A STUDY OF THE RELATIVE EFFICIENCY OF A SYMMETRICAL VERSUS A NON SYMMETRICAL HAND MOTION PATH IN THE PERFORMANCE OF SHORT RUN INDUSTRIAL OPERATIONS

BY

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

I. INTRODUCTION

With present wage levels already high, and with organized labor demanding still higher wages for the future, it is necessary for management to secure higher productivity from labor in the future than has been secured in the past. In some cases organized labor has demanded that future wage increases be granted with the understanding that such increases will not be followed by compensating price increases. Wage increases without compensating price increases can be satisfactorily granted only if the wage increases are accompanied by increased labor productivity. At the present time, such increased productivity cannot be obtained by speeding up the operator to an unreasonable pace. Labor will not tolerate such practices. The increased labor productivity necessary to compensate for wage increases must, therefore, be obtained by the use of more efficient production methods. In some cases, increased productivity is secured by the installation of more efficient machinery and equipment. In other cases, particularly with assembly operations, rearrangement of the stock bins, the installation of simple jigs and fixtures, and the revision of work methods to eliminate unnecessary motions and to increase the efficiency of performing the remaining motions may cause considerable increases in labor productivity without unreasonable speed up. This latter method of increasing efficiency is known by various names, some of the more common of which are motion study, methods engineering, and work simplification.

The average person usually visualizes modern production as being performed almost exclusively by large numbers of workers who constantly repeat the same operation for long periods of time. Doctor Ralph M. Barnes, on page 359 of Motion and Time Study (1), points out that such long-run production is not the typical situation even in larger plants. On the other hand, Doctor Barnes states that most operators work on relatively short-run production with frequent work changes. Any method of increasing the productivity of short-run production would, therefore, be applicable to a wide range of industrial effort.

Motion study literature recognizes the fact that, other things being equal, a person tends to perform an operation faster if the work is arranged so that it can be performed by a symmetrical motion path rather than if it is performed by a nonsymmetrical motion path. Small assembly work is usually performed symmetrically by the expedient of arranging the work place so that each hand builds a complete assembly simultaneously with the other hand.

A hand motion path is said to be symmetrical when it meets two requirements. First, at any point in the cycle the right and left hands are equal distances to the right and left respectively of the center line of the body; to fulfill this requirement, components of motion to the right and left of the center line of the body must be performed by the hands moving simultaneously, in opposite directions, and for equal distances. Secondly, at any point in the cycle the right and left hands are equal distances in front of the body; to fulfill this requirement, components of motion toward or away from the body must be performed by the hands moving simultaneously, in the same direction, and for equal distances.

Several years ago, while the author was employed as a motion study engineer by a large automotive accessory manufacturer, he studied some operations which led him to believe that considerably larger time savings could be made by the application of symmetrical motion paths to short-run production, than could be made on long-run production where the worker changed operations infrequently. It appeared that less practice was required to attain a given level of skill if the motion path were symmetrical than if it were nonsymmetrical. Since, as has already been pointed out, short-run production represents a very large proportion of all industrial effort, it appeared profitable to make a study to determine if the application of symmetrical motion paths would actually yield greater savings on short-run production than on long-run production; any methods producing time savings on short-run production would have a wide field of possible applications.

It was the purpose of this study to determine if the impressions mentioned in the preceding paragraph could or could not be verified. An operation was arranged so that it could be performed by either a symmetrical or a nonsymmetrical motion path. Several operators performed short 25-cycle runs of the operation by one motion path and then shifted to the alternate motion path at the end of each 25-cycle run. This procedure was continued until 29 runs by each motion path had been completed by each operator. Such a procedure produced the effect of the operators working on short-run production with frequent changes of operation. All operating times were recorded. A comparison of the time records for the two motion paths gave an index of their relative efficiency. Such comparison did indicate that greater time savings could be expected from the application of symmetrical motion paths to short-run production than by application to long-run production.

II. REVIEW OF THE LITERATURE

Although a large mass of literature has been published on the subject of motion and time study, little of it appears to apply directly to the problem investigated in this study. Frank B. and Lillian M. Gilbreth, consulting industrial engineers, published a set of sixteen rules for motion economy in 1923 (2). Included in this list of rules was one which stated in substance that work can be performed more efficiently by the use of two-handed simultaneous symmetrical motion paths. The Gilbreths' emphasis, however, was upon the fact that, in most cases, if symmetrical motion paths were not used, the hands would perform entirely different motions at the same time, and, as a result, the distribution of the work between the two hands would be unbalanced; one hand would then lose time while it waited for the other to complete its greater work load. With a simultaneous symmetrical motion path, the hands will always be performing identical motions simultaneous with perfect time balance resulting. In this present study it should be noted that by either motion path the hands always performed identical motions simultaneously with a perfectly balanced work load; the only difference was in the symmetrical or nonsymmetrical path followed by the hands in performing their motions.

The above mentioned rule of the Gilbreths is frequently quoted or restated in slightly different words by a large number of writers on motion study subjects. Among the authors who have referred to this Gilbreth rule are Allan H. Mogenson (3), Walter G. Holmes (4), Harold B. Maynard and G. B. Stegemerten (5), and George W. Chance (6). These authors simply state the rule without adding significant comments.

In his Work Methods Manual (7) Doctor Ralph M. Barnes states the Gilbreth rule and in addition comments upon the fact that the symmetrical motion path tends to reduce body twisting, to maintain definite balance between body members, and to eliminate the shock produced by unbalanced movements. Doctor Barnes points out that these tendencies result in reduced fatigue and in reduced time consumption.

Herbert G. Sampter, in Motion Study (8), states the Gilbreths' rule and then proceeds to explain that a person can experience the difference between symmetrical and nonsymmetrical motion by moving the hands in symmetrical and nonsymmetrical paths in front of the body. The experimenter will then be able to observe the body twist and the unbalanced forces produced by the nonsymmetrical motion, as compared to the smooth balanced movements of the symmetrical motion.

Steward M. Lowry, Harold B. Maynard, and G. M. Stegemerten (9) change the wording of the Gilbreths' rule slightly but retain the general meaning. They state that, when symmetrical motion paths are used, rhythm and automaticity develop most naturally. They discuss the fact that, when one hand follows a path dissimilar from the path of the other hand, there is a tendency for the operator to work first with one hand and then with the other. This tendency, of course, results in time losses.

Doctor Barnes has conducted a considerable amount of fundamental research in the field of motion study. Most of the results of his experiments have been reported in various University of Iowa Engineering Bulletins. In University of Iowa Engineering Bulletin 17 (10), Doctor Barnes and Doctor Marvin E. Mundel report the results of certain studies regarding simultaneous symmetrical hand motions which they conducted. They investigated the effect produced on operation time by changing the angle at which the hands moved relative to the body when performing operations by a symmetrical motion path. Mention is made of the fact that time savings can frequently be made by the use of symmetrical motion paths. No direct comparison is made, however, between symmetrical and nonsymmetrical motion paths.

Doctor Barnes, Doctor Mundel, and John M. MacKenzie, in University of Iowa Engineering Bulletin 21 (11), describe some investigations into the difference of time required to perform certain operations by one-handed and by two-handed simultaneous symmetrical motions. Although they compare the symmetrical two-handed motion path with one-handed work, they make no comparison between symmetrical and nonsymmetrical two-handed motion paths.

This review of the literature reveals that the writers on the subject of motion and time study recognize that operations can be performed more rapidly by symmetrical motion paths. It does not reveal, however, that any investigation has been made as to whether or not proportionately greater time savings may be expected by application of symmetrical motion paths to short-run than to long-run production.

III. THE INVESTIGATION

OBJECT OF THE INVESTIGATION

The object of the investigation was to determine the relative efficiency between a symmetrical motion path and a nonsymmetrical motion path for performing an industrial operation, other conditions being equal. To achieve this objective, the following major steps were taken. First, two motion paths having equal work content were set up; one motion path was symmetrical and the other was nonsymmetrical. Second, eight operators were chosen to perform the operations; they alternated between the symmetrical and nonsymmetrical motion paths at the end of each 25-cycle run. Third, an accurate record was kept of the time required by each operator to perform each 25-cycle run. Fourth, by comparing the time required to perform corresponding symmetrical and nonsymmetrical runs, an index of the relative efficiency of the two motion paths was obtained.

THE TWO MOTION PATHS

The Operation. It was desired to select an operation which would have certain characteristics. It should be possible to arrange the operation so that it would retain the same work content whether performed by a symmetrical motion path or by a nonsymmetrical motion path. The operation must be simple enough to be within the capabilities of the available laboratory equipment. It should be similar to operations found in industry. It should be of short duration so that a rather large number of cycles could be performed in a relatively short time. The operation should be two-handed, with each hand beginning and ending similar motions simultaneously.

The operation selected fulfilled all of the preceding requirements. It consisted of assembling a lock washer and a plain washer onto a 3/8 inch by 1 inch square head machine bolt. Each hand constructed a separate assembly simultaneously.

The operation may be described as follows: Each hand reaches to the bins and secures a bolt. The bolts are carried to the assembly fixture and placed therein with the heads down. Each hand reaches to the bins and secures a lock washer. The lock washers are carried to the bolts and placed thereon. Each hand reaches to the bins and secures a plain washer. The plain washers are carried to the bolts and placed thereon. Each hand secures a finished assembly from the fixture and disposes of it down the assembly chutes. The cycle is then repeated.

