SOME WORK CYCLE CHARACTERISTICS OF A SIMPLE, HIGH RATE, FORCED-PACE ASSEMBLY OPERATION

by

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INTRODUCTION

In the course of the last quarter century, many predetermined elemental time systems have been developed, which are designed to take place of the traditional time study method. As a result of this technique, many authors have written numerous articles regarding the validity as well as invalidity of the use of the standard time values for rating procedures. The main comment against these standard time values is that they vary too much and therefore will not provide the same results. So, it has been pointed out in many papers and articles that standard times are not reliable enough for practical purposes.

The supporters of the predetermined motion time techniques frequently describe them as an accurate system. They agree there is a slight variation between work cycles, but they argue that these variations are not large enough to hinder the establishment of a range of standard times for elemental motions.

Due to this conflict between authors, it was felt that a study of some of the characteristics of a specific type of assembly work might prove to be of some value. The type of assembly work chosen was that of a simple, high-rate, forced-pace assembly operation. Moving pictures were taken of this type of operation in order to obtain data to be used in the study.

EXPERIMENTAL PROCEDURES

General Method

The data used in this project were obtained from a micromotion film. With instruction from department personnel, the writer prepared the equipment required for this experiment and filmed a number of operators while they were assembling sets of specially designed parts, Fig. 1. This project was the third phase of a project begun as doctoral research performed at the University of Illinois (12).

The films were used to obtain data concerning the length of time spent by the operators in performing an assembly.

Statistical analysis of the data was done as explained later. From the findings of this data, and from the graphical examination, some useful conclusions were formulated.

Details of the equipment used, procedures followed, and other information is presented in the pages that follow.

Equipment

The data were obtained by using 50 sets of simple brass parts. These parts were ½ in. thick and 1 11/16 in. in diameter, Fig. 1. The weight of an assembly of the three parts was approximately one pound. The film was taken when the operators were preparing the assembly of the three parts and disposing of it.

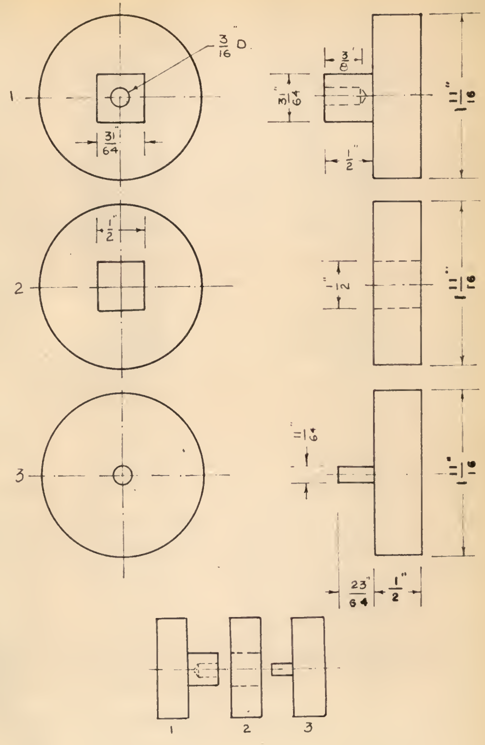


Fig. 1. Parts assembly.

A work surface was prepared at ordinary table height. Three chutes, each filled up with one type of the brass parts, supplied the parts to the work surface. Cycle starting switches, delivery chute, pacing device, and timer were also located on the work surface, Figs. 2 and 3.

In order to get a front view and top view simultaneously in each frame of film, a mirror was fixed above the work surface. The mirror was fixed in a separate frame and this frame was bolted to the main structure. Special provisions were made so that the mirror could be raised or lowered as required and the inclination could also be adjusted, if necessary.

The forced-pace mechanism consisted of a box-shaped obstruction, operated by a solenoid through a lever, Fig. 4. To avoid vibration and shock, the complete mechanism was mounted on a separate table which was located below the work surface. Only the box-shaped obstruction could come above the work surface.

The timer used to operate the solenoid was from the Eagle Signal Corporation. It could be set from 0 to 20 seconds at intervals of 1/12 of a second. It was set at different locations for the investigation.

