By RALPH M. BARNES

WORK METHODS MANUAL

136 pages. 110 figures.

MOTION AND TIME STUDY

390 pages. 200 figures.

MOTION AND TIME STUDY APPLICATIONS

188 pages. 104 figures.

WORK
METHODS MANUAL

BY

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PREFACE

Before any job can be started someone must plan it and set it up. This includes determining the steps to be followed in doing the work, selecting the tools and equipment to be used, and training the operator.

When the production of a given article is large, staff engineers usually work out the details and aid the foreman and supervisors in putting the job into production. However, most work is not highly repetitive, and an operator may do several different jobs during the course of a day or a week. In such cases the supervisor usually decides how the job is to be done, lays out the work place, selects the tools and equipment, and instructs the operator. For this reason it is desirable that those people in immediate charge of operations know the fundamentals of good work methods. Even when the production of the article is expected to be large and when industrial engineers are assigned to work out the manufacturing methods, the foremen and supervisors usually play an important part in aiding the engineers to develop the procedures to be followed. Here, too, it is desirable for the supervisor to have a working knowledge of the industrial engineer's techniques as they pertain to methods improvement.

However, in the final analysis it is the worker who does the job. It is the worker who uses the tools and equipment selected by the supervisor or the engineer and employs the methods suggested by him. Therefore it is logical that the worker too should understand those methods and techniques which will enable him to do his job in the easiest and most efficient manner possible.

Although this book has been written for the foreman and supervisor it will be of value to workers as well. It has been demonstrated many times that both supervisors and workers can profitably use the principles of motion economy. Naturally the supervisor should take the initiative in using these tools for improving job methods. When this is done the worker may be expected to absorb this knowledge more quickly either through instruction from the foreman or through a formal training course.

Incidentally, this book contains the same principles and techniques that are used in training professional industrial engineers. Although the subject of stop-watch time study and rate setting has been omitted, this book contains a full discussion of process charts, man and machine charts, and operation analysis. Ten principles of motion economy which have widest application have been included with specific illustrations indicating how they may be applied and showing what results may be expected from their use. Several series of photographs have been used to aid in defining fundamental hand motions, thus enabling the reader to master this classification of hand motions without the tedious task of memorizing definitions. This material on hand motions is included as a separate chapter so that it may be omitted when the book is used in a course that does not allow sufficient time for discussion of this subject. However, for a thorough understanding of motion study it is essential not only that the reader know the fundamental hand motions but also that he practice motion analysis until he becomes "motion minded," that is, until he can visualize any manual task in terms of the motions of the right hand and of the left hand.

The author wishes to express his great indebtedness to those people who have supplied the cases and examples used in this book, and he has endeavored to give full credit for this assistance. To the many other people who have had a part in the development of this book he would also express his sincere appreciation.

RALPH M. BARNES

IOWA CITY, IOWA
January, 1944

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CHAPTER 1

INTRODUCTION

Since the first crude stone ax was fashioned ages ago man has gradually developed better tools, better machines, and better processes to increase the effectiveness of his efforts. Despite the present high perfection of our mechanical equipment men and women are needed to build, operate, adjust, and maintain all these machines. Although the machine is man's servant he can never expect it to do all the work. There is still much work that can be done best and most economically by hand. Most of the 50 million men and women in this country who work in the offices and factories, in the restaurants and hospitals, and on the farms do considerable manual work each day. Many spend the entire day in such activities, and almost every man, woman, and child performs some manual work.

Since so many people do physical work and since the human body is such an intricate mechanism, considerable thought has been given to the problem of finding better and easier ways to work. This subject has grown in importance during the past fifty years, and today many business concerns and industries employ a staff of people whose job it is to develop better work methods for the people employed in these organizations.

The principles and techniques for developing good work methods have been so simplified in recent years that many people have become acquainted with them and are applying these principles in their everyday jobs with the result that they not only get their day's work done with less effort but usually they also turn out more work. This book presents the simple principles which can be applied in a common-sense way to any manual task or office procedure.

However, this book will be of little value to you unless you approach the subject with an open mind. If you think your present work methods are satisfactory, if you think your job is different, if you feel that you should postpone applying the ideas presented in this book until next week or next month, you will be failing to take full advantage of your time and talents. This book will profit you only if you are willing to try out the methods described. It is human nature to resent change, to resist the new, particularly when it pertains to the work from which we earn our livelihood. Inertia is perhaps the biggest single factor preventing us from realizing our full worth on the job today.

Now, with changes of many kinds being forced on all of us by circumstances beyond our control, perhaps it will be easier for us to adopt a new point of view concerning the work we do. We may be more willing to question a good many things about our work methods and try to find practical answers to these questions. When a person has reached the point where he is willing to admit to himself that there is room for improvement, that present methods are not perfect, he has overcome the biggest single hurdle to the improvement of his job or the simplification of work under his supervision.

Why Work Efficiently? Most of us work for a living. We know that in general the more we do the more we earn. In many offices and factories wages are paid in direct relation to output. We all know that for the country as a whole we cannot consume more than we produce, and therefore our standard of living is in direct proportion to our productivity. However, no one wants to work inordinately hard, and in peacetime few people want to work long hours. There seems to be every reason why we as individuals and as a nation should want to accomplish as much in a day as we can and yet do our work in the easiest and most satisfying way possible.

This book is intended for those who want to know how to find better methods of doing manual work whether he be workman, supervisor, or executive. The fundamental principles are the same for all types of work. They apply equally well in the office or factory, in the restaurant or hospital, or in the bank or on the farm.

Easier and Better Work Methods. It has been demonstrated countless times that a person unfamiliar with this subject can very quickly learn the principles and methods involved and can apply them to his own job with the almost inevitable result that his efficiency will be increased. If, for example, by devising a better work method the operator's hourly output is doubled this means that the improved method is so much easier than the original way that the operator is able to do his usual day's work in a half day, or that he can produce twice as much work per day with the same expenditure of energy. Naturally, we are not talking about a system of "speed up" or "stretch out." The greater output results from the elimination of unnecessary elements of the job and from making the necessary elements easier and less fatiguing.

COMPARISON OF NUMBER OF MOTIONS USED PER HOUR IN ASSEMBLING ELECTRIC METERS

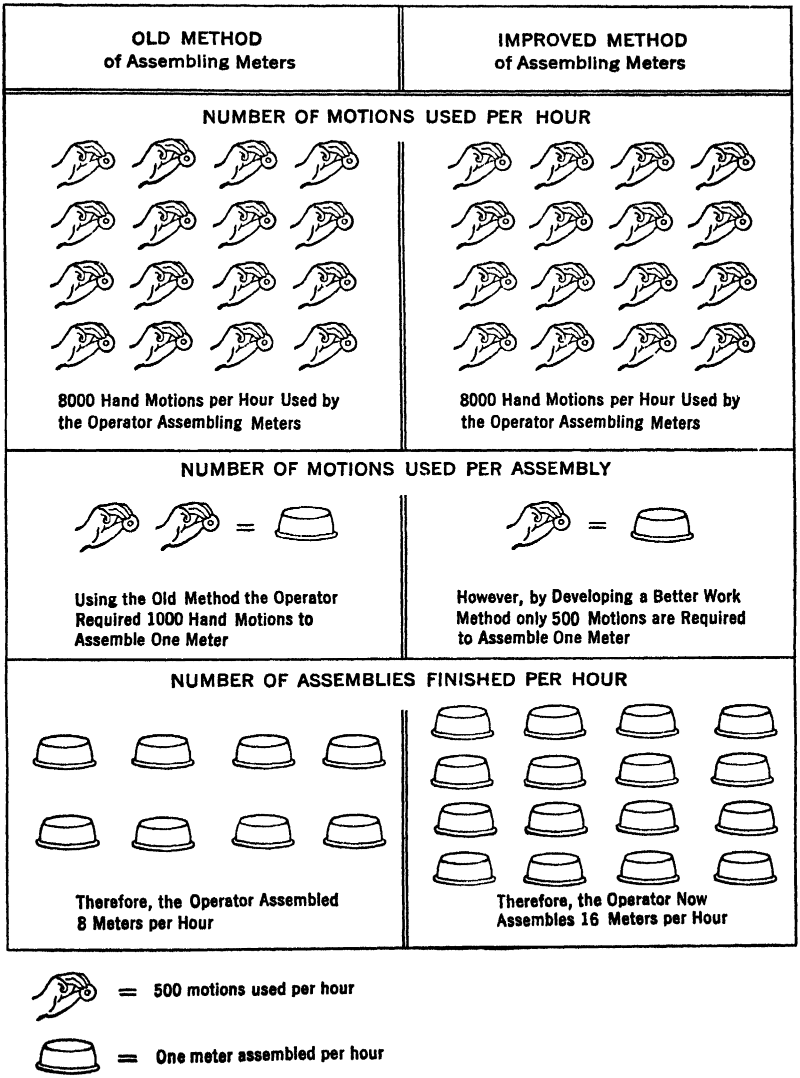


Fig. 1.

To illustrate this point let us assume that an operator assembling electric meters uses 8000 hand motions per hour and that 1000 motions are required to assemble one meter. Thus the operator can assemble 8 meters per hour. (See Fig. 1.) However, by developing a special holding fixture, by a better arrangement of the work place, and by the use of a power wrench let us assume that the operator is able to assemble a meter with but 500 motions. Therefore, it is obvious that under these conditions 16 meters can be assembled per hour. Output can be doubled with no increase in the number of motions used.

To cite a specific case,[1] in one glass plant the operation of cresting or etching glasses was improved and the following results were obtained. Using the old method, the operator crested 439 glasses per hour, with a total of 7726 motions. The improved method was so much simpler and easier than the old method that the operator crested 1051 glasses per hour, using 7253 motions. The better method enabled the operator to increase her output 140 per cent and at the same time use 6 per cent fewer motions. In this particular case the new method was much easier than the old method since several very fatiguing motions of the wrist were eliminated. The goal of work analysis and motion study is maximum accomplishment with minimum effort.

	Number of Motions Required			Number of Glasses Crested per Hour
	Per Carton	Per Glass	Per Hour	
Old method	1266	17.6	7726	439
Improved method	498	6.9	7253	1051

It seems that until recent years few employers expected the worker to take an active interest in his job and the neighboring jobs with which he was familiar. Today, however, there is a rapidly growing spirit of cooperation—a desire to get the job done in the easiest and best manner possible. The worker and the employer both realize that only through increased worker productivity can we have higher wages,

[1] Numbers refer to the list of references and acknowledgments at the end of the book.

lower prices, shorter working hours, and a sufficient profit to allow the enterprise to continue in business year after year.

The employer also knows, or should know, that if he asks for and gets the cooperation of the members of his organization he must make absolutely certain that every person benefits from this cooperation, both in the "short run" as well as in the "long run." It seems absurd to expect a person to suggest better methods if, as a result of such suggestions, employees are laid off or if excessive work assignments are made.

Employment, Wages, and Prices. If, for example, a new machine is installed or a new method is put into effect which enables the operator, exerting no greater effort than formerly, to double his output, it is not expected that the operator's wages will be immediately doubled. However, it is expected that a fair reward and full credit will be given to the person or persons who suggested the new idea and to those who aided in its development. Moreover, it is expected that those using the new method will earn as much as, or more than, formerly for the same expenditure of effort, that no one will be laid off, and that in the long run wages will be raised, working hours shortened, and the selling price of the product reduced. The last three points are not new. We need only to compare the selling price during the early days of development of the automobile, the electric refrigerator, or the many other products in daily use with the price, say, in 1940, fully to appreciate the fact that the prices of manufactured products in this country have steadily decreased. We also know that the average length of the working day has been reduced and that hourly wages as well as real annual earnings have greatly increased over this period.

In order to make this point clear an actual case is presented here. The curves show the record of the Eastman Kodak Company[2] for the twenty-six-year period from 1915 through 1940. The number of people employed by this company increased from 7000 to 27,000 during this period. In other words the number of employees increased over threefold, whereas the total population of the country increased 30 per cent. (See Fig. 2.) The real weekly earnings increased 60 per cent (see Fig. 3), and the real annual earnings increased 45 per cent over the twenty-six-year period. (See Fig. 4.) It should be noted that this increase in the annual purchasing power of the employees took place in spite of a decrease of over 20 per cent in the number of hours worked.

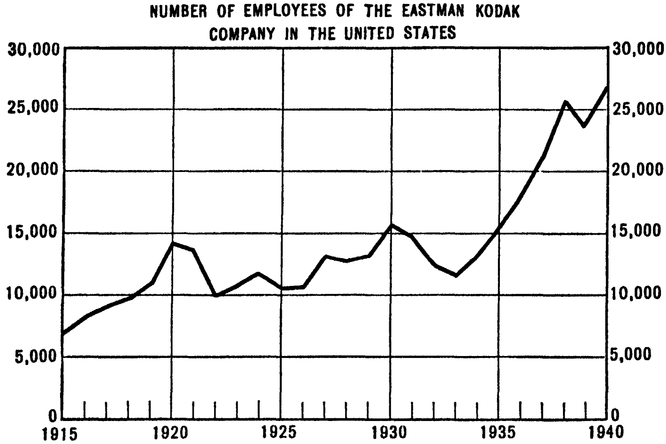


FIG. 2. Number of employees of the Eastman Kodak Company in the United States.

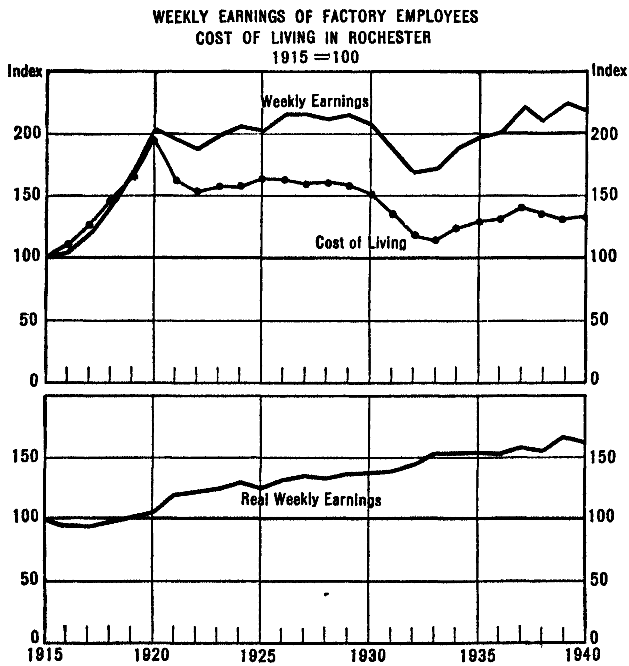


FIG. 3. Weekly earnings of factory employees and cost of living in Rochester, N. Y.

As Fig. 5 shows, the price level of the products sold by this company decreased 25 per cent below the 1915 base whereas the level

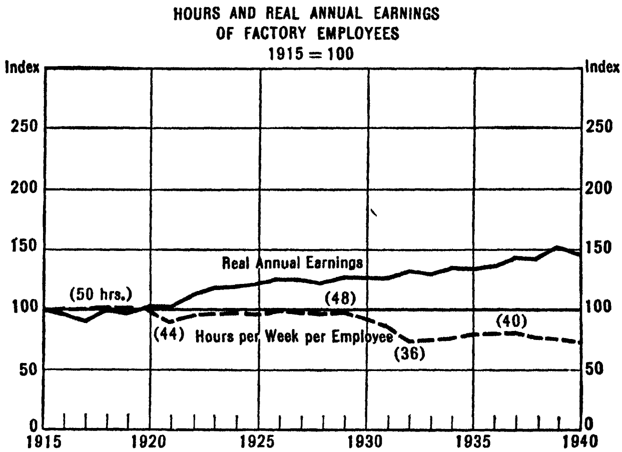


Fig. 4. Hours and real annual earnings of factory employees.

of general prices was 19 per cent above the 1915 base. The net profits of the company were maintained at a satisfactory level, as shown in Fig. 6.

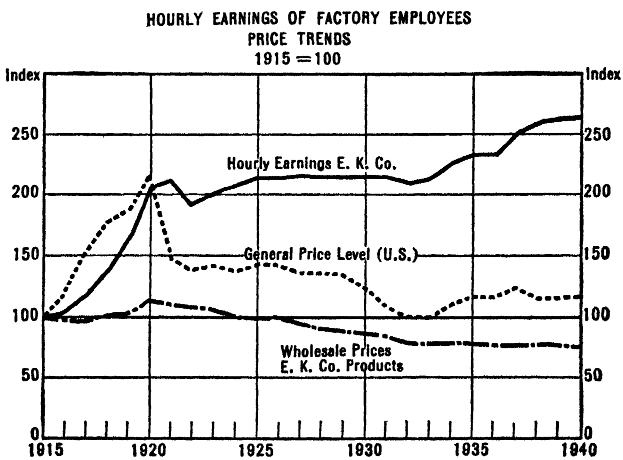


Fig. 5. Hourly earnings of factory employees—price trends.

The record of this company is presented here to show that it is possible for an industry over a period of years to increase real wages, reduce hours of work, lower the selling price of the products it makes and at the same time maintain or increase the number of people employed, and produce sufficient profits to enable the company to re-

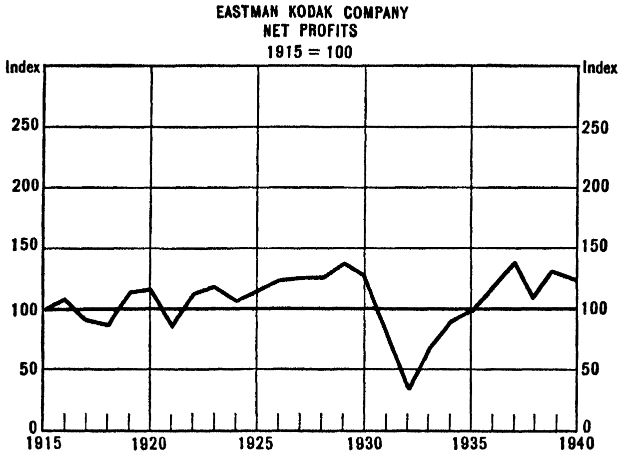


Fig. 6. Net profits of the Eastman Kodak Company.

main in business. A record like this is possible only when a business is well managed *and* when the productivity of the organization is constantly increasing.

CHAPTER 2

DEVELOPING A BETTER METHOD

The first step in developing a better and easier work method is to get an accurate picture of the present method. This may be obtained by making a list of all the details in the process. It is important to have a bird's-eye view of the work from start to finish. This is desirable even though the job singled out for special study involves but one operation in the process. The simplest form of work analysis consists of taking a sheet of paper and listing in sequence all the steps in the process.

After a careful record of the entire process has been made a similar breakdown should be made of each operation in the process, starting with the most important operation first, that is, the operation that has the greatest potential savings. For example, suppose we consider the process of bottling milk in a small dairy plant. The over-all picture would show the unloading of empty milk bottles from the delivery truck at the milk plant, then washing the bottles, removing washed bottles from the washing machine, inspecting the bottles, filling and capping the bottles, moving filled bottles to the refrigerator, and finally removing the cases of full milk bottles to the delivery truck.

In addition to this over-all analysis, a detailed breakdown of each operation in the process might also be made. If washing empty bottles required the greatest number of man hours and if the method in use seemed particularly inefficient, then that operation should be studied first.

It is fairly easy to record the steps used in a process, and likewise it is a rather simple task to make a breakdown of the operations involved. The real problem is to make changes that will result in a better and easier method of doing the work.

Question Everything about the Job. One of the best ways to approach the problem of methods improvement is to question everything about the job—the *way* the job is being done now, the *materials* that are being used, the *tools* and *equipment*, the *working conditions*, and even the *design* of the product. Assume that nothing about the job is perfect.

As you make the job breakdown, process chart, or flow diagram question every item that you put down on your chart. Begin by asking the questions What? Why? Who? Where? When? How? *

1. *What* is done? What is the purpose of the operation?
2. *Why* is the work done? What would happen if it were not done? Is every part of the job necessary?
3. *Who* does the work? Who could do it better? Can changes be made to permit a person with less skill and training to do the work?
4. *Where* is the work done? Could it be done somewhere else more economically?
5. *When* is the work done? Would it be better to do it at some other time?
6. *How* is the work done? This suggests a careful analysis and the application of the principles of motion economy.

Analyze the Work—Develop a Better Method. After all phases of the work have been subjected to the above questions, consider the following possibilities for job improvement:

A. Eliminate all unnecessary work.
B. Combine operations or elements.
C. Change the sequence of operations.
D. Simplify the necessary operations.

Each of these four approaches to the development of better methods will be discussed more fully here.

A. Eliminate All Unnecessary Work. The very first question that should be asked about any job is why do it at all? Can it be eliminated? The *what* and *why* questions are the pertinent ones here. These questions should be asked about each transportation, storage, delay, and inspection as well as about every operation in the entire process.

It is obvious that if the job in question can be eliminated that particular problem is solved. No effort should be wasted in trying to

* Many years ago Kipling wrote:

"I keep six honest serving men
(They taught me all I knew).
Their names are Why, and What, and When,
And Where, and How, and Who."

combine elements, change the sequence, or simplify the method if the operation, or a part of it, can be dispensed with. We all know of many commonplace illustrations of unnecessary operations. The use of the window envelope makes it unnecessary to address the envelope; placing the address on the magazine itself makes it unnecessary to use a wrapper or mailing envelope. The carton for milk replaces the bottle and eliminates the work of handling and washing empty milk bottles in the milk plant.

B. Combine Operations or Elements. We all know how desirable it is to break down a process into many simple operations. In some instances, however, the division of labor has been carried too far. It is possible to subdivide a process into too many operations, causing excessive handling of materials, tools, and equipment. Also such problems as the following may be created: difficulty in balancing the many operations; accumulation of work between operations when improper planning exists; and delays when inexperienced operators are employed or when operators are off the job. Thus it is sometimes possible to make the work easier by simply combining two or more operations or by making some changes in method permitting operations to be combined.

C. Change the Sequence of Operations. When a new product goes into production it frequently is made in small quantities on an "experimental" basis. Often production increases gradually and in time output becomes large, but the original sequence of operations may be kept the same as when production was small. For this and other reasons it is desirable to question the order in which the different operations are performed.

For example, in one plant small assemblies were made on semi-automatic machines in Department A. (See Fig. 7.) They were stored in Department B, inspected in Department C, and packed for shipment in Department D. The manufacturing methods were such that normally only 10 per cent of the finished assemblies were inspected. When an excessive number of defects were found, however, then all work was given a 100 per cent inspection until the cause of the trouble was found and corrected.

Since there was always a bank of several days' work in Department B awaiting inspection, when trouble was encountered it was necessary to give this entire bank of work a 100 per cent inspection and moreover defective assemblies had to be repaired or scrapped. To correct this difficulty the inspectors were placed immediately adjacent to the assembly department and the bank of finished assemblies awaiting inspection was eliminated as shown in Fig. 8. Since each unit was

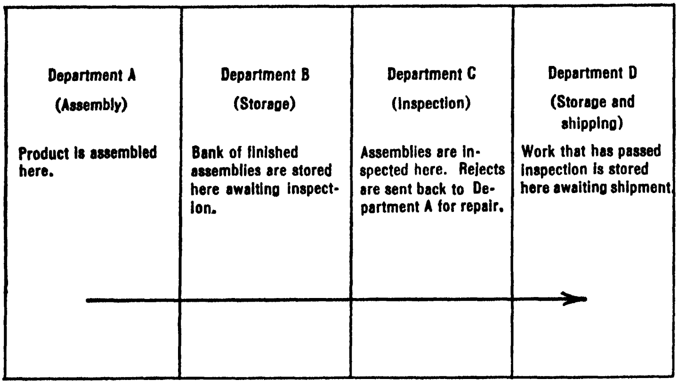


FIG. 7. Layout of building for assembly and inspection of small parts produced on semi-automatic machines—old arrangement of departments. Notice that inspection was done in Department C.

inspected as it came from the assembly line, rejects were found in a few minutes after the units were completed and the cause of the difficulty could be corrected before other "scrap" parts had been made.

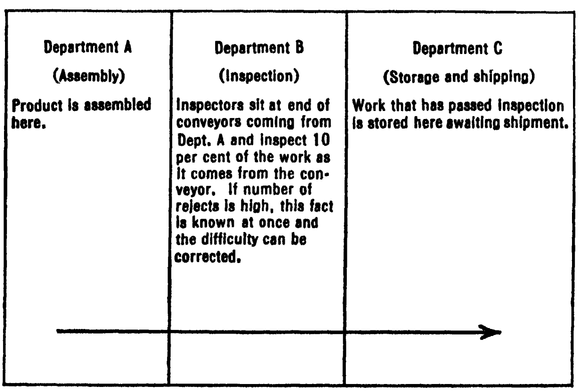


FIG. 8. Layout of building for assembly and inspection of small parts—improved arrangement of departments. Inspection now takes place immediately adjacent to the assembly department.

This simple rearrangement, which was easy and inexpensive to make, saved the company tens of thousands of dollars in inspection costs and greatly reduced the number of scrapped parts.

The job breakdown, process chart, and flow diagram described in Chapters 3 and 4 serve a useful purpose in pointing out the desirability of changing the sequence of operations to eliminate backtracking, to reduce transportation and handling, and to effect a smooth flow of work through the plant.

D. Simplify the Necessary Operations. After the process has been studied and after all improvements that seem worth while have been made, the next step is to analyze each operation in the process and try to simplify or improve it. In other words, the over-all picture is studied first and major changes are made, then the smaller details of the work are studied.

There are several ways to approach the problem of operation analysis and simplification. The first step is to draw a sketch of the work place and list the details of the operation as it is performed now. If the job is not too long or too complex, the motions of the right hand and the left hand may be listed on a sheet of paper, such as the chart in Fig. 49 on page 52. Then using the Ten Principles of Motion Economy as a check list, see if some of them cannot be applied to the job. Question each element or hand motion. Just as in an analysis of the process we tried to eliminate, combine, and rearrange the sequence of operations, now in the case of a single operation we try to eliminate motions, combine them, or rearrange the sequence of necessary motions in order to make the job easier.

Tools for Methods Improvement. Before better and easier methods of doing a task can be developed it is necessary to get all the facts pertaining to the job. This involves getting sufficient information to answer the what, why, who, where, when, and how questions as well as to answer satisfactorily the four other questions already suggested. Most people find it useful to list the information in tabular or graphic form. Since several different methods of visualizing a process or an operation have found wide use, each of these will be fully described in the next five chapters. Of course all these different methods would not be used on any one job. For example, many supervisors find that a simple job breakdown is all they need; others prefer the process chart and the flow diagram. If a single operation is the subject for study, then either the job breakdown or the right- and left-hand chart may be used. The activity chart and the man and machine chart are also useful, and occasionally it may be worth while to make a motion analysis of the job, particularly if the cycle is short and if a large number of people are employed on it.

Therefore, it should be clearly understood that the job breakdown, process chart, flow diagram, activity chart, man and machine chart, right- and left-hand chart, and the simo chart are merely tools to be used as needed.

Extent to Which a Study Should Be Carried. Before a study of work methods is started it is essential that an estimate be made of the expected savings that will result. The extent to which an investigation of this kind can profitably be carried will depend largely on anticipated savings and costs.

The problem is parallel to that of selecting a device for measuring length. The carpenter framing a house would need no more accurate scale than his two foot rule, whereas the machinist grinding a steel shaft would require a micrometer, and the toolmaker building a master gauge for the most accurate work in the manufacture of airplane motor parts would need precision gauge blocks as a measuring device. Each of these three devices has its place in measuring length, and in a similar manner each of the several tools or techniques described in this book has its place in improving work methods.

Each job investigated will not require all of the refinements that are available. Some classes of work will justify thorough analysis, others will not warrant such an expenditure of time. The more extensive the study, the greater the amount of time required to make it. Only such expenses should be incurred in investigating an operation or a process as will be economically justified.

Although the savings in direct labor is usually the greatest factor it is also well to consider material costs and overhead. This last item will include machine costs, tool costs, indirect labor costs, floor space costs, etc. Also, if it is possible to reduce the time the work is in process such factors as faster delivery and reduction of capital investment of work-in-process should be evaluated.

In making the preliminary estimate of potential savings it is wise to be conservative. It is better to actually save more than was anticipated rather than less.

CHAPTER 3

THE JOB BREAKDOWN

One of the simplest ways of getting a picture of a job is to take a sheet of paper and write down each element or step as it is performed. The elements may be short or long as the nature of the work

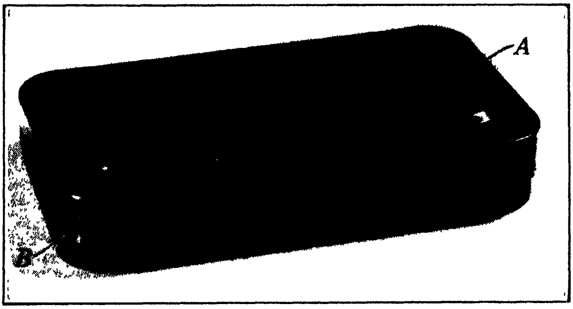


FIG. 9. Metal box: *A*, box cover; *B*, box bottom.

indicates. Such a breakdown should be made on the job and not from memory at a desk. It is well to allow space at the right hand side of the sheet on which to note suggestions for improvement. In fact the what and why questions should be asked about each element as it is listed on the sheet. Also the four questions, Can it be eliminated?, Can it be combined?, Can the sequence be changed to advantage?, Can it be simplified? often suggest worth-while changes in the job. Time for each element may be included in a special column on the breakdown sheet if this seems desirable.

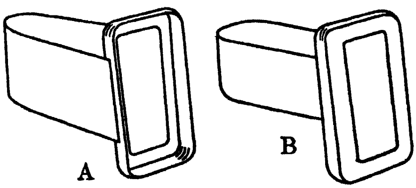


FIG. 10. Clamps for holding box covers and bottoms for spraying by the original method: *A*, for spraying inside; *B*, for spraying outside.

For example, the breakdown for the old method of spray-painting black enamel on small metal boxes is shown in Fig. 11. These boxes, made in slightly different sizes and shapes, are used for such products as surgical instruments and sewing machine attachments. The box is composed of a cover and a bottom which fit together as shown in Fig. 9. The boxes are manufactured in lots of 5000 to 10,000.

Original Method of Spraying Boxes. The operator, standing in front of the spray booth, procured an unsprayed box cover or bottom with the right hand from a tote box at her right and placed it on the metal fixture *A* shown in Fig. 10 which she held in her left hand. She then grasped the spray gun in her right hand, and holding the box cover inside the spray booth she sprayed the inside surface and disposed of it on a screen tray. When the tray was filled (35 box covers or bottoms) it was placed in an oven rack and an empty tray was positioned at the left of the spray booth.