In motion study work, it is a frequent practice to describe an operation in terms of fundamental motions which are called therbligs. The operation selected for use in this study is described by the use of therbligs in Table 1, pages 11 and 12. It should be borne in mind that the description in Table 1 covers only one hand. The other hand is performing the same therbligs simultaneously. The therbligs used in this description are defined in Appendix I, page 60. A complete discussion of the nature and use of therbligs may be found on pages 62 to 66 and 107 to 133 of Motion and Time Study by Barnes (1).

The Symmetrical Motion Path. The arrangement of the work place for the symmetrical motion path is illustrated in Figure 1, page 13. A pair of bins was provided for bolts, a pair for lock washers, and a pair

TABLE 1

THERBLIG DESCRIPTION OF THE OPERATION

This Description Applies to Either the Left Hand or Right Hand; They Perform Identical Therbligs Simultaneously.

THERBLIG	TRANSPORT DISTANCE INCHES	DESCRIPTION
Transport Empty	8	Reach for bolt
Grasp	-	Pick up bolt
Transport Loaded And Pre-position	12	Carry bolt to assembly fixture And turn head down
Position	-	Align bolt head with fixture
Assemble	-	Place bolt in fixture
Release Load	-	Open fingers from bolt
Transport Empty	12	Reach for lock washer
Grasp	-	Pick up lock washer
Transport Loaded And Pre-position	12	Carry lock washer to bolt And turn horizontal
Position	-	Align lock washer with bolt
Assemble	-	Slide lock washer onto bolt
Release Load	-	Open fingers from lock washer
Transport Empty	12	Reach for plain washer
Grasp	-	Pick up plain washer
Transport Loaded And Pre-position	12	Carry plain washer to bolt And turn horizontal

Table 1 continued on next page

TABLE 1, CONTINUED

THERBLIG	TRANSPORT DISTANCE INCHES	DESCRIPTION
Position	-	Align plain washer with bolt
Assemble	-	Slide plain washer onto bolt
Release Load	-	Open fingers from plain washer
Grasp	-	Close fingers on assembly and lift from fixture
Transport Loaded	4	Carry assembly to disposal chute
Release Load	-	Drop assembly down chute

FIGURE 1. Work Place Arranged For Symmetrical Motion Path. Bins From Left To Right Are: Plain Washers, Lock Washers, Bolts, Bolts, Lock Washers, And Plain Washers.

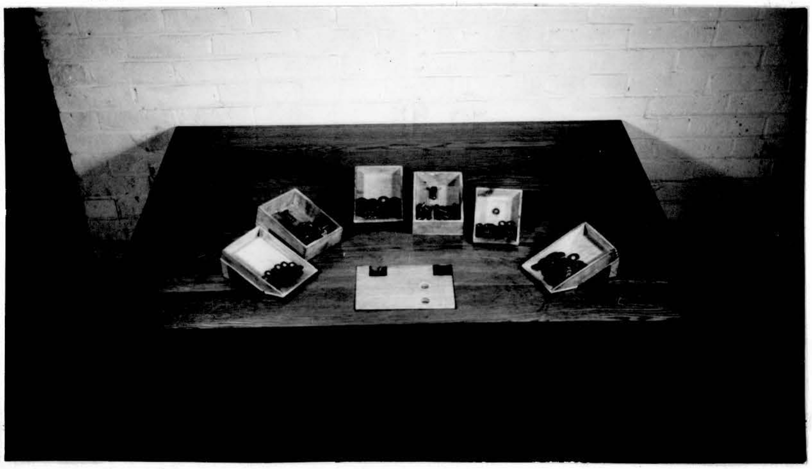

FIGURE 2. Work Place Arranged For Nonsymmetrical Motion Path. Bins From Left To Right Are: Lock Washers, Bolts, Plain Washers, Bolts, Lock Washers, And Plain Washers.

for plain washers. One bin of each pair supplied the right hand, while the other bin supplied the left hand. Each pair of bins was arranged in a symmetrical manner. The bins of each pair were located equidistant to the right and left of the center line of the work place and equidistant from the front edge of the table. The relative location of the different bins can be best visualized by reference to Figure 1. A disposal chute and an assembly nest for each hand were also located in a similar symmetrical manner. The distance from each assembly nest to the center of its corresponding disposal chute was 4 inches, the distance from the disposal chute to the corresponding bolt bin was 8 inches, and the distance from each stock bin to its corresponding assembly nest was 12 inches. With the work place arranged in this manner, both hands moved simultaneously in a symmetrical motion path.

<u>The Nonsymmetrical Motion Path</u>. The arrangement of the work place for the nonsymmetrical motion path is illustrated in Figure 2, page 13. The same stock bins were used for the nonsymmetrical motion path as were used for the symmetrical. Reference to Figure 2, however, will show that, for the nonsymmetrical motion path, the bins were arranged in a nonsymmetrical pattern. The assembly fixture also located the disposal chutes and the assembly nests in a nonsymmetrical manner. All the transport distances, however, remained the same as the corresponding distances in the symmetrical arrangement. The distance from each assembly nest to the corresponding disposal chute was 4 inches, the distance from each disposal chute to its corresponding bolt bin was 8 inches, and the distance from each stock bin to its corresponding assembly nest was 12 inches. With the work place arranged in this manner, both hands performed identical therbligs simultaneously, but the

hands moved nonsymmetrically in the performance of all transport therbligs.

Summary of the Two Motion Paths. The same operation was the basis for each motion path. Corresponding transport distances were identical for both motion paths. The two motion paths had an equal work content. The hands performed identical therbligs simultaneously in either path. The basic operation is similar to some assembly operations performed in industry.

DESIGN OF THE APPARATUS

Table. The apparatus was arranged on a solid hard wood table 29-1/4 inches high, with a working surface 48 inches by 35 inches. A rectangular hole 8 inches by 6 inches was cut in the surface of the table. It was 2 inches back from the front edge of the table and centrally located with respect to the ends of the table. The long axis of the hole was parallel to the front edge of the table. Wooden strips were screwed along the lower edges of the hole in such a manner as to support either the symmetrical or the nonsymmetrical assembly fixture in the hole, with the top of the fixture flush with the table top. The location of the mounted fixtures is well illustrated in Figures 1 and 2, page 13.

Two sheet metal disposal chutes were screwed to the underside of the table. One was so located that assemblies dropped through the right hand disposal slot of either the symmetrical or the nonsymmetrical assembly fixture would fall into the chute and be carried away. The other chute was so located that assemblies dropped through the left hand disposal slot of either fixture would fall into that chute and be carried away.

Locating holes 3/32 inches in diameter and 3/8 inches deep were drilled in the table top to receive the locating pins of the stock bins. A set of two holes was drilled for each location of each bin. The holes were so placed that, when the locating pins of a bin were in the corresponding set of holes in the table, the bin would be in the proper location for the motion path being performed. A black circle was drawn around each locating hole for the symmetrical motion path. A red circle was drawn around each locating hole for the nonsymmetrical motion path. Lettering on the table top indicated which bin was to be placed on each set of locating holes.

Stock Bins. Four similar stock bins were provided for washers, and two similar stock bins of a slightly different design were provided for the bolts. All bins were improvised from chalk boxes. The washer bins were 6 inches by 4 inches by 1-1/4 inches deep. The bolt bins were 6 inches by 4 inches by 1-3/4 inches deep. The bins had sufficient forward slope to cause parts to feed down to the front of the bin. The washer bins had a lip to facilitate grasping the washers. The bolt bin did not have a lip. The general characteristics of the bins are illustrated in Figure 3, page 17.

Two locating pins, 5/64 inches in diameter and extending 1/4 inch beyond the bottom of the bin, were driven into the bottom of each bin. When these pins were inserted into the corresponding locating holes in the table, the bin was located in its proper position for the motion path being performed. The pins also prevented the displacement of the bins from their proper location during the performance of the operation.

During the test, it was discovered that these bins did not function very efficiently. The grasp which the operator was able to perform

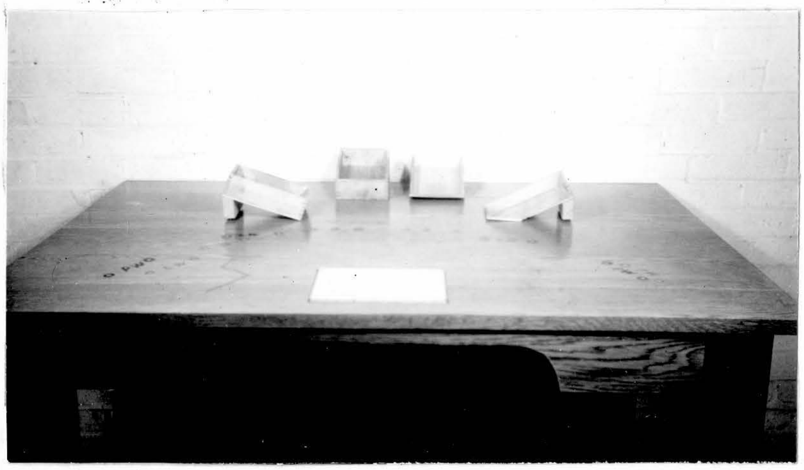

FIGURE 3. STOCK BINS.
BOLT BINS AT LEFT - WASHER BINS AT RIGHT.

was not the most efficient possible grasp. Since this condition affected both motion paths equally, it did not affect the comparison of results between the two motion paths.

Assembly Fixtures. An assembly fixture was provided for each motion path. Each fixture provided an assembly nest and a disposal slot for each hand. Each fixture was made of a piece of hard wood 8 inches by 6 inches by 7/8 inches. The fixtures fitted snugly into the hole in the table and were supported there with the top of the fixture flush with the table top. The disposal slots matched the disposal chutes of the table. The details of the layout of the symmetrical fixture are shown in Figure 4, page 19. The details of the layout of the nonsymmetrical fixture are shown in Figure 5, page 20.