The camera mount was made from steel tubes. The mount provided a means of controlling vertical movement, rotating movement, and also for leveling the camera in the horizontal plane, Fig. 5. The camera used for this project was a 16 mm.

Fig. 2. The work place as filmed.

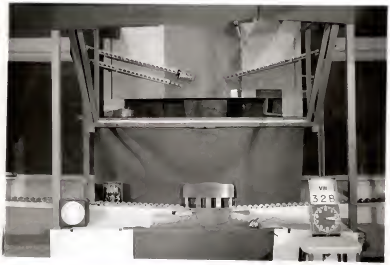


Fig. 3. Over-all view of apparatus.
(curtains lifted upwards)

Fig. 4. Specially designed forced pacer.
(shown in two positions)

Fig. 5. Camera and mount.

Bell and Howell - 70-TMR, operated at 32 frames per second and using a 10 mm. wide angle lens.

A continuous reading microchronometer was placed near the work surface, Figs. 2 and 3. This technique provided a method of determining time while analyzing the film.

The projector used for analyzing the film was a Bell and Howell projector with a hand crank, frame counter, and a 5/8 in. wide angle lens.

Two flood lamps each of 375 watts were used to provide sufficient light on the work surface while filming. A third lamp of the same type was used on the microchronometer. Temperature, humidity, and barometric pressure were noted for each operator setting as shown in Fig. 6. The chair used by the operator was an ordinary wooden chair without arms, Figs. 2 and 3.

The Experiment

The data were produced by filming three sets of work cycles at three rates of production for 11 different operators. The rates set as goals were:

Rate A: 127/2000 minute per assembly
Rate B: 110/2000 minute per assembly
Rate C: 97/2000 minute per assembly

These times were taken from a phase of the experiment performed at the University of Nebraska during the school year of 1958-59. These were the mean times to prepare one complete assembly at the three different rates.

FILMING RECORD FORM

Scene Number, Including Code ______VIII 06 A-C-B______

Rate Goal ______A,C,B______

Operator Code ______VIII______

Assistant Code ______-______

Operator Day (which of 3 runs) ______1______

Day and Date ______Tuesday, February 13, 1962.______

Temperature ______90______

Humidity ______37%______

F Stop ______3.5______

Frames Per Second ______32______

Barometer ______28.83______

Fig. 6. An example of the standard form used to record filming data. (with typical data)

Then, the sum of mean times for the standard motions 7R, 8R, and delivery (See Table 1) were found from the same data and subtracted from the total time. The remaining time for each rate, known as "paced time", was as follows:

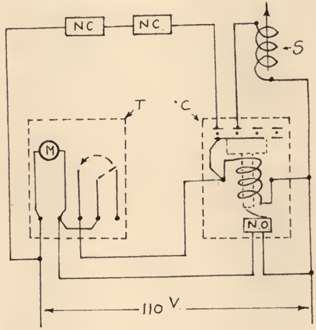
Rate A: 77/2000 minute
Rate B: 70/2000 minute
Rate C: 64/2000 minute

This was the most important part of this experiment. As the name of this experiment indicates, all operators were forced to grasp the third brass part to complete the assembly before the "paced time" was over. Whenever the operator missed the "paced time", he would not be able to finish that assembly. A specially designed force pacer was introduced in this experiment to prevent the operator from performing anymore work once the "paced time" elapsed. A complete electrical circuit of the pacer is shown in Fig. 7. As soon as the operator removed his finger tips from the two cycle starting switches, the timer started automatically. After the "paced time" elapsed, the energized solenoid lifted the box shaped obstruction into the up position so the third part could not be grasped by the operator.

This meant that for each rate, the operator was forced to grasp the third part before the respective "paced time" elapsed, otherwise, the third part was blocked by the pacer. When this happens, the assembly remains incomplete.