When an oven rack was full it was moved into the baking oven on the other side of the room where it was baked for 1½ hours. The rack

JOB BREAKDOWN SHEET

OPERATION: Spray metal boxes with black enamel	**DATE:** 1-21-43
	OPERATION NO: P-62
PART NAME: Metal boxes (covers and bottoms)	**PART NO:** B354-A-B
OPERATOR'S NAME: J. R. Wilson	**BY:** W. S. Hale
ELEMENTS	**A. Can it be eliminated?** **B. Can it be combined?** **C. Can the sequence be changed?** **D. Can it be simplified?**
1. Spray inside of box cover or bottom and place on tray.	
2. Move truck containing 15 trays to baking oven. 30 feet.	
3. Bake in oven 1½ hours.	
4. Remove truck from oven and allow boxes to cool.	
5. Remove boxes from truck and inspect enamel finish on inside.	
6. Spray outside of box cover or bottom and place on tray.	Combine both spraying operations.
7. Move truck containing 15 trays to baking oven. 30 feet.	
8. Bake in oven 1½ hours.	Bake boxes once only.
9. Remove truck from oven and allow boxes to cool.	
10. Remove boxes from truck and inspect enamel finish on outside.	Inspect enamel on inside and outside in one operation.

FIG. 11. Job breakdown sheet for spray-painting metal boxes—old method.

was then removed, cooled, and the outside of the box covers were sprayed, using fixture *B* shown in Fig. 10. The sequence of motions used in spraying the outside was similar to that used for spraying the inside. The box covers were again baked in the oven for 1½ hours and when removed and cooled were ready for the final inspection.

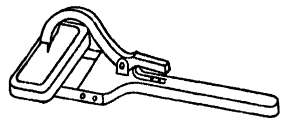


FIG. 12. Fixture for holding box covers and bottoms. The inside and the outside of the box cover or bottom can be sprayed at one operation.

Improved Method of Spraying Boxes. As indicated on the Job Breakdown Sheet, Fig. 11, the questions "Why not combine the two spraying operations?" and "Why not eliminate one of the baking operations and one of the inspection operations?" suggest themselves at once.

A simple fixture was made as shown in Fig. 12 which held the box cover while both the inside and the outside were sprayed. The box

JOB BREAKDOWN SHEET

OPERATION: Spray metal boxes with black enamel	**DATE:** 2-26-43
	OPERATION NO: P-62
PART NAME: Metal boxes (covers and bottoms)	**PART NO:** B354-A-B
OPERATOR'S NAME: J. R. Wilson	**BY:** W S Hale
ELEMENTS	**A. Can it be eliminated?** **B. Can it be combined?** **C. Can the sequence be changed?** **D. Can it be simplified?**
1. Spray inside and outside of box cover or bottom and place on tray.	
2. Move truck containing 15 trays to baking oven.	
3. Bake in oven 1½ hours.	
4. Remove truck from oven and allow boxes to cool.	
5. Remove boxes from trays and inspect enamel finish on inside and outside.	

FIG. 13. Job breakdown sheet for spray-painting metal boxes—improved method.

cover rested on the two parallel knife edges and was held firmly in place with a needle point on top. After the box cover was completely sprayed it could easily be slid off of the knife edges onto the tray without damage to the wet enamel. Each operator is supplied with two fixtures so that one can be allowed to soak in solvent while the other one is being used.

Results: The improved method, using this fixture, proved to be superior to the old method in the following ways:

1. The operator now sprays both the inside and the outside of the box cover or bottom at one operation. This effects a saving of approximately 25 per cent in direct labor.

2. The box covers and bottoms are baked only once instead of twice. This reduces the use of the baking ovens 50 per cent and also reduces the labor for handling racks and trays 50 per cent.

3. An additional saving results in that the investigation showed that the inside of the box covers and bottoms were being sprayed with a dull-finish enamel and the outside with a glossy-finish enamel. As there is no need for the dull finish on the inside and since dull-finish enamel is more expensive than glossy, use of the dull has been discontinued and the entire box sprayed with glossy enamel. This alone saved in one year more than enough to pay for all the experimental fixtures that were used in the development work.

CHAPTER 4

PROCESS CHARTS

FLOW DIAGRAMS

Many people, especially those working in large factories and offices, do not fully understand how their work ties in with the preceding and following operations required to manufacture a product or perform a complete office function. In most cases each person does his own particular job without much thought or concern for the work that others must perform on the same part. However, not only is it much more interesting to know something about the entire process, but very often an understanding of the process shows up unnecessary operations, excessive handling of materials or tools, or awkward and tiresome methods of performing specific operations.

The process chart is a device for recording, in a compact manner, a process as a means of better understanding it and improving it. The chart usually begins with the raw material entering the factory and follows it through every step, such as transportation to storage, inspection, machining operations, assembly, until it either becomes a finished unit itself or a part of a subassembly. The process chart might, of course, record the process through only one or a few departments. In the office the process chart might show the flow of a time card, material requisition, purchase order, or any other form through the various steps. The chart might begin with the first entry on the form and show all the steps until the form is finally permanently filed or destroyed.

Many years ago Frank B. Gilbreth and his wife Lillian M. Gilbreth devised a complete set of symbols to aid in making process charts.[3] In recent years the abbreviated set of four symbols shown in the first vertical column of Fig. 14 have been widely used and are all that are needed for most kinds of work. These symbols serve as a special sort of shorthand to aid in quickly listing the steps or operations in a process.

Steps Used in Watering Garden. In order to illustrate how these symbols may be used, a process chart is shown in Fig. 15 giving the

PROCESS CHART SYMBOLS

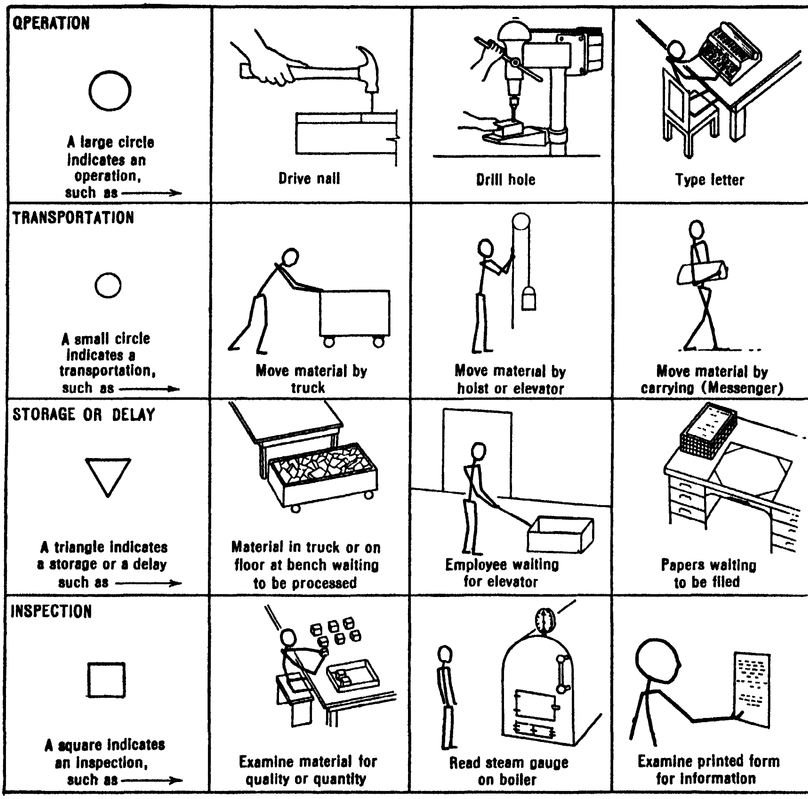


FIG. 14. These four symbols save time in recording the steps used in doing work.

Operation. The large circle indicates an operation and represents the main steps in the process. The transportations, storages, and inspections are more or less auxiliary to the processing operations.

Transportation. The small circle indicates a transportation, that is the movement of the object being studied from one position or location to another. It is often desirable to show the means by which the move was accomplished by placing a letter inside the circle. For example, (M) = man; (H) = hand truck; (K) = power truck; (C) = conveyor; (E) = elevator; (L) = mail.

When material is stored beside or within two or three feet of a bench or machine on which the operation is performed, the movement used in obtaining the material preceding the operation and the movement in disposing of the processed piece to the tote box are considered a part of the operation.

Storage or Delay. The triangle indicates a storage or delay. If it seems desirable to differentiate between a temporary storage and a permanent storage, a P may be placed inside the triangle (P) to indicate the latter. A storage is considered a permanent storage when a requisition must be obtained to move it to the next stage in the process.

When an individual rather than a part or a printed form is being charted, the triangle is used to indicate a delay or a wait. This symbol would be used when the individual waits for parts, materials, elevator, or for another person.

Inspection. A square indicates an inspection for either quality or quantity. The quantity inspection may consist of measuring, counting, or weighing. A quality inspection may consist of testing the part to see whether it will pass a predetermined standard. Quality inspection may also take the form of grading. Members of the inspection department often do the inspecting, although this may be done by the operator or in some instances by the supervisor.

In making a process chart it is possible to follow either a person or a part. However, the entire chart should be of one type or the other.

steps used by Mr. Smith in getting ready to water his garden. Mr. Smith, sitting on his porch, decides to water the garden. He leaves the porch, walks to the garage at the other end of the house, opens

PROCESS CHART OF WATERING GARDEN

Original Method

Travel in Ft.	Symbol	Description	Explanation*
			John Smith has been sitting on porch, decides to water his garden.
85	○	To garage door	He leaves the porch, walks 85 feet to garage door. This is called a transportation since he moves from one place to another.
	(1)	Open door	Opening the garage door is an operation.
10	○	To tool locker in garage	He walks 10 feet to locker to get hose.
	(2)	Remove hose from locker	This is an operation.
15	○	To rear garage door	He carries hose to rear garage door.
	(3)	Open door	This is an operation.
10	○	To faucet at rear of garage	This is a transportation.
	(4)	Attach hose to faucet and open faucet	This is considered one operation.
	(5)	Water garden	He begins the main operation of watering garden.

Summary of work done

Number of operations	5
Number of transportations	4
Total distance walked in feet	120

*This explanation is included here to aid the reader in understanding the use of process chart symbols. It is not a part of the process chart.

Fig. 15.

the garage door, and walks to the tool locker. There he lifts the reel of garden hose from the locker, carries it to the rear garage door, opens the door, and carries the hose to the faucet at the rear of the garage. He attaches the hose to the faucet, turns on the faucet, and begins to water the garden. If you will examine the process chart on the left-hand side of Fig. 15 you will see that the use of nine symbols, five numbers, and nine phrases are all that are needed to describe the entire process fully.

Flow Diagram of Watering Garden. Sometimes a better picture of the process can be obtained by putting flow lines on a plan drawing of the building or area in which the activity takes place. A sketch of the plan view of the house, lawn, and garden is shown in Fig. 16. Lines are drawn on this sketch to show the path of travel, and the

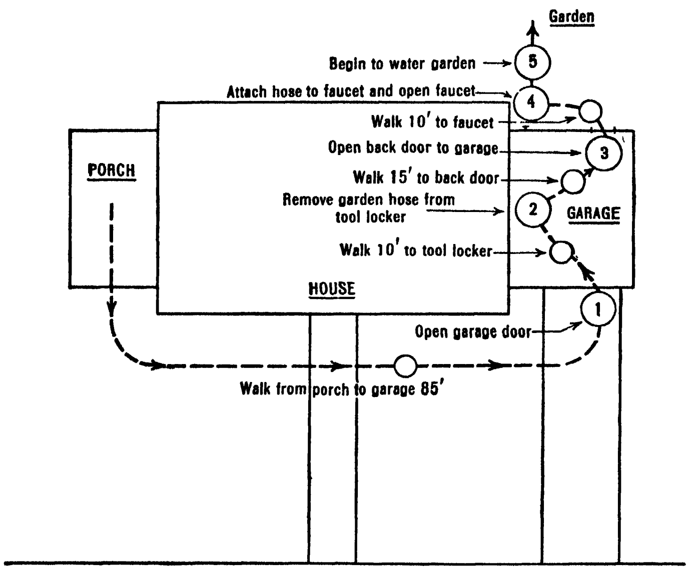


Fig. 16. Flow diagram of watering garden.

process chart symbols are inserted in the lines to indicate what is taking place. Brief notations are included to amplify the symbols. This is called a flow diagram. Sometimes both a process chart and a flow diagram are needed to show clearly the steps in a manufacturing process, office procedure, or other activity.

In one factory where supervisor-employee discussions of job improvements were being started, footprints were painted on the floor in one department to dramatize the excessive walking required by machinists going to and from an arbor press which was located at a remote corner of the department. The savings which resulted from moving this press to a central location were obvious to everyone.

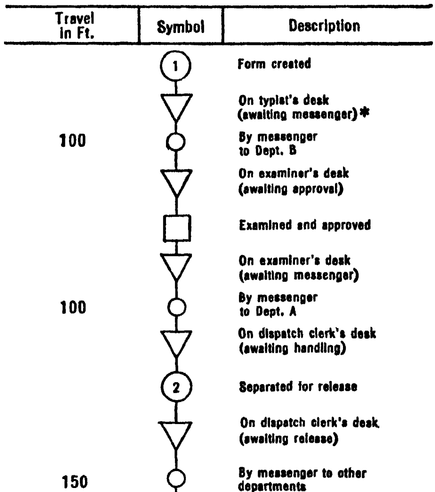
Analysis of an Office Procedure. Although the process chart and the flow diagram have had widest use in the factory, these devices are valuable aids in studying office procedures also. The process chart in Fig. 17 shows form No. 116F created in Department A, sent to Department B for approval, and then returned to Department A for disposal. This is the way it was originally done.

An analysis of the process chart (Fig. 17) of this procedure might lead one to ask the following questions: *Why* was the form returned to Department A? *Where* could this distribution be done to better advantage? Could this release be done in Department B? An operation could be eliminated if the separation for release could be combined with the examination and approval. This results in the chart shown under "First Proposal" on the left-hand side of Fig. 18.

There are, however, still possibilities for further study. *Why* are the operations in Department B necessary? Assuming that investigation indicated that the functions of Department B were not essential, the final proposal would take the form shown under "Second Proposal" on the right-hand side of Fig. 18.

PROCESS CHART OF OFFICE PROCEDURE

Original Method



* The phrases in parentheses on this chart are included to aid the reader in better visualizing the process. In practice these phrases should be omitted.

Summary

Number of operations	2
Number of storages and delays	5
Number of inspections	1
Number of transportations	3
Total travel in feet	350

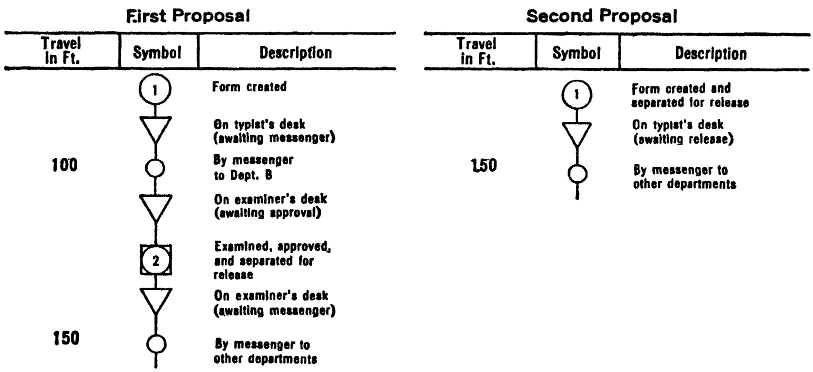
FIG. 17. Process chart showing form No. 116F created in Department A, sent to Department B for approval, and then returned to Department A for disposal—original method.

The summary reflects a distinct change—11 steps have been reduced to 3 and the distance traveled from 350 feet to 150. There is probably a reduction of delay, as there is only 1 storage in place of 5. The questions, Why the operation was done?, Who should do it?, Where it should be done?, etc., have been asked, and definite improvements have resulted.[4]

Re-coating Buffing Wheels with Emery. In large factories where heavy polishing and buffing operations are required it is customary to re-coat buffing wheels (see Fig. 19) with emery in the plant and thus keep a supply of fresh wheels always available.

Originally the method used was to coat the circumference of the worn wheel with glue (see Fig. 20) and then roll the wheel by hand through a shallow trough filled with emery dust, thus coating the wheel (see Fig. 21). After the glue had dried, a second coat of glue and emery dust was applied in a similar manner. The wheels were

PROCESS CHART OF OFFICE PROCEDURE



Summary

	Original	1st Proposal	2nd Proposal	Saved
Number of operations	2	2	1	1
Number of storages and delays	5	3	1	4
Number of inspections	1	1	0	1
Number of transportations	3	2	1	2
Total travel in feet	350	250	150	200

FIG. 18. Process chart showing form No. 116F created in Department A, sent to Department B for approval, and then returned to Department A for disposal—first and second proposals.

then hauled to a drying oven where they were hung on racks in the oven until the glue was thoroughly dry. Figure 22 shows the flow diagram and Fig. 23 the process chart.

The following questions might be asked about this job: *Why* coat the wheels by hand? *Why* handle the wheels so often? Could the wheels be coated on the first floor instead of on the second? These questions were answered in the following way.

Improved Method. A special coating machine (see Fig. 24) was built making it possible to apply the glue and emery to the wheel in one operation with much less time and effort than by the old method. Since this machine was located on the first floor between the storage area and the drying oven (see Fig. 25), it was unnecessary to move the wheels to the second floor. Special truck-racks (see Fig. 27) were used instead of regular platform trucks, thus eliminating much unnecessary handling of wheels. The coated wheels remained on the truck-racks while in the drying oven. Figure 26 shows the process chart for the improved method as well as a summary of the savings.

Results. The new coating machine, the special truck-rack for handling wheels, and the better location of the coating machine reduced the number of *operations* needed to coat the wheels from 9 to 2, the number of *storages* from 8 to 5, and the *length of travel* from 240 to 70 feet.[5]

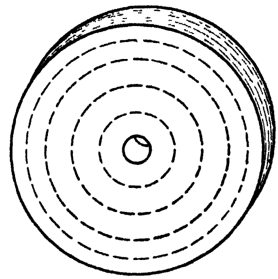


FIG. 19. Buffing wheel. These wheels are made of layers of fabric sewed together. The wheels vary in diameter from 18 to 24 inches and in width of face from 3 to 5 inches. The circumference or face of the wheel is coated with glue and emery dust.

Assembly Process Charts. A special type of process chart, sometimes called an assembly process chart, is useful for showing such situations as the following: when several parts are processed separately and are then assembled and processed together; when a product is disassembled and the component parts are further processed, such as the animal in the packing house; and when it is necessary to show a division in the flow of work, such as separate action on different copies of an office form.

Figure 28 shows the assembly process chart for the bolt and washer assembly described on page 74. The chart shows the bolts, lock washers, and flat steel washers received in the stores department as purchased

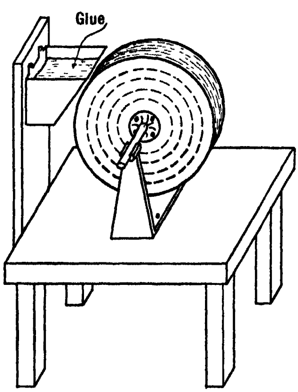


FIG. 20. Operator applies glue to circumference of worn wheel by means of a brush.

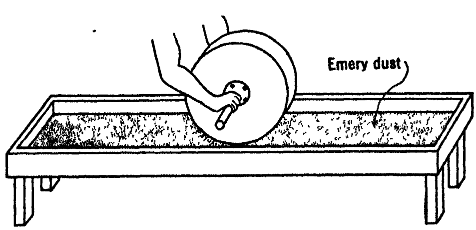


FIG. 21. Old method of re-coating wheel. Operator rolls glue-covered wheel back and forth in trough containing emery dust.

parts. They are inspected and stored there, and when needed they are drawn out and moved to the assembly bench. The material for the special rubber washers for the assembly is received in sheets. This material is inspected and stored. When needed it is drawn out, moved to the punch press where it is made into washers, and then the washers are moved to the assembly bench in Department A37. There the two steel washers and the rubber washer are assembled onto the bolt. This unit forms a subassembly, which is moved to the final

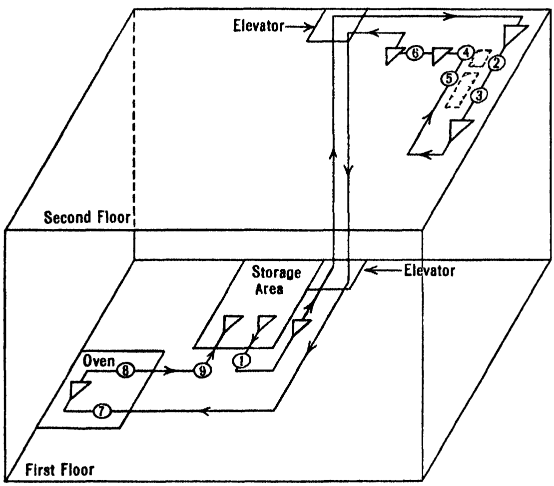


FIG. 22. Flow diagram of old method of re-coating buffing wheels with emery.

assembly floor where it goes into the assembly of a steel cabinet. The entire process, from receipt of the materials until the subassembly goes to the final assembly floor, is pictured on this process chart.

Figure 29 shows a longer and more complicated process, that of baking soda crackers.

Process Charts and Flow Diagrams Used by the Army Service Forces. The Army Service Forces initiated an extensive training program in February, 1943, designed to acquaint all supervisory military and civilian personnel throughout the organization with the basic principles of methods analysis and office procedure study. The process chart and flow diagram were the two main tools presented.[6]

The program was initiated by lectures given to the staff officers at Headquarters and at Service Commands and installations throughout the United States. It was then the responsibility of each head-

PROCESS CHART

Re-coating Buffing Wheels with Emery
Old Method

Travel in Ft.	Symbol	Description
	▽	Worn wheels on floor (to be re-coated)
	1	Load wheels onto truck
40	H	To elevator
	▽	Wait for elevator
20	E	To second floor by elevator
35	H	To coating bench
	▽	At coating bench
	2	Coat with glue
	3	Coat with emery (1st coat)
	▽	On floor to dry
	4	Coat with glue
	5	Coat with emery (2nd coat)
	▽	On floor at coating table
	6	Load onto truck
15	H	To elevator
	▽	Wait for elevator
20	E	To first floor by elevator
75	H	To drying oven
	7	Unload coated wheels onto racks in oven
	▽	Dry in oven
	8	Load wheels onto truck
35	H	To storage area
	9	Unload wheels onto floor
	▽	Storage

Summary

Number of operations	9
Number of storages and delays	8
Number of inspections	1
Number of transportations	7
Total travel in feet	240

FIG. 23. Process chart of old method of re-coating buffing wheels with emery.

quarters to indoctrinate the next lower group in these techniques all the way down to the supervisors of operating units.

The Headquarters of the Army Service Forces assisted in coordinating the plans of the various agencies and brought together a comprehensive program with scheduled completion dates for each project. The initial program included over 4000 projects and covered the activities of 186,000 people. Within a period of three months 1500 process charts had been completed and analyzed, proposed process charts were drawn and approved, and the simplified processes

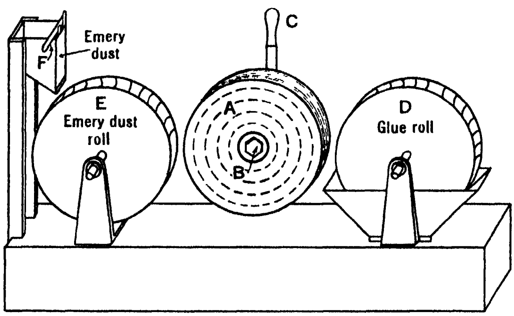


FIG. 24. Schematic drawing showing coating machine. The wheel *A* to be coated is mounted on power-driven shaft *B*, which is attached to lever *C*. By swinging lever to right it makes contact with glue roll *D*, which coats circumference of wheel. Lever *C* is then swung to left and makes contact with roll *E*, which coats wheel with emery. The lever at *F* controls the amount of emery dust which is fed onto roll *E*.

put into effect. The average reduction in operational steps has been over 18 per cent.

Careful Process Analysis Is Required for Mechanized Production Lines. When a factory is laid out for the production of a specific product in quantity, the process of manufacture is studied with great care, and the machinery, equipment, and work stations are located so that the product will flow through the plant with the least amount of backtracking and lost motion. The path of travel for each part and subassembly is worked out before the equipment is installed in the plant.

The flow diagram for the assembly of the Consolidated Vultee Dive Bomber (Fig. 30) illustrates this type of manufacture. Most factories, however, are not laid out in this manner. Rather the material moves from work station to work station intermittently by truck, and in many cases little thought has been given to the sequence of opera-

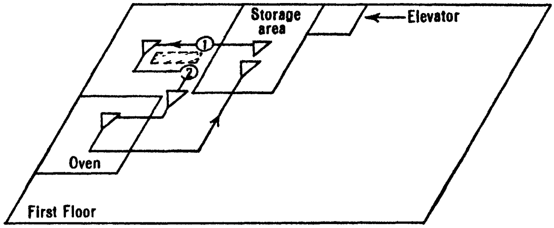


FIG. 25. Flow diagram of improved method of re-coating buffing wheels with emery.

PROCESS CHART

Re-coating Buffing Wheels with Emery
Improved Method

Travel in Ft.	Symbol	Description
	▽	Worn wheels on special truck-racks according to grit size
10	(H)	To coating machine
	(1)	Coat with glue and emery (1st coat) and place on truck-rack
	▽	On truck-rack for glue to dry
	(2)	Coat with glue and emery (2nd coat)
	▽	On rack at coating machine
25	(H)	Rack into drying oven
	▽	Dry in oven
35	(H)	Truck-rack to storage
	▽	Storage of finished coated wheels on truck-rack

	Old Method		Improved Method		Saved	
Number of operations	9		2		7	
Number of storages and delays	8		5		3	
Number of inspections	1		1		0	
Transportations	No.	Dist.	No.	Dist.	No.	Dist.
By truck (H)	5	200	3	70	2	130
By elevator (E)	2	40	0	0	2	40
Total	7	240	3	70	4	170

FIG. 26. Process chart of improved method of re-coating buffing wheels with emery.

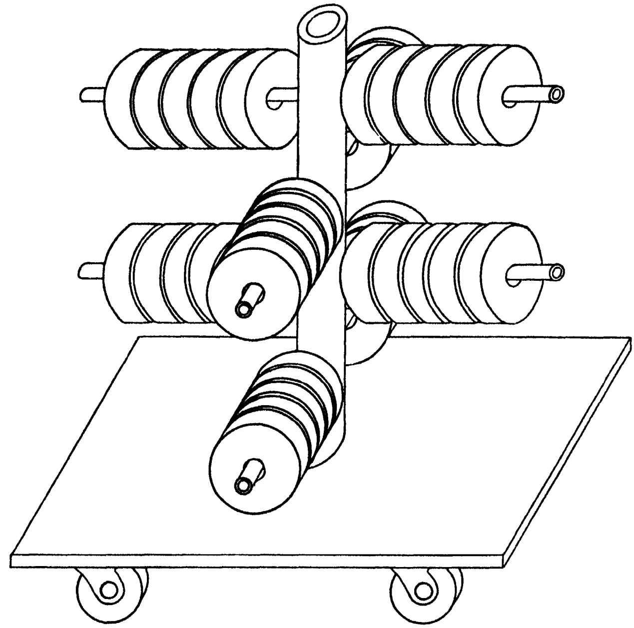


FIG. 27. Special truck-rack for holding buffing wheels. Racks are used for wheel storage between operations and also hold wheels while they are in drying oven.

PROCESS CHART

Bolt and Washer Assembly

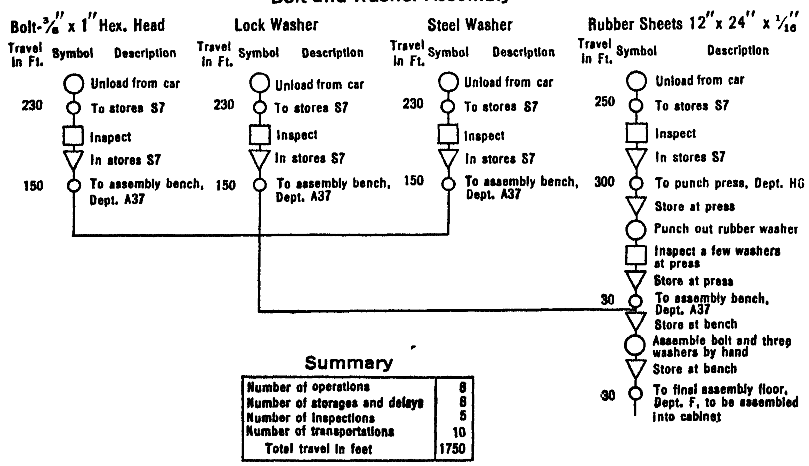
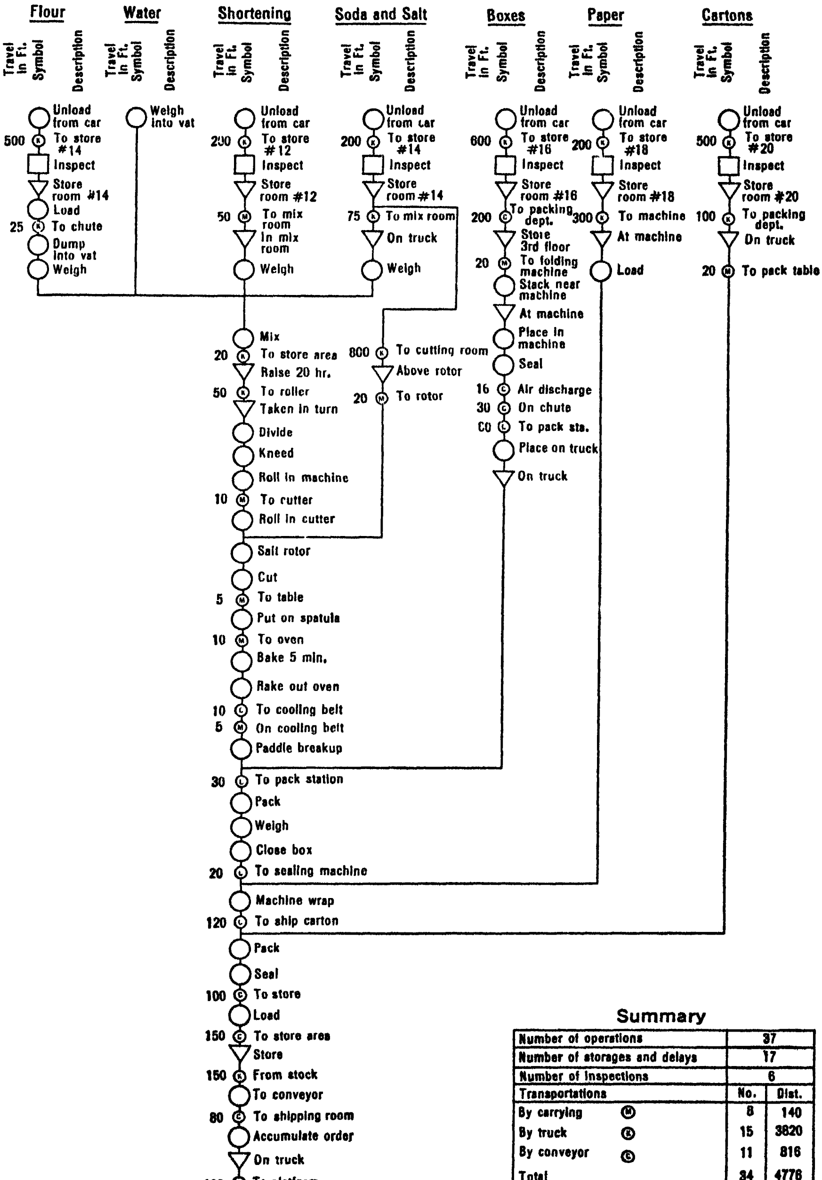


FIG. 28. Assembly process chart—Bolt and washer assembly.