Each assembly nest was constructed by drilling a 51/64 inch hole 7/16 inches deep. A 5/16 inch washer was fastened into the bottom of the hole with a wood screw in order to give the nest a flat bottom. When the head of a bolt was placed in the nest, the head fitted snugly enough to hold the bolt upright while the washers were being assembled.

Disposal Boxes. Two disposal boxes were provided. They were constructed of 5/32 inch plywood, and were 12 inches long, 5-1/2 inches wide, and 12 inches deep. One box was placed under each disposal chute to catch the assemblies as they slid down the chute.

Stool. The operator was seated on an adjustable height backless stool while performing the operation. The stool was adjusted to a height of 19-1/2 inches.

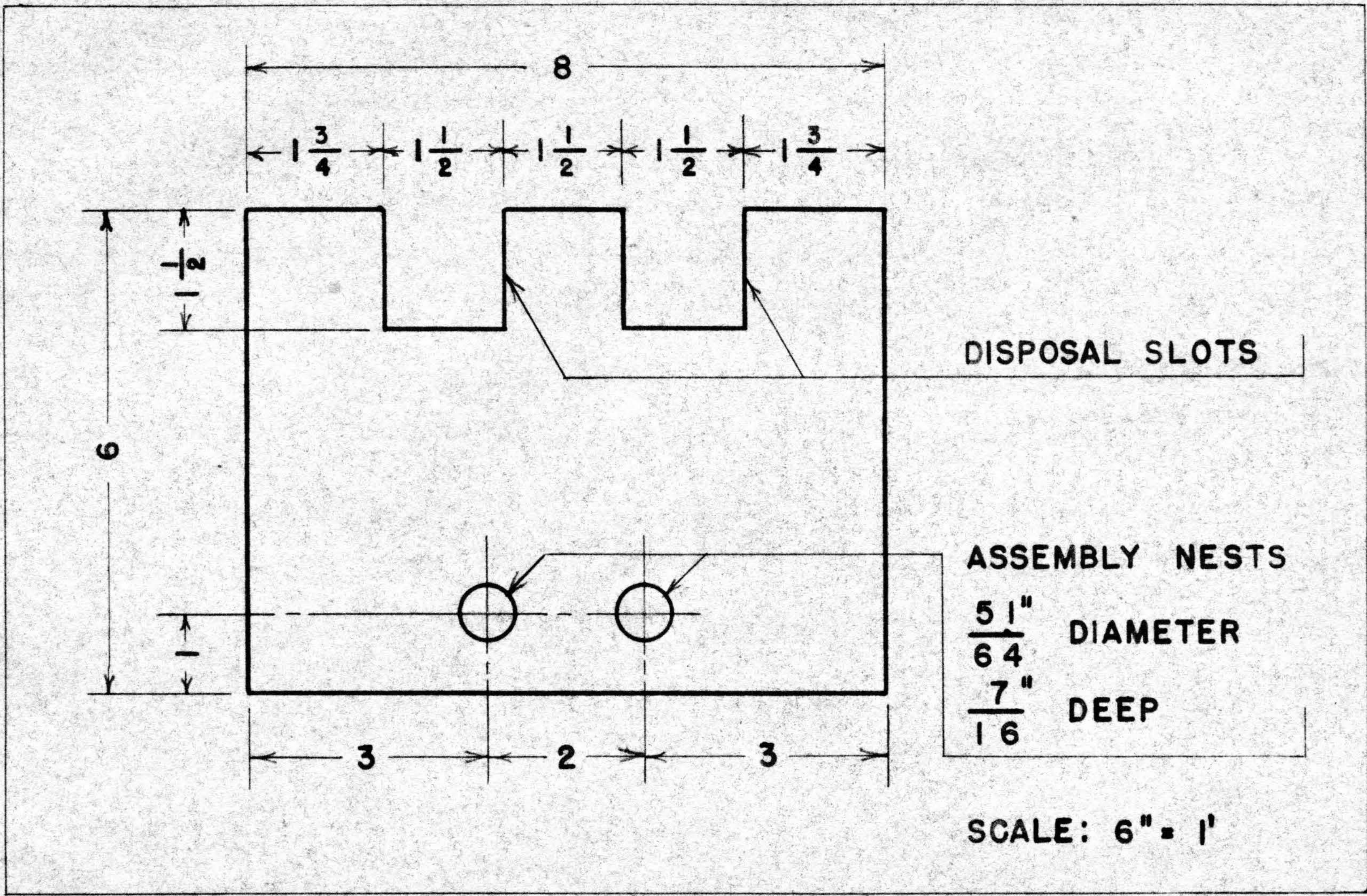

FIGURE 4. LAYOUT OF SYMMETRICAL ASSEMBLY FIXTURE.

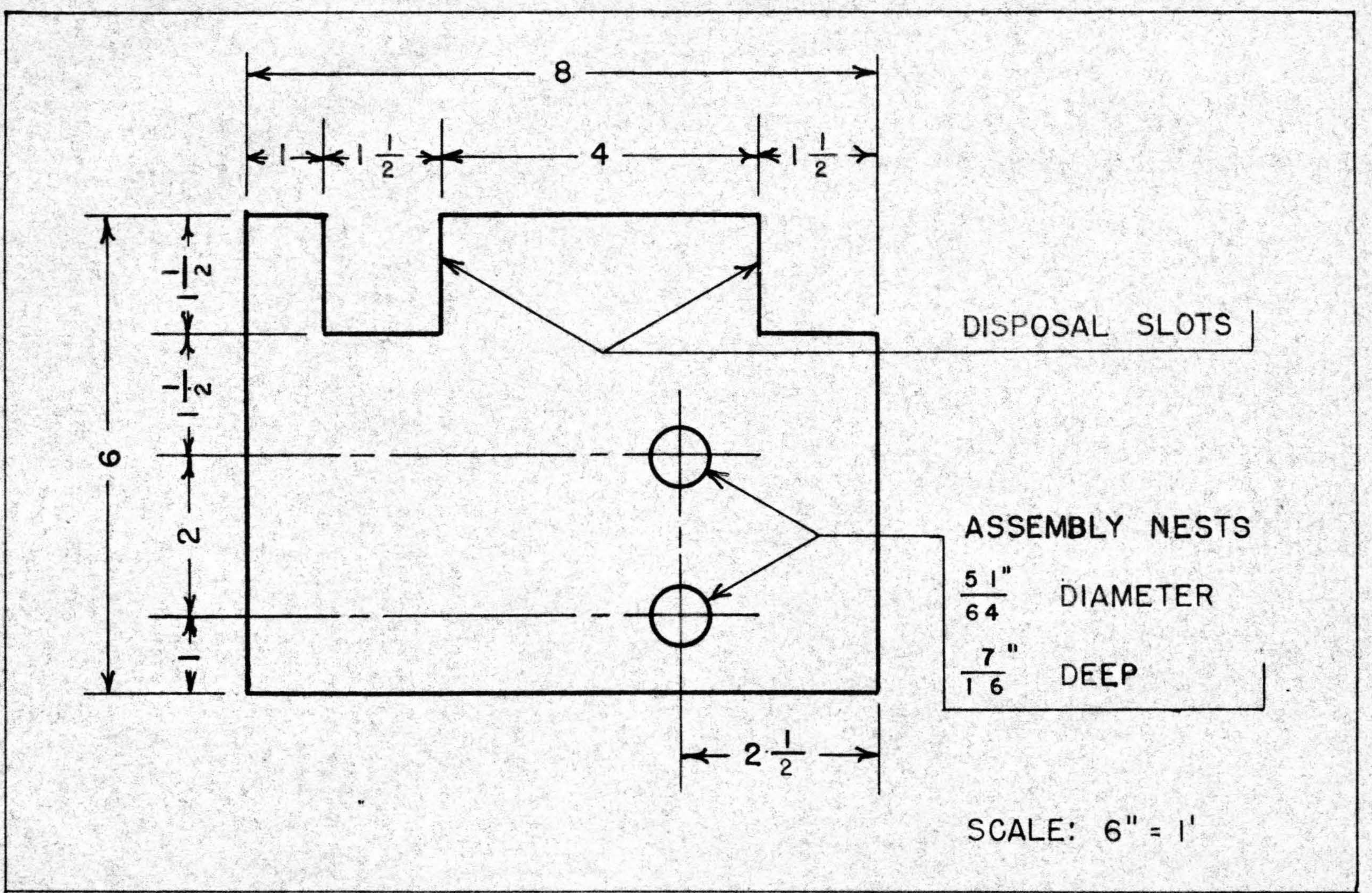

FIGURE 5. LAYOUT OF NONSYMMETRICAL ASSEMBLY FIXTURE.

Bolts. The bolts used in performing the assembly operation were 3/8 inch by 1 inch square head machine bolts. Fifty-two bolts were used.

Lock Washers. The lock washers used in performing the assembly operation were 3/8 inch S.A.E. Standard regular section lock washers. Approximately 80 lock washers were used.

Plain Washers. The plain washers used in performing the assembly operation were 7/16 inch S.A.E. Standard plain washers. Approximately 80 washers were used.

Stop Watch. The stop watch used to time each 25-cycle run was a decimal minute watch. It had a sweep hand making one revolution per minute and reading in hundredths of a minute. A small minute hand read by minutes up to 30 minutes.