Table 1. Standard Motion Pattern

Motion	Right hand	Motion	Left hand
Start	First finger over cycle starting button, light just out.	Start	First finger over cycle starting button.
1R	Transport Empty to end of motion, fingers over part 2.	1L	Transport Empty to end of motion, fingers over part 1.
2R	Grasp to point where part lifts clear	2L	Grasp to point where part lifts clear
3R	Transport Loaded until motion stops for assembly	3L	Transport Loaded until motion stops for assembly
4R	Assembly to point where right hand clears parts.	4L	Assembly to point where right hand clears parts
5R	Transport Empty to end of motion, fingers over part 3.	5L	Hold to contact of parts
6R	Grasp to point where part lifts clear		
7R	Transport Loaded until motion stops for assembly		
8R	Assembly to point where either hand clears.	6L	Assembly to point where either hand clears.
Del.	Delivery to point where assembly drops below work surface.	Del.	Delivery to point where assembly drops below work surface.



N. C. - Normally closed micro switch
N. O. - Normally open micro switch
M. - Motor to run timer
T. - Timer, Eagle Signal Corp.
type-HG90A6 110 V. 60 cycles
10 amps. max. cycle time 20 sec.
S. - Solenoid for pacing device
C. - Solenoid for breaking circuit
Square D. Company. 110 V. 60 cycles

Fig. 7. Electrical circuit of the pacer.

Three rolls of 100 feet of film were used for each operator. Each roll consisted of all three rates, which were shot in random order. The order was determined from a table of random numbers, except for the first rate of the first roll, which was the slowest rate. For each filming, each operator was given some practice time.

Selection of Rates, Cycles, Operators, and Groups

Rate Selection. At the outset of this project, rate C alone was selected for analysis. The following was the reason for selecting rate C:

The data of rate C were more consistent. The other rates usually did not require as much effort by the operator to maintain the required pace. Rate C, however, was difficult to achieve and required a consistent effort by the operators at all times. While performing rates A and B, some of the operators needed to try harder to achieve the rate, whereas, to achieve rate C, an all out effort was required by all operators.

Cycle Selection. All complete cycles of rate C were used for the analysis, except those in which the operator made a serious positioning error or dropped one of the parts. It was obvious that if these cycles were included in the analysis, they would inject erroneous data into the results.

Operator Selection. During the experiment, eleven operators were recruited and data were collected for all. The data of operator No. 8 had to be omitted from the study because he delivered the assembled parts alternatively with both hands.

<u>Grouping Selection</u>. The data obtained by analyzing rate C cycles were broken into four groups. The groups were chosen according to the length of time spent from the beginning of the assembly to the end of the delivery of the assembled parts.

Group I included all cycle times faster than the goal. This group had a time value range from 75/2000 minute to 87/2000 minute or a 13/2000 minute included cycle, Fig. 8.

Group II included all cycle times from 88/2000 minute to 100/2000 minute. This meant that this group also had the range of 13/2000 minute, Fig. 8.

Group III was also chosen with the same time value range. Thus, the values of this group ran from 101/2000 minute to 113/2000 minute, Fig. 8.

Group IV included all cycle time values greater than 114/2000. Above this cycle time value, observations were scattered and varied. The number of readings in this group was too small to compute a comparable analysis with the rest of the groups. Most of the points of this group were caused by some positioning error by the operators while assembling the parts.

Since these errors were not found in the other groups and since there was insufficient data in this group, the fourth group was omitted from the analysis.

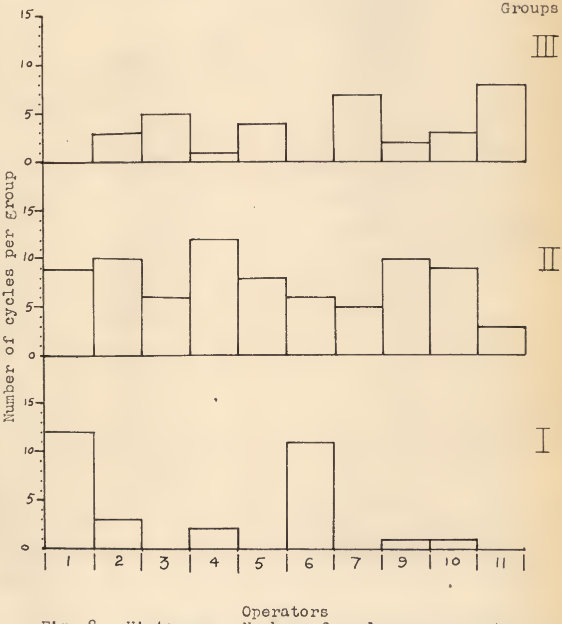


Fig. 8. Histogram: Number of cycles per operator per group.