PROCESS CHART

Baking Soda Crackers



Summary

Number of operations		37
Number of storages and delays		17
Number of inspections		6
Transportations	No.	Dist.
By carrying (M)	8	140
By truck (K)	15	3820
By conveyor (C)	11	816
Total	34	4776

Fig. 29. Assembly process chart—baking soda crackers.

FIG. 30. Mechanized production line at the Nashville Division of Consolidated Vultee Aircraft Corporation, where Vengeance dive bombers are manufactured. Careful analysis of the process was made before the conveyors were installed.

tions or to the path of travel through the plant. Because of this fact there are usually many opportunities to save time and money through an analysis of the process.

Steps to be Followed in Making a Process Chart and Flow Diagram:

1. The process chart should be drawn on a sheet of paper of sufficient size to allow space for (*a*) the heading, (*b*) the description, and (*c*) the summary. The heading should identify the process being studied. The body of the process chart should contain a column for *Travel* (distance in feet), *Symbol, Description*, and possibly *Time*. The four process chart symbols should be used. Every step in the process should be shown if the analysis is to be of real value. Unnecessary steps and inefficiencies in the work must first be "seen" before they can be eliminated.

2. Include at the bottom of the process chart a tabular summary showing the number of operations, number of moves of each kind and distance the part was moved, number of inspections, and number of storages and delays. After improvements have been made a combined summary should be compiled giving the above information for the old method, the new method, and the savings.

3. Obtain floor plans of the department or the plant showing location of machines and equipment used in making the part. If these are not available, draw floor plans to scale. It is frequently desirable to mount the floor plans on a drawing board or table, cut out templates from cardboard the size of the machines, and use these as new arrangements for the equipment are suggested.

4. Draw on the floor plans in pencil the path of the part through the plant, noting the direction of travel by means of arrows. The flow diagram should be made on location and not from memory at a desk. Distances should be actually measured or paced off.

Problem 1. Suggest changes that could be made which would reduce the time and effort required to get ready to water the garden. (See Figs. 15 and 16 on pages 21 and 22. Make a process chart and a flow diagram of your proposed method. One solution to the problem is given on page 125.

CHAPTER 5

ACTIVITY CHARTS

MAN AND MACHINE CHARTS

ACTIVITY CHARTS

Although the process chart and the flow diagram give a picture of the various steps in the process, it is often desirable to have a breakdown of the process or of a series of operations plotted against a time scale. Such a picture is called an activity chart. Figure 32 shows an activity chart for the operation of picking up castings from a tote box, carrying them 10 feet, and placing them in a sand blast. The sketch shown in Fig. 31 was made to emphasize the fact that the operator carried the castings 10 feet and returned empty handed the same distance.

The chart suggests the obvious fact that walking could be eliminated by placing the tote box beside the sand blast. The reason this was not done originally was because the sand blast was located on a 4-inch concrete platform. However, when an inclined plank runway was built, the power lift truck was able to move the tote box of castings up to the sand blast, as shown in Fig. 33. Figure 34 shows how this eliminated the walking and enabled the operator to sandblast twice as many castings per hour. Incidentally, one man can now feed this sand blast where it originally required two. At 90 cents per hour, which is the rate paid these men, the company was paying $7.20 per day or $2000 per year for unnecessary walking. The runway was built of plank and cost but a few dollars.

The activity chart is of special value for analyzing maintenance work, jobs involving people working in gangs, and operations where the work is unbalanced and where there is "necessary" idle time.[7]

MAN AND MACHINE CHARTS

The operator and the machine work intermittently on some types of work. That is, the machine is idle while the operator loads it and while he removes the finished work from it, and the worker is idle while the machine is in operation. Not only is it desirable to eliminate idle time for the worker but it is also equally important that the machine be kept operating as near capacity as possible. In many instances an idle machine costs almost as much per hour as one in operation.

The first step in eliminating unnecessary waiting time for the operator and for the machine is to record exactly when each works and what each does. Most operations consist of three main steps: (1) **GET READY,** such as putting material in the machine; (2) **DO** (doing the work), such as drilling a hole; and (3) **PUT AWAY** or clean up, such as removing the finished piece from the machine.

In Fig. 35, which shows the drilling of a hole in a steel casting with a power feed drill, the steps performed by the man are listed on the left-hand side of the figure and the operation performed by the machine is listed on the right-hand side. This is a man and machine chart in its simplest form.

Very often a clearer picture of the relationship of the operator's working time and the machine time can be obtained by showing the information graphically.

Purchasing Coffee. The simple task of purchasing a pound of coffee is used here to illustrate the operations performed by the customer, the clerk, and the coffee grinder (machine) in a grocery store. The customer walks into the coffee department, asks the clerk for one pound of coffee, specifying the brand and grind. The clerk gets the coffee, opens the package, sets the grinder, dumps the coffee into the grinder, and starts the machine. The customer and the clerk are idle during the 21 seconds the coffee is being ground.

After the coffee is ground the clerk places it in the package and gives it to the customer. The customer then pays the clerk, who rings up the sale, gives the customer her change, and places the money in the register. The "work" or activity of the customer, clerk, and coffee grinder is shown graphically on the man and machine chart (see Fig. 36) and in tabular form at the bottom of the chart.

Possible Changes. The man and machine chart in Fig. 36 shows the excessive waiting time on the part of the customer and clerk while the coffee is being ground. This at once suggests that a supply of coffee be ground somewhat in advance so that the customer would not need to wait for her coffee to be ground. If this were done, the clerk could serve more than twice as many customers per hour, and the customer would spend less than half as much time at the coffee counter.

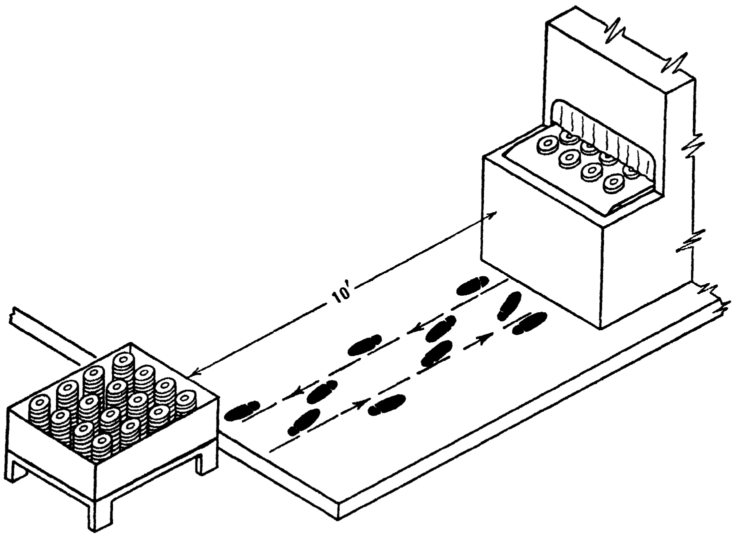


FIG. 31. Layout of work place for sandblasting castings—old method. Notice excessive walking.

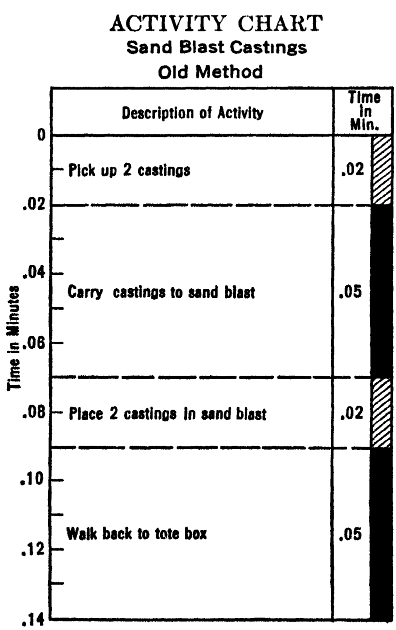


FIG. 32. Activity chart for sandblasting castings—old method.

If the store were a large one employing a number of clerks and using a number of coffee grinders, the man and machine chart would indicate that the activities of the clerk be divided into two parts, one clerk selling the coffee and another clerk grinding the coffee. Thus, in this hypothetical case, the coffee grinders would be kept in almost constant use, which would mean that fewer grinders would be needed. The clerks could work to better advantage inasmuch as there would be less idle time and the customer would receive faster service. This would also tend to relieve congestion in the store during rush hours. Moreover, this would mean that the store could handle more customers with a given floor area and with a given amount of equipment. However, it would be necessary to seal and date the bags containing the ground coffee so the customer would be assured of receiving freshly ground coffee.

Slitting Coated Fabric. Special fabric is coated with adhesive on continuous coating machines, and the finished material is taken off the drying racks in rolls approximately three feet wide and two feet in diameter. These rolls go to storage and later are removed and slit into narrower rolls to customers' orders.

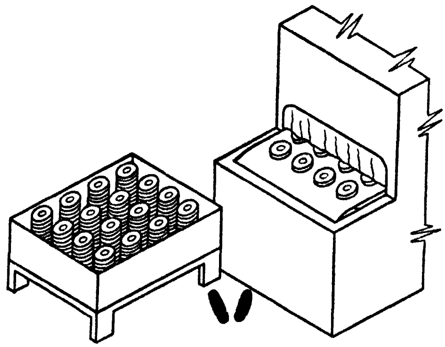


Fig. 33. Layout of work place for sandblasting castings—improved method. Unnecessary walking has been eliminated. One man now does the work of two.

The material is slit on machines similar to the one shown in Fig. 37. The roll is placed on the shaft *A* at the back of the machine. The material is passed under rotating cutters *B* which press against a rotating cylinder *C*, thus slitting the material into the desired width. The material is then rolled onto cardboard cores which are held in place on a shaft at *D*. After the desired length of fabric has been spooled the machine is stopped and the cloth is cut parallel to shaft *D*. The operator with the assistance of a helper then places wrapping paper around the spooled material, attaches a label to each roll, and marks the grade, roll length, and other information on the label. The rolls are then removed from shaft *D* and placed on a skid. During this time the slitting machine is idle.

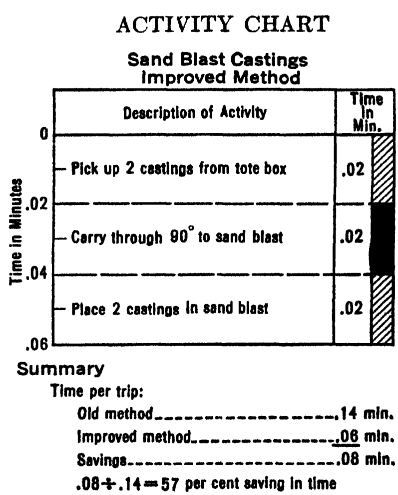


Fig. 34. Activity chart for sandblasting castings—improved method.

Improved Method. The following change was made in the method, which increased the capacity of the slitting machines 44 per cent. A shaft was mounted on a pedestal

MAN AND MACHINE CHART

Drill Hole in Casting

Man	Machine
1. Pick up piece, place in jig, clamp, lower drill, throw in feed. Time, ½ minute. (GET READY)	Idle
Idle	2. Drill ½-inch hole in piece. Time, 2.5 minutes. (DO)
3. Raise drill, remove piece, dispose, blow chips out of jig. Time, ¾ minute. (CLEAN UP OR PUT AWAY)	Idle

SUMMARY

	Man	Machine
Idle time	2.50 minutes	1.25 minutes
Working time	1.25	2.50
Total cycle time	3.75	3.75
Utilization in per cent	Operator utilization $= \frac{1.25}{3.75} = 33\%$	Machine utilization $= \frac{2.50}{3.75} = 67\%$

FIG. 35. Man and machine chart (simple form). It required a total of 3.75 minutes to drill the hole in the casting. During this time the operator worked 1¼ minutes and the machine was in operation 2½ minutes. The operator working time was 33 per cent of the cycle, and the machine working time was 67 per cent of the cycle.

MAN AND MACHINE CHART

Purchasing Coffee in Grocery Store

MAN				MACHINE	
Customer	Time in Sec.	Clerk	Time in Sec.	Coffee Grinder	Time in Sec.
1. Ask grocer for 1 pound of coffee (Brand and grind)	5	Listen to order	5	Idle	5
2. Wait	15	Get coffee and put in machine, set grind and start grinder	15	Idle	15
3. Wait	21	Idle while machine grinds	21	Grind coffee	21
4. Wait	12	Stop grinder, place coffee in package and close it	12	Idle	12
5. Receive coffee from grocer, pay grocer and receive change	17	Give coffee to customer, wait for customer to pay for coffee, receive money and make change	17	Idle	17

Time in Seconds: 0, 10, 20, 30, 40, 50, 60, 70

Summary

	Customer	Clerk	Coffee Grinder
Idle time	48 sec.	21 sec.	49 sec.
Working time	22	49	21
Total cycle time	70	70	70
Utilization in per cent	Customer utilization= $\frac{22}{70}$=31%	Clerk utilization= $\frac{49}{70}$= 70%	Machine utilization= $\frac{21}{70}$=30%

FIG. 36. Man and machine chart showing activities involved in purchasing coffee in grocery store. The customer, the clerk, and the coffee grinder (machine) are involved in this operation. It required 1 minute and 10 seconds for the customer to purchase a pound of coffee in this particular store. During this time the customer spent 22 seconds, or 31 per cent of the time, giving the clerk her order, receiving the ground coffee, and paying the clerk for it. She was idle during the remaining 69 per cent of the time. The clerk worked 49 seconds, or 70 per cent of the time, and was idle 21 seconds, or 30 per cent of the time. The coffee grinder was in operation 21 seconds, or 30 per cent of the time, and was idle 70 per cent of the time.

as shown in Fig. 38. Then after the desired length of coated fabric had been slit, spooled, and cut off, the rolls were slid from shaft *D* of the slitting machine onto shaft *A* of the pedestal, as shown in Fig. 38. This is a short and simple operation. The helper then wraps, labels, and marks the rolls while the machine operator immediately starts the slitting machine, thus eliminating much of the idle machine time. Because of the design of the machine it is necessary for the operator to

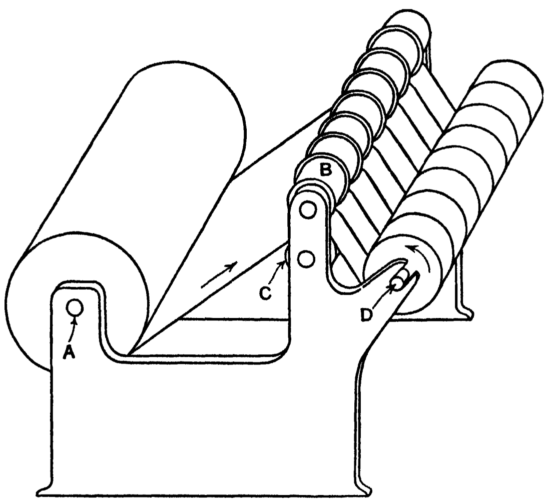


FIG. 37. Slitting machine. Coated fabric is drawn under slitting knives *B* onto the "wind up" shaft at *D*.

manipulate the slitting machine controls while the fabric is being slit. The man and machine charts, Figs. 39 and 40, show the idle time and the working time before and after the new method was developed.

Results. The total cycle time was 5.2 minutes, using the old method, or 11.5 cuts were made per hour whereas the new method reduced the cycle time to 3.6 minutes, which increased the output to 16.6 cuts per hour. This increase of 5.1 cuts per hour represents an increase of 44 per cent. As the man and machine charts show, the machine utilization was increased from 42 to 61 per cent. This was especially important in this case as these slitting machines were operating 24 hours per day 7 days per week and were still unable to supply the demand for the product. Moreover, it was impossible to obtain new machines of this type.

Brushing Burrs from Studs. In addition to using a man and machine chart as an aid in devising ways of eliminating idle machine time and in smoothing out the operator's work, such a chart is often valuable in emphasizing the need for a better method or perhaps an entirely new way of doing the job.

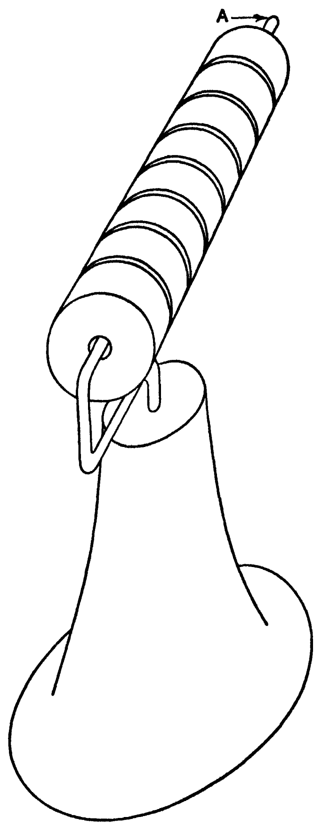
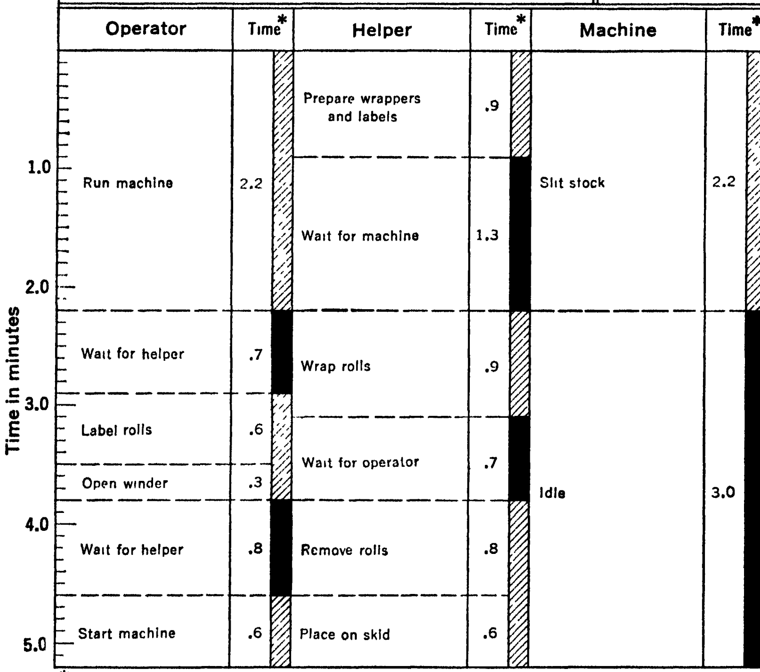


FIG. 38. Special pedestal. The rolls of fabric are transferred onto arm *A* to be wrapped and labeled.

The operation of brushing the chips and burrs from a bolt or stud illustrates this very well. These studs are used in airplane motors and must be accurately machined, and after they are threaded all burrs must be removed. Originally this was done by brushing each end of the stud by rotating it by hand against a buffing wheel, as shown in Fig. 41. The operator picked up a stud from the bin on the

MAN AND MACHINE CHART

OPERATION: Slitting Coated Fabric	OP. NO. S46
PART NAME: Coated Fabric	PART NO. F261
MACHINE NAME: Slitting Machine (Special)	MACH. NO. S431
OPERATOR NAME: J S. Wilson S K. Smith (Helper)	DATE: 5-3-43
OLD METHOD: [X] IMPROVED METHOD: [ ]	CHART BY: J. S. K.



*Time in minutes

Summary			
	Operator	Helper	Machine
Idle time	1.5 min.	2.0 min.	3.0 min.
Working time	3.7	3.2	2.2
Total cycle time	5.2	5.2	5.2
Utilization in per cent	Operator utilization = $\frac{3.7}{5.2}$ = 71%	Helper utilization = $\frac{3.2}{5.2}$ = 62%	Machine utilization = $\frac{2.2}{5.2}$ = 42%

FIG. 39. Man and machine chart for slitting coated fabric—old method. Total cycle time 5.2 minutes. Total number of cuts per hour = 11.5.

MAN AND MACHINE CHART

OPERATION: Slitting Coated Fabric	**OP. NO.** S46
PART NAME: Coated Fabric	**PART NO.** F261
MACHINE NAME: Slitting Machine (Special)	**MACH. NO.** S431
OPERATOR NAME: J. S. Wilson S. K. Smith (Helper)	**DATE:** 5-20-43
OLD METHOD: ☐ **IMPROVED METHOD:** ☒	**CHART BY:** J. S. K.

Operator	Time*	Helper	Time*	Machine	Time*
Run machine	2.2	Wrap-Cont'd	.3	Slit stock	2.2
		Label rolls	.6		
		Place on skid	.5		
		Prepare wrappers and labels	.9		
Open winder	.3	Wait for operator	.2	Idle	1.4
Remove rolls	.5	Help remove rolls	.5		
Start machine	.6	Wrap rolls	.6		

Time in minutes: 1.0, 2.0, 3.0

*Time in minutes

Summary			
	Operator	Helper	Machine
Idle time	0.0 min.	0.2 min.	1.4 min.
Working time	3.6	3.4	2.2
Total cycle time	3.6	3.6	3.6
Utilization in per cent	Operator utilization = $\frac{3.6}{3.6} = 100\%$	Helper utilization = $\frac{3.4}{3.6} = 95\%$	Machine utilization = $\frac{2.2}{3.6} = 61\%$

FIG. 40. Man and machine chart for slitting coated fabric—improved method Total cycle time 3.6 minutes. Total number of cuts per hours = 16.6.

bench, and held one end of the stud in his hand while he brushed the other end. He then turned the stud end for end, brushing the other end. The finished stud was dropped into a bin on the table to his right. The man and machine chart for this job is shown in Fig. 44.

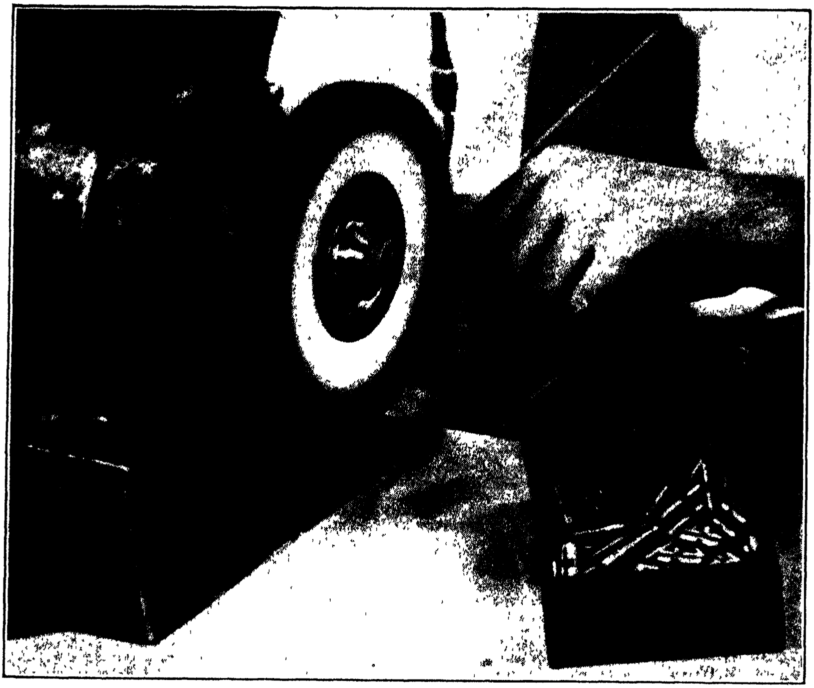


FIG. 41. Brushing studs for airplane engines—old method.

Improved Method. A simple fixture[8] was built consisting of two metal tubes placed parallel to the bench top. (See Figs. 42 and 43.) A section was cut out of each tube to permit the rotating buffing wheel to brush the studs as they were fed through the tubes. The operation then consisted of picking up the studs two at a time, inserting them in the front end of the two tubes, and shoving them toward the buffing wheel. The friction of the buffing wheel on the studs rotated them so that the entire surface of each stud was exposed to the brushing action of the wheel. The operator now sits at a considerable distance from the wheel, and there is no danger of finger or eye injuries. The operation is so easy that more than three times as many studs are buffed per hour using this method than was possible using the old method. The man and machine chart for the improved method is shown in Fig. 45.

Note: A further improvement has just been made in the plant whereby the buffing wheel is mounted at an angle under the table and

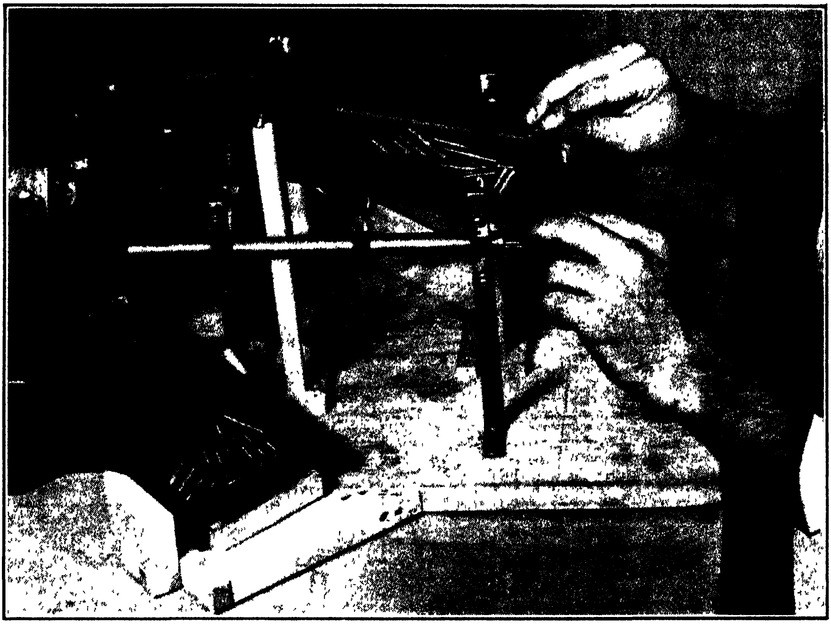


FIG. 42. Brushing studs for airplane engines—improved method.

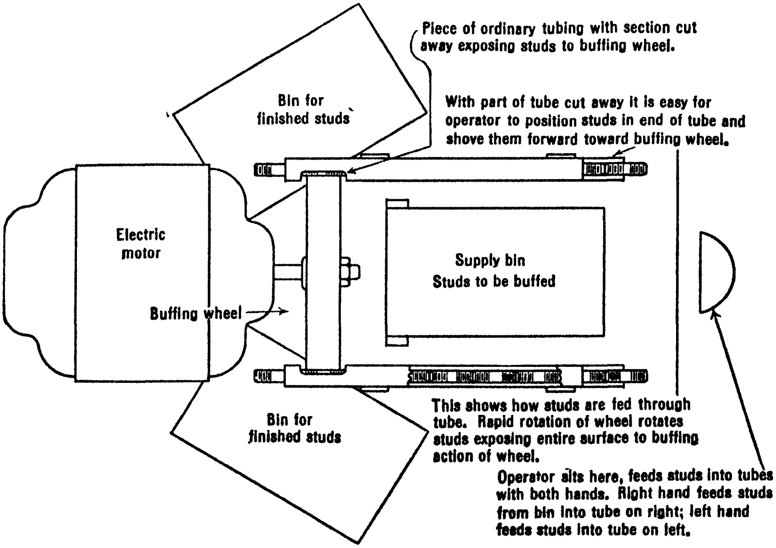


FIG. 43. Schematic drawing of layout for brushing studs—improved method.

MAN AND MACHINE CHART

OPERATION: Brushing Studs	OP. NO. B931
PART NAME: Steel Studs ½″ x 2½″	PART NO. S3764
MACHINE NAME: Buffer	MACH. NO. B61
OPERATOR NAME: S. R. Wilkinson	DATE: 5-20-43
OLD METHOD: [X] IMPROVED METHOD: [ ]	CHART BY: S. W. W.

Time in thousandths of a minute

MAN		MACHINE			
Operator	Time*	Buffing Wheel Left-hand Side	Time	Buffing Wheel Right-hand Side	Time
1. Grasp stud and position one end against wheel	16	Idle	16	This side of wheel was not used	0
2. Rotate stud against wheel	7	Brush end of stud	7		0
3. Turn stud end for end and position other end against wheel	18	Idle	18		0
4. Rotate stud against wheel	7	Brush end of stud	7		0
5. Dispose of finished stud	5	Idle	5		0

Summary

	Man	Machine: Left-hand Side of Buffing Wheel	Machine: Right-hand Side of Buffing Wheel
Idle time	00	39*	00
Working time	53	14	00
Total cycle time	53	53	53
Utilization in per cent	Operator utilization= $\frac{53}{53}$ = 100%	Machine utilization= $\frac{14}{53}$ = 26%	Machine utilization= $\frac{0}{53}$ = 0%

*Time in thousandths of a minute

FIG. 44. Man and machine chart for brushing studs—old method. Production rate 1132 pieces per hour.

MAN AND MACHINE CHART

OPERATION: Brushing Studs	**OP. NO.** B931
PART NAME: Steel Studs $\frac{1}{2}''$ x $2\frac{1}{4}''$	**PART NO.** S3764
MACHINE NAME: Buffer	**MACH. NO.** B61
OPERATOR NAME· S R. Wilkinson	**DATE:** 7-12-43
OLD METHOD: ☐ **IMPROVED METHOD:** ☒	**CHART BY:** S W. W.

MAN		MACHINE			
Operator	Time*	Buffing Wheel Left-hand Side	Time	Buffing Wheel Right-hand Side	Time
Pick up stud in each hand, insert in tubes, and release	30	Brush studs as fed through tube on left side of wheel (continuous)	30	Brush studs as fed through tube on right side of wheel (continuous)	30

Time in thousandths of a minute: 0, 10, 20, 30

Summary			
	Man	Machine	
		Left-hand Side of Buffing Wheel	Right-hand Side of Buffing Wheel
Idle time	0	0	0
Working time	30*	30	30
Total cycle time	30	30	30
Utilization in per cent	Operator utilization = $\frac{30}{30}$ = 100%	Machine utilization = $\frac{30}{30}$ = 100%	Machine utilization = $\frac{30}{30}$ = 100%

*Time in thousandths of a minute

FIG. 45. Man and machine chart for brushing studs—improved method. Production rate 4000 pieces per hour.

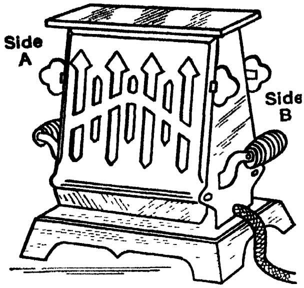


FIG. 46. Electric toaster.