SELECTION OF THE OPERATORS

Source of Operators. The operators were selected from the author's Motion and Time Study class at Virginia Polytechnic Institute. All candidates examined were male veterans of World War II. Each of 15 prospective operators was interviewed, and a record was made of his personal data. He was then given a finger dexterity test similar to the one used by Johnson O'Connor (12).

The Finger Dexterity Test. The equipment used for the dexterity test consisted of the following items:

Three-hundred-fifteen pins 0.066 inches in diameter and 1 inch long made of hard brass wire.

A minute decimal stop watch for timing the test.

A work table 29-1/4 inches high upon which the test was performed.

An adjustable height backless stool upon which the operator was seated while being tested.

One hardwood board 6 inches wide, 12 inches long, and 1 inch thick. In one half of the board 100 holes were drilled in lines of 10 holes each with the lines 1/2 inch apart in both directions. The holes had a depth of 3/4 inches and a diameter of 0.196 inches (number 9 drill). The other end of the board consisted of a shallow tray approximately 4 inches by 5 inches by 1/4 inches with sides sloping gently so that the pins could not be grasped by gathering them against the sides of the tray.

The examiner gave the following instructions to the examinee: "Seat yourself at the table with the board in a comfortable working position in front of you. Turn the board so that the tray is at your right if you are right handed, or at your left if you are left handed. The board should be at approximately right angles to the working hand. You may or may not rest the working arm or elbow on the table according to your own preference. The board contains 100 holes each of which has room for three pins. As rapidly as you can, pick up three pins at a time and fill the holes with three pins each. Use one hand only. Start in the farthest hole of the top row and, working toward the tray, fill all the holes in the top row. Next, start at the farthest hole of the second row and fill that row. Then fill the third row, the fourth row, and so on until all rows are filled. If you attempt to fill the holes in any other order, you may have difficulty reaching the empty holes, or you may knock pins out of the previously filled holes. Fill each row completely before you start the next. Do not skip around. There are extra pins in the tray. If you drop a few pins on the floor, do not stop to pick them up."

After giving the examinee the instructions, the examiner made sure that the subject complied with the starting conditions. The examiner demonstrated the operation by filling the first three holes himself. The pins were then returned to the tray. The examinee was directed to practice by filling the first row, after which the pins were again returned to the tray. The examinee was given a chance to ask any questions at this time. The subject was then directed to fill all 100 holes as rapidly as possible without stopping.

By means of the stop watch, the examiner determined the elapsed time from the filling of the first hole to the filling of the fiftieth hole, and the elapsed time from the filling of the fifty-first hole to the filling of the last hole.

The examinee's score was determined by the following equation:

$$\frac{(\text{Time holes 1 to 50})1.00 + (\text{Time holes 51 to 100})1.10}{2} = \text{Score}$$

The results of administering the dexterity test to the 15 examinees are shown in Table 2, page 24. Although the test used in this investigation is not exactly like the O'Connor test, it is believed that it is sufficiently similar to produce substantially the same results. In column three of Table 2, are shown the ranges of scores covered by each quarter of the distribution obtained by O'Connor by giving his test to a large number of persons covering a wide range of personal characteristics. Table 2

TABLE 2

RESULTS OF DEXTERITY TEST

OPERATOR	SCORE	COMPARISON TO O'CONNOR'S RESULTS
*	3.30	
4A	3.87	
*	3.89	FIRST
4B	3.93	QUARTER,
3A	3.97	0 to 4.08
*	4.05	
3B	4.06	
*	4.07	
*	4.15	SECOND
2A	4.36	QUARTER,
2B	4.37	4.09 to 4.40
*	4.68	THIRD
1B	4.71	QUARTER,
*	4.73	4.41 to 4.76
1A	4.89	FOURTH QUARTER, 4.77 and up

* These operators were tested, but they were not selected as subjects for the investigation.

indicates graphically into which quarter of O'Connor's distribution each operator tested during this investigation would fall. It will be noted that, as a group, the operators examined scored in the faster brackets of the O'Connor distribution.

<u>Selection and Grouping of the Operators.</u> From the 15 subjects tested, 8 operators were selected and divided into two groups on the basis of the dexterity test. Selection was so made that the following two conditions were satisfied.

1. The operators selected were distributed fairly uniformly throughout the scoring distribution of the entire group examined. Columns 1 and 2 of Table 2 show how successfully this condition was satisfied.

2. The eight operators were so selected that they could be divided into two 4-man groups of approximately equal dexterity score. When this division had been completed, Group A had a total score of 17.04, and Group B had a total score of 17.07. Operators in Group A were numbered 1A, 2A, 3A, and 4A; operators in Group B were numbered 1B, 2B, 3B, and 4B. The comparative scores of all operators are recorded in Table 2.

<u>Personal Data of Operators.</u> The personal data of the eight selected operators are outlined on the following pages.

OPERATOR NUMBER 1A

Age:	24 years
Weight:	165 pounds
Height:	6 feet 1 inch
Health:	Good
Vision:	Normal without glasses
Dexterity Score:	4.89
Hobbies:	None
Jobs Held:	None
Military Service:	Aerial navigator assigned to air-sea rescue work.
	Four months foreign service.
	36 months total service.
	Separated as second lieutenant.
Remarks:	Worked at a slow, steady, easily maintained pace.
	Was never hurried or excited.
	Seldom fumbled.

OPERATOR NUMBER 2A

Age:	23 years
Weight:	165 pounds
Height:	5 feet 10 inches
Health:	Good
Vision:	Normal without glasses
Dexterity Score:	4.36
Hobbies:	Sports
Jobs Held:	Shipyard apprentice machinist for two years.
Military Service:	Aerial navigator on heavy bombers.
	Based in England for five months.
	Flew 15 combat missions.
	30 months total service.
	Separated as a first lieutenant.
Remarks:	Was exceptionally smooth and accurate.
	Appeared to work with little effort, but achieved excellent operating times.
	His pace appeared to be easy to maintain.

OPERATOR NUMBER 3A

Age:	23 years
Weight:	150 pounds
Height:	5 feet 7 inches
Health:	Good
Vision:	Normal without glasses
Dexterity Score:	3.97
Hobbies:	Hunting, fishing, and riding
Jobs Held:	None
Military Service:	Infantry platoon leader.
	Seven months of combat on Italian Front.
	Wounded in Action.
	Left wrist was stiff as a result of a training accident.
	36 months total service.
	Separated as a first lieutenant.
Remarks:	Worked at a uniform, easily maintained speed.
	Occasionally suffered from a series of successive fumbles for which no reasons were apparent.

OPERATOR NUMBER 4A

Age:	23 years
Weight:	170 pounds
Height:	6 feet
Health:	Good
Vision:	Near vision good Far vision fair
Dexterity Score:	3.87
Hobbies:	Baseball, gardening, and hiking
Jobs Held:	Clerk at railroad reservation desk between school terms.
Military Service:	Army Specialized Training Program for 9 months. Infantryman for 9 months. X-ray repairman for 15 months. 33 Months total service. Separated as a private first class.
Remarks:	Combined rapid movement with a considerable degree of skill. Appeared to be able to maintain the pace he set. Was a very consistent operator.

OPERATOR NUMBER 1B

Age:	23 years
Weight:	155 pounds
Height:	6 feet
Health:	Good
Vision:	Normal without glasses
Dexterity Score:	4.71
Hobbies:	None
Jobs Held:	None
Military Service:	Gunner in an infantry howitzer company.
	30 months total service.
	Separated as a corporal.
Remarks:	Steady consistent operator.
	Set an easily maintained pace.

OPERATOR NUMBER 2B

Age:	24 years
Weight:	185 pounds
Height:	6 feet
Health:	Good
Vision:	Normal without glasses
Dexterity Score:	4.37
Hobbies:	Flying
Jobs Held:	Worked in production planning department for three months.
Military Service:	Instructor and platoon leader in army corps of engineers. Served one year in the European Theater of Operations. Two months of combat. 36 months total service. Separated as a first lieutenant.
Remarks:	Had only average skill, but developed extreme energy and speed. Could not have maintained his speed over an entire working day. His great speed and exertion resulted in an excessive amount of fumbling.

OPERATOR NUMBER 3B

Age:	22 years
Weight:	145 pounds
Height:	5 feet 7 inches
Health:	Good
Vision:	Normal without glasses
Dexterity Score:	4.06
Hobbies:	Sports
Jobs Held:	None
Military Service:	Aerial navigator on heavy bombers.
	Two months foreign service.
	Two combat missions.
	27 months service.
	Separated as a second lieutenant.
Remarks:	Worked at an easily maintained pace.
	Was calm and steady.

OPERATOR NUMBER 4B

Age:	21 years
Weight:	150 pounds
Height:	5 feet 11 inches
Health:	Good
Vision:	Normal without glasses
Dexterity Score:	3.93
Hobbies:	Reading
Jobs Held:	None
Military Service:	Heavy bomber pilot.
	26 months service.
	Separated as a second lieutenant.
Remarks:	Was fast and accurate.
	Although he exerted considerable energy and moved at high speed, he worked with little fumbling.

<u>Discussion of Operators.</u> The following facts regarding these operators should be noted:

1. The operators' ages ranged from 21 to 24 years.

2. All operators had served in the armed forces during World War II. Such service indicates a good physical condition.

3. Four operators had served as air crew members. Because of the high physical standards of the air arms, such service indicates a superior physical development on the part of these operators.

