99.73 per cent of all our observations will fall within $\bar{x} \pm 3 \sigma$.

This is in fact the degree of confidence we have in our observations. To make things easier, however, we try to avoid using decimal percentages; it is more convenient to speak of a 95 per cent confidence level than of a 95.45 per cent confidence level. To achieve this we can change our calculations and obtain:

- 95 per cent confidence level or 95 per cent of the area under the curve = 1.96σ ;
- 99 per cent confidence level or 99 per cent of the area under the curve = 2.58σ ;
- 99.9 per cent confidence level or 99.9 per cent of the area under the curve = 3.3σ .

In this case we can say that if we take a large sample **at random** we can be confident that in 95 per cent of the cases our observations will fall within $\pm 1.96 \sigma$.

In work sampling the most commonly used level is the 95 per cent confidence level.

4. Determination of sample size

As well as defining the confidence level for our observations we have to decide on the margin of error that we can allow for these observations. We must be able to say that: "We are confident that for 95 per cent of the time this particular observation is correct within ± 5 per cent, or 10 per cent", or whatever other range of accuracy we may decide on.

Let us now return to our example about the productive time and the idle time of the machines in a factory. There are two methods of determining the sample size that would be appropriate for this example: the statistical method and the nomogram method.

Statistical method

The formula used in this method is:

$$\sigma p = \sqrt{\frac{pq}{n}}$$

where

σp = standard error of proportion

p = percentage of idle time

q = percentage of working time

n = number of observations or sample size we wish to determine.

Before we can use this formula, however, we need to have at least an idea of the values of p and q . The first step is therefore to carry out a number of random observations in the working area. Let us assume that some 100 observations were carried out as a preliminary study and at random, and that these showed the machine to be idle in 25 per cent of the cases ($p = 25$) and to be working 75 per cent of the time ($q = 75$). We thus have approximate values for p and q ; in order now to determine the value of n , we must find out the value of σp .

Let us choose a confidence level of 95 per cent with a 10 per cent margin of error (that is, we are confident that in 95 per cent of the cases our estimates will be ± 10 per cent of the real value).

At the 95 per cent confidence level:

$$\begin{aligned} 1.96 \sigma p &= 10 \\ \therefore \sigma p &= 5 \text{ (approx.)} \end{aligned}$$

We can now go back to our original equation to derive n :

$$\begin{aligned} \sigma p &= \sqrt{\frac{pq}{n}} \\ \therefore 5 &= \sqrt{\frac{25 \times 75}{n}} \\ \therefore n &= 75 \text{ observations.} \end{aligned}$$

If we reduce the margin of error to ± 5 per cent, we have

$$\begin{aligned} 1.96 \sigma p &= 5 \\ \therefore \sigma p &= 2.5 \text{ (approx.)} \\ \therefore 2.5 &= \sqrt{\frac{25 \times 75}{n}} \\ \therefore n &= \frac{25 \times 75}{(2.5)^2} \\ &= 300 \text{ observations.} \end{aligned}$$

In other words, if we reduce the margin of error by half, the sample size will have to be quadrupled.

10. Structured estimating

Estimating is probably the earliest “measurement” technique. People have always used the basis of past experience to predict future events. Normally, however, simple estimates are too unreliable to be used as the basis of effective planning and control. The accuracy of estimating depends on the experience of the estimator in the field in which he or she is estimating. Structured estimating techniques are an attempt to make use of this fact and at the same time to impose a structure and a discipline on the estimating process so that results derived from it can be treated with confidence.

The advantages of estimating are that:

- it is cheap to apply, and therefore may be the only technique appropriate to one-off jobs;
- it can be used to predict times for work which has not been observed and thus can be used as a basis for price estimating for large, one-off jobs.

Estimating is normally used where the required time values are not required in great detail. Thus such techniques are useful in long-cycle work and in situations where aggregated measurement data are used for planning, control or payment over reasonably lengthy time periods.

Analytical estimating

Analytical estimating is a combination of estimating and synthesis from standard data. The technique is based on the fact that if jobs are broken down into constituent elements and individual elements are measured or estimated, errors in those individual times will be random and will compensate for one another to leave an overall time that will be within acceptable limits. Similarly, when a number of jobs are combined into a larger time accumulation (such as the workload for a given week), individual errors in job times will be random and compensated by one another, leaving an overall time that is acceptable.

The estimating is normally carried out by a worker who is skilled in the area of work being measured and who has been trained in work study techniques. The estimator then:

- breaks a job into elements;
- applies any standard or synthetic data that are available;
- carries out measurement on elements which are considered to warrant such effort and expenditure;
- estimates any remaining elements using his or her experience and knowledge of the working conditions, safety factors, etc.

Element times which are estimated may then be incorporated into the standard data for future use, although such data should be revalidated at intervals.

Comparative estimating

Comparative estimating relies on the identification and measurement of “benchmark” jobs of known work content against which all other jobs to be measured are compared. The benchmark jobs are selected to represent the

whole range of work involved and to represent intermediate points on the overall scale of job. These benchmark jobs are measured with some precision using an established work measurement technique.

The next stage is to identify time bands or slots. These are determined by statistical analysis and may not be of equal width. Commonly, a logarithmic progression is selected with each slot being allocated a basic or standard time equivalent to its mid-point.

Thus:

Slot	1	2	3	4
Range (min.)	0-30	31-60	61-120	121-240
Basic time	15	45	90	180

Each of the benchmark jobs is assigned to the appropriate slot.

When estimating work subsequently, the estimator refers to the benchmark jobs and compares the job being measured. On the basis of experience, he or she makes a comparison of the work content of the job to be estimated with a number of the benchmark jobs. When he or she is satisfied that the correct slot for the job has been identified, he or she assigns the slot basic time to that job. Because this time is to be combined with others to give a total workload over a long period, the fact that this one time is "inaccurate" does not matter. It is dangerous, however, to use such individual times outside the planned period designed to offer the statistically correct error compensation period.

Because of the high set-up cost of this system (in terms of measuring all the benchmark jobs, training estimators, and so on), comparative estimating is most suitable for situations where there is a lot of long-cycle, non-repetitive work. A common area of application is in maintenance work, where the work is similar but no two jobs may be identical. To reduce the set-up time, it is possible to "import" data on benchmark jobs from another organization (such as a consulting firm). If this is done, it is important to validate the data (as with any imported standard data) in its field of operation through carrying out some comparative studies.