Analytical Technique

Over-all Film Analysis. The first step in the over-all analysis was to record the total time of all complete cycles of three different rates. As mentioned previously, in each roll of film, an operator was filmed at the three different rates and for each rate the data was recorded on a form as shown in Fig. 9.

A special coding was used while recording the observations. The scene number was noted in the ordinary way, such as, a code number, consisting of operator number, roll number, and rate. Location of this particular rate in the roll was designated by 1, 2, or 3. For example, if 2 was written in the blank, it meant that the location of the rate in this particular roll was in the middle portion of the roll. Similarly, 1 and 3 were noted for the first portion and last portion of the roll, respectively.

In the second and third column of the form, the readings of the microchronometer were recorded. Column four was calculated by finding the difference between the 2nd and 3rd column. The remark column was used to note the type of error committed during the cycle. If the cycle was acceptable, no comments were noted. E-1, E-2, etc. were the codes used to indicate the causes to reject the cycle. The last column was for some future investigation. A summary of these readings,

CYCLE TIMES

Scene No. VI 22 C Location 2

Sr. No.	1 Unit = 1/2000 Min.			Remark	Select or Reject
	Start	End	Cycle Time		
1	120	213	93		
2	282	382	100		
3	445	525	80		
4	605	697	92		
5	702	777	-	E-1	
6	858	935	77		
7	020	110	-	E-5	
8	205	285	-	E-1	
9	358	433	75		

Good Cycles	Sub Total	Film Ave.
6	517	86.17

Fig. 9. An example of the standard form used to record cycle time and film average with a typical set of values.

the number of good cycles, the total of all cycle time, and the average film time were noted in tabular form.

Detailed Film Analysis. After completing the over-all analysis of the film, a detailed film analysis for rate C was performed. The first step in this detailed analysis was to break the assembly cycle into the component motions to be studied. The same motions as those used in the previous study (12) were used in this study. The standard motion pattern used is shown in Table 1.

It may be noted from this table that the starting point of a cycle is indicated by a flashing light, which was obtained when the starting buttons were pushed simultaneously. The switches and light are shown in Figs. 2 and 3.

After the standard motion pattern was identified, all cycles of rate C were projected on a screen and the time for each component part was recorded. An example of the form and a set of typical cycle time values is shown in Fig. 10. The cycle number consisted of scene number and serial number, both as noted in Fig. 9. After recording the time for each component part and checking the total time with the one recorded previously, the group number for the cycle was noted.

Cycle Percentage Data. After recording the time values and component motions for each cycle, the component motions were converted into the percentage of their respective total cycle times. The percentage cycle times were also recorded in the motion pattern time data form, Fig. 10.

MOTION PATTERN TIME DATA

Cycle No. II 09 C-8

Right Hand				Left Hand			
Motion	Begin	Req'd	Cycle%	Motion	Begin	Req'd	Cycle%
1	360			1	360		
2	369	9	9.47	2	371	11	11.57
3	379	10	10.52	3	380	9	9.47
4	388	9	9.47	4	388	8	8.42
5	407	19	19.99	5	407	19	---
6	411	4	4.21	6	421	14	---
7	414	3	3.16	7	448	27	---
8	421	7	7.36	8	454	6)	7.36
9	448	27	28.40	9	455	1)	
10	469	21	---	10	469	14	---

Cycle Time 95 Group No. II

Fig. 10. An example of the standard form used to record motion time values, cycle time, Group No. and cycle%. (with typical values).

There were two reasons for converting the absolute time values for the component motions into a percentage of the total cycle time;

1. This method allowed for a comparison, of the percentage values to the absolute values, to be made and thus gave a more complete study of the available data.

2. If absolute values would have been used when considering a component motion time value which varied between groups, it could be ascertained only that the component motion time values did vary between the groups. By using percentages, the variance could be tested first to see whether the percentage between groups was the same or if they still contained a significant variance. After performing this test, it could be determined if a particular component motion time value increased or decreased in proportion to the increase or decrease of the total cycle time for different groups.