4. The finger dexterity test used in this study was not exactly like that used by Johnson O'Connor (12), but it should give reasonably similar results. Table 2, page 24, shows that the subjects examined scored principally in the faster brackets of O'Connor's distribution. Since O'Connor's study covered subjects with a wide range of personal characteristics, it was expected that the subjects of this study would, because of their youth and good health, score better than O'Connor's average.

5. The facts stated in the four preceding paragraphs indicate that the selected operators are not representative of the average industrial worker because these operators are younger and in better physical condition. However, they are fairly representative of a large group of workers who are now entering industrial employment - namely, the veterans of World War II. Since the results of the study will be based, not on total speed, but on the difference of speed between the two motion paths, it is not believed that the variance of these subjects from the average industrial worker will materially affect the results of this study.

METHOD OF PROCEDURE

Arrangement Of Work Schedule. The tests covered a span of four weeks. Each operator worked two periods per week, or eight periods during the study. Each work period lasted approximately one hour. The work periods for each operator were arranged so that they occurred at the same time each week and so that either three or four days elapsed between consecutive periods. For example, one schedule used consisted of work periods on Monday and Thursday, while another consisted of work periods on Monday and Friday.

The work was broken down into runs, each of which consisted of 26 cycles with 25 of the cycles being timed. All cycles of a run were performed by the same motion path. The motion path was alternated at the end of each run. Two consecutive runs representing the same cumulative number of cycles of each motion path were combined to form a unit. During the first work period each operator completed two units, during the second period he completed three units, and during each of the six remaining periods he completed four units representing eight runs. The increased output after the first and second periods was made possible by the increased skill resulting from practice on the part of both operators and observers. During the course of the study, each operator completed a total of 29 units representing 725 timed cycles of each motion path.

As was explained under the selection and grouping of operators, two operator groups of approximately equal dexterity score were formed - Group A and Group B. During the first, third, fifth, and seventh work periods, Group A executed each unit by performing the first run of the unit symmetrically and the second run nonsymmetrically; during the same periods, Group B executed each unit by performing the first run of the unit nonsymmetrically and the second run symmetrically. During the second, fourth, sixth, and eighth work periods, Group A executed each unit by performing the first run nonsymmetrically and the second run symmetrically; during these periods, Group B executed each unit by performing the first run symmetrically and the second run nonsymmetrically. By cancellation between the two operator groups, this arrangement of the schedule minimized the tendency to carry skill acquired in the motion path of the first run of a unit over into the opposite motion path of the second run.

Introduction Of Operator To Job. At each operator's first work period, the object of the investigation was explained to him. He was requested to cooperate by appearing promptly for each scheduled work period, by endeavoring to apply the same amount of effort to each motion path, and by trying to perform both motion paths by exactly the same methods. The observer demonstrated the proper method of performing the operation by each motion path, and the operator then performed 10 cycles of each motion path. These 10 cycles were not regarded as practice, but rather as a means of familiarizing the operator with both motion paths. Any questions asked by the operator were answered, after which the two units scheduled for the first period were performed.

Conduct Of The Work Period. With the exception of each operator's first work period, all periods were conducted in a similar manner. The first period differed from the others only in that the first part of that period was devoted to introducing the operator to the job in the manner described in the preceding paragraph.

At the beginning of a period, the observer recorded on the data sheet the date, the operator's name and number, the observer's name, the room temperature, the starting time, and appropriate remarks regarding the current physical condition of the operator. The observer removed the finished assemblies from the disposal boxes and replaced a box under each disposal chute. The assemblies were disassembled, and the bolts, lock washers, and plain washers were placed in their respective bins. The bolts were counted to make certain that 26 were placed in each bin. Since several extra washers of each type were provided, the washers were not counted; the observer simply divided them equally by eye between each respective pair of bins. By placing the locating pins of the bins in the proper locating holes of the table, the stock bins were arranged in the proper location for the motion path scheduled for the first run. The observer placed the proper assembly fixture in the table and checked the set-up for errors or omissions. The operator was seated comfortably on the stool in the working position. When all starting conditions were fulfilled, the observer directed the operator to begin work. As the operator dropped the first completed assembly into the disposal chute, the observer started the stop watch. As the last completed assembly was dropped into the disposal chute, the observer stopped the watch. The watch time then represented the time consumed in performing 25 cycles. Twenty-six cycles performed as described, with 25 of the cycles being timed, comprised the first run. Upon the completion of the run, the observer recorded the run number, the time for the 25 cycles, the type of motion path used, any appropriate remarks, and the cumulative number of cycles of that motion path which had been completed at the end of the run. In determining the cumulative number of cycles, only the timed cycles were included; the first or untimed cycle of each run was not counted. After all data pertaining to the run had been recorded, the work place was rearranged for the opposite motion path, and the second run was accomplished in the same manner as the first - except that it was performed by the opposite motion path. These two runs - one run using each motion path, and each run completing the same number of cycles for the motion path by which it was performed - comprised the first unit of the period.

Succeeding units were accomplished in a similar manner until the number of units scheduled for the period had been performed. Upon the completion of the schedule for the period, the observer recorded the finish time on the data sheet and entered any appropriate remarks regarding the period as a whole.

RESULTS OF THE INVESTIGATION.

Each operator completed the eight periods as scheduled. Thus each operator completed 29 units or 58 runs. The time in minutes for each run is tabulated in Table 3, page 40. The top horizontal line of Table 3 gives the operator's number. The second horizontal line shows the type of run, symmetrical or nonsymmetrical, by which the run was performed. The first vertical column shows the period number, and the second vertical column shows the unit number. The third vertical column shows the cumulative number of cycles which had been performed by each motion path at the completion of the unit. The remainder of the columns show the time in minutes for performing each 25-cycle run.

TABLE 3. TIME IN MINUTES FOR PERFORMING EACH RUN

OPERATOR			1A		2A		3A		4A	
TYPE OF RUN			SYM.	NON.	SYM.	NON.	SYM.	NON.	SYM.	NON.
PERIOD NUMBER	UNIT NUMBER	CUM. CYCLES	TIME	TIME	TIME	TIME	TIME	TIME	TIME	TIME
1	1	25	3.86	4.08	3.27	3.24	3.53	3.65	2.88	3.03
1	2	50	3.64	4.09	2.96	3.08	3.28	3.78	2.79	2.90
2	3	75	3.26	3.60	2.80	2.98	2.99	3.18	2.79	2.88
2	4	100	3.05	3.19	2.69	2.85	2.88	3.10	2.69	2.93
2	5	125	3.05	3.14	2.67	2.86	2.98	3.19	2.60	2.79
3	6	150	3.20	3.19	2.77	2.80	3.10	3.22	2.61	2.71
3	7	175	3.03	3.20	2.67	2.78	3.07	3.01	2.81	2.72
3	8	200	2.89	3.01	2.47	2.68	2.85	2.92	2.64	2.65
3	9	225	2.85	2.87	2.48	2.62	2.92	2.97	2.53	2.69
4	10	250	3.06	3.16	2.54	2.67	2.78	2.94	2.58	2.59
4	11	275	2.87	2.92	2.46	2.64	2.58	2.79	2.59	2.64
4	12	300	2.75	2.69	2.30	2.48	2.48	2.90	2.65	2.46
4	13	325	2.77	2.92	2.33	2.45	2.60	2.72	2.43	2.54
5	14	350	2.86	2.81	2.38	2.51	2.50	2.70	2.42	2.49
5	15	375	2.76	2.80	2.31	2.55	2.76	2.66	2.40	2.35
5	16	400	2.78	2.80	2.35	2.68	2.56	2.65	2.33	2.45
5	17	425	2.72	2.86	2.40	2.56	2.54	2.60	2.35	2.32
6	18	450	2.83	2.83	2.73	2.57	2.55	2.68	2.41	2.37
6	19	475	2.56	2.64	2.49	2.50	2.58	2.72	2.47	2.43
6	20	500	2.61	2.55	2.40	2.54	2.49	2.81	2.38	2.41
6	21	525	2.45	2.64	2.46	2.47	2.55	2.64	2.36	2.39
7	22	550	2.50	2.72	2.43	2.40	2.56	2.49	2.25	2.31
7	23	575	2.49	2.51	2.34	2.47	2.44	2.45	2.19	2.31
7	24	600	2.53	2.55	2.35	2.39	2.68	2.52	2.18	2.24
7	25	625	2.39	2.54	2.43	2.46	2.40	2.55	2.20	2.27
8	26	650	2.46	2.52	2.33	2.44	2.38	2.54	2.26	2.29
8	27	675	2.54	2.82	2.33	2.50	2.35	2.58	2.27	2.35
8	28	700	2.54	2.50	2.30	2.41	2.27	2.47	2.17	2.20
8	29	725	2.45	2.53	2.26	2.39	2.22	2.40	2.28	2.41

Abbreviations used in Table 3: Sym. - Symmetrical.
Non. - Nonsymmetrical.
Cum. - Cumulative.