MAN AND MACHINE CHART

Toasting Three Slices of Bread — Old Method

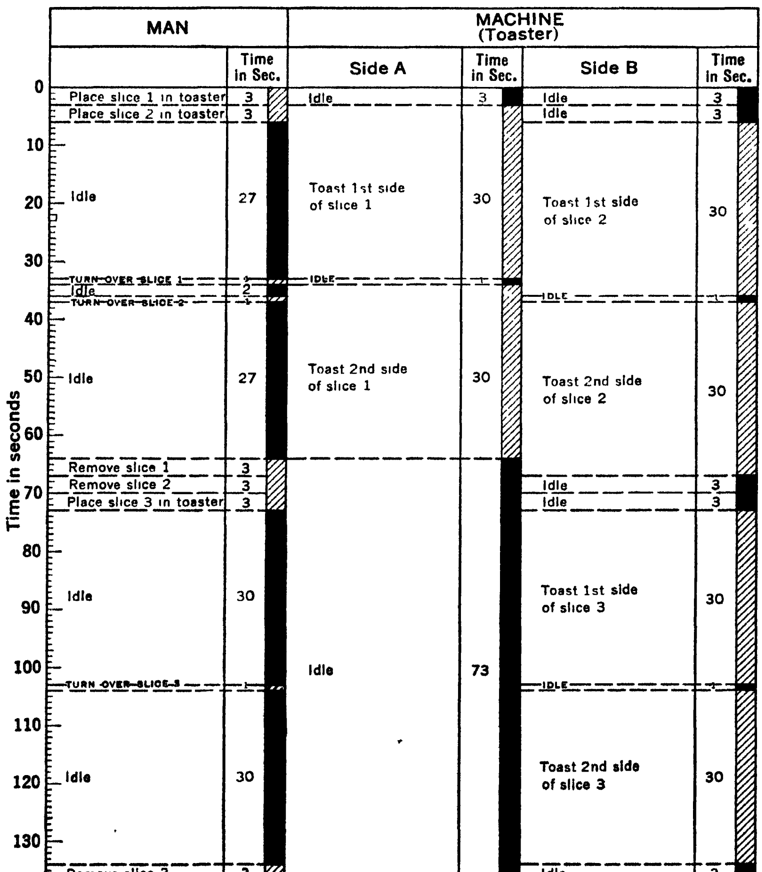


FIG. 47. Man and machine chart for toasting three slices of bread in 137 seconds.

the studs are fed into the tube through a slot in the table top. This makes the positioning of the studs so much easier that a blind man is now employed in the factory to do this job. This man turns out 550 per cent more work with less effort than was possible using the original method.

Problem 2. The electric toaster shown in Fig. 46 is hand-operated, each side being operated independently of the other. A spring holds each side of the toaster shut, and each side must be held open in order to insert bread. In toasting three slices of bread in the above toaster, what method would you recommend to obtain the best equipment utilization—that is, the very shortest over-all time? Assume that the toaster is hot and ready to toast bread.

The following are the elemental times necessary to perform the operations. Assume that both hands can perform their tasks with the same degree of efficiency.

Place slice of bread in either side of toaster	3 seconds
Toast either side of bread . . .	30 seconds
Turn slice of bread on either side of toaster	1 second
Remove toast from either side of toaster . . .	3 seconds

Incidentally, most people would use the method shown in Fig. 47, that is, toast two slices on both sides and then the third slice on both sides. Can you devise a method that will take less than the 137 seconds required by this method? After you have solved the problem, turn to page 127 for the answer.

CHAPTER 6

OPERATION ANALYSIS

RIGHT- AND LEFT-HAND CHARTS

The over-all study of the process should result in a reduction in the amount of travel of the operator, materials, and tools, and should bring about orderly and systematic procedures. The man and machine chart often suggests ways of eliminating idle machine time and promotes a better balancing of the work of the operator and the machine.

After such studies have been completed it is time to investigate specific operations in order to improve them. The purpose of motion study is to analyze the motions used by the worker in performing an operation in order to find the most economical way of doing it. A systematic attempt is made to eliminate all unnecessary motions and to arrange the remaining necessary motions in the best sequence. It is when we come to the analysis of specific operations that motion study principles and techniques become most useful.

RIGHT- AND LEFT-HAND CHARTS

Since all manual work consists of a series of movements of the hands it is desirable to have some means of analyzing and recording hand motions. The right- and left-hand chart serves this purpose very well. Moreover this chart is a valuable aid in developing a better way of doing the job and also has value as a device for training operators.

Two symbols are commonly used in making right- and left-hand charts. The small circle indicates a transportation, such as moving the hand to grasp an article, and the large circle is used to denote such actions as grasping, positioning, using, or releasing the article. Thus in signing a letter with a fountain pen the left hand holds the paper while the right hand performs the various movements indicated in Fig. 48.

The first step in making a right- and left-hand chart is to draw a sketch of the work place, indicating the contents of the bins and the location of tools and materials. Then watch the operator and

RIGHT- AND LEFT-HAND CHART

Signing Letter

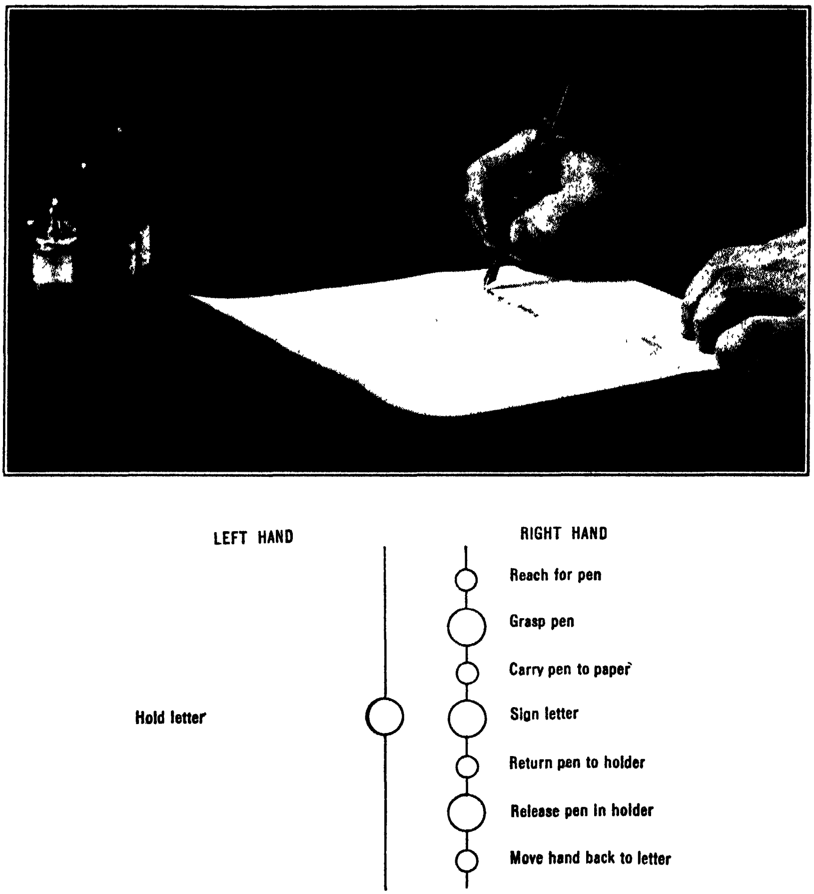


Fig. 48. Right- and left-hand chart showing the movements of the two hands in signing a letter.

make a mental note of his motions, observing one hand at a time. Record the motions or elements for the left hand on the left-hand side of a sheet of paper and then in a similar manner record the motions for the right hand on the right-hand side of the sheet. As

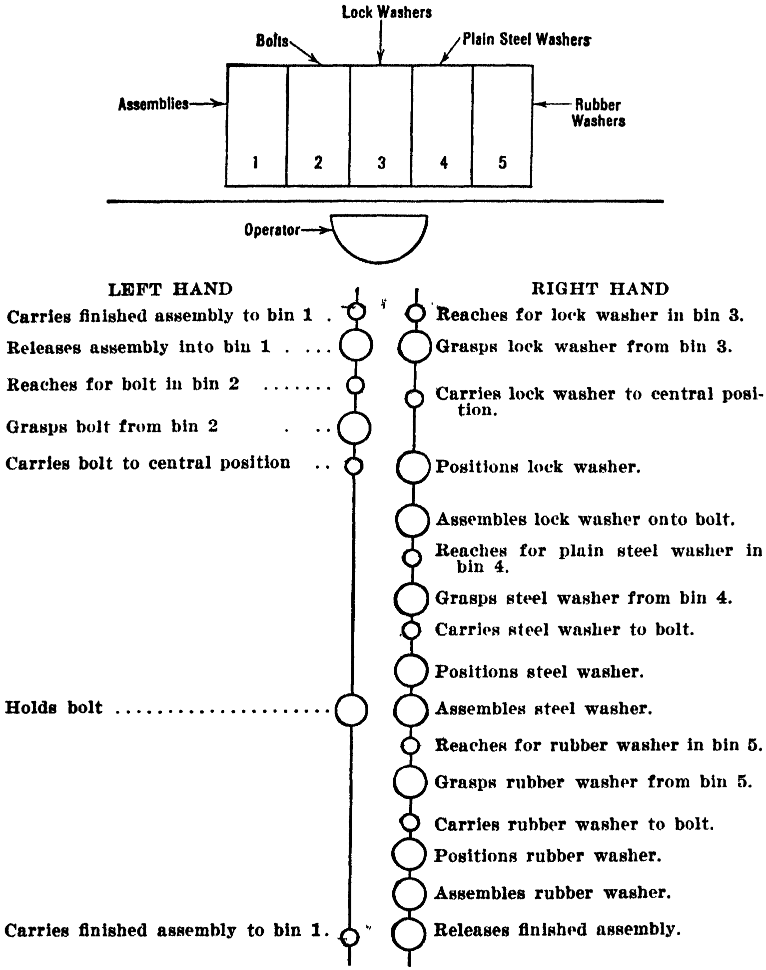
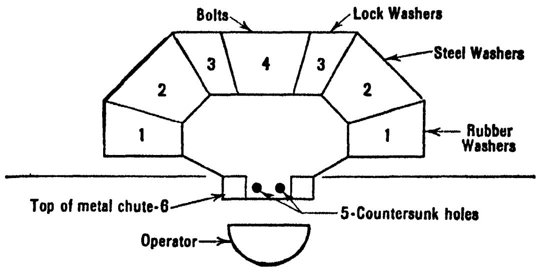


FIG. 49. Right- and left-hand chart of bolt and washer assembly—old method



LEFT HAND	RIGHT HAND
Reaches for rubber washer in bin 1	Reaches for rubber washer in bin 1
Grasps rubber washer from bin 1 .	Grasps rubber washer from bin 1.
Slides rubber washer to countersunk hole .	Slides rubber washer to countersunk hole.
Positions rubber washer in countersunk hole 5 . .	Positions rubber washer in countersunk hole 5.
Reaches for plain steel washer in bin 2	Reaches for plain steel washer in bin 2.
Grasps steel washer from bin 2 . . .	Grasps steel washer from bin 2.
Slides steel washer to countersunk hole	Slides steel washer to countersunk hole.
Positions steel washer in countersunk hole 5 . .	Positions steel washer in countersunk hole 5.
Reaches for lock washer in bin 3 .	Reaches for lock washer in bin 3.
Grasps lock washer from bin 3 . .	Grasps lock washer from bin 3.
Slides lock washer to countersunk hole	Slides lock washer to countersunk hole.
Positions lock washer in countersunk hole 5	Positions lock washer in countersunk hole 5.
Reaches for bolt in bin 4	Reaches for bolt in bin 4.
Grasps bolt from bin 4	Grasps bolt from bin 4.
Carries bolt to washers at 5	Carries bolt to washers at 5.
Positions bolt preparatory to inserting it into washers at 5 . .	Positions bolt preparatory to inserting it into washers at 5.
Assembles bolt and washers	Assembles bolt and washers.
Lifts bolt and washers, carries to left and releases into top of chute 6	Lifts bolt and washers, carries to right and releases into top of chute 6.

FIG. 50. Right- and left-hand chart of bolt and washer assembly—improved method.

it is seldom possible to get the motions of the two hands in proper relationship on the first draft, it is usually necessary to redraw the chart.

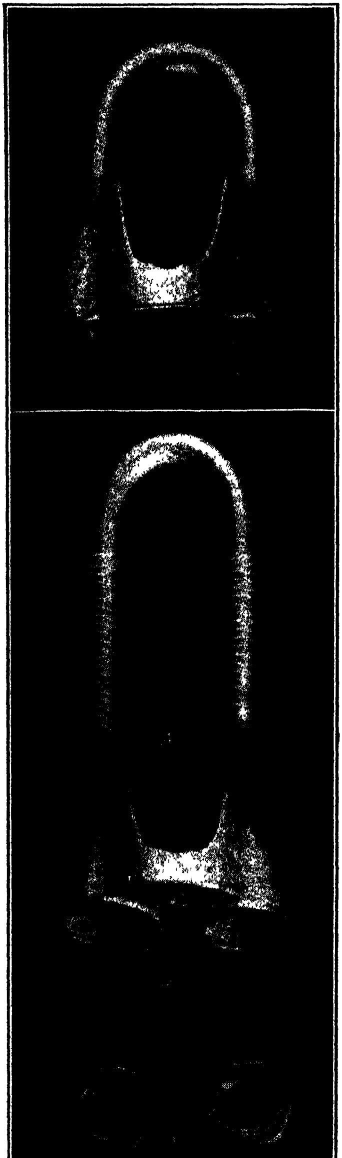


FIG. 51. Rope clip assembly: *A*, U bolt; *B*, casting; *C*, nuts.

Bolt and Washer Assembly. A right- and left-hand chart of the operation of assembling a lock washer, a steel washer, and a rubber washer onto a bolt is shown in Fig. 49. This operation is described fully on page 74. A glance at the chart shows that the left hand is holding the bolt while the right hand is doing useful work, that is, assembling the washers. It is obvious that the motions of the two hands are unbalanced. The chart in Fig. 50 shows how the operation would appear if an assembly fixture were used and if the two hands worked together simultaneously.

When one has a detailed breakdown of the operation before him he is in a much better position to question each element of the job and work out an easier and better method.

Assembling Rope Clips. The rope clip shown in Fig. 51 consists of three different parts: *A*, the U bolt; *B*, the casting; *C*, the hexagonal nuts. The rope clips were originally assembled in the following manner: The operator grasped a U bolt from bin 1 (see Fig. 52) with her left hand and carried it up in front of her. Then she grasped a casting from bin 3 with her right hand and assembled it onto the bolt; and in a similar manner she grasped (from bin 2) and assembled in succession the two nuts onto the threaded ends of the bolt. She then disposed of the assembly with her left hand into bin 4 at her right. The right- and left-hand chart for this operation is shown in Fig. 52.

Problem 3. Work out a better method for assembling the rope clips. Assume that there is sufficient production to keep two operators employed on this job forty hours per week during the next year. Make a right- and left-hand chart of your proposed method. Then turn to page 128 for a description of the improved method now being used.

RIGHT- AND LEFT-HAND CHART

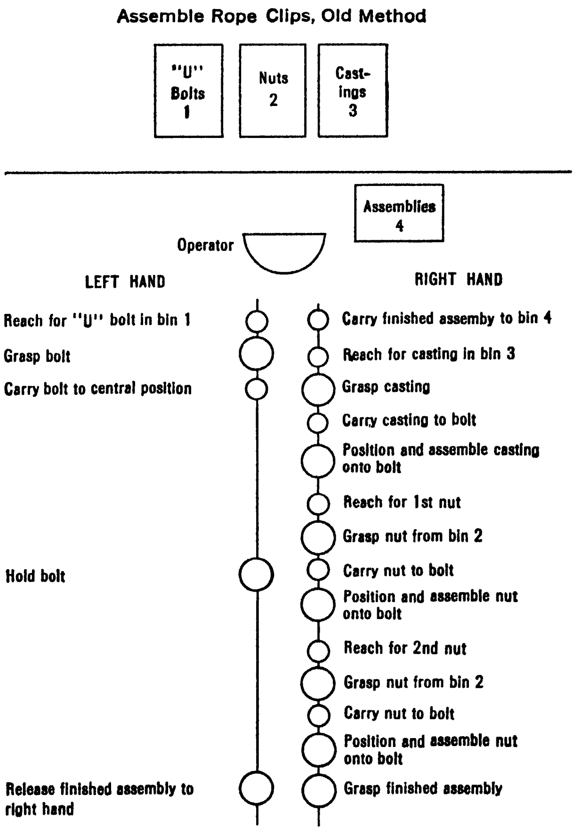


FIG. 52. Right- and left-hand chart of assembling rope clips—old method.

Check Sheet for Operation Analysis. In addition to studying the motions used in performing an operation, it is also desirable to give consideration to materials, tools, jigs, fixtures, handling equipment, working conditions, and other factors affecting the job. The following is typical of a check sheet that can be prepared for use in one's own plant:

I. *Materials:*
1. Can cheaper material be substituted?
2. Is the material uniform and in proper condition when brought to the operator?
3. Is the material of proper size, weight, and finish for most economical use?
4. Is the material utilized to the fullest extent?
5. Can some use be found for scrap and rejected parts?
6. Can the number of storages of material and of parts in process be reduced?

II. *Materials Handling:*
1. Can the number of times the material is handled be reduced?
2. Can the distance moved be shortened?
3. Is the material received, moved, and stored in suitable containers? Are the containers kept clean?
4. Are there delays in the delivery of material to the operator?
5. Can the operator be relieved of handling materials by the use of conveyors?
6. Can backtracking be reduced or eliminated?
7. Will a rearrangement of the layout or combining of operations make it unnecessary to move the material?

III. *Tools, Jigs, and Fixtures:*
1. Are the tools the best kind for this work?
2. Are the tools in good condition?
3. If metal-cutting tools, are the cutting angles of the tools correct, and are they ground in a centralized tool-grinding department?
4. Can tools or fixtures be changed so that less skill is required to perform the operation?
5. Are both hands occupied by productive work in using the tools or fixtures?
6. Can "slide feeds," "ejectors," "holding devices," etc., be used?
7. Can an "engineering change" be made to simplify the design?

IV. *Machine:*

A. Setup:
1. Should the operator set up his own machine?
2. Can the number of setups be reduced by proper lot sizes?
3. Are drawings, tools, and gauges obtained without delay?
4. Are there delays in making inspection of first pieces produced?

B. Operation:
1. Can the operation be eliminated?
2. Can the work be done in multiple?

3. Can the machine speed or feed be increased?
4. Can an automatic feed be used?
5. Can the operation be divided into two or more short operations?
6. Can two or more operations be combined into one? Consider the effect of combinations on the training period.
7. Can the sequence of the operation be changed?
8. Can the amount of scrap and spoiled work be reduced?
9. Can the part be pre-positioned for the next operation?
10. Can interruptions be reduced or eliminated?
11. Can an inspection be combined with an operation?
12. Is the machine in good condition?

V. *Operator:*

1. Is the operator qualified mentally and physically to perform this operation?
2. Can unnecessary fatigue be eliminated by a change in tools, fixtures, layout, or working conditions?
3. Is the base wage correct for this kind of work?
4. Is supervision satisfactory?
5. Can the operator's performance be improved by further instruction?

VI. *Working Conditions:*

1. Are the light, heat, and ventilation satisfactory on the job?
2. Are washrooms, lockers, restrooms, and dressing facilities adequate?
3. Are there any unnecessary hazards involved in the operation?
4. Is provision made for the operator to work in either a sitting or a standing position?
5. Are the length of the working day and the rest periods set for maximum economy?
6. Is good housekeeping maintained throughout the plant?

CHAPTER 7

FUNDAMENTAL HAND MOTIONS

MOTION ANALYSIS—SIMO CHARTS

HAND MOTIONS

Did you ever stop to realize that most work is done with the two hands and that all manual work consists of a relatively few fundamental motions which are performed over and over again?

Perhaps you have noticed that "get" or "pick up" and "place" or "put down" constitute two of the most frequently used groups of motions. In most cases "get" is followed by some "use" or "process" operation such as driving a nail with a hammer, using a wrench to tighten a bolt, or writing with a pen. In using a fountain pen the sequence would be *get* pen, write, that is, *use* pen, *put* pen in holder. Although *get* and *place* represent two very common groups of motions, they are not fundamental motions in themselves.

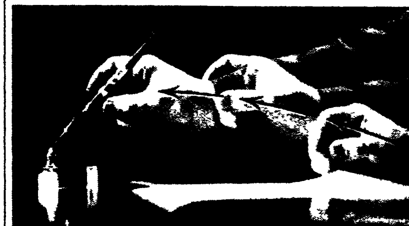
The Gilbreths, many years ago, suggested that all manual work could be subdivided or broken down into a relatively few fundamental motions and that an understanding of this classification of hand motions was useful in developing better and easier ways to work.

Motions Used in Signing a Letter. It is a relatively easy matter to learn the names of these fundamental motions. For example, in signing a letter, the sequence of motions is *transport empty* (reach for pen), *grasp* (take hold of pen), *transport loaded* (carry pen to paper), *position* (place pen on paper at correct position for writing), *use* (sign letter), *transport loaded* (return pen to holder), *pre-position* (position pen in holder), *release load* (let go of pen), and *transport empty* (move hand back to letter). These motions are fully defined and illustrated on the next three pages.

Motions Used in Removing the Cap from a Mechanical Pencil. In order to obtain further practice in learning the fundamental motions and in order to become familiar with some motions not already described, a chart (Fig. 53) is included showing the motions used in picking up a mechanical pencil from a tray, removing the cap from

FUNDAMENTAL MOTIONS USED IN SIGNING A LETTER

Motions of the Right Hand

	Name and Definition of Motion	Symbol	Description of Motion	Illustration
1	TRANSPORT EMPTY (Transport empty consists of moving the empty hand in reaching for an object. This motion usually begins the instant the hand begins to reach for an object and ends the instant a part of the hand comes in contact with the object to be grasped.)	TE	Reach for pen.	
2	GRASP (Grasp refers to taking hold of an object, closing the fingers around it preparatory to manipulating it, picking it up, or holding it. This motion begins when the hand or fingers first make contact with the object being grasped and ends when the hand or fingers have reached the position necessary for the performance of the next motion.)	G	Take hold of pen – close thumb and fingers around pen.	
3	TRANSPORT LOADED (Transport loaded requires that a change in the location of an object be made. It is the moving of an object from one place to another. The object may be carried in the hands or fingers or it may be moved from one place to another by sliding, dragging, or pushing it along.)	TL	Carry pen to paper.	

FUNDAMENTAL MOTIONS USED IN SIGNING A LETTER *(Continued)*

	Name and Definition of Motion	Symbol	Description of Motion	Illustration
4	**POSITION** (Position consists of turning or locating an object in such a way that it will be properly oriented to fit into the location for which it is intended. It is possible to position an object during the motion transport loaded. The carpenter, for example, may turn the nail into position for using while he is carrying it to the board into which it will be driven. Position usually follows the motion transport loaded and precedes the motion use.)	P	Position pen on paper for writing.	
5	**USE** (Use may refer to an almost infinite number of particular cases. It always consists of manipulating a tool, device, or piece of apparatus for the purpose for which it was intended. Use is the most important of all motions. It represents the motion for which the preceding motions have been more or less preparatory and for which the ones that follow are supplementary. Use begins the instant the hand applies itself in manipulating a device in such a way that the device functions for the purpose it was intended and ends the instant the hand ceases the application and begins the next motion.)	U	Sign letter.	
6	**TRANSPORT LOADED**	TL	Return pen to holder.	

	Name and Definition of Motion	Symbol	Description of Motion	Illustration
7	**PRE - POSITION** (This motion is the same as position with the added qualification that pre - position refers to positioning an object in a pre - determined place in such a way that it may be grasped in the position in which it is to be held when it is needed. This eliminates the position which would otherwise be necessary after the object was grasped. Usually a holder, bracket, or special container of some kind is used for holding the object in a way that permits it to be grasped easily in the position in which it will be used. Pre - position is the abbreviated term used for pre - position for the next operation.)	PP	Position pen in holder.	
8	**RELEASE LOAD** (Release load refers to that part of the cycle during which the hand is letting go of the object grasped - letting it slip out of the hand. This motion begins when the object starts to leave the hand and ends as the object has been completely separated from the hand or fingers.)	RL	Let go of pen.	
9	**TRANSPORT EMPTY**	TE	Move hand back to letter.	

the pencil, and examining the pencil to see whether the eraser needs renewing.

Notice that in this case for the left hand there is a *select* following the transport empty and preceding the grasp. *Select* refers to the choice of one object from among several. In removing the fountain pen from the holder (see page 51) there was but one pen present, consequently, there was no selection required. In the second case the mechanical pencil was located in a box along with other pencils and consequently the particular pencil desired was *selected* from the others.

Hold denotes the retention of the object after it has been grasped, no movement of the object taking place. *Unavoidable delay* refers to a delay beyond the control of the operator. *Disassemble* consists of separating one object from another object of which it is an integral part. *Inspect* consists of testing a piece to determine whether or not it complies with standard size, shape, color, or other qualities previously determined. Inspection may employ sight, hearing, touch, odor, or taste. Inspection is predominantly a mental reaction and may occur simultaneously with other motions. *Assemble* consists of placing one object into or on another object with which it becomes an integral part.

Pin Board. It seems natural for most people when observing another person at work to notice the material being handled or the tools being used rather than to observe the motions made in performing the task. After one becomes "motion-minded," that is, after one has learned the classification of hand motions, this situation is changed. The observer then notices the motions made with the right hand and those made with the left hand and then proceeds to use those motions which are easy and effective and to discard the awkward, fatiguing, and ineffective motions. Those people who accomplish the most do not necessarily work hardest. Rather, they make every motion count—they use good work methods. We are not at all interested in the "speed up" or "stretch out." We are interested in getting more quality work done with less expenditure of energy. Excessive speed is no substitute for good work methods.

To illustrate what is meant by developing a better method through the analysis of hand motions and the application of principles of motion economy, let us consider the task of filling a board containing thirty holes with thirty wooden pins. You will notice that there are five rows of six holes to a row in the board. (See Fig. 54.) The

Motions of the Left Hand

Illustration	Name of Motion	Symbol
	TRANSPORT EMPTY Reach for pencil in tray.	TE
	SELECT Select the automatic pencil from among the other pencils in the tray. The eyes aid the hand in searching for and selecting the automatic pencil.	St
	GRASP Close thumb and fingers around barrel of pencil.	G
	TRANSPORT LOADED Carry pencil from tray to vertical position in front of body. Also: POSITION (in transit) Pencil is in horizontal position when grasped. It is turned to vertical position in transit	TL P
	HOLD Left hand holds pencil while right hand removes the cap. Operator looks at eraser and then replaces cap.	H

Motions of the Right Hand

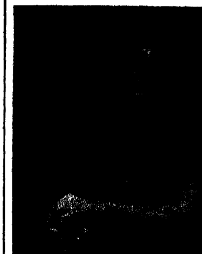
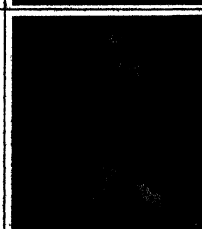
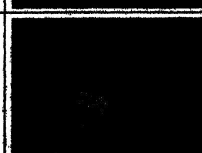
Symbol	Name of Motion	Illustration
UD	UNAVOIDABLE DELAY The right hand is idle—there is nothing for it to do. Therefore this delay is called unavoidable.	
TE	TRANSPORT EMPTY Right hand moves empty to pencil cap	
G	GRASP Close thumb and fingers around pencil cap	
DA	DISASSEMBLE Right hand removes cap from pencil.	
I	INSPECT Look at eraser of pencil to see whether it needs renewing. Note that the eyes perform the inspection operation. Both the right and left hands hold during this interval.	
A	ASSEMBLE Right hand places the cap back on the pencil.	

FIG. 53. Motions used in removing cap from mechanical pencil and examining eraser to see whether it needs renewing.

FIG. 54. Inserting pins in board, using the one-handed method. Left hand *holds* pins, right hand works productively. It takes 38 seconds to fill the board.

FIG. 55. Inserting pins in board, using simultaneous motions, both hands working together. It takes but 23 seconds to fill the board using this method.

pins are square on one end and bullet-shaped on the other. The job is to fill the board with the pins as quickly as possible, inserting the pin in the hole with the bullet nose down.

Ninety-five people out of a hundred would fill the board using the method shown in Fig. 54. The left hand grasps a handful of pins from the box and holds them while the right hand gets pins from the left, one at a time, and places them in the board. The right hand is working in a very effective manner inasmuch as it is performing the desired task, that is, filling the board with pins. However, notice that the left hand is doing very little productive work. Most of the time it is merely holding the pins.

If both hands were to work simultaneously getting and placing the pins in the holes, the operator's efforts would be much more effective. Incidentally, we are now applying one of the "Ten Principles of Motion Economy" which will be presented later (page 72). We are having a preview of one of these principles now.

Using this improved method it is obvious that the left-hand "hold" has been eliminated, and instead the left hand like the right now performs useful motions. The two hands work together in a symmetrical manner getting the pins and placing them in the holes in the board. (See Fig. 55.)

Results: It requires approximately 38 seconds to fill the board using the one-handed method, whereas but 23 seconds are required to fill the board using the two-handed method. This represents a saving of 39 per cent in time.

The fundamental motions of the left hand in filling the pin board are illustrated on the next two pages.