After recording all data in the table, the forms were sorted according to the group classification. Then a final summary was prepared for each rate in each group. This was done by rearranging the percentage cycle time of each sheet. This gave the final summary of all rates separately. Then the time value average for each operator was calculated for each rate, Fig. 11.

SUMMARY OF CYCLE PERCENTAGE DATA

Time 1R Group II

Cycle No.	OPERATORS									
	#1	#2	#3	#4	#5	#6	#7	#9	#10	#11
1	8.42	9.27	9.00	8.16	7.14	7.53	7.00	6.12	11.45	9.00
2	7.14	10.10	8.60	8.89	7.78	5.00	6.31	6.18	8.42	8.00
3	7.78	9.47	8.89	8.50	7.21	4.44	8.33	7.21	8.60	8.00
4	7.29	9.47	9.00	9.27	8.24	5.68	8.33	6.25	8.98	
5	7.78	8.16	11.22	8.89	8.08	7.86	9.47	7.14	8.24	
6	7.21	10.30	9.09	8.50	7.36	5.56		8.00	7.36	
7	7.21	9.09		9.27	7.14			9.09	8.42	
8	7.78	8.08		8.98	6.12			8.16	8.24	
9	7.29	11.23		10.11				8.42	8.89	
10		10.98		9.00				8.24		
11				8.42						
12				9.09						
Average %	7.54	9.61	9.30	8.92	7.38	6.01	7.88	7.48	8.73	8.33

Fig. 11. An example of the standard form used to record the summary of the cycle percentage with a typical set of values.

ANALYSIS OF DATA

Over-all Analysis

The next step after recording all time values for all rates, was to prepare the summaries for the three rates. The number of good cycles, the total of all cycle times, and the average film time from each time data form was transferred to the respective summary sheets according to the rate classification. Then the final average film averages were calculated by dividing the total of all cycle times by the total number of good cycles. This was the method used to calculate the three final average film times.

A table was prepared showing allowable time and actual mean time of this project for each rate. The percentage change (drop or rise) was calculated as shown in Table 2.

$\overline{X}$ and R Charts

After completing the tables of the summary of the cycle percentage data, one of the first phases of the analysis was to determine whether the operators were performing the various motions of the assembly cycle in a similar and homogeneous pattern.

One of the methods of checking homogeneity regarding the data is by means of constructing $\overline{X}$ and R charts. A control

Table 2. Summary of the cycle times.

Rate	Total Given Time	Overall Average Cycle Time (Calculated)	Difference in Time	% Decrease or Increase in Given Time
A	127 Units	106.64	20.36	18.65% Decrease
B	110 Units	100.23	9.77	8.88% Decrease
C	97 Units	97.23	.23	.23% Increase

chart is a statistical device used principally for the study and control of repetitive processes, such as the operation performed in this project.

The component motion percentage of total time as recorded in Fig. 10 was defined as the X values. Similarly, the difference between the largest and smallest X value per operator, which was called the range, R, was calculated. The points plotted on the $\overline{X}$ chart and R chart were the $\overline{X}$ values and R values.

According to the standard procedure of the statistical methods, it was necessary to determine the control limits for both types of charts. This complete data was recorded on a control chart data form as shown in Fig. 12. The upper and lower limits for the control charts were set at plus and minus three standard deviations. This gave 99.7% surety that any point that fell out of control had an assignable cause. In this case it could be said that a lack of homogeneity appeared among the operators.

CONTROL CHART DATA

Time 1R

Group III

Value	OPERATORS						
	#2	#3	#5	#7	#9	#10	#11
n	3.000	5.000	4.000	7.000	2.000	3.000	8.000
$\overline{X}$	8.950	9.350	6.500	7.350	6.670	6.840	8.210
R	4.000	4.980	2.470	1.100	1.910	1.940	5.710
d_2	1.693	2.326	2.059	2.704	1.128	1.163	2.847
R/d_2	2.364	2.141	1,200	0.407	1.694	1.147	2.004
D_2	4.358	4.918	4.698	5.203	3.686	4.358	5.307
D_1	0.000	0.000	0.000	0.205	0.000	0.000	0.387
$D_2 \sigma X'$	6.820	7.700	7.350	8.140	5.770	6.820	8.310
$D_1 \sigma X'$	0.000	0.000	0.000	0.320	0.000	0.000	0.610
A	1.732	1.342	1.500	1.134	2.121	1.732	1.061
$A \sigma X'$	2.710	2.100	2.350	1.770	3.320	2.710	1.660
$\overline{\overline{X}}+A \sigma X'$	10.530	9.920	10.170	9.590	11.140	10.530	9.480
$\overline{\overline{X}}-A \sigma X'$	5.110	5.720	5.470	6.050	4.500	5.110	6.160