Table 3 continued on next page

TABLE 3. CONTINUED

TIME IN MINUTES FOR PERFORMING EACH RUN

OPERATOR			1B		2B		3B		4B	
TYPE OF RUN			SYM.	NON.	SYM.	NON.	SYM.	NON.	SYM.	NON.
PERIOD NUMBER	UNIT NUMBER	CUM. CYCLES	TIME	TIME	TIME	TIME	TIME	TIME	TIME	TIME
1	1	25	3.16	3.75	3.15	3.20	3.26	3.70	3.03	3.50
1	2	50	3.08	3.13	2.83	2.98	3.24	3.35	2.94	3.16
2	3	75	2.98	2.92	2.78	2.86	3.26	3.27	2.72	3.02
2	4	100	2.85	3.12	2.64	2.77	3.02	3.35	2.70	3.00
2	5	125	2.86	3.00	2.51	2.75	3.12	3.17	2.71	2.82
3	6	150	2.76	2.93	2.62	2.87	3.13	3.18	2.72	3.27
3	7	175	2.62	2.78	2.50	2.52	3.01	3.12	2.77	2.80
3	8	200	2.67	2.74	2.41	2.74	2.79	2.88	2.53	2.78
3	9	225	2.68	2.83	2.28	2.43	2.92	2.97	2.58	2.59
4	10	250	2.56	2.59	2.49	2.55	3.06	3.13	2.55	2.47
4	11	275	2.45	2.57	2.22	2.54	2.98	3.19	2.47	2.50
4	12	300	2.39	2.57	2.38	2.70	2.90	3.05	2.35	2.56
4	13	325	2.40	2.53	2.45	2.41	2.92	3.09	2.49	2.54
5	14	350	2.50	2.62	2.22	2.50	2.88	3.07	2.30	2.55
5	15	375	2.59	2.66	2.19	2.44	2.84	2.88	2.30	2.54
5	16	400	2.48	2.62	2.52	2.35	2.71	2.93	2.30	2.36
5	17	425	2.52	2.50	2.27	2.48	2.56	2.87	2.32	2.38
6	18	450	2.47	2.51	2.31	2.42	2.70	2.68	2.41	2.33
6	19	475	2.31	2.46	2.32	2.29	2.50	2.52	2.17	2.25
6	20	500	2.40	2.53	2.48	2.38	2.55	2.57	2.22	2.24
6	21	525	2.37	2.55	2.32	2.37	2.41	2.56	2.21	2.32
7	22	550	2.44	2.42	2.18	2.35	2.50	2.57	2.22	2.24
7	23	575	2.40	2.42	2.34	2.27	2.47	2.58	2.30	2.32
7	24	600	2.29	2.40	2.22	2.32	2.64	2.42	2.20	2.35
7	25	625	2.42	2.40	2.22	2.31	2.39	2.60	2.27	2.28
8	26	650	2.37	2.45	2.25	2.41	2.43	2.45	2.32	2.30
8	27	675	2.27	2.30	2.20	2.21	2.48	2.53	2.12	2.32
8	28	700	2.24	2.35	2.16	2.38	2.40	2.37	2.21	2.23
8	29	725	2.30	2.29	2.19	2.27	2.35	2.23	2.21	2.07

IV. DISCUSSION OF RESULTS

A study of Table 3, reveals that the operator usually performed the symmetrical run of a unit faster than he performed the nonsymmetrical run of the same unit. In some cases, however, the nonsymmetrical run of a unit was accomplished faster than the symmetrical run. Each operator performed the nonsymmetrical run faster in from 3 to 6 of his 29 units. In 195 units the symmetrical run was faster; in 36 units the nonsymmetrical run was faster; in the one remaining unit the times for both runs were identical. The occurrence of units in which the nonsymmetrical run is faster than the symmetrical run is attributable to the fact that the human body does not function like a machine; more or less minor delays and fumbling accompanied each run. It was entirely possible, with 25-cycle runs, for an operator to experience considerably more minor delays and fumbling in one run of a unit than in the other run. If appreciably more time was consumed by minor delays and fumbles in the symmetrical run than in the nonsymmetrical run of a unit, it was possible for the nonsymmetrical run to be faster. Such occurrences account for units in which the nonsymmetrical run was faster. Since there was no practicable method of dropping the time consumed by these delays and fumbles from the record, the time for each run was accepted at its face value regardless of the amount of minor delays and fumbling in the run. It is believed that, in the long run, the time for such minor delays and fumbling tended to cancel out when the run times of the various operators were averaged. In order to minimize the effect of the above mentioned delays on the comparison of the recorded times of the two motion paths, the remaining discussion of the results will be based on averages of all operators' times, rather than on the times of any single operator.

The significant details of the raw data of Table 3 are summarized in Tables 4, 5, and 6, and are presented graphically in Figures 6, 7, and 8.

In the first, second, and third columns of Table 4, page 44, are recorded respectively the work period number, the unit number, and the cumulative number of cycles of each type completed at the finish of the unit. The fourth column records the average run time of all operators for performing the symmetrical runs of the unit. The last column records the average run time of all operators for performing the nonsymmetrical runs of the unit.

The data of Table 4 are presented graphically in Figure 6, page 45. In this figure the average run time by units for each motion path is plotted against the unit number. Vertical broken lines indicate the location of boundaries between work periods. Work period numbers are recorded at the lower end of the period boundaries.

Table 4 and Figure 6 show that the average run time for either motion path decreases as the amount of practice increases. This decrease is neither continuous nor constant; in some cases the time for a run may be greater than the corresponding time for the preceding run. The general trend of the time for both motion paths, however, is steadily downward. A decrease of the time required to perform an operation as the amount of the operator's experience increases is a common occurrence in industry. Since the human body is subject to variations in performance from run to run, it should not be expected that a plot of the run times will produce a smooth

TABLE 4

AVERAGE RUN TIME OF ALL OPERATORS BY UNITS

PERIOD NUMBER	UNIT NUMBER	CUMULATIVE CYCLES	AVERAGE SYMMETRICAL TIME IN MINUTES	AVERAGE NONSYMMETRICAL TIME IN MINUTES
1	1	25	3.268	3.496
1	2	50	3.095	3.309
2	3	75	2.948	3.098
2	4	100	2.815	3.039
2	5	125	2.813	2.965
3	6	150	2.864	3.021
3	7	175	2.810	2.866
3	8	200	2.656	2.800
3	9	225	2.655	2.746
4	10	250	2.703	2.763
4	11	275	2.578	2.724
4	12	300	2.525	2.676
4	13	325	2.549	2.650
5	14	350	2.508	2.656
5	15	375	2.519	2.610
5	16	400	2.504	2.605
5	17	425	2.460	2.571
6	18	450	2.506	2.549
6	19	475	2.425	2.476
6	20	500	2.441	2.504
6	21	525	2.391	2.493
7	22	550	2.385	2.438
7	23	575	2.371	2.416
7	24	600	2.386	2.399
7	25	625	2.340	2.426
8	26	650	2.350	2.425
8	27	675	2.320	2.451
8	28	700	2.286	2.364
8	29	725	2.283	2.324

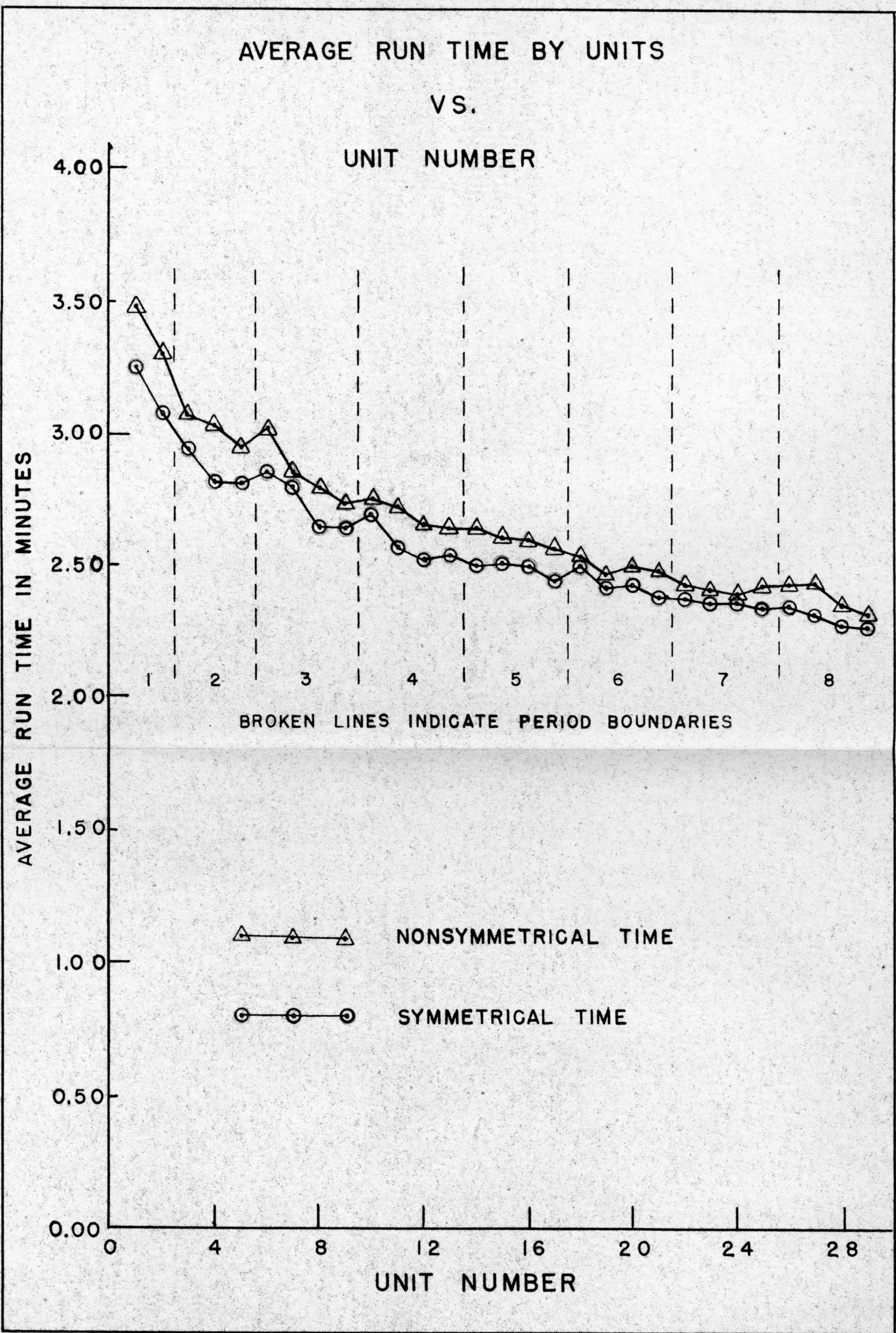
AVERAGE RUN TIME BY UNITS
VS.
UNIT NUMBER
AVERAGE RUN TIME IN MINUTES
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0
4
8
12
16
20
24
28
UNIT NUMBER
1
2
3
4
5
6
7
8
BROKEN LINES INDICATE PERIOD BOUNDARIES
NONSYMMETRICAL TIME
SYMMETRICAL TIME

FIGURE 6

curve. A second significant fact revealed by Figure 6 is the fact that the average nonsymmetrical run time is consistently greater than the average symmetrical run time. This fact indicates a greater efficiency for the symmetrical motion path.