MOTION ANALYSIS—SIMO CHARTS

Occasionally it is desirable to break down an operation into the fundamental hand motions for the two hands, listing the motions for each hand in sequence and balancing them much as in the right- and left-hand charts already described. Such a chart is called a "Simo Chart." This is an abbreviation for "Simultaneous Hand Motion Chart." The main difference between these two charts is that right- and left-hand charts may consist of fairly large elements or a combination of several hand motions whereas the simo chart always shows each fundamental hand motion. Although simo charts can best be made from an analysis of motion pictures of the job,[9] it is possible

FUNDAMENTAL MOTIONS USED IN INSERTING PIN IN PIN BOARD

The operator is using simultaneous symmetrical motions in filling the pin board. (See Fig. 55.) Since the motions of the left hand and the right hand are the same, the motions of the left hand only will be shown here

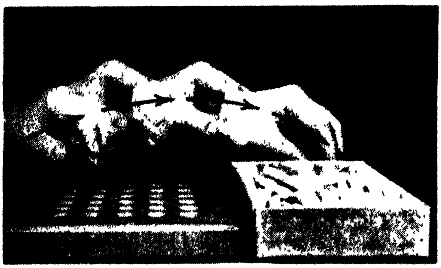
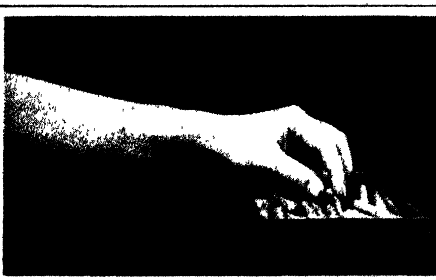
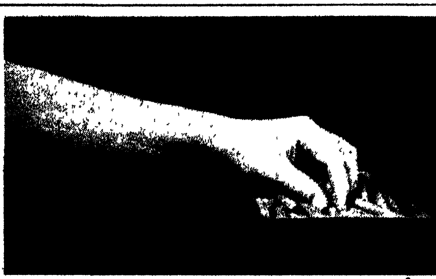
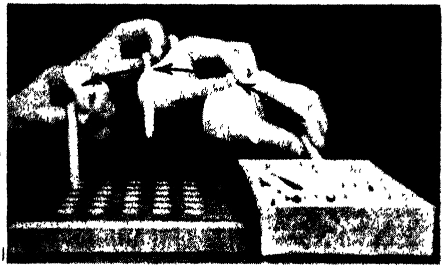
Illustration	Name of Motion	Symbol
	TRANSPORT EMPTY Reach for pin.	TE
	SELECT Select one pin from among those in box. The eyes aid the hand in searching for a particular pin. This searching and then spotting or finding a particular pin is called <u>select</u>.	St
	GRASP Close thumb and fingers around the pin selected.	G

Illustration	Name of Motion	Symbol
	TRANSPORT LOADED Carry pin from tray to hole in board into which it will be inserted. Also: POSITION (in transit) Pin is turned into vertical position as it is transported to board.	TL P
	POSITION Pin is lined up directly over the hole in the board into which it is to be inserted.	P
	ASSEMBLE Insert pin into hole in board.	A
	RELEASE LOAD Open fingers - let go of pin.	RL

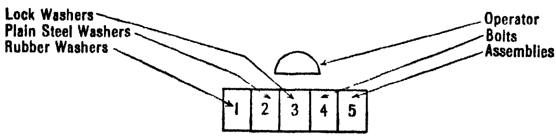
Name of Fundamental Motion	Symbol	Description
Select	St	Select refers to the choice of one object from among several.
Grasp	G	Grasp refers to taking hold of an object.
Transport loaded	TL	Transport loaded refers to moving an object from one place to another.
Position	P	Position consists of turning or locating an object in such a way that it will be properly oriented to fit into the location for which it is intended.
Assemble	A	Assemble consists of placing one object into or on another object with which it becomes an integral part.
Use	U	Use always consists of manipulating a tool, device, or piece of apparatus for the purpose for which it was intended.
Disassemble	DA	Disassemble consists of separating one object from another object of which it is an integral part.
Inspect	I	Inspect consists of testing a piece to determine whether or not it complies with standard size, shape, color, or other qualities previously determined.
Pre-position	PP	Pre-position refers to positioning an object in a predetermined place in such a way that it may be grasped in the position in which it is to be held when it is needed.
Release load	RL	Release load refers to that part of the cycle during which the hand is letting go of the object grasped, allowing it to slip out of the hand.
Transport empty	TE	Transport empty consists of moving the empty hand in reaching for an object.
Rest for overcoming fatigue	R	Rest for overcoming fatigue is a fatigue or delay allowance provided to permit the worker to recover from the fatigue incurred by his work.
Unavoidable delay	UD	Unavoidable delay refers to a delay beyond the control of the operator.
Avoidable delay	AD	Avoidable delay refers to any delay of the operator for which he is responsible and over which he has control.
Plan	Pn	Plan refers to a mental reaction which precedes the physical movement, that is, deciding how to proceed with the work.
Hold	H	Hold denotes the retention of the object after it has been grasped, no movement of the object taking place.

Fig. 56. Symbols and short description of the most commonly used fundamental hand motions.

for one familiar with the classification of hand motions to make a satisfactory analysis from observing the operator at work.

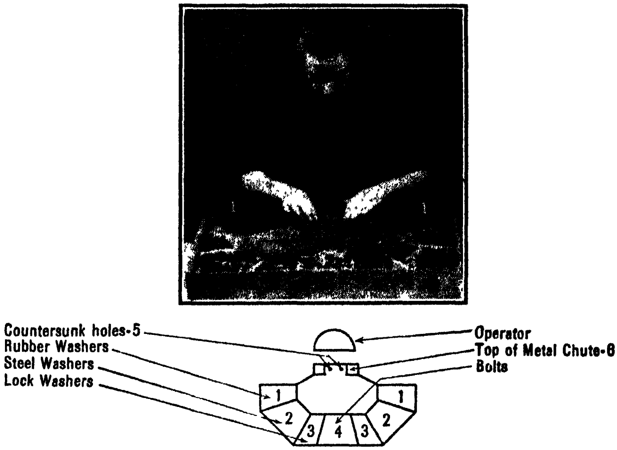
Figure 58 shows the enlargement of a motion picture film of the old method of the bolt and washer assembly.[10] Figure 57 describes in detail how the analysis is made from film. Figure 58 shows the actual motions of the two hands with the names of these motions listed at the side of the photographs. Figure 59 shows the simo chart of the old method of the bolt and washer assembly, and Fig. 60 shows a similar chart for the improved method. Ordinarily the motions of the left hand are listed on the left-hand side of the page and the motions of the right hand are listed on the right-hand side. In Figs. 59 and 60, however, this order has been reversed to make it easier to follow the film enlargements in Figs. 57 and 58.

Problem 4. Make a list of the motions of the left hand and of the right hand used in opening a bottle with the conventional type of bottle opener. The left hand reaches to back of table, gets bottle, carries it to front edge of table in convenient position for opening. The right hand already has the opener, moves it up to cap of bottle and removes the cap, opening the bottle. After you have solved this problem, turn to page 129 to check your answer.



Motions of Operator's Right Hand	Symbol	Symbol	Motions of Operator's Left Hand
Reach for lock washer in bin 3.	TE	TE	Reach for bolt in bin 4.
Grasp lock washer from bin 3.	St + G	St + G	Grasp bolt from bin 4.
Carry lock washer to central position.	TL	TL	Carry bolt to central position.
Position and assemble lock washer onto bolt.	P + A		
Reach for plain steel washer in bin 2.	RL+TE		
Grasp steel washer from bin 2.	St + G		
Carry steel washer to bolt.	TL		
Position and assemble steel washer.	P + A	H	Hold bolt.
Reach for rubber washer in bin 1.	RL+TE		
Grasp rubber washer from bin 1.	St + G		
Carry rubber washer to bolt.	TL		
Position and assemble rubber washer.	P + A		
Release finished assembly.	RL		
Wait for left hand.	AD	TL	Carry finished assembly to bin 5.
		RL	Let go of assembly.

FIG. 59. Simo chart of bolt and washer assembly—old method. Output 12 assemblies per minute.



Motions of Operator's Right Hand	Symbol	Symbol	Motions of Operator's Left Hand
Reach for rubber washer in bin 1.	TE	TE	Reach for rubber washer in bin 1.
Select and grasp rubber washer from bin 1.	St + G	St + G	Select and grasp rubber washer from bin 1.
Slide rubber washer to countersunk hole 5.	TL	TL	Slide rubber washer to countersunk hole 5.
Position rubber washer in countersunk hole 5 and release.	P + RL	P + RL	Position rubber washer in countersunk hole 5 and release.
Reach for steel washer in bin 2.	TE	TE	Reach for steel washer in bin 2.
Select and grasp steel washer from bin 2.	St + G	St + G	Select and grasp steel washer from bin 2.
Slide steel washer to countersunk hole 5.	TL	TL	Slide steel washer to countersunk hole 5.
Position steel washer in countersunk hole 5 and release.	P+RL	P+RL	Position steel washer in countersunk hole 5 and release.
Reach for lock washer in bin 3.	TE	TE	Reach for lock washer in bin 3.
Select and grasp lock washer from bin 3.	St + G	St + G	Select and grasp lock washer from bin 3.
Slide lock washer to countersunk hole 5.	TL	TL	Slide lock washer to countersunk hole 5.
Position lock washer in countersunk hole 5 and release.	P+ RL	P+ RL	Position lock washer in countersunk hole 5 and release.
Reach for bolt in bin 4.	TE	TE	Reach for bolt in bin 4.
Select and grasp bolt from bin 4.	St + G	St + G	Select and grasp bolt from bin 4.
Carry bolt to washers at 5.	TL	TL	Carry bolt to washers at 5.
Position bolt preparatory to inserting it into washers at 5.	P	P	Position bolt preparatory to inserting it into washers at 5.
Insert bolt through the three washers.	A	A	Insert bolt through the three washers.
Withdraw bolt and washer assembly and carry to right.	DA+TL	DA+TL	Withdraw bolt and washer assembly and carry to left.
Release into top of chute 6.	RL	RL	Release into top of chute 6.

Fig. 60. Simo chart of bolt and washer assembly—improved method. Output 18 assemblies per minute.

TEN PRINCIPLES OF MOTION ECONOMY

1. Motions of the two hands should be simultaneous and symmetrical.

2. Tools and materials should be located close in and directly in front of the operator so as to be within easy reach of the hands. Transport distances should be as short as possible and movements should be as few as possible.

3. There should be a definite and fixed place for all tools and materials.

4. Gravity feed bins and containers should be used to deliver materials close to the point of use.

5. Tools and materials should be pre-positioned wherever possible.

6. "Drop deliveries" should be used wherever possible.

7. The hands should be relieved of all work that can be done more advantageously by the feet. Power-operated tools and equipment should be used wherever economical. A vise, jig, or fixture should be used to hold the work wherever possible, thus releasing the hands for productive work.

8. Materials and tools should be located to permit the best sequence of motions. Rhythm is essential to a smooth easy work pattern.

9. Smooth continuous motions of the hands are preferable to zigzag motions or straight-line motions involving sudden and sharp changes in direction.

10. The height of the work place and the chair should preferably be arranged to permit alternate sitting and standing at work. Adequate lighting should be provided, and the worker should be made as comfortable as possible.

CHAPTER 8

TEN PRINCIPLES OF MOTION ECONOMY

Over a period of years certain rules or principles of motion economy have come into wide use. Frank Gilbreth first listed some "rules for motion economy and efficiency, which govern hand motions," and from time to time other investigators in this field have added to this list.[11] Although there is much yet to be learned about this matter of using the body members with the greatest ease and efficiency, it seems that the so-called principles of motion economy do have wide application.

It is the purpose of this chapter and the following one to interpret by means of specific illustrations some of the general rules or principles of motion economy which have been and are now being successfully used in connection with many different kinds of work. All the ten principles presented here are not of equal importance nor does this discussion include all the factors that enter into the determination of better methods of doing work. The principles do, however, form a basis—a code, or a body of rules—which, if applied by one familiar with the classification of fundamental hand motions, will make it possible to increase greatly the output of manual labor with a minimum of fatigue.

1. MOTIONS OF THE TWO HANDS SHOULD BE SIMULTANEOUS AND SYMMETRICAL.

It seems natural for most people to work productively with one hand while holding the object being worked on with the other hand. This is usually undesirable. The two hands should work together, each beginning a motion and completing a motion at the same time. Motions of the two hands should be simultaneous and symmetrical.

It is obvious that in many kinds of work more can be accomplished by using both hands than by using one hand. For most people it is advantageous to arrange similar work on the right- and left-hand side of the work place, thus enabling the right and left hands to move together, each performing the same motions. The symmetrical movements of the arms tend to balance each other, reducing the shock and jar on the body and enabling the worker to perform his task with less mental and physical effort. There is apparently less body strain present when the hands move symmetrically than when they make nonsymmetrical motions because of this matter of balance.

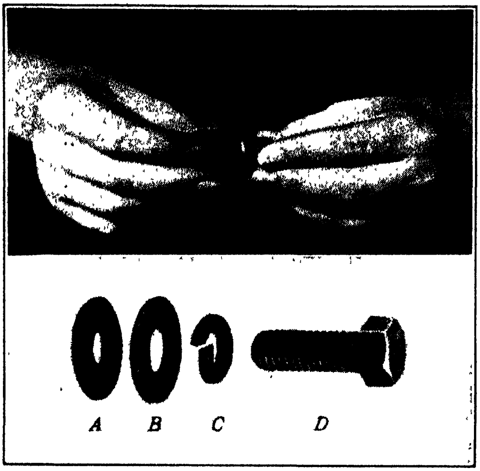


FIG. 61. Bolt and washer assembly: *A*, special rubber washer; *B*, flat steel washer; *C*, lock washer; *D*, ⅜-inch × 1-inch bolt.

Some examples are presented here to show the value of simultaneous symmetrical motions. In each of these cases the better method was developed through the analysis of the hand motions with which you are now familiar, and through the application of principles of motion economy, the first of which is under discussion here.

Bolt and Washer Assembly. A manufacturing concern uses eight bolts ⅜ inch by 1 inch, fitted with three washers each (see Figs. 61 and 62), in the final assembly of one of its products. This operation was facilitated by having the three washers previously assembled onto the bolt; consequently the bolt and washers were assembled by girls at benches in another department.

FIG. 62. The hole in the rubber washer is slightly smaller than the outside diameter of the bolt so that when the bolt is forced through the hole it is gripped, thus preventing the washers from falling off of the bolt.

Old Method. The bolt and washer assembly was originally made in the following manner. Containers with the bolts, lock washers, steel washers, and rubber washers were arranged on the top of the bench as shown in Fig. 59. The operator reached over to the container of bolts, picked up a bolt with her left hand, and brought it up to position in front of her. Then

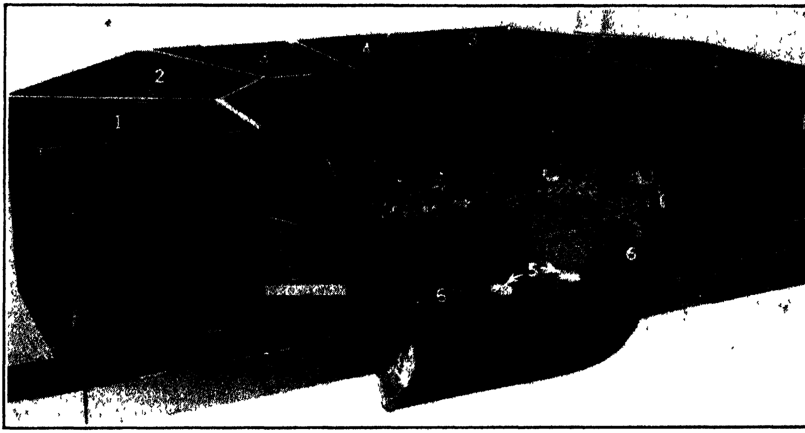


FIG. 63. Bins, fixture, and chute for bolt and washer assembly.

with the right hand she in turn picked up a lock washer from the container on the bench and placed it on the bolt, then a flat steel washer, and then a rubber washer. This completed the assembly, and with the left hand the operator disposed of it in the container to her left. Figure 59 gives an analysis of this operation, and Fig. 58 (folded insert) shows the pictures of one cycle.

The left hand *holds* the bolt during most of the time while the right hand works productively. The motions of the two hands are neither simultaneous nor symmetrical.

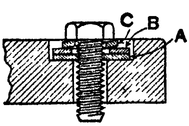


FIG. 64. Enlarged view of recess in wood fixture for assembling bolt and washers: *A*, rubber washer; *B*, steel washer; *C*, lock washer.

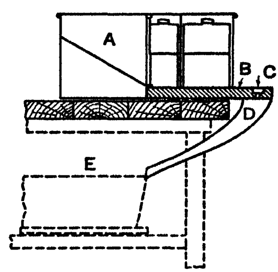


FIG. 65. Cross section of bins showing chute for drop delivery: *A*, bins with sloping bottom; *B*, top of fixture; *C*, countersunk holes in top of fixture; *D*, chute; *E*, container for finished assemblies.

Improved Method. A simple fixture was made of wood and surrounded by metal bins of the gravity feed type as shown in Figs. 63, 64, and 65. The bins containing the washers are arranged in duplicate so that both hands can move simultaneously, assembling washers for two bolts at the same time. As seen from Fig. 63, bins 1 contain the rubber washers, bins 2 the steel washers, bins 3 the lock washers, and bin 4, located in the center of the fixture, contains the bolts. The bottom of the bins slope toward the front at a 30-degree angle so that the materials are fed out onto the fixture board by gravity as the parts are used in assembly.

Two countersunk holes or recesses were made in the front of the fixture (see Fig. 64) into which the three washers fitted loosely, the rubber washer on the bottom, the steel washer next, and the lock washer on top. A hole slightly larger than the diameter of the bolt went through the fixture, as shown in Fig. 65. A metal chute was placed around the front of the wood fixture with openings to the right and to the left of the two recesses so that assembled bolts and washers might be dropped into the top of this chute and carried down under the bench to a container.

In assembling the bolt and washers, as the chart in Fig. 60 shows, the two hands move simultaneously toward the duplicate bins, and slide the rubber washers into place in the two recesses in the fixture. The two hands, then, in a similar way, slide the steel washers into place on top of the rubber washers, and then the lock washers are slid into place on top of these. Each hand, then, grasps a bolt and slips them through the washers which are lined up so that the holes are concentric. The hole in the rubber washer is slightly smaller than the outside diameter of the threads on the bolt so that when the bolt is forced through the hole it is gripped and thus permitted, with the three washers, to be withdrawn vertically upward without losing the washers. (See Fig. 62.) The two hands release the assemblies simultaneously over the metal chute. As the operator begins on the next cycle with the hands in this position, the first and second fingers of each hand are in position to grasp the rubber washer, which is almost at the tip of the fingers.

A detailed study of the old and the improved methods of assembling the bolt and washers shows:

Average time required to make one bolt and washer assembly by the old method	0.084 minute
Average time required to make one bolt and washer assembly by the improved method	0.055 minute
Time saved	0.029 minute

0.029 ÷ 0.055 = 53 per cent possible increase in output

The improved method as opposed to the old method of assembling the bolt and washers conforms to the first principle of motion economy already mentioned. Moreover, the two hands begin and end their motions at the same instant, and they move simultaneously in opposite directions. There is no idle time, and neither hand is used as a "vise" for holding material while the other one does the work, as under the old method.

Incidentally, the operator slid the washers from the bin to the countersunk holes in the fixture. This took only one half as long as if she had picked up the washers and carried them. *In general it is easier and quicker to transport small flat objects by sliding than by carrying.*

Filling Mailing Envelope with Advertising Material. This operation consisted of inserting four sheets of advertising material in a mailing envelope and tucking in the envelope flap. The job consisted of picking up the sheets one at a time with the right hand, transferring them to the left hand, jogging them, and then inserting them in the envelope. (See Fig. 66.) It is obvious that the *left* hand was idle part of the time, held the sheets part of the time, and worked in an inefficient manner during the rest of the cycle. Also, the *right* hand was idle part of the time.

Improved Method. Two small triangular pieces were made from cardboard and tape and fastened to flat sheets of cardboard. (See Fig. 67.) The advertising material was stacked against the two sides of the triangular pieces which served as fixtures enabling the operator to pick up two sheets at a time with each hand.[12] Rubber finger stalls facilitated the grasping. Since the sheets of the particular size shown in Fig. 68 were mailed out at frequent intervals, the work place to handle this job was set up permanently. Triangular wood blocks are shown at *A*. The operation now consists of grasping two sheets of paper at a time with each hand, drawing them together, jogging them on block *B* (see Fig. 68), and inserting them in the envelope.

When the operator used the old method of filling envelopes, picking up the sheets one at a time, her production was 350 per hour. However, using the improved work place layout and the better method, she was able to fill 750 envelopes per hour. The new method is so much easier than the old that she has more than doubled her output.

Folding Paper Cartons. Frankfurters are usually packed in cardboard cartons for shipment to the retail meat market. The cartons are delivered to the packing house in flat bundles, and these flat cartons must be formed and the end flaps folded over and locked together before they can be filled with frankfurters. A cover slightly larger than the bottom is placed over the filled carton bottom, tele-

FIG. 66. Arrangement of work place—old method. Filling mailing envelope with four sheets of advertising material.

scope fashion. (See Fig. 69.) The shape and design of the cover and bottom of the carton are alike, that is, both the cover and the bottom are folded the same way.

Old Method. The operator walked ten feet, got bundle of fifty carton "flats," and carried them to carton-folding table. Using both hands, the operator grasped a group of eight flat cartons, broke all seams or scored lines to facilitate forming, and placed flats on table with ends toward her. She then grasped the sides of the carton flap

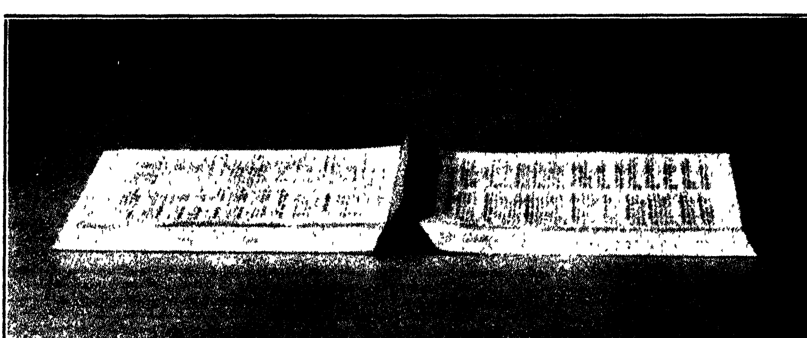


FIG. 67. Temporary fixture for assembling two sheets of advertising material.

FIG. 68. Arrangement of work place—improved method. Filling mailing envelope with four sheets of advertising material. Since sheets of this particular size were sent out at frequent intervals, the work place shown above was set up permanently. *A*. Triangular blocks. *B*. Block on which sheets are jogged.

and simultaneously bent bottom and side flaps toward center of carton. (See Fig. 70.) Holding the left side flap in position, she inserted the tongue of the right flap into retaining groove of left flap. She then pushed the partly formed carton forward approximately four inches to nest. The above procedure was repeated until four cartons were folded at one end.

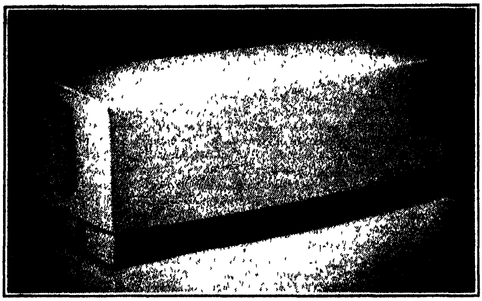


FIG. 69. Carton for packing frankfurters.

The operator then took the group of partly formed cartons from position on table and turned them end for end so the unfolded ends were toward her. The operator then repeated the fold-

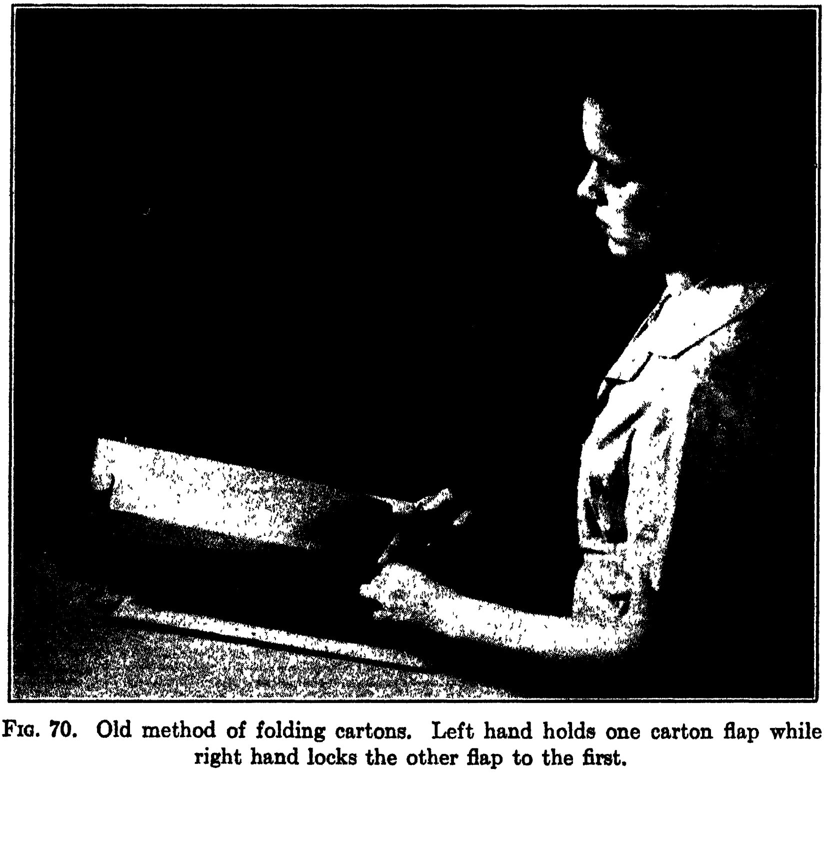


FIG. 70. Old method of folding cartons. Left hand holds one carton flap while right hand locks the other flap to the first.

ing operation on the second end of the carton flat and placed completely formed carton on the conveyor to be filled with frankfurters.

Improved Method. A simple wood fixture, as shown in Fig. 71, was designed and built.[13] Bundles of flat cartons are now delivered by truck near packing table. The operator gets bundle of fifty flats, carries them to the table, and places them in holder *A* in Fig. 71. With her left hand she reaches to lower end of pile of carton flats, grasps end of middle flap, brings flap to position over forming fixture *B* in Fig. 71. With the right hand she disposes of previously formed carton to conveyor. Then with her right hand she grasps middle flap on right end of carton, which is already positioned in the fixture. Holding both middle end flaps, one in each hand, she bends flaps upward and pushes carton into fixture. The fixture forces rear side flap up 90 degrees, folds two rear end flaps forward 90 degrees, and folds front side and end flaps up approximately 45 degrees. With both hands simultaneously, the operator then reaches to front end

FIG. 71. Improved method of folding cartons. Fixture aids in forming carton and holds it while both hands lock the flaps. Flaps on both ends of carton are assembled at the same time. Operator doubled her output.

FIG. 72. Normal and maximum working areas in the horizontal plane.

flaps, folds end flaps to rear and toward center of carton until end of tongues on front flaps are inside notches of rear end flaps. While holding end flaps in position with fingers, the operator reaches with thumbs to front corners of carton, pushes front of carton to rear in order to lock tongues of front end flaps into notches of rear end flaps, and thus completes forming carton. The operator then disposes of finished carton onto conveyor.

Results. The improved method enabled the operator to double her output. The fixture cost approximately $10.00 to make. The improved method was superior to the old method for the following two reasons: (1) elimination of the operation of breaking "seams" or scored lines of fold on carton flats before forming; (2) elimination

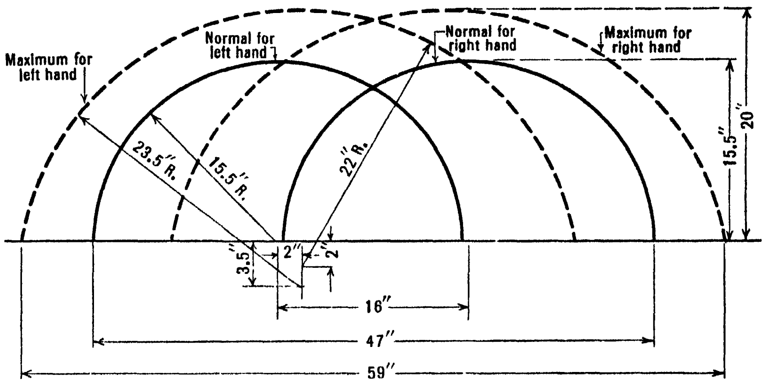


FIG. 73 *A*. Dimensions of normal and maximum working areas in the horizontal plane. Dimensions obtained from measurements made of thirty men.[14]

of holding one flap in position with one hand while assembling the second flap with the other hand.

2. *TOOLS AND MATERIALS SHOULD BE LOCATED CLOSE IN AND DIRECTLY IN FRONT OF THE OPERATOR SO AS TO BE WITHIN EASY REACH OF THE HANDS. TRANSPORT DISTANCES SHOULD BE AS SHORT AS POSSIBLE AND MOVEMENTS SHOULD BE AS FEW AS POSSIBLE.*

Very frequently the work place, such as a bench, machine, desk, or table, is laid out with tools and materials in straight lines. This is incorrect, for a person naturally works in areas bounded by lines which are arcs of circles.

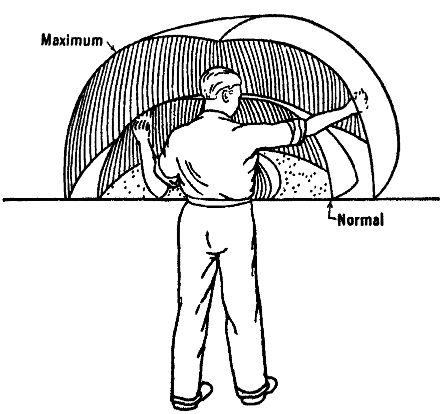


FIG. 73 *B*. Normal and maximum working space in three dimensions.

Normal Working Area. Considering the horizontal plane, there is a very definite and limited area which the worker can use with a normal expenditure of effort. There is a normal working area for the right hand and for the left hand, working separately, and for both hands working together. (See Figs. 72 and 73.) The normal working area for the right hand is determined by an arc drawn with a sweep of the right hand across the table. The forearm only is extended, and the upper arm hangs at the side of the body in a natural position until it tends to swing away as the hand moves toward the outer part of the work place. The normal working area for the left hand is determined in a similar manner. The normal arcs drawn with the right and left hands will cross each other at a point in front of the worker. The overlapping area constitutes a zone in which two-handed work may be done most conveniently.

Maximum Working Area. There is a maximum working area for the right hand and for the left hand, working separately, and for both hands working together. (See Figs. 72 and 73.) The maximum working area for the right hand is determined by an arc drawn with a sweep of the right hand across the table with the arm pivoted at the right shoulder. The maximum working area for the left hand is determined in a similar manner by an arc drawn with a sweep of the left hand. The overlapping area formed by these two maximum arcs constitutes a zone beyond which two-handed work cannot be performed without causing considerable disturbance of posture accompanied by excessive fatigue.

Each hand has its normal working space in the vertical plane as well as in the horizontal plane in which work may be done with the least time and effort. (See Fig. 73.) A maximum work space in the vertical plane may also be determined beyond which work cannot be performed without disturbing the posture. In locating materials or tools above the work place, consideration should be given to these facts.

Moving Radio Parts Six Inches Closer to Fixture Saves $20,000 per Year. The production of one model of a radio requires the assembly of 260 separate parts or subassemblies. Two hand movements are required to pick up each part from the supply bin and process or assemble it—one movement of the hand to the bin and one from the bin. By shortening the distance six inches for reaching each of these parts there is a saving in time of 34,000 hours per year.

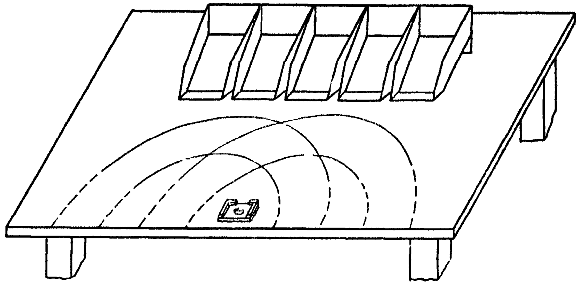


FIG. 74. Incorrect work place layout. Bins are located too far from the assembly fixture. The operator must bend forward to get parts from bins.