$$\overline{\overline{X}} = \frac{\Sigma X}{N} = 7.820$$

$$\sigma X' = \Sigma(R/d_2)\ /n = 1.565$$

$$UCL_{\overline{X}} = \overline{X} + A\ \sigma X' \qquad UCL_R = D_2\ \sigma X'$$

$$LCL_{\overline{X}} = \overline{X} - A\ \sigma X' \qquad LCL_R = D_1\ \sigma X'$$

Fig. 12. An example of the standard form used to record the control chart data with a typical set of values.

The method of obtaining the limits for the control chart is used by A. J. Duncan (4) and recorded in the forms as follows:

Row 1: n, the number of observations per operator.

Row 2: $\bar{X}$, the average percentage per operator.

Row 3: R, the range of X values of operator.

Row 4: d_2, constant from Duncan, page 886.

Row 5: R/d_2, calculated.

Row 6: D_2, constant from Duncan, page 886.

Row 7: D_1, constant from Duncan, page 886.

Row 8: $D_2 \sigma X'$, calculated, UCL for R chart.

Row 9: $D_1 \sigma X'$, calculated, LCL for R chart.

Row 10: A, constant from Duncan, page 886.

Row 11: $A \sigma X'$, calculated.

Row 12: $\bar{\bar{X}} + A \sigma X'$, calculated, UCL for $\bar{X}$ chart.

Row 13: $\bar{\bar{X}} - A \sigma X'$, calculated, LCL for $\bar{X}$ chart.

For completion of the calculation, it was necessary to compute $\bar{\bar{X}}$ and $\sigma X'$ for each data form. The procedure for this calculation has been noted on the data form.

Most of this computation seemed to be repetitive and similar in procedure, so, a computer program was written in SOAP and the IBM 650 Computer was used for the calculations. The complete program is shown in Appendix B.

It was found from the printed output of the accounting machine (IBM 402) that 31 points fell outside the control limits of $\bar{X}$ chart and R chart. This led to an immediate question of whether any one operator or any one motion within a certain group contained more points out of control than the other operators or motions. So, to discover an answer to this question, Tables 3 and 4 were constructed.

Analysis of Variance

One of the most powerful tools of statistical analysis is the analysis of variance. Basically, it consists of classifying and cross-classifying the data and testing whether the means of a specified classification differ significantly.

In this project, it was desired to know whether the percentages of total cycle time for each motion varied significantly from group to group and from operator to operator. Thus, this was the two-way classification analysis of variance, for operators and groups.

A table was prepared for one motion time data and it was realized that in some of the cells of the table there were no data. This happened because of the different characteristics used to prepare the assembly by different operators. So, to analyze the data for the analysis of variance it was necessary to divide the data into two parts.

In the first part there were four operators and three groups, Fig. 13, while in the second part, there were four operators and two groups, Fig. 14.

Table 3. Summary of points outside the control limits from the $\overline{X}$ and R Charts comparing operators against groups.

Oper. No.	Groups												Sub Total				Total
	I				II				III								
	$\overline{X}$&R: 5				$\overline{X}$&R: 20				$\overline{X}$&R: 6				31				31
	X:5		R:0		X:17		R:3		X:5		R:1		X:27		R:4		,
	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H	L	
.	5	0	0	0	8	9	3	0	4	1	1	0	17	10	4	0	
1					1	1	1						1	1	1		3
2	4				2		1		2				8		1		9
3					1	1				1			1	2			3
4	1				1	1							2	1			3
5						1								1			1
6					1	2							1	2			3
7											1				1		1
9		1			1								1	1			2
10					1	2							1	2			3
11					1		1		1				2		1		3

H - is a point that fell above the upper control limit.