In Table 5, page 47, is tabulated the average time of all operators for performing the symmetrical and nonsymmetrical runs of each period. The first column records the period number. The second column records the average run time for the symmetrical runs of the period; this column was prepared by adding the time for all symmetrical runs performed during the period by all eight operators and then dividing that sum by the total number of symmetrical runs performed during the period. The average run time for the nonsymmetrical runs of the period was computed in a similar manner, and the results were tabulated in the third column. The ratio of the average nonsymmetrical run time for the period to the average symmetrical run time for the period is recorded in the fourth column.

Figure 7, page 48, presents graphically the data of the first, second, and third columns of Table 5. The average run time by periods is plotted against the period number. This plot smooths out the irregularities of Figure 6. The average run time for each motion path decreases continuously from each period to the next; the decreases occur at a relatively uniform rate, thereby producing fairly smooth curves. The symmetrical time is consistently less than the corresponding nonsymmetrical time. A tendency is displayed for the distance between the two curves to decrease as the number of work periods increases.

Tables 4 and 5 and Figures 6 and 7 present the same evidence in

TABLE 5

AVERAGE RUN TIME OF ALL OPERATORS BY PERIODS

PERIOD NUMBER	AVERAGE SYMMETRICAL TIME IN MINUTES	AVERAGE NONSYMMETRICAL TIME IN MINUTES	RATIO OF NONSYMMETRICAL TO SYMMETRICAL TIME
1	3.181	3.403	1.0698
2	2.858	3.031	1.0605
3	2.746	2.858	1.0408
4	2.588	2.703	1.0444
5	2.498	2.611	1.0452
6	2.441	2.505	1.0262
7	2.371	2.420	1.0207
8	2.310	2.391	1.0351

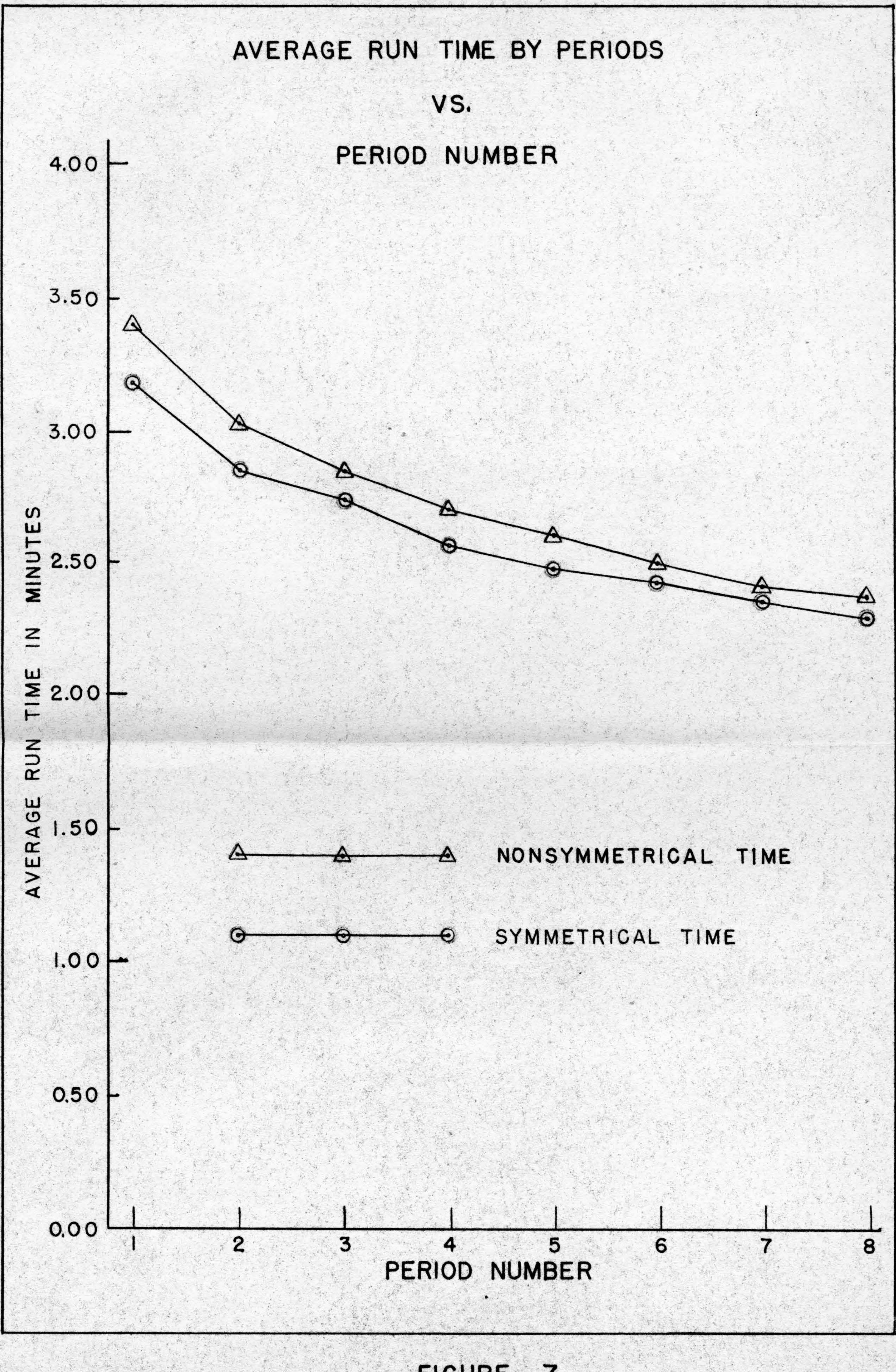
AVERAGE RUN TIME BY PERIODS
VS.
PERIOD NUMBER
AVERAGE RUN TIME IN MINUTES
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
1
2
3
4
5
6
7
8
PERIOD NUMBER
NONSYMMETRICAL TIME
SYMMETRICAL TIME

FIGURE 7

slightly different forms. They indicate that the average run time for both motion paths decreases as the operator becomes more experienced. This is a tendency which is already well recognized throughout industry. These tables and figures indicate that, under the conditions of the study, the operation may, on the average, be performed in less time by the symmetrical than by the nonsymmetrical motion path. The additional time required by the nonsymmetrical motion path ranged from 6.98% in the first work period to 2.07% in the seventh period. Although the operation used in this study is not an industrial operation, it is believed that the superior efficiency of the symmetrical motion path as revealed by the performance of the operation of this study would be duplicated to a greater or lesser extent in typical industrial operations. It is believed that the results of this study indicate that, other conditions being equal, less time will be required to perform an industrial operation by a symmetrical than by a nonsymmetrical motion path.

In Figure 8, page 50, the data of the last column of Table 5 are presented graphically. The ratio of the average nonsymmetrical run time by periods to the average symmetrical run time by periods is plotted against the work period number. The chart shows a tendency for this ratio to decrease as the number of work periods increases. The plotted points show considerable dispersion from period to period, but they do indicate a definite tendency for the ratio to decrease as the amount of practice increases. Such a tendency of this ratio to decrease with practice indicates that, as the operator becomes more experienced in the performance of this operation, the difference in efficiency between the two motion paths may be expected to decrease. It is believed that a similar tendency would be exhibited by