Number of parts moved	= 260
Movements (motion of hand to and from bin)	= 2
Average saving in time to move hand six inches shorter distance	= 0.002 minute

or

$$260 \times \frac{(2 \times 0.002)}{60} = 0.017 \text{ hour per radio set}$$

This saving of 0.017 hour or 62 seconds per radio set per day is extremely small. However, since this comapny makes 8000 sets per day, the savings per day would be:

$$8000 \times 0.017 = 136 \text{ hours per day}$$

Consider this production to run 250 working days per year:

$$250 \text{ days} \times 136 \text{ hours per day} = 34{,}000 \text{ hours saved per year}$$

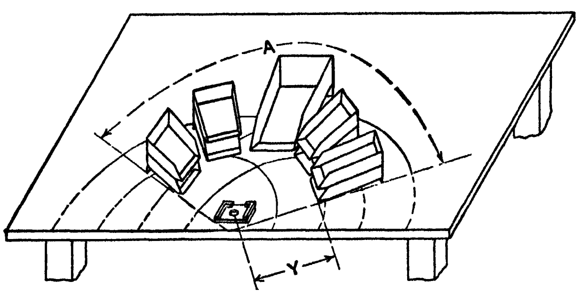


FIG. 75. Correct work place layout. Bins are located close to the fixture enabling the operator to get parts from any of the bins with easy quick forearm motions. In many kinds of work the eyes must direct the hands. In such cases the work area should be located directly in front of the operator so that eye fixations will be as few and as close together as possible. In other words, angle *A* should be as small as possible, and distance *Y* should be as short as the nature of the work will permit.

Assuming that the average rate paid to the people on radio assembly is 60 cents per hour, the total savings would amount to $20,400.00 per year.[15]

Moving Radio Parts Six Inches Closer to Fixture Reduces Hand Movement 98,500 Miles per Year. Another way to look at this is in

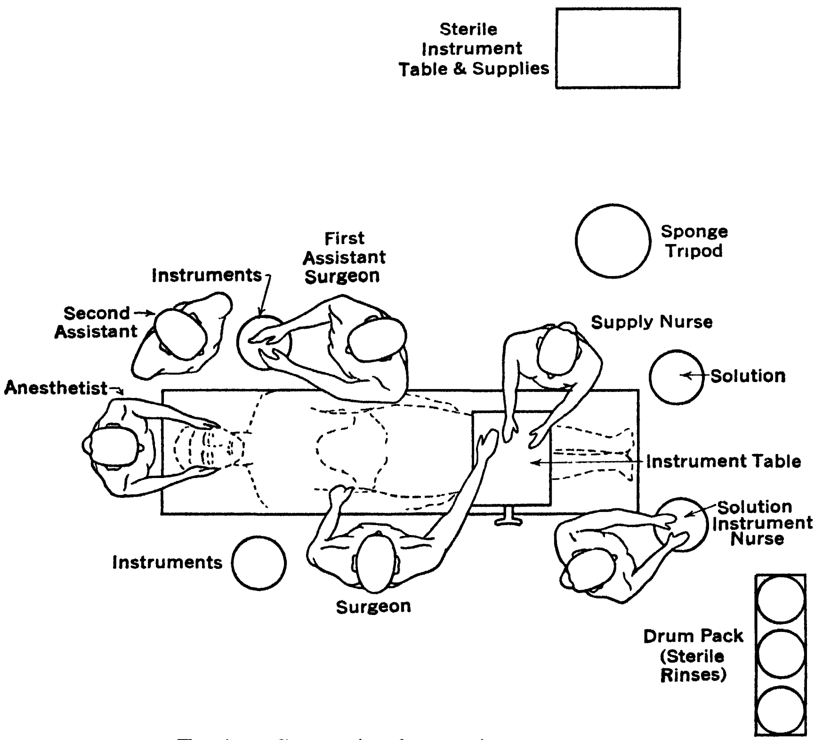


FIG. 76. Conventional operating room setup.

total distance saved. If six inches are saved in the movement of the hand to the bin and another six inches from the bin, the total savings are 12 inches, or 1 foot per piece.

260 pieces × 1 foot = 260 feet saved per set

8000 sets × 260 feet per set = 2,080,000 feet or 394 miles saved per day

250 working days × 394 miles per day

= 98,500 miles saved per year, or a distance almost four times around the earth at the equator

Arrangement of Operating Room in Hospital. The accepted operating room practice causes much useless motion and delay on the part of assistants and nurses in handling instruments and supplies. (See Fig. 76.) The redesigned arrangements shown in Fig. 77 eliminates many motions in that the instruments and supplies are on either side of the surgeon, enabling the nurses to face the operating table instead of turning around to procure necessary articles from tables ordinarily located behind them.[16] The two tables are adjustable in

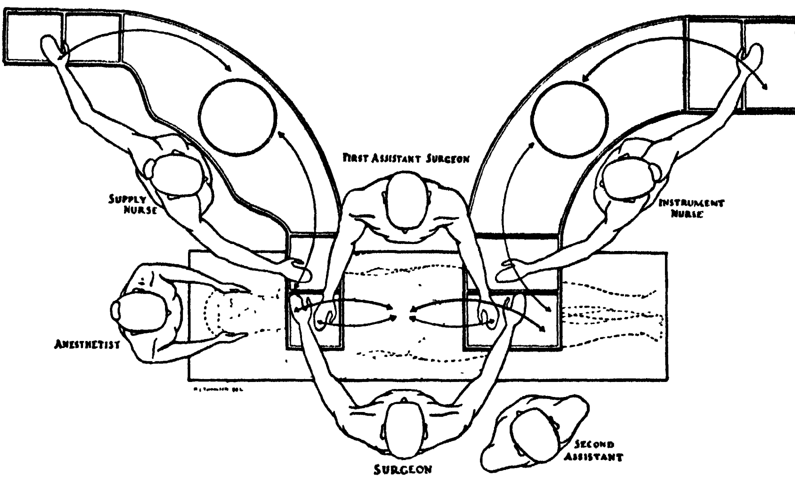


Fig. 77. Operating room setup showing tables for instruments and supplies designed to facilitate the work of the surgeon, his assistants, and the nurses.

height, built with removable metal tops and separate basins for clean and soiled instruments.

Typewriting. One important mark of an inefficient operator is that he uses excessive hand and body movements. Besides this, the ineffective operator often uses motions of the forearm when he should use finger movements and motions of the shoulder and trunk when he should use lower arm movements. For example, the typist who turns out a small amount of work with an excessive number of errors in many cases is not only using improper finger motions but she is also using excessive hand and arm motions. Of course poor typists often maintain incorrect posture, lack rhythm, and are not correctly seated with respect to the typewriter keyboard.

In order to demonstrate how little hand and body movement is present when the typing technique is good, Miss Margaret Hamma, world champion typist, typed at 118 words per minute with two small glasses of water attached to each wrist, as shown in Fig. 78.

Her easy, smooth, rhythmic movements were important factors in enabling her to typewrite continuously for one hour in competition with the fastest typists in the world, at a rate of 149 net

Courtesy of International Business Machines Corporation.

FIG. 78. Miss Margaret Hamma, world champion typist, demonstrates smooth, rhythmic arm movements by typing 118 words per minute with a glass of water attached to each wrist.

(5-stroke) words per minute when she set a world's all-time typing record in 1941. She wrote continuously at a pace of 13 key strokes per second or 46,578 strokes per hour and made only 40 errors out of 46,578 strokes. Miss Hamma, incidentally, now holds the World Championship, the Woman's Professional Championship, and the World Amateur Championship.

Problem 5. **Make a pin board and pins according to the drawing shown in Fig. 79 and try the experiment described below.**

(*a*) Determine the time required to fill the thirty holes in the board with thirty pins under each of the three conditions indicated in Fig. 80. Time five

consecutive cycles and take the average. If a stop watch is not available, use an ordinary pocket watch.

(*b*) Determine the number of pin boards that could be filled in an 8-hour day under each of the three conditions. Assume that an operator could maintain the pace used in the experiment and that no fatigue nor delay allowances were made.

(*c*) Calculate in percentage how much more time was required to fill the pin board under condition *B* than *A*; under condition *C* than *A*.

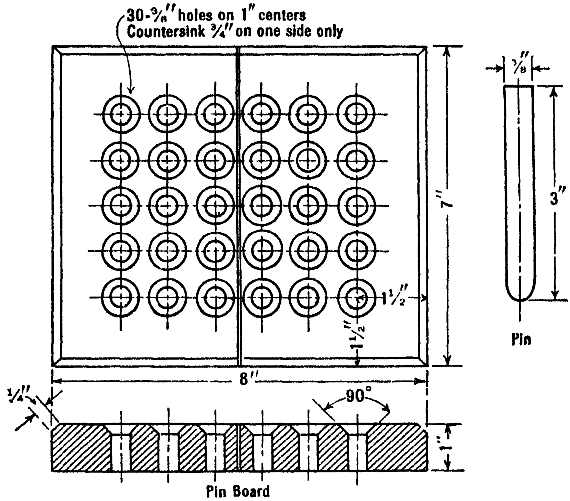


FIG. 79. Details for making pin board and pins.

(*d*) Compute the total distance in feet through which the two hands would move in filling 1000 pin boards under each of the three conditions.

(*e*) Calculate in percentage how much farther the hands would move under condition *B* than *A*; under condition *C* than *A*.

Turn to page 130 for typical results.

3. THERE SHOULD BE A DEFINITE AND FIXED PLACE FOR ALL TOOLS AND MATERIALS.

The operator should always be able to find the tools and materials in the same location. Likewise, finished parts and assembled units should be disposed of in fixed places. For example, in the assembly of the bolt and washers, the hand should move without mental direction to the bin containing the rubber washers, then to the bin containing the steel washers, then to the lock washers, and finally to the bolts. It should be unnecessary for the operator to have to think where the materials are located.

Definite stations for materials and tools aid the worker in habit formation and permit the rapid development of automaticity. It cannot be emphasized too strongly that it is greatly to the worker's

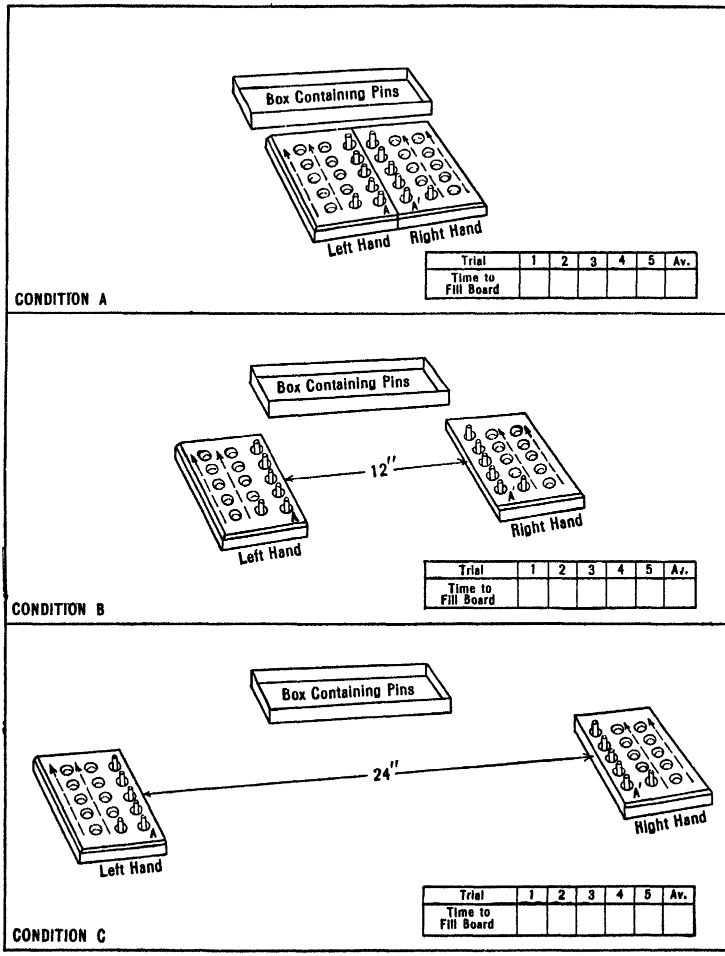


FIG. 80. Arrangement of work place for pin board study.

advantage to be able to perform the operation with the least conscious mental direction. Frequently, materials and tools are scattered over the work place in such a disorderly fashion that the operator must not only exert mental effort, but must also hunt around in order to locate the part or tool needed at a given instant. The

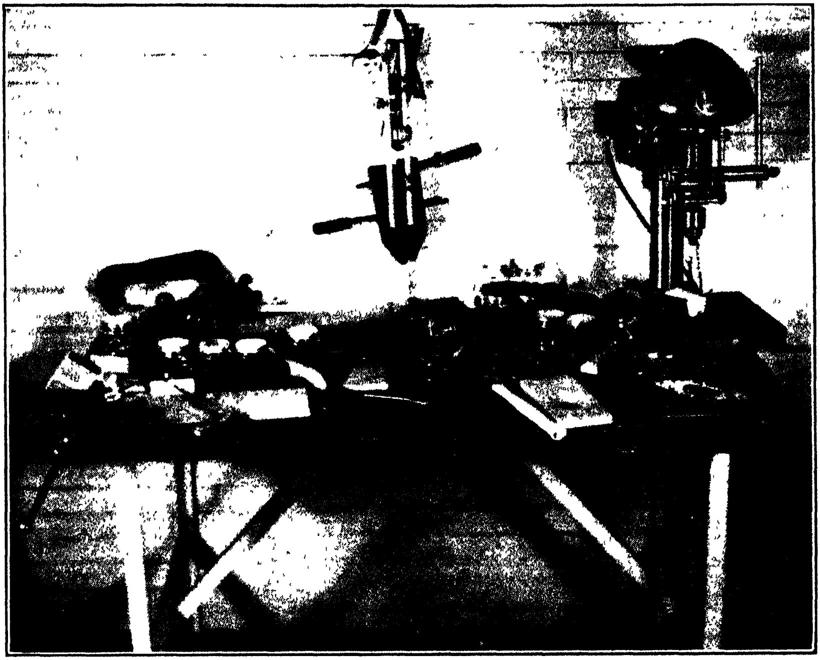


FIG. 81. A disorderly bench makes it necessary for the worker to hunt through the heap of tools and material on the bench to find what he wants.

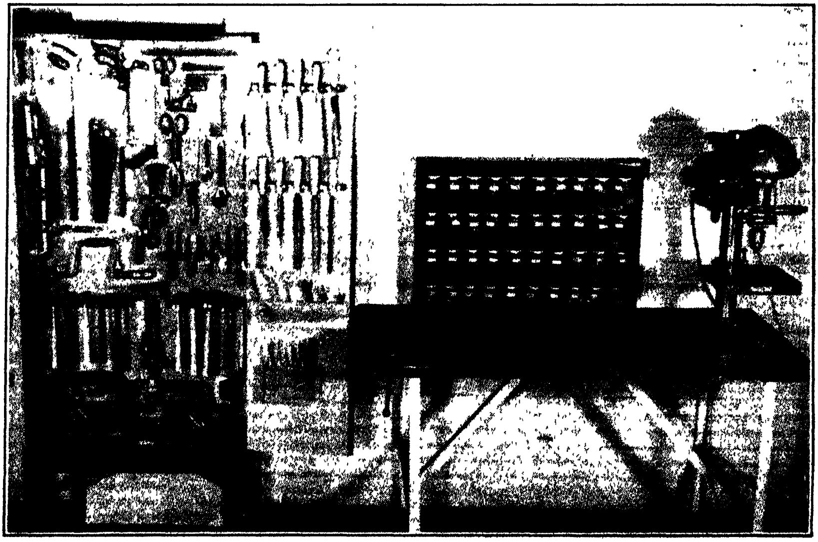


FIG. 82. A "definite place for everything" is desirable whether the work is "general repair and maintenance" or whether it is a repetitive operation.

workers are very much in favor of having definite stations for materials and tools, since this reduces fatigue and saves time. There can

FIG. 83. Special tool rack used at the Kaiser Company shipyards contains all tools needed by the joiner, yet his hands are free enabling him to climb up and down holds.

be no virtue in requiring the worker to exert the unnecessary effort to decide just what tool to pick up next or what part to assemble next, when, by simply arranging the materials and tools properly, the operator, with a little practice, will automatically perform the work in the proper sequence, at a rapid rate, and with a minimum expenditure of effort.

When the eyes must direct the hand in reaching for an object, the eyes ordinarily precede the hand. However, if materials or tools are lo-

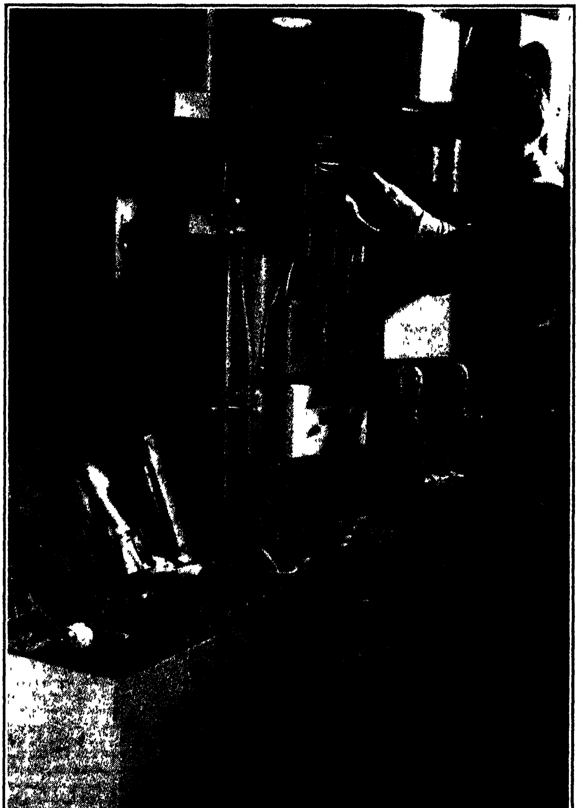


FIG. 84. Special tool chest—trucks are provided for maintenance electricians at Douglas Aircraft Company plants. Service cribs or shops are centrally located in the production areas, thus enabling electricians to answer trouble calls by travelling short distances with all the tools they will need.[17]

cated in a definite place and if they are always grasped from the same place, the hand automatically finds the right location and the eyes may be kept fixed on the point where the tools or materials are used.

Figure 83 shows a special tool rack designed by Clarence Hoborn of the Kaiser Company to aid him in doing his job of ice box finish-ing on ships.[18] The rack is made of wood and has a slot or pocket for each tool that a joiner needs on this work. Not only is there a place for everything but the tools are easy to reach also, and the whole kit can be carried on the worker's back, leaving both hands free when he climbs up and down holds.

Shipping Room Table. Motion study principles have been successfully applied in many "non-manufacturing" activities such as offices,

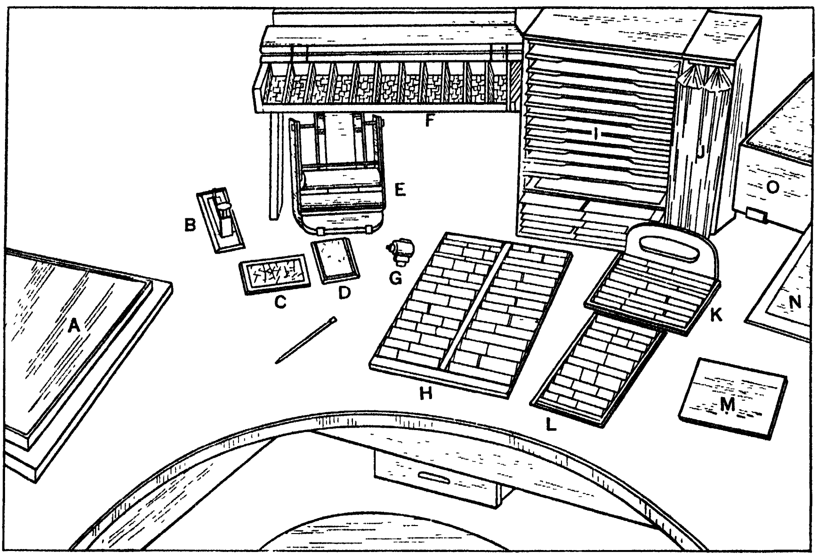


FIG. 85. Special table for weighing, stamping, and billing parcel post packages for shipment in mail order house. *A*. Scales, *B*. Stapler, *C*. Pin-disposal box, *D*. Stamp pad, *E*. Gum tape dispenser, *F*. Postage stamps, *G*. Counter, *H*. Refund vouchers, *I*. Supply of form letters, *J*. Re-order blanks, *K*. "Due us" forms, *L*. Postal collection forms, *M*. Scratch pad, *N*. Adding machine, *O*. Irregular billing papers.

restaurants, hotels, department stores, and mail order houses. Figure 85 shows a special semicircular work table designed for weighing, stamping, and billing parcel post packages in the shipping room of a large mail order house.[19] The packages to be shipped come down to the work table on a slide at the extrême left of the table, are weighed, stamped, billed, and pushed off onto a belt conveyor at a point adjacent to the incoming slide. It is not necessary to lift the package. Note that the table has "cutouts" for scales, pins, forms, stamp pad, adding machine, etc. A drawer under the table provides a place for the operator's personal belongings. This work place layout is typical of the care with which every activity in this organization has been studied and indicates how the work has been made easier.

4. GRAVITY FEED BINS AND CONTAINERS SHOULD BE USED TO DELIVER MATERIAL CLOSE TO THE POINT OF USE.

A bin with sloping bottom permits the material to be fed to the front by gravity and so relieves the operator of having to dip down into the container to grasp parts. (See page 63.) However, it is not always possible to slide material into position as in the bolt and washer assembly. More frequently bins such as those shown in Fig. 86*A* are used. Where many different parts are required, as in the assembly of an electric switch, it becomes necessary to nest the bins one above the other in order to have the material within convenient reach of the operator.

Bins of standard sizes, such as those shown in Fig. 86, are standard equipment in many plants. The bins are interchangeable and are made in three heights and three widths. By the use of these standard unit bins, any combination can be made to suit the particular job. It is difficult to give a general rule as to the proper size of bins for a particular operation. Some companies try to have their bins large enough to hold material for four hours' work, which probably is an economical size for many kinds of material.

Figure 86*B* shows how these bins were arranged for the assembly of a special doorknob. With such standard bins available it is a simple task to set up for a new job. Incidentally the assembly fixture and the work place arrangement shown in Fig. 86*B* made the job so much easier that the operator increased her output 143 per cent.[20]

Figure 87 shows standard work place equipment used by the RCA Manufacturing Methods Division.[21] Bins, tool holders, flat trays, solder iron holders, etc., are interchangeable and may be mounted with equal facility on a work bench, drill press, riveting machine, or hung on any standard rack in any position. This standard equipment is entirely flexible and can be readily adapted for use in the manufacture of new radio apparatus. When a new type of radio is to be put into production it is a simple matter to disassemble the standard bins and equipment and set it up again for the new job. The work bench itself is made in standard sections and is fitted with pipe to carry compressed air and conduit for electric power. When a long bench is needed, several standard bench sections are bolted together,

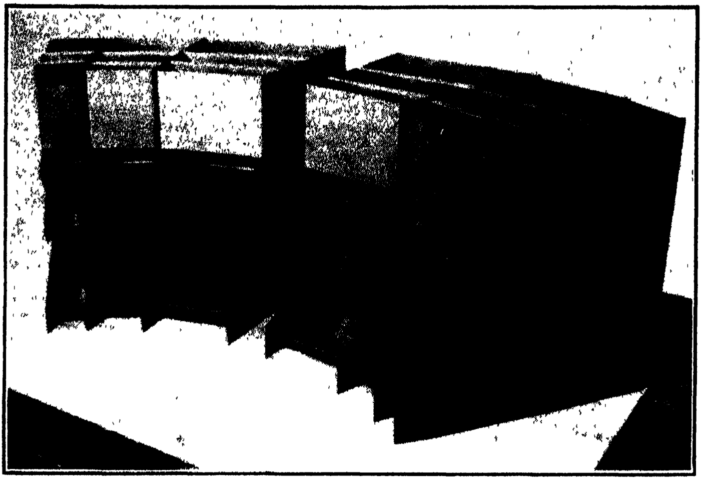


FIG. 86 *A*. Standard bins of the gravity feed type.

FIG. 86 *B*. Bins and fixture for assembling special door knobs. The standard bins are shown on either side of the fixture. The two small bins in the center have a lip on the front edge to facilitate grasping nuts and washers. In this case tests showed that it required 40 per cent less time to grasp nuts from the bins with lip than from an ordinary rectangular bin.

electric lines being coupled together and plugged into the main power circuit. The regular setup man is able to complete the job, thus making it unnecessary to have an electrician or a pipe fitter.

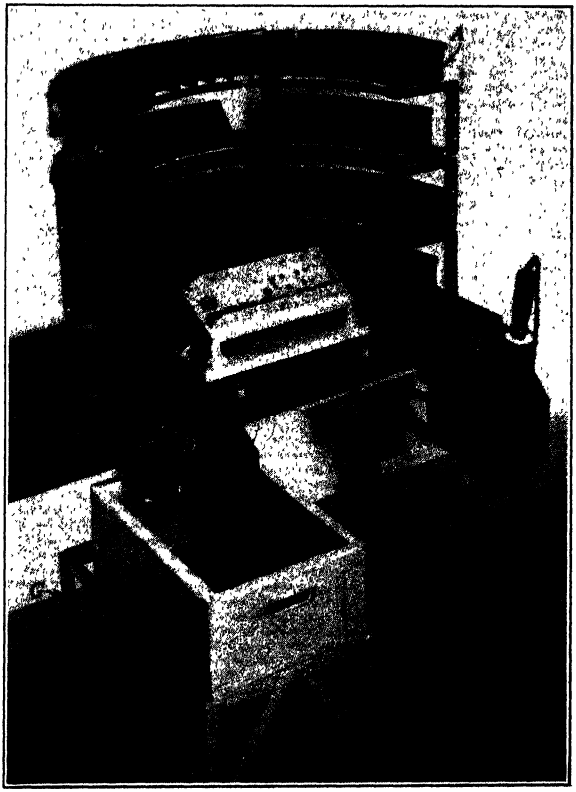


FIG. 87. Standard workplace equipment. *A*. Lip tray, length (from back to lip) 5½ inches; width 2⅛ inches, 4¼ inches, or 8½ inches. *B*. Edge tray, length (from back to lip) 4¼ inches or 8½ inches; width 5½ inches. *C*. Open bin—bench type, length (from back to front) 8 inches; width 5 inches, 8 inches, or 10 inches; depth 8 inches. *D*. Open bin—rack type, length (from back to front) 8 inches; width at back 8½ inches; width at front 5½ inches; depth 3 inches. *E*. Curved rack to support trays, depth 5⅜ inches; height 4⅞ inches. *F*. Universal brackets for mounting fixtures. *G*. Tote box dolly designed to hold tote boxes of material or finished work.

5. TOOLS AND MATERIALS SHOULD BE PRE-POSITIONED WHEREVER POSSIBLE.

Pre-positioning refers to placing an object in a predetermined place in such a way that when next needed it may be grasped in the position in which it will be used. For pre-positioning tools, a holder in the form of a socket, compartment, bracket, or hanger should be provided into which or by which the tool may be returned after it is used, and where it remains in position for the next operation. The tool is always returned to the same place. The holder should be of such design that the tool may be quickly released into its place from the hand. Moreover, the holder should permit the tool to be grasped in the same manner in which it will be held while being used. The most familiar example of pre-positioning is the fountain pen desk set,

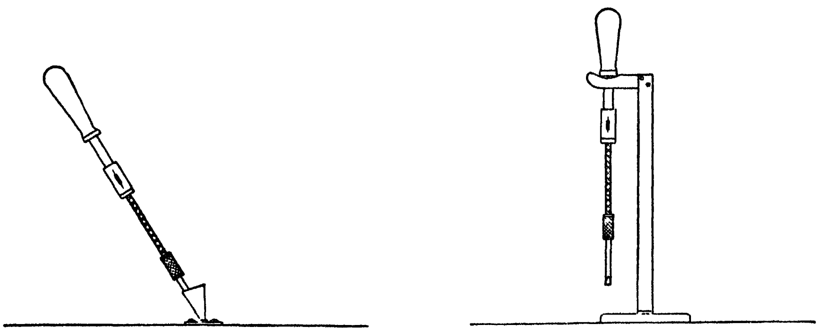


Fig. 88. Devices for pre-positioning spiral screwdriver.

where the pen is held in writing position even when not in use, and from or to which it may be easily and quickly removed or returned. Figure 88 shows two holders for pre-positioning a screw driver. Figure 91 shows a power wrench suspended (pre-positioned) directly over the fixture.

In order to show how pre-positioning the power wrench made it unnecessary for the operator to move "8 tons of power wrench" per day, the cast iron plate assembly operation will be described in detail.

Cast Iron Plate Assembly. The two cast iron plates shown in Fig. 89 were assembled and a bolt with washer was placed through the hole in the plates. A washer and nut were then assembled onto the end of the bolt.

Old Method. Originally the work place was arranged as shown in Fig. 90. The operation was performed by first placing a nut in the fixture, then a washer on top of the nut; then the two plates were placed on top of the nut and washer. Finally, the bolt and top washer were assembled into the hole in the plate and the power-driven wrench or electric "nut runner" was picked up from the edge of the table, carried over to the fixture, and the bolt was driven into the nut until tight. The power wrench was then carried back and placed on the edge of the table again. The normal time for this

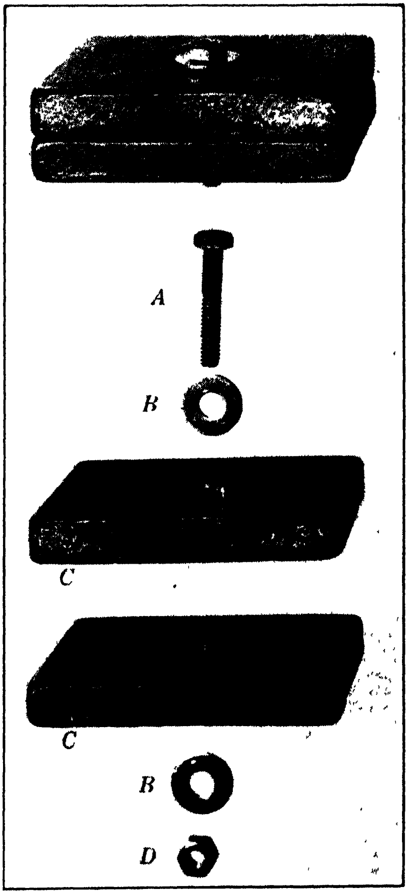


Fig. 89. Cast iron plate assembly. *A*. Machine bolt ½ inch × 1⅝ inches. *B*. Steel washers. *C*. Cast iron plates ½ inch × 2½ inches × 3½ inches. *D*. Hexagonal nut.

assembly operation was 18 seconds, that is, an operator could complete 200 assemblies per hour.

The power wrench, weighing 5 pounds, had to be lifted up and carried to the fixture, used, and then carried back to the table—two trips per assembly or 400 trips per hour or 3200 trips per eight-hour day.