L - is a point that fell below the lower control limit.

Table 4. Summary of points outside the control limits from the $\overline{X}$ and R Charts comparing motions against groups.

Motions.	Groups												Sub Total				Total
	I				II				III								
	$\overline{X}$&R: 5				$\overline{X}$&R: 20				$\overline{X}$&R: 6				31				31
	X:5		R:0		X:17		R:3		X:5		R:1		X:27		R:4		
	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H	L	
	5	0	0	0	8	9	3	0	4	1	1	0	17	10	4	0	
1R	2				1	1							3	1			4
2R	1				1	2	1		1				3	2	1		6
3R							1				1				2		2
4R					1								1				1
5R										1				1			1
6R																	0
7R					1								1				1
8R																	0
1L	1				1	2							2	2			4
2L	1				2	2			1				4	2			6
3L									1				1				1
Del.					1	2	1		1				2	2	1		5

ANALYSIS OF VARIANCE

Time 1R

Oper.	Groups			$\overline{X}i.$
	I	II	III	
2	9.68	9.61	8.95	28.24
4	10.29	8.92	7.62	26.83
8	7.22	7.48	6.67	21.37
9	8.04	8.73	6.87	23.64
$\overline{X}j.$	35.23	34.74	30.11	100.08

(1) $\Sigma(\Sigma\ \overline{X}i.)^2/3 = 2352.87/3 = 844.29$

(2) $\Sigma(\Sigma\ \overline{X}j.)^2/4 = 3554.63/4 = 838.66$

(3) $\Sigma(\overline{X}ij)^2 = 850.29$

(4) $(\Sigma\ \overline{X}ij)^2/12 = 10016.01/12 = 834.67$

(5) (1)-(4) = 9.62

(6) (2)-(4) = 3.99

(7) (8)-(5)-(6) = 2.01

(8) (3)-(4) = 15.62

Source of Variation	Sum of Squares	D.F.	Mean Square	Variance Ratio
Operators	9.62	3	3.21	9.44*
Groups	3.99	2	2.00	5.88*
Residuals	2.01	6	0.34	

Fig. 13. An example of the standard Form No. 1 used to record computations of analysis of variance with typical values.

ANALYSIS OF VARIANCE

Time 1R

Oper.	Groups		$\bar{X}i.$
	II	III	
3	9.30	9.35	18.65
5	7.38	6.50	13.88
7	7.88	7.35	15.23
10	8.33	8.21	16.54
$\bar{X}j.$	32.89	31.41	64.30

(1) $\Sigma(\Sigma\bar{X}i.)^2/2 = 1046.00/2 = 523.00$

(2) $\Sigma(\Sigma\bar{X}j.)^2/4 = 2068.34/4 = 517.09$

(3) $\Sigma(\bar{X}ij)^2 = 523.54$

(4) $(\Sigma\bar{X}ij)^2/8 = 4134.49/8 = 516.81$

(5) (1)-(4) = 6.19

(6) (2)-(4) = 0.28

(7) (8)-(5)-(6) = 0.26

(8) (3)-(4) = 6.73

Source of Variation	Sum of Squares	D.F.	Mean Square	Variance Ratio
Operators	6.19	3	2.06	22.89*
Groups	0.28	1	0.28	3.11
Residuals	0.26	3	0.09	

Fig. 14. An example of the standard Form No. 2 used to record computations of analysis of variance with typical values.

The method, used to compute the analysis of variance for these data, was to find the mean squares for the operators and groups, and compare the variance ratios to the critical $F_{0.05}$ and $F_{0.01}$ values found in the table of "Percentage Point of the F-Distribution", such as may be found in Duncan (4).

For the first part of the data, the computational procedure was as follows:

(1) A table of the cycle percentage averages per operator per group was constructed as shown in Fig. 13.

(2) The $\Sigma \bar{X}_i$ and $\Sigma \bar{X}_j$ were computed for the rows and columns respectively.

(3) Complete computation of the sum of squares was done as shown in the eight steps in the form, Fig. 13.

(4) The next step was to determine the degrees of freedom.