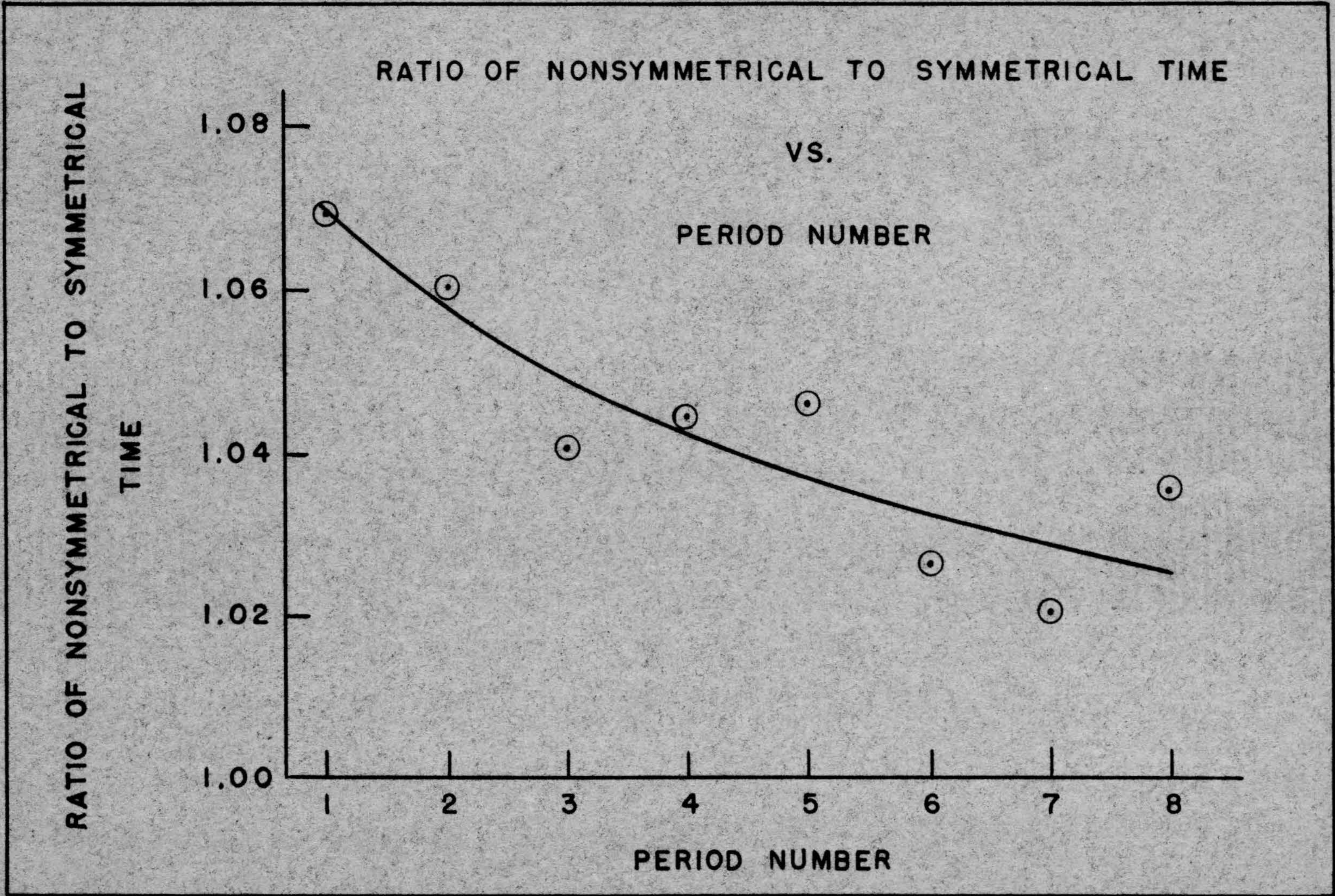
RATIO OF NONSYMMETRICAL TO SYMMETRICAL TIME
VS.
PERIOD NUMBER
RATIO OF NONSYMMETRICAL TO SYMMETRICAL TIME
1.08
1.06
1.04
1.02
1.00
1
2
3
4
5
6
7
8
PERIOD NUMBER

FIGURE 8

industrial operations. On short-run production, where the operator gains a minimum of practice on one operation before changing to another, it would appear that the use of a symmetrical motion path would produce maximum time savings, since this study shows a tendency of the superiority of the symmetrical motion path to decrease as the amount of practice increases. On long-run production, however, where the operator gains a maximum of practice on one operation before changing to another, it would appear that the symmetrical motion path would enjoy less superiority over the nonsymmetrical motion path. It is indicated that, on continuous operations - where the operators repeat the same operation for long periods of time - the difference in time between the two motion paths might become quite small. It should be noted that, although the times for the two motion paths might approach equality, there is reason to believe that the nonsymmetrical motion path might cause more fatigue for the operator. An investigation of the relative amount of operator fatigue produced by the two motion paths is beyong the scope of this study.

An incidental result of the study was a chance to compare the results of the dexterity test with the actual accomplishment of the operators. The dexterity test was used in an attempt to divide the operators into two groups having reasonably equal skill, and to obtain distribution of the operators through a rather wide range of skill. Table 6, page 52, compares the operators' ranking by the dexterity test to their ranking by accomplishment during the test. The first column shows the ranks from 1 to 8 inclusive. Number 1 is the fastest, and number 8 is the slowest. In the second column is entered each operator's number opposite his rank as

TABLE 6

COMPARISON OF OPERATOR RANKING BY DEXTERITY TEST

TO OPERATOR RANKING BY ACCOMPLISHMENT

RANK	OPERATOR RANK BY DEXTERITY TEST	OPERATOR RANK BY ACCOMPLISHMENT
1	4A	4B
2	4B	2B
3	3A	4A
4	3B	2A
5	2A	1B
6	2B	3A
7	1B	3B
8	1A	1A

determined by the dexterity test. In the third column is entered each operator's number opposite his rank as determined by his accomplished time during the study. Table 6 reveals the following facts:

1. The two fastest men, as determined by the dexterity test, finished in the faster half of the accomplishment ranking.

2. The two slowest men, as determined by the test, finished in the slower half of the accomplishment ranking.

3. Of the four middle men (rank 3 to 6 inclusive) as determined by the test: two finished in the middle section; one finished above the middle section; one finished below the middle section; none finished first or last.

4. The operators of both groups were distributed with reasonable uniformity throughout the range of the rank distribution as determined by accomplishment.

The observations of the preceding four sub-paragraphs indicate that the dexterity test used predicted the relative potential performance of the operators in a most acceptable manner. No test could be expected to predict the operators' future performance exactly. The test produced a very satisfactory selection and grouping of the operators.

V. CONCLUSIONS

It is believed that the results of this study warrant the statement of three conclusions.

1. Other things being equal, an industrial operation may be performed in less time by a symmetrical motion path than by a non-symmetrical motion path if the operators obtain only a moderate amount of practice on the operation. This study was not carried through sufficient practice cycles to prove positively that the symmetrical motion path would be more efficient on extremely long-run operations.

2. The time savings to be gained by the application of a symmetrical motion path to the performance of short-run production may be expected to be considerably larger than the time savings to be gained by the application of the symmetrical motion path to the performance of long-run production. This condition appears to be due to the fact that a symmetrical motion path can be learned more rapidly than can a nonsymmetrical motion path, particularly during the early stages of practice.

3. In the case of this study, the dexterity test furnished a most satisfactory means of selecting operators distributed throughout a wide range of skill, and of grouping those operators into two groups of approximately equal skill. It appears that there was a significant relation between the operators' dexterity scores and their accomplishment.

VI. SUMMARY

It is evident that a rising wage level makes it imperative for management to secure greater productivity from labor. Such greater productivity must be secured by the use of more efficient work methods, rather than by forcing operators to work at a faster pace.

The results of this study indicate that the use of symmetrical motion paths offers one method of increasing operator productivity without unreasonable speed up. It is also indicated that the performance of an operation by a symmetrical motion path yields greater time savings when applied to short-run production. It appears that management should endeavor to insure that the work place is so arranged that industrial operations are performed by a symmetrical motion path whenever practicable. It is doubly important that the symmetrical motion path be applied to short-run production whenever possible, as it enables the operators to attain acceptable proficiency more quickly. One commonly used method of attaining a symmetrical motion path in small assembly work is to use an assembly fixture which allows each hand to build a separate assembly independently of but simultaneously with the other hand.

VII. SUGGESTIONS FOR FURTHER STUDY

This study carried the practice through only twenty-nine 25-cycle runs of each motion path, representing a total of 725 cycles of each type. It appears profitable to extend a similar study through several thousand cycles to determine if the tendency of the ratio of nonsymmetrical to symmetrical time continues to decrease with increased practice.

No attempt was made during this study to determine the relative amount of fatigue produced by the two motion paths. Most of the operators commented upon the fact that the nonsymmetrical motion path seemed more fatiguing because it required closer concentration, it involved more twisting of the body, and it incurred unbalanced movements of body members. These operator observations were, of course, simply impressions which could not be measured quantitatively. It is suggested that an investigation of the relative fatigue produced by performing an operation by symmetrical and by nonsymmetrical motion paths might produce valuable information.

Reference to Figures 1 and 2, page 13, will show that, in the symmetrical assembly fixture, the two assembly nests were arranged side by side, while they were arranged one behind the other in the nonsymmetrical fixture. No definite record was kept of the amount of fumbling which occurred in assembling the washers onto the bolts, but there appeared to be more time lost by fumbles of this nature with the symmetrical fixture. An investigation of the relative ease of assembling and of the relative amount of fumbling with assembly nests arranged in each of these patterns might reveal valuable information regarding the most efficient relative location of assembly nests for two-handed simultaneous assembly operations.

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X. APPENDIX

DEFINITIONS OF THE THERBLIGS
USED IN DESCRIBING THE OPERATION

Transport Empty. Transport empty is the act of moving a transportation means, usually the hand, without external resistance or without a load.

Grasp. Grasp is the act of gaining control of an object so that it can be moved in the desired direction. Grasp is usually accomplished by closing the fingers upon the object.

Transport Loaded. Transport loaded is the act of moving a transportation means, usually the hand, against an external resistance or while carrying a load.

Pre-position. Pre-position is the act of moving or turning an object into such a position as to prepare the object for the next operation.

Position. Position is the act of bringing two or more objects into such relative position or alignment that they may be placed together by the next therblig.

Release Load. Release load is the act of the transportation means relinquishing control of an object.

Assemble. Assemble is the act of placing two or more objects together so that they form a unit or a part of a unit.