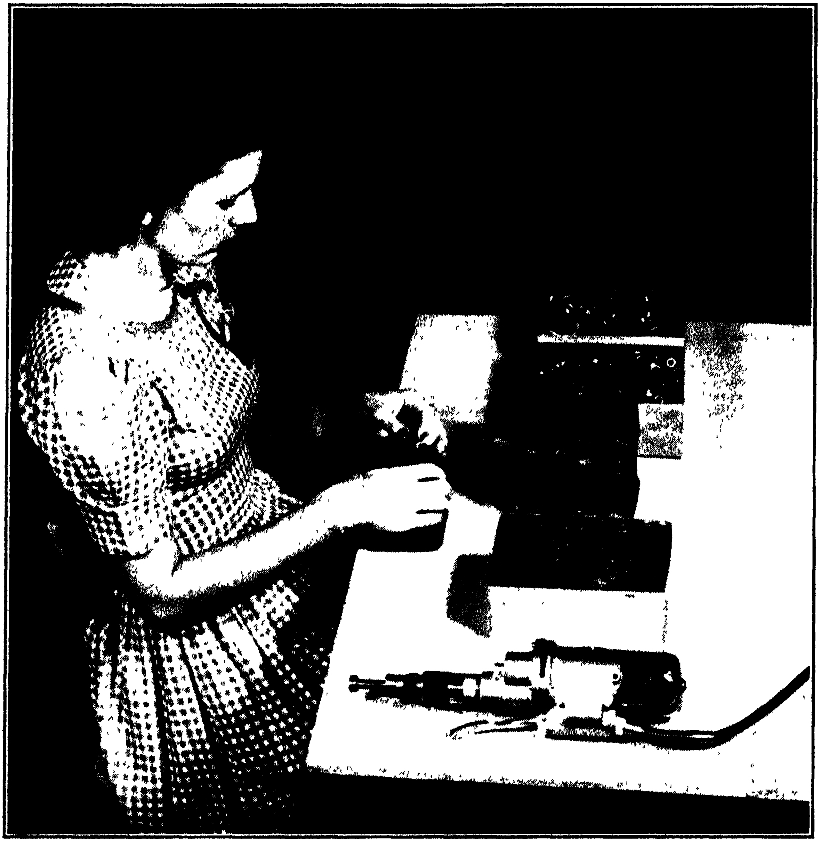


FIG. 90. Layout of work place for assembly of cast iron plates—old method. Power wrench weighs 5 pounds, is picked up and put down for each assembly. Operator moves "8 tons of power wrench" each day.

That is, 3200 trips × 5 pounds = 16,000 pounds per day = 8 tons per day. That means that the operator lifts "8 tons of power wrench" during the day.

Improved Method. By suspending the power wrench directly above the fixture by means of a spring attached to a gooseneck, the operator does not need to lift the wrench at all. The spring can be adjusted so that it almost exactly counterbalances the weight of the wrench. Thus only a few ounces of force are required to pull the wrench down into position for tightening the bolt and nut. After the wrench has been used it can be swung upward out of the way with practically

Fig. 91. Layout of work place for assembly of cast iron plates—improved method. Power wrench is suspended above fixture eliminating the lifting. Duplicate fixture enables hands to work to better advantage. Output is increased 31 per cent.

no effort. Thus the lifting of the "8 tons of power wrench" has been practically eliminated.

Moreover, by using a duplicate fixture for the plate assembly as shown in Fig. 91, the two hands can work to better advantage in assembling the plates, and 262 assemblies can be made per hour as against 200 by the old method. This is an increase in output of 31 per cent.

CHAPTER 9

TEN PRINCIPLES OF MOTION ECONOMY (*Continued*)

6. "DROP DELIVERIES" SHOULD BE USED WHEREVER POSSIBLE.

The work should be arranged so that the finished units may be disposed of by releasing them in the position in which they are completed, thus delivering them to their destination by gravity. This saves time, and moreover the disposal of the objects by simply releasing them frees the two hands so that they may begin the next cycle

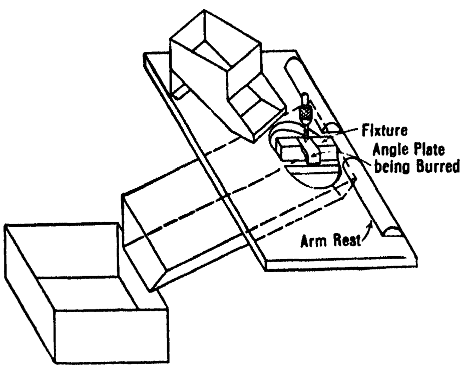


FIG. 92. Foot-operated drill press for burring small parts. Finished parts drop out of the fixture into the disposal chute by gravity and slide down into tote box on floor. One of the two supply bins in the illustration has been removed in order better to show the fixture.

simultaneously without breaking the rhythm. If a chute is used to carry the finished parts away, it should be located so that the parts can be released in the position in which they are finished, or as close to this point as possible.

A perfect example of this is shown in Fig. 92. The operation is that of burring a hole in the end of a small angle plate. The drill is fed by means of a foot pedal, and the angle plate is held in position for burring by means of a fixture. The fixture is mounted on the drill press table and extends up through a plywood board which is mounted six inches above the drill press table. This board serves as an auxiliary work place, making it unnecessary to cut disposal holes through the drill press table itself. Holes cut in the board on either side of the the fixture lead to a disposal chute underneath.

The part to be burred is placed in the fixture, and the drill is brought down against it. This holds the part in position while it is

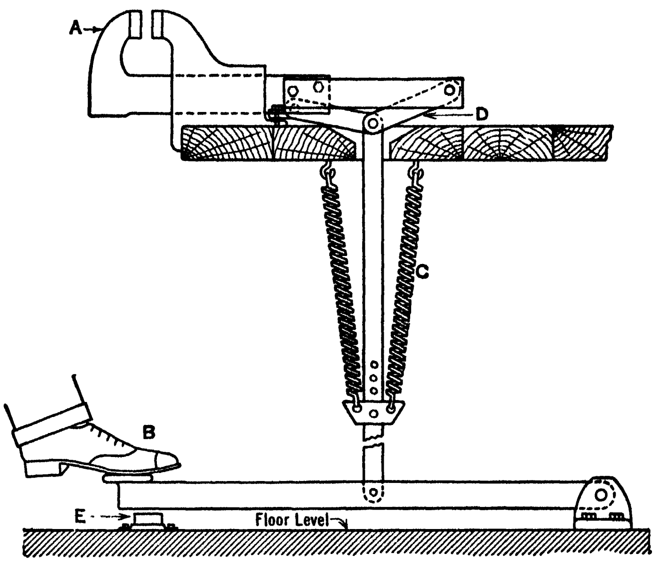


FIG. 93. Foot-operated bench vise.

being burred, and, when the burring is completed and the drill is raised, the burred plate drops out of the jig by gravity into the top of the disposal chute. It was economical to equip the drill press as described above because of the large quantity of burring to be done.

In the bolt and washer assembly (see Fig. 63) it was necessary to lift the finished assemblies out of the fixture and move them a few inches to one side before releasing them into the chute. A still better arrangement would have been to have the assemblies drop through the fixture by moving some sort of a trip on the bottom of the fixture which could have been actuated by a foot pedal. This, however, would have added to the cost of the fixture and was not justified in the factory where this fixture was used.

7. THE HANDS SHOULD BE RELIEVED OF ALL WORK THAT CAN BE DONE MORE ADVANTAGEOUSLY BY THE FEET. POWER-OPERATED TOOLS AND EQUIPMENT SHOULD BE USED WHEREVER ECONOMICAL. A VISE, JIG, OR FIXTURE SHOULD BE USED TO HOLD THE WORK WHEREVER POSSIBLE, THUS RELEASING THE HANDS FOR PRODUCTIVE WORK.

From an observation of the tools and fixtures usually found in the factory, one is convinced that most tool designers do not give much thought to the principles of motion economy when they design them. In most cases the fixtures are made for hand operation only, whereas foot-operated ones would permit the operator to have both hands free to perform other motions.

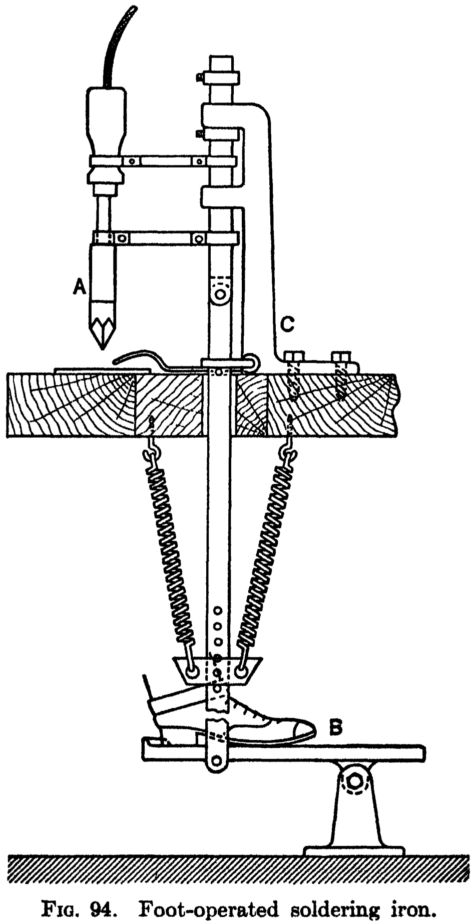


FIG. 94. Foot-operated soldering iron.

Foot-Operated Tools and Fixtures. Figure 93 shows an ordinary bench vise converted into a foot-operated one. Depressing the foot pedal *B* opens the vise jaw *A*, and then the piece to be held is placed in the vise and the pedal is released. The heavy coil springs *C* close the vise, and the toggle joint *D* holds the vise in the closed position while the operation is being performed on the piece. One end of the

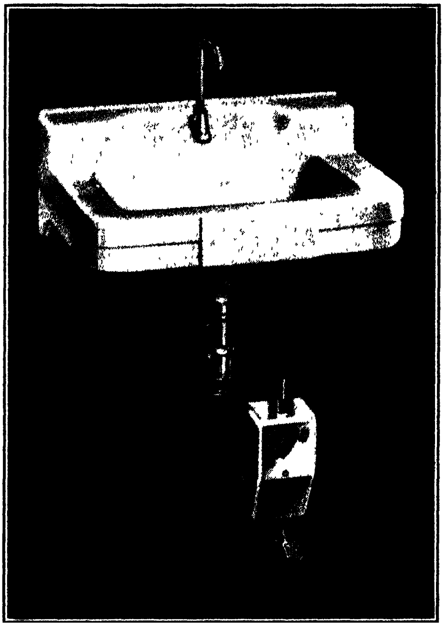
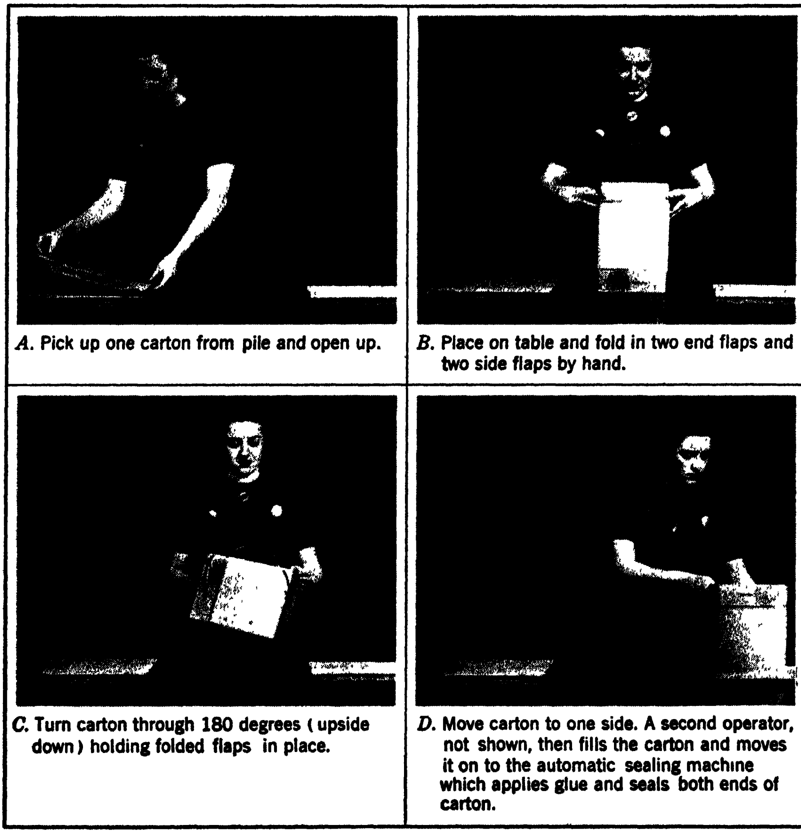


FIG. 95. Lavatory equipped with pedal valve permits free use of hands.

toggle joint is linked to the stationary vise jaw, and the other end is connected to an extension of the movable jaw. Where greater gripping power is needed, a special vise may be built with a compressed-air-operated piston to actuate the vise jaws, the air being controlled by a foot-operated valve.

Hand tools can often be attached to or incorporated with a simple foot press or a modified arbor press in such a way that the tool is manipulated entirely by the foot. The electric soldering iron *A* in Fig. 94 is raised and lowered by the foot pedal *B*. After the soldered joint is made and as the iron is raised, valve *C* on the compressed air line opens and a stream of air cools the soldered joint. One company saved 50 per cent in time on the operation of soldering a wire to the end of a flat metal electric static shield by the use of this foot-operated soldering iron.

All modern hospitals now have the lavatories equipped with pedal valves which permit free use of both hands and also prevent their contamination. (See Fig. 95.)



A. Pick up one carton from pile and open up.

B. Place on table and fold in two end flaps and two side flaps by hand.

C. Turn carton through 180 degrees (upside down) holding folded flaps in place.

D. Move carton to one side. A second operator, not shown, then fills the carton and moves it on to the automatic sealing machine which applies glue and seals both ends of carton.

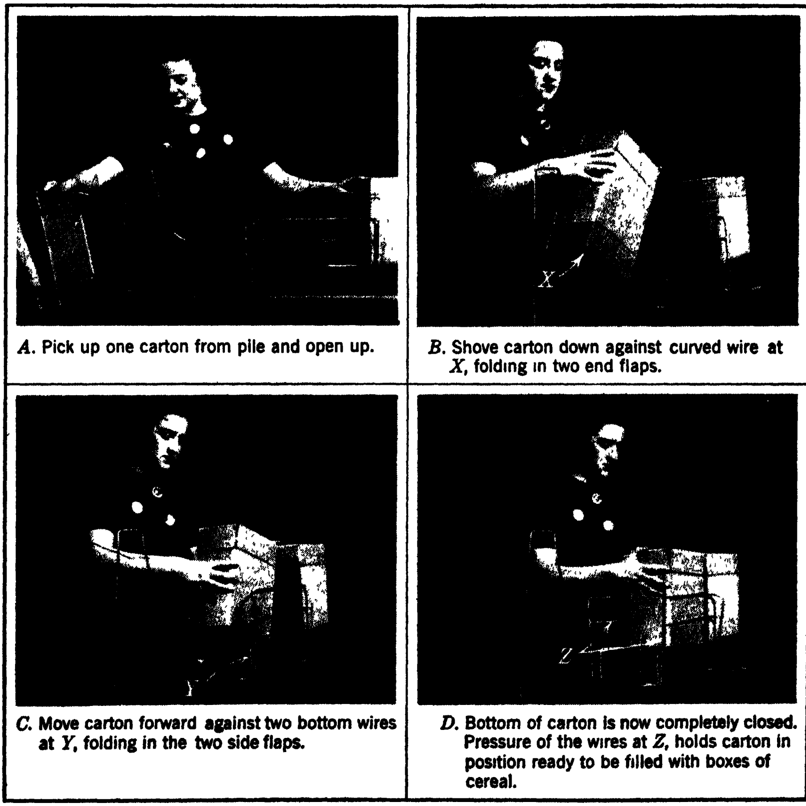
FIG. 96. Opening shipping cartons—old method.

Opening a Shipping Carton. The operation shown in Fig. 96 consists of opening up a flat shipping carton and folding over the bottom flaps preparatory to filling it with boxes of breakfast cereal in the packing room of the cereal factory. Cartons are delivered to the packing table and are stacked horizontally as shown in Fig. 96*A*.

Improved Method. This operation is the same as the one described above. However, the cartons are stacked on the table vertically (see

Fig. 97*A*) instead of horizontally. A simple fixture, designed by E. H. Hollen, is made of heavy wire and is used to aid the operator in folding in the two end flaps and the two side flaps.

Since the time required to open up the carton and fold in bottom flaps is so short using this improved method, the same operator who



A. Pick up one carton from pile and open up.

B. Shove carton down against curved wire at *X*, folding in two end flaps.

C. Move carton forward against two bottom wires at *Y*, folding in the two side flaps.

D. Bottom of carton is now completely closed. Pressure of the wires at *Z*, holds carton in position ready to be filled with boxes of cereal.

FIG. 97. Opening shipping cartons—improved method. Output was increased 112 per cent. Also as a result of this study the carton was redesigned saving over $20,000 per year in carton cost.

does this also fills the carton. Therefore the carton is filled with boxes of cereal in position *D*, Fig. 97. The carton is then moved on to the automatic sealing machine which applies glue and seals both ends of the carton. Notice that the fixture contains no moving parts, and it was made from twenty feet of No. 9 gauge wire and a piece of board at a total cost of a few dollars. Using this fixture, the operator can open cartons in less than half the time required when using the original method. The actual increase in output was 112 per cent. The fixture saves many hand motions in opening cartons.

Harvesting and Preparing Asparagus for Market. Studies[22] of methods of doing certain tasks on farms show great differences in the time used. For example, one farmer can harvest and prepare for market five times as many carrots per day as another farmer in the same neighborhood. Records show that the total amount of labor used per acre on such crops as carrots and asparagus varies from 350 to 500 man-hours. Some crops require as much as 1000 man-hours of labor per acre. Harvest labor on asparagus, for example, is about 75 per cent of the total cost of the crop.

After the asparagus has been picked the tips have to be sorted into bunches and tied. Then the ends are trimmed off, and the bunches are packed in crates for shipment to market. Three different methods of trimming asparagus are described here.

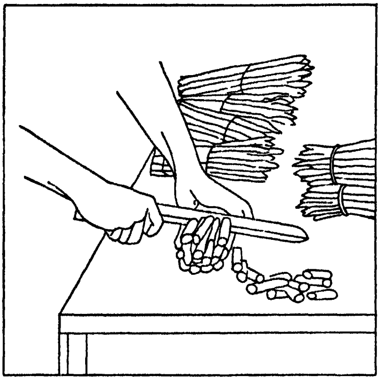


Fig. 98. Method A. Usual method of trimming asparagus.

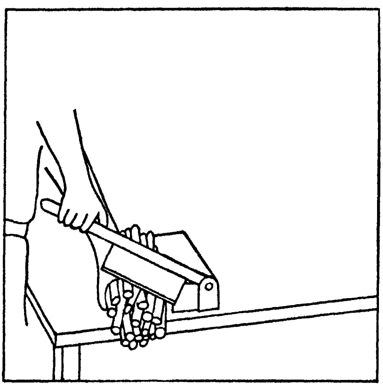


Fig. 99. Method B. One stroke of special knife trims asparagus.

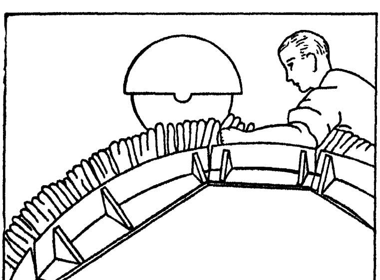


Fig. 100. Method C. Asparagus is placed on outer edge of turntable and is moved past rotating motor-driven saw which trims asparagus.

Method A. The usual method of trimming asparagus is to use a large butcher knife to cut off the ends on a table. Several strokes of the knife are required for each bunch of asparagus. Also, the ends accumulate on the table and have to be removed at intervals. (See Fig. 98.)

Method B. A better method than the one described above is shown in Fig. 99. The bunch of asparagus to be trimmed is placed against a block with the ends of the asparagus projecting beyond the end of the table. A special homemade knife hinged at the back is drawn down, cutting off the ends of the asparagus at one stroke. The ends fall into a basket on the floor.

Method C. A still better method of trimming asparagus which can be devised is profitable for those farmers who raise a considerable quantity of asparagus for market. A simple homemade turntable is constructed as shown in Fig. 100. A band or hoop is placed on top of and around the turntable at a distance from the outside circumference equal to the length of the trimmed asparagus. Then, as the asparagus is sorted, bunched, and banded, it is placed on the edge of the turntable with the butts out. When the table is full it is rotated so that the asparagus comes against a rapidly rotating motor-driven circular saw which trims the butt ends of the asparagus. The operator holds the bunches of asparagus in position as they are fed past the saw. Later the trimmed bunches of asparagus are removed from the turntable by the packer who places them in crates for shipment.

Results. Methods B and C are both superior to method A, and the method to be used depends somewhat upon the quantity of asparagus to be marketed per season. Although we have described the three different methods of trimming only, there are also similar shortcuts that may be used in sorting, bunching, and crating asparagus. The combined savings may be summarized as follows:

Method A—65 minutes per crate of 24 bunches
Method B—38 minutes per crate of 24 bunches
Method C—26 minutes per crate of 24 bunches

This means that a farmer using method C can get 150 per cent more work done per day than if he used method A. In other words, one man using the best method can do the work of two and a half men using the poorest method.

8. MATERIALS AND TOOLS SHOULD BE LOCATED TO PERMIT THE BEST SEQUENCE OF MOTIONS. RHYTHM IS ESSENTIAL TO A SMOOTH EASY WORK PATTERN.

The material required at the beginning of a cycle should be placed next to the point of release of the finished piece in the preceding cycle. In the assembly of the bolt and washers (see Fig. 63), the rubber washers were in bins located next to the chute into which the assemblies were disposed as the last motion of the previous cycle. This arrangement permitted the use of the two hands to best advantage at the beginning of the new cycle.

The position of the motion in the cycle may affect the time for its performance. For example, the time for the motion transport empty is likely to be longer when it is followed by the motion select than when it is followed by a well-defined motion such as a grasp of a pre-positioned part. The reason for this is that the mind begins to select during the transport empty. When the motion transport loaded is followed by a position motion it is slowed down by the mental preparation for the position. The time for the motion grasp is affected by the hand velocity preceding the grasp. A satisfactory sequence of motions in one kind of work may aid in determining the proper sequence in other types of work.

Rhythm is essential to the smooth and automatic performance of an operation and the work should be arranged to permit an easy and natural rhythm wherever possible.

Rhythm may be interpreted in two different ways. Some people think of rhythm as a regular sequence of uniform motions; others understand it to mean a regular sequence of motions with at least one accented point in the cycle. Rhythm in either sense is desirable.

It seems that most people on repetitive work like to have the operation so arranged that they can pass from one movement to another in a smooth easy manner with an opportunity to introduce rhythmic beats as they proceed with the job. For example, every punch press operator, feeding the press by hand, tends to feed the sheet of material forward with a sudden thrust which constitutes an accented point in the cycle. On fast press operations the operator's every move is attuned to the movement of the machine. In a similar manner on jobs that are not machine-paced there is an opportunity for the worker to develop rhythm if the job layout permits it.

Increased output, less fatigue, and greater satisfaction to the worker are likely to result when the work sequence permits the development of rhythm.

9. SMOOTH CONTINUOUS MOTIONS OF THE HANDS ARE PREFERABLE TO ZIGZAG MOTIONS OR STRAIGHT-LINE MOTIONS INVOLVING SUDDEN AND SHARP CHANGES IN DIRECTION.

The simple operation of moving a pencil back and forth across a sheet of paper consists of two phases, the movement and the stop and change direction. Studies[23] show that 75 to 85 per cent of the time to make a complete back and forth movement is used in actually moving the hand, and the remaining 15 to 25 per cent of the time is used in changing direction of the hand; that is, during the 15 to 25 per cent of the time the hand and the pencil are motionless. Further studies show that continuous curved motions are preferable to straight-line motions involving sudden and sharp changes in direction. The folding of rectangular sheets of paper used in packing X-ray films illustrates this idea very well.

The sheets vary in size from 3 inches by 5 inches to 12 inches by 15 inches folded. Although several million of these sheets of paper are folded per year, it was found to be more economical to fold them by hand than by machine because of the many different sizes used.

Old Method of Folding Paper. The worker, holding a smooth piece of bone in the palm of her right hand, grasped the lower right-hand corner *A* of the sheet of paper to be folded. (See Fig. 101.) She folded this corner of the sheet over to point *B*, where the two hands matched or lined up the two corners of the sheet of paper. Then, swinging the right hand away from the body and using the bone as a creasing tool, she struck the folded sheet of paper about mid-point at *C*, creasing the fold from *C* to *D*. At *D* she stopped and changed direction abruptly, doubled back, creasing the entire length of the fold from *D* to *E*. At *E* the hand again changed direction and swung around to *F*, where the end of the bone was inserted under the edge of the creased sheet to assist the left hand in disposing of it on the pile of folded sheets at *G*.

Improved Method. In the improved method the worker grasps the lower right-hand corner *A* of the sheet of paper to be folded. (See Fig. 102.) She folds this end of the sheet over to point *B*, where the two hands match or line up the two corners of the sheet of paper, as in the old method. She then moves the right hand through a smooth "S" curve, the bone striking the paper and beginning to crease at *X* and ending at *Y*. Thus the entire crease is completed with the single stroke of the bone. The hand then swings around in a curved motion from *Y* to *Z*, where, as in the old method, the end of the bone is inserted under the creased sheet to assist the left hand in disposing of it on the pile of folded sheets at *G*.

Results. By using the improved method described above only one creasing motion was required to complete the cycle instead of the two (one short and one long one) in the old method. Moreover, in the improved method two curved motions of the hand were used instead

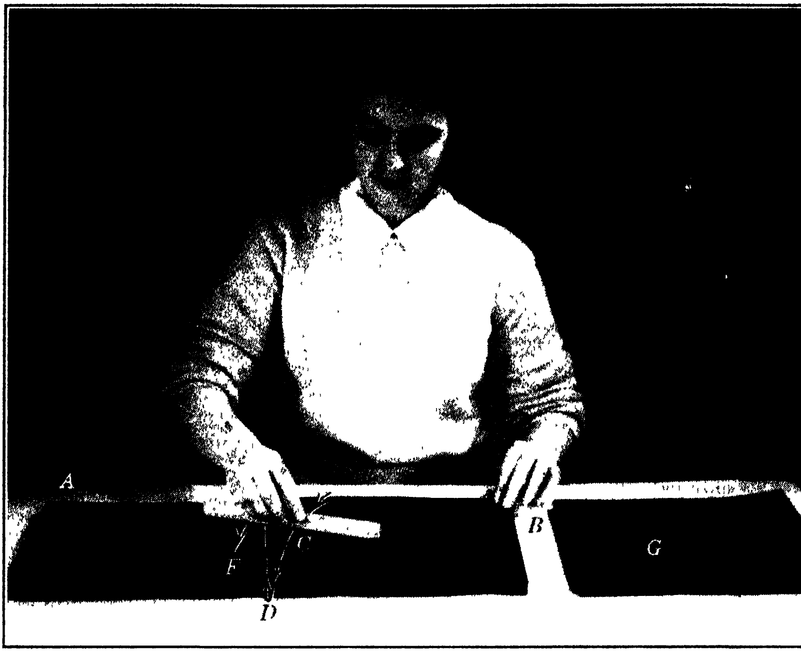


FIG. 101. Path of hand in creasing folded sheet of paper—old method. There is an abrupt change in direction at *D* and also at *E*. Two strokes of the bone are used to crease the fold.

of the two complete change directions and the one 90-degree change direction of the old method. The improved method of creasing the fold, plus some other changes in the operation, reduced the total folding and creasing time from 3.5 seconds to 2.0 seconds per sheet, enabling the operator to increase her output 43 per cent.

10. THE HEIGHT OF THE WORK PLACE AND THE CHAIR SHOULD PREFERABLY BE ARRANGED TO PERMIT ALTERNATE SITTING AND STANDING AT WORK. ADEQUATE LIGHTING SHOULD BE PROVIDED, AND THE WORKER SHOULD BE MADE AS COMFORTABLE AS POSSIBLE.

The worker should be permitted to vary his position by either sitting or standing, as he prefers. Such an arrangement enables the individual to rest certain sets of muscles, and a change of position always tends to improve the circulation. Either sitting or standing for long periods of time produces more fatigue than alternately sitting or standing at will. In many kinds of work provision can easily

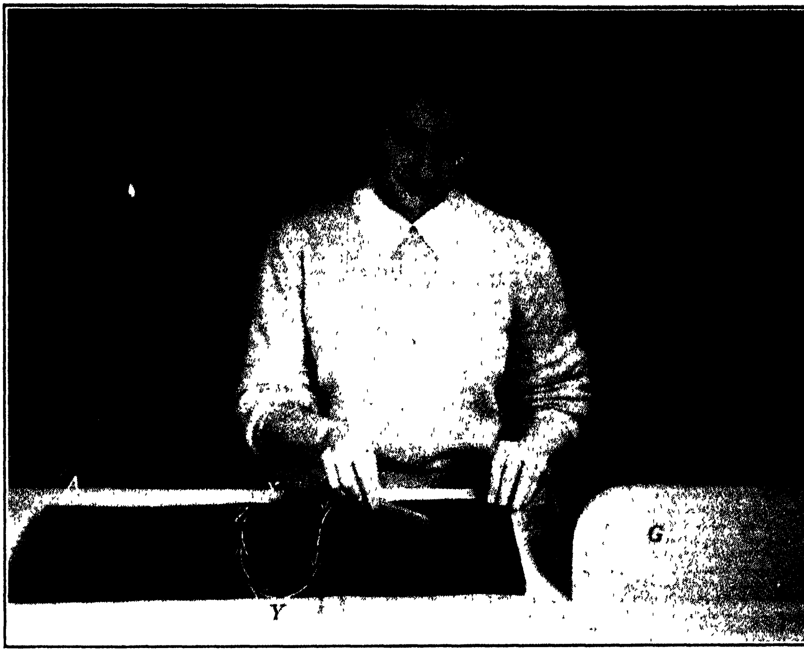


FIG. 102. Path of hand in creasing folded sheet of paper—improved method. The hand makes a smooth "S" curve, creasing the fold with one stroke of the bone. Output was increased 43 per cent.

be made for this sitting-standing combination. So important is this from the point of view of health that some states have laws requiring that the work place be arranged to permit either sitting or standing. The following is such a regulation:

Seats and Work Tables. As far as, and to whatever extent, in the judgment of the commission, the nature of the work permits, the following provisions shall be effective: Seats shall be provided at work tables or machines for each and every woman or minor employed, and such seats shall be capable of such adjustment and shall be kept so adjusted to the work tables or machines that the position of the worker relative to the work shall be substantially the same whether seated or standing. Work tables, including cutting and canning tables and sorting belts, shall be of such dimensions and design that there are no physical impediments to efficient work in either a sitting or a standing position, and individually adjustable foot rests shall be provided. New installations are to be approved by the commission. (California Industrial Welfare Commission.)