   (a) For the operator, the number of degrees of freedom was one less than the number of rows or three degrees of freedom.

   (b) Similarly for groups, the number of degrees of freedom was two.

   (c) The residual degrees of freedom was equal to the operator's degrees of freedom, times the group's degrees of freedom, or six degrees of freedom.

(5) The mean squares were computed by dividing the sum of squares by the respective degrees of freedom.

(6) The mean squares of the operators and the groups were divided by the mean squares of residuals and these two ratios, known as variance ratios, were tabulated in the last column of Fig. 13.

(7) The critical variance ratio, F, was determined for the operators for $n_1 = 3$ degrees of freedom, $n_2 = 6$ degrees of freedom at the 5% and 1% level of significance. It was also determined for the groups at 2 and 6 degrees of freedom at both significance levels.

(8) The last step was the comparison. The variance ratios found in step 6 were compared, for both operators and groups, with the critical variance ratios derived in step 7 at both the 5% and 1% levels of significance. If the variance ratios were larger than the critical variance ratio values, the source of variations (either operators or groups) were significant sources of variation at the level of significance tested. Variance ratios that are significant at the 0.05 level are starred. Those significant at the 0.01 level are double starred.

A summary of the analysis of variance for all twelve motions is shown in Tables 5 and 6.

Histograms

For the graphical analysis two histograms were constructed. The main purpose of these two histograms was to compare

Table 5. The summary of analysis of variance according to the types of motions for Form No. 1.

Motion	Comparison of	Significant Variance ?		Motion Type
		5%	1%	
1R	Operators Groups	Yes Yes	No No	Reach
2R	Operators Groups	Yes No	Yes No	Grasp
3R	Operators Groups	No No	No No	Return
4R	Operators Groups	No No	No No	Assembly
5R	Operators Groups	Yes Yes	No No	Reach
6R	Operators Groups	No No	No No	Grasp
7R	Operators Groups	No No	No No	Return
8R	Operators Groups	No Yes	No Yes	Assembly
1L	Operators Groups	Yes No	Yes No	Reach
2L	Operators Groups	Yes No	Yes No	Grasp
3L	Operators Groups	Yes No	No No	Return
Del.	Operators Groups	Yes Yes	Yes Yes	Delivery

Table 6. The summary of analysis of variance according to the types of motions for Form No. 2.

Motion	Comparison of	Significant Variance ?		Motion Type
		5%	1%	
1R	Operators	Yes	No	Reach
	Groups	No	No	
2R	Operators	No	No	Grasp
	Groups	No	No	
3R	Operators	No	No	Return
	Groups	No	No	
4R	Operators	Yes	Yes	Assembly
	Groups	Yes	No	
5R	Operators	Yes	Yes	Reach
	Groups	Yes	No	
6R	Operators	No	No	Grasp
	Groups	No	No	
7R	Operators	No	No	Return
	Groups	No	No	
8R	Operators	Yes	No	Assembly
	Groups	Yes	No	
1L	Operators	Yes	No	Reach
	Groups	No	No	
2L	Operators	Yes	No	Grasp
	Groups	No	No	
3L	Operators	No	No	Return
	Groups	Yes	No	
Del.	Operators	No	No	Delivery
	Groups	No	No	

graphically the amount of time needed, and the percentage of total cycle time needed to complete a component of motion for the three groups. The histograms constructed appear in Figs. 15 and 16. These two histograms permitted a complete comparison of increases and decreases in time from group to group for all component motions to be made.

As the percentages of total cycle time were plotted for both hands on the same histogram, the summation of the within-group percentage did not total 100%. The same thing was true for the motion time histogram. If motions 1R through "delivery" were plotted, they would total 100%. Similarly, if all left hand motions were plotted, they would also total 100%.

SUMMARY OF RESULTS

An examination of Table 2 provides some interesting aspects of the characteristics of the work cycles at different rates. It could be pointed out from Table 2 that in the slower rates, the mean of total cycle time dropped considerably, while the cycle time for rate C remains constant.

This indicates that at the slower rates, A and B, even though the operator had more time to complete the assembly he tried to work faster because of the forced-pace device. Once the operator had started in such an environment, he could not adjust his speed in the last few operations where there were no restrictions.