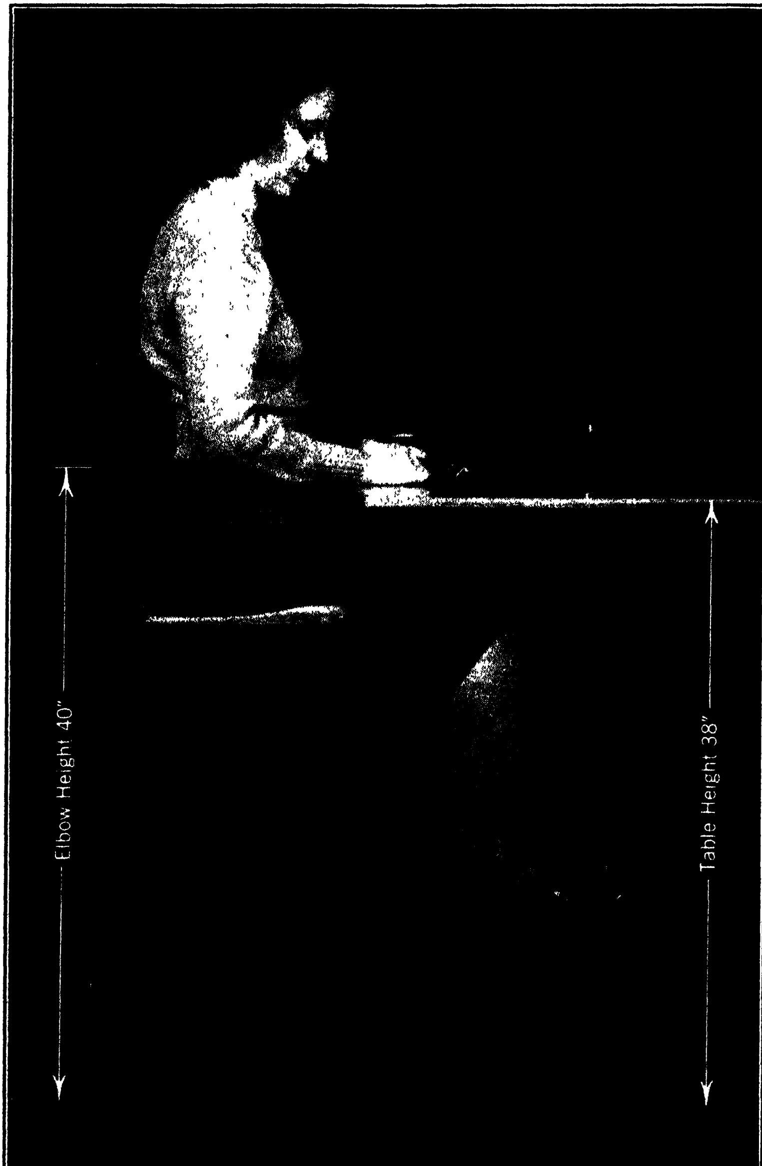


FIG. 103. For greatest comfort the work place and the chair should be so arranged that alternate sitting and standing at work are easily possible. For most kinds of work the top of the work bench should be 1 to 3 inches lower than the worker's elbow.

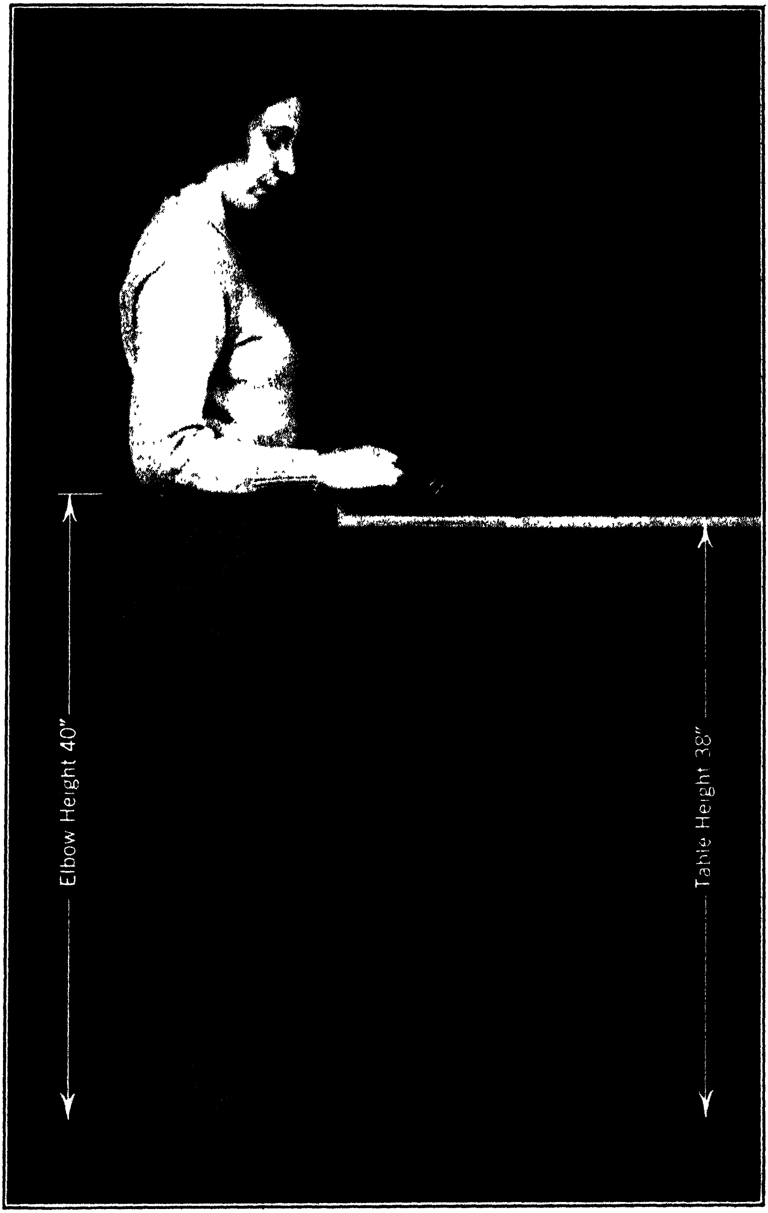


FIG. 104. It is possible to adjust chair and table heights to permit the elbow and the hand to maintain the same position relative to the work place whether sitting or standing.

Although it would be preferable to have the height of the work place and the chair fit the particular operator who has to use it, this cannot always be done. It may be necessary in many cases to make the benches of such height that they will be most suitable for the average worker.

The height of the worker's elbow above the standing surface is commonly taken as the starting place for determining the proper height of the work place and the chair. The Industrial Welfare Commission of California has found that the height of the average worker's elbow above the standing surface is 40 inches for women (for men this would be 3 or 4 inches higher) and that a large percentage of the workers will not vary 1½ inches from this measurement.

With 40 inches taken as the average elbow height of the female workers (the range being from 34 to 45 inches) and with the hand allowed to work 1 to 3 inches lower than the elbow, the average height of the working surface should be 37 to 39 inches. The chair should be 25 to 31 inches high, depending upon the proportions of the individual. With such table and chair heights the worker is permitted either to stand or to sit at work, with the elbow and the hand maintained at the same position relative to the work place.

Space between Top of Seat and Under Surface of Bench Top. The work place should be constructed to permit plenty of leg room for the worker. Braces, shafts, and other obstructions under the work place often interfere with the natural position of the worker and so cause poor posture and discomfort. Such obstructions should not be permitted. The work bench should preferably be not over 2 inches thick and there should be 6 to 10 inches of space between the top of the chair seat and the under surface of the bench.

A bench 37 inches high will be too high for the short person but this can be corrected by placing a rack of the proper height on the floor for the worker to stand on. For the tall worker a small rack or platform can sometimes be placed on top of the bench to raise the height of the work place. Where this cannot be done the tall worker is handicapped while standing at work but, of course, this is not necessarily true when she is seated.

In some kinds of work it is necessary to have equipment or material containers mounted on top of the work bench. This has the effect of adding to the "thickness" of the bench. A work place more than 5 inches thick cannot ordinarily provide a comfortable sitting-standing position for the worker. The Industrial Welfare Commission of California was confronted with the problem of specifying a standard work place for their fruit and vegetable canning industries where a pan 3 inches high was placed on top of the work table. The work place which their studies led them to recommend is shown in Fig. 105. Considering the average elbow height as 40 inches above the floor and allowing for the hands to work at a position 1 inch lower than the elbow, and allowing furthermore 3 inches for the height of the ordinary fruit pan, we see that the top of the work bench should be about 36 inches above the standing surface in this case.[21]

As Fig. 105 shows, a foot rest is attached to the bench, and a chair that can be adjusted for height is specified. This arrangement permits

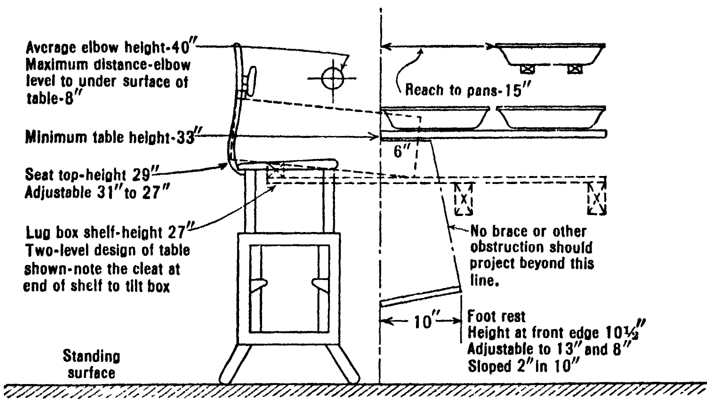


FIG. 105. Cutting table dimensions. Table designed by the Industrial Welfare Commission of California.

the worker to sit or stand while working and still maintain the same relative position of the elbow.

The minimum table height for a comfortable position is determined by another limiting factor. A distance of not more than 8 inches between the elbow height and the under side of the table can be permitted if a restful position is to be maintained. A distance much greater than this interferes with the natural position of the knees. Using this distance of 8 inches as the limiting factor and allowing 1 inch for the thickness of the bench, we find the minimum height of the top of the bench to be 33 inches.

Arm Rest. Occasionally the work is of such a nature that it is desirable to have arm rests provided at the work place. Arm rests are most effective on work that requires little movement of the forearms, with the hands working at approximately the same position, often at some distance from the body, for long periods of time. Light drilling, tapping, and reaming operations are frequently of this type. (See Fig. 92.) On such work it is restful to have padded, fiber, or wood arm rests placed on top of, or at the edge of, the work bench in a position to support the forearm. The arm rests need not interfere with the necessary working movements of the arms or hands.

Foot Rest. When high chairs are used a foot rest should be provided. This foot rest should preferably be attached to the floor or the bench but, even though less desirable, it may be fastened to the chair. The foot rest should be of ample width and depth to permit the entire bottoms of both feet to rest on it and allow for some movement. This usually requires a depth of twelve inches or more. The absence of a foot rest forces the worker to hook the heel of his shoe over the rung of the chair, or else let the feet dangle in the air, both of which positions are uncomfortable.

Chair. The following statements are included here to explain clearly just what is meant by good posture.

Good standing posture is one in which the different segments of the body—head, neck, chest, and abdomen—are balanced vertically one upon the other so that the weight is borne mainly by the bony framework and a minimum of effort and strain is placed upon the muscles and ligaments. In this posture under normal conditions the organic functions—respiration, circulation, digestion, etc.—are performed with least mechanical obstruction and with greatest efficiency.

Good sitting posture. The thing which should always be insisted upon in the use of the body in any way is that the body should be kept straight from the hips to the neck and should not be allowed to flex or bend at the waist line. Any position which allows this lowers the vitality of the individual, leads to strain of the back, and naturally lessens the efficiency of the worker.

The most frequent violation of the good sitting posture occurs when the individual slumps in his chair or assumes a sideways slouch, both of which are fatiguing and impair the health.

When the worker is seated, the chair should aid and not hinder him in maintaining good posture. A good chair should have the following features:

1. The chair should be adjustable in height so that it may be readily fitted to the particular individual who is to use it. Non-adjustable chairs may be obtained in different sizes and issued to the workers according to their height. Such chairs are generally considered not so practical as the adjustable type. The chair should be

adjusted to a height that permits the worker to sit comfortably with both feet resting on the floor or the foot rest.

2. The chair should be rigidly built, preferably of steel frame with wood seat and back. It is important that a wood or fiber seat and back be provided since wood is more comfortable than metal. The edges of the seat and back should be rounded so that no sharp edges can cause discomfort and impede the circulation. Swivel chairs and chairs with casters are not recommended for factory work unless absolutely necessary. The easy movement of such chairs tends to cause unsteadiness while being used. This is particularly noticeable if the work requires some muscular effort. The chair may be provided with smooth metal "sliders" which permit the operator to shove it back out of the way without disturbing his work when he wishes to work standing.

3. The chair seat should be form fitting. A saddle seat permits the weight of the body to be evenly distributed and so promotes comfort. The front edges of the seat should be well rounded. For normal work the front edge of the chair should be approximately 1 inch higher than the back edge. When the person works leaning forward, the seat of the chair should be approximately flat. The seat should be of sufficient width to accommodate the body—16 to 17 inches is none too wide. However, the seat should not be over 13 or 14 inches in depth. The shallow seat permits the body to bend at the hip when leaning forward, whereas a deep seat tends to prevent this and to cause the body to bend at the waist line, putting a curve in the spine and disturbing the posture. The deep seat also tends to cut off the circulation of blood through the underside of the thighs near the knee.

4. A back rest should be provided to support the lower part of the spine. To do this the chair should not have a horizontal cross slat or bar lower than 6 inches above the seat. The body should sit well back on the seat so that the back rest can support the small of the back. The lower edge of the back rest should be 6 to 7 inches above the seat, depending upon the individual. The back rest may be 3 to 4 inches wide and 10 to 12 inches broad. The back rest may be small and yet give satisfactory support. It can be so designed that it will not interfere with the movements of the individual's arms while working. It is important that the back rest be adjustable so that it may be fitted to the worker's body. When the worker leans forward while working, the chair back is of no use. However, the worker can use

it while resting, and it serves a very valuable purpose in being there for momentary relaxation.

Provisions should be made for adequate conditions for seeing. Good illumination is the first requirement for satisfactory visual perception.

Visual perception may take place under such widely varying conditions that adequate provisions for seeing in one kind of work are not always most suitable for another. For example, the provisions for seeing on such very fine work as watch making would be different from those recommended for inspecting cloth or tin plate for surface defects. However, if adequate illumination is provided, seeing is made easier in every case although this may not be the complete solution to the problem. By adequate illumination is meant (1) light of sufficient intensity for the particular task, (2) light of the proper color and without glare, and (3) light coming from the right direction.

It should be borne in mind that the visibility of an object is determined by the following variables: [25] brightness of the object, its contrast with its background, the size of the object, the time available for seeing, the distance of the object from the eye, and other factors such as distractions, fatigue, reaction time, and glare. These variables are so related that a deficiency in one may be compensated by an augmentation of one or more of the others, provided all factors are above certain limiting values.[26]

The intensity of illumination falling on an object and the reflection factor of the object, or that of its background, should be considered together in providing adequate illumination. For example, the pages of a telephone directory are dark in color and the contrast between the printed letter and the page is not so great as that of printing on good book paper. The paper of the directory reflects only 57 per cent of the incident light, whereas the book paper reflects about 80 per cent. Two to three times as much light is required to read a telephone directory as is required to read with equal facility the same critical details of names and numbers printed with blacker ink on white book paper. The task of sewing on very dark cloth is difficult even under the best conditions of lighting. For example, dark cloth of 4 per cent reflection factor would require 200 foot-candles to produce the same brightness as 10 foot-candles on white cloth. A knowledge of this point suggests the use of greater intensity of illumination or lighter background for work with objects with a low reflection factor or for very fine work.

Time for Seeing. Seeing can take place only after the eyes come to a stop and are focused on the object. In the process of reading a printed page, for example, the eyes do not make a continuous movement along the line, but rather move in a series of jumps or leaps. The eyes begin at the left-hand end of the printed line and progress from one fixation to the next along the line to the right-hand end of the line. The eyes then move back to the left-hand end of the next line with a single smooth sweep, during which movement the eyes see nothing. The movements of the two eyes are coordinated, and one cannot move voluntarily without the other. The number of movements and pauses which the eyes make in reading a line of print will vary, usually from three to seven, depending upon the length of the line, the visibility of the print, the skill of the reader, and other factors.

Fixation pauses require on the average 0.17 second.[27] Tests show that the shortest interval of time possible for a person to see an object to gain an adequate visual impression varies from 0.07 second to 0.30 second, the average being 0.17 second. The intensity of illumination affects the time required for seeing.

Inspection Work. The provision for adequate conditions for seeing is of paramount importance in inspection work. Such work is usually highly repetitive, exacting in nature, and predominantly mental in its demands. Constant attention and almost continuous use of the eyes are required in many kinds of inspection work. Perception of a defect must be followed by instant action on the part of the inspector to reject the defective part. Some individuals are able to see smaller differences than others and to perceive the same differences with greater speed. Since reaction time and visual acuity are important elements in most inspection work, it is essential that persons be selected by means of suitable tests before being employed for such work.

Check Sheet

A Check Sheet for Motion Economy and Fatigue Reduction

Ask the following questions about every job. They may suggest better and easier work methods:

Yes No

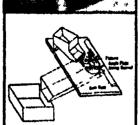
1. Are the motions balanced?

2. Are the tools and materials within easy reach?

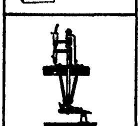
3. Is there a definite and fixed place for all tools and materials?

4. Does gravity bring the materials to the point of use?

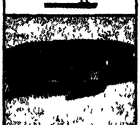
5. Are tools and materials pre-positioned?



6. Are drop deliveries used?



7. Are devices used to free the hands from holding?



8. Does the work sequence permit rhythmic motions?

9. Are the motions smooth and continuous?

10. Have a comfortable work place and chair been provided? Is there adequate light?

CHAPTER 10

PUTTING THE NEW METHOD INTO EFFECT

Whatever your position in the organization you have the opportunity of applying the methods and techniques presented in this book. If you are employed on manual work, you may improve your own job. If you are a supervisor, you should show those who work for you how to work more effectively. Some companies have suggestion systems, other companies have labor-management committees to promote the development of ways of increasing production. Today there is every reason for trying to improve work methods. Everyone is interested in greater output.

Get Help. If you are working on the development of a better method than the one now being used do not hesitate to ask for help from your associates, from your boss, or from the people who work for you. These people can often make valuable suggestions, or point out difficulties that you may encounter, or perhaps ask questions that may give you a lead. By all means discuss the proposed method with those people who are in a position to help you most.

Try Out Your Proposed Method. When you have an improvement that seems like a good one, try it out. If a jig, fixture, holding device, special tool, or other gadget is needed, make one. Even a temporary one made of wood, fiber, or cardboard may be sufficient to show you whether your idea will work. Moreover a preliminary trial of the improved method aids in estimating the time that will be saved.

Some companies have shops equipped with simple power tools and hand tools just for those who want to build fixtures or apparatus to try out a new idea. Some people become so enthusiastic about such projects that they build the needed fixture in the basement shop at home on their own time.

Many organizations have industrial engineers whose job it is to carry through suggestions and put them into effect. If you are not in a position to do all the development work on your idea, you may be able to get others to do this for you.

Of course once it has been demonstrated that the new method is practical and that it can be profitably used, the company will proceed to have permanent tools or fixtures built for use on the production line.

Get Approval. After the method has been carried through to the point that you feel confident that it will work and that it will be a profitable investment to the company, it is necessary to get approval to put it into effect. This is largely a selling job, and because it is all the tactics of a salesman should be employed. It is necessary to prove the need for the new method, to show the savings in time that will be effected, the reduction in cost that will result, the effect on the quality of the product, the absence of fire and accident hazards, and the floor space requirements. In most cases the new method will require less effort on the part of the operator, which fact should be emphasized.

Make It Work. Even though the proposed method is approved and the necessary changes are made, there is still the big task of actually putting the improved method into effect. The desire to keep things as they are is always present, and a selling job is necessary in order to make changes successfully. Because of this fact it is a good plan to start early to get the cooperation of all persons likely to be affected by the proposed change. There is every reason for taking them into your confidence, explaining to them what is being undertaken, inviting them to contribute their ideas and suggestions, and getting them to assist in trying out the new methods as they are being developed. When this procedure is followed the new development is partially theirs, and consequently they will want to see it work successfully. Then after the new method is in operation, see to it that all those who helped develop it receive full credit for their efforts.

It is frequently necessary to do some "maintenance work" on improved methods, particularly while the operators are learning the new methods. It is easy to revert to the old way, and frequent checkups are desirable.

As was pointed out in the beginning of this book, the day has passed when the top executives and engineers in the front office were supposed to have all the good ideas and a monopoly on the "know how" to put their ideas into effect. Today the assistance and cooperation of every person in the organization are needed. There is every reason why the men and women close to the job should be consulted on matters that affect their work. Indeed the ingenuity, ability, and ideas of foremen, supervisors, and workers are among the greatest untapped resources of this country.

PROBLEMS

Problem 1. One solution to this problem consists of keeping the garden hose on a reel beside the faucet and keeping the hose permanently attached to the faucet. The flow diagram in Fig. 106 and the process chart in Fig. 107 show this. There are savings of three operations, three transports, and a reduction of forty-five feet, or 37 per cent, in distance walked.

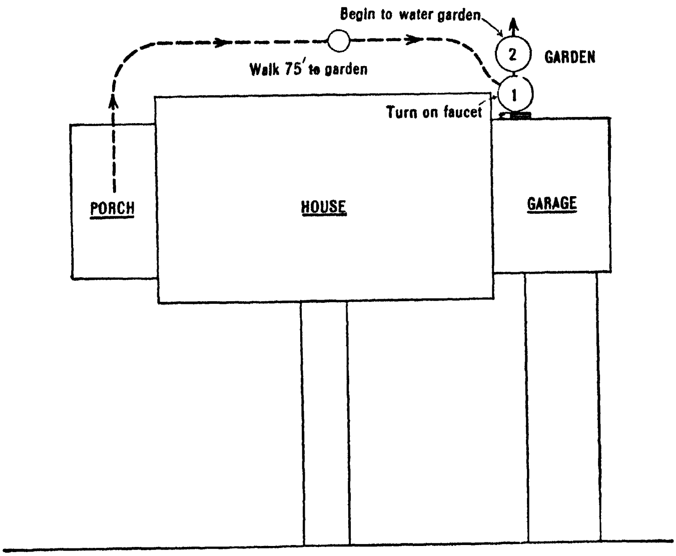


FIG. 106. Flow diagram of watering garden—a better method.

PROCESS CHART OF WATERING GARDEN

Better Method

Travel in Ft.	Symbol	Description	Explanation *
			John Smith has been sitting on porch, decides to water his garden.
75	○	To garden hose	He leaves the porch, walks 75 feet to garden hose which is wound on reel, and is already attached to faucet.
	1	Open faucet	Turning on faucet is an operation.
	2	Water garden	He begins the main operation of watering garden.

* This explanation is included here to aid the reader in understanding the use of process chart symbols. It is not a part of the process chart.

Summary

	Old Method	Better Method	Saved
Number of operations	5	2	3
Number of transportations	4	1	3
Total distance walked in feet	120	75	45

FIG. 107. Process chart of watering garden—a better method.

Problem 2. The chart in Fig. 108 illustrates a better method of toasting three slices of bread. Since there are three slices of bread, each to be toasted on two sides, there are six sides to be toasted. This suggests using each side of the toaster to toast both sides of one slice and one side of another slice. This method requires but 106 seconds instead of 137 seconds, a saving of 31 seconds or 22 per cent in time.

MAN AND MACHINE CHART

Toasting Three Slices of Bread—Better Method

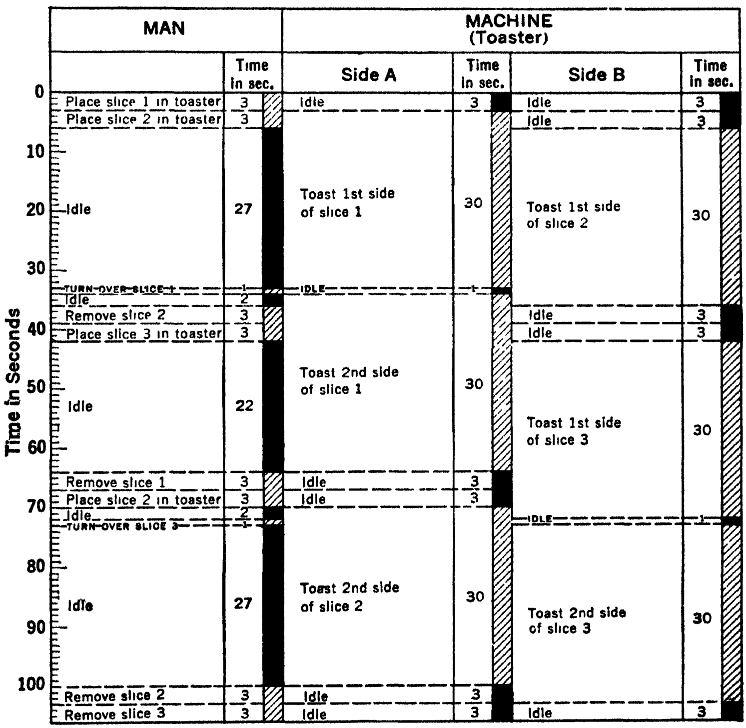


FIG. 108. Man and machine chart for toasting three slices of bread in 106 seconds.

Problem 3. Two power-driven socket wrenches are mounted under the table with the wrench sockets flush with the table top, as shown in Fig. 109. The operator grasps a nut with each hand and slides them into position in the sockets. Then the casting is picked up with the left hand and the "U" bolt with the right hand. The threaded ends of the bolt are assembled through the holes in the casting and into the rotating nuts. The nuts are run onto the ends of the bolt and the completed assembly disposed into the chute at the front edge of the table. This improved method increased output 117 per cent.[28]

RIGHT- AND LEFT-HAND CHART

Assemble Rope Clips—Improved Method

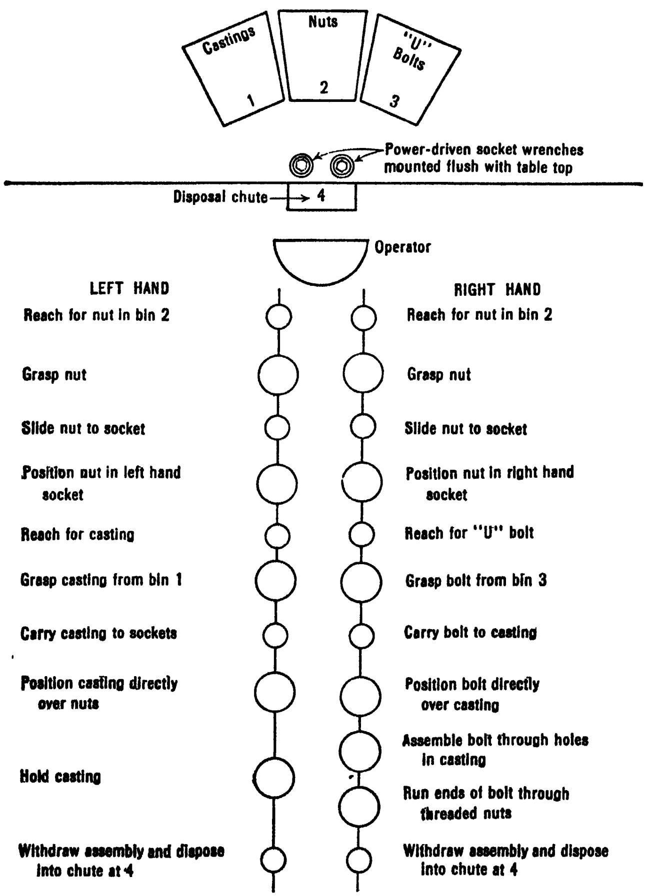


FIG. 109. Right- and left-hand chart of assembling rope clips—a better method.

Problem 4. The motions used by the two hands in opening a bottle are shown in Fig. 110. Sketches have been included to illustrate the motion sequence better.

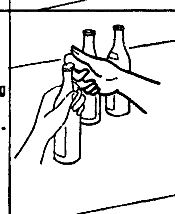
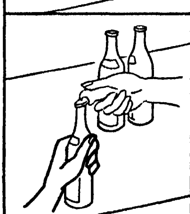
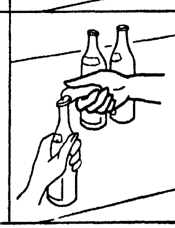
Motions of the Left Hand		Symbol		Motions of the Right Hand	
	TRANSPORT EMPTY Reach for bottle.	TE	H	HOLD Hold bottle opener in right hand (while left hand reaches for bottle).	
	GRASP Close thumb, fingers, and palm of hand around bottle. (Since the bottle is a large object and separated from the other bottles there is no SELECT.)	G	TL	TRANSPORT LOADED Carry opener toward bottle.	
	TRANSPORT LOADED Carry bottle to front edge of table. (If the bottle had been placed on a specific spot or place on the table, then there would have been a POSITION)	TL	P	POSITION Place opener on cap of bottle preparatory to opening bottle. (Most people would have opener partly positioned on cap before bottle came to a still position on edge of table.)	
	HOLD Hold bottle (while right hand opens bottle.)	H	U	USE Use opener— remove cap from bottle.	

FIG. 110. Motions used by the two hands in opening a bottle with an ordinary bottle opener.

Problem 5. The time shown below to fill the pin board is the average time of 100 people who filled the board five times for each of the three conditions. These people had no previous practice with the pin board, and they worked under conditions *A*, *B*, and *C* in the order named.

Condition	Distance of Blocks Apart in Inches	Time in Seconds to Fill Board with 30 Pins
A	0	22
B	12	26
C	24	30

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4. From *Manual for Control Officers,* Volume III, *Work Simplification,* written by Col. John A. Aldridge, Headquarters Army Service Forces, War Department, Washington, D. C.

5. Illustration Courtesy of James D. Shevlin.

6. Program under the direction of Col. John A. Aldridge.

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11. For a full discussion of twenty-two principles of motion economy, see *Motion and Time Study,* Second Edition, Chapters 12, 13, and 14, by Ralph M. Barnes.

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14. Dimensions for Fig. 73*A* taken from "A Study of Workplace Layout," a thesis by M. L. Asa, University of Iowa, 1942.

15. This case developed for use in RCA training course by G. A. Godwin, Industrial Engineer, RCA Victor Division of Radio Corporation of America.

16. "Rhythmic Surgery," by W. H. Lawrence and C. H. Berry, *The American Journal of Surgery,* Vol. XLI, No. 3, pp. 393–398, September, 1938. Figure 77 is used with the permission of *The American Journal of Surgery.*

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18. Tool rack designed by Clarence Hoborn, Richmond Shipyard Number Two, Richmond, California.

19. Illustration and data courtesy of Lt. Col. John A. Aldridge.

20. Improved method developed by James Hardey. For a full description of this job, see *Motion and Time Study,* Second Edition, p. 220, by Ralph M. Barnes.

21. Illustration and data courtesy of Joseph H. Quick, RCA Victor Division of Radio Corporation of America.

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Photographs by Ruth Weller Nelson and F. W. Kent.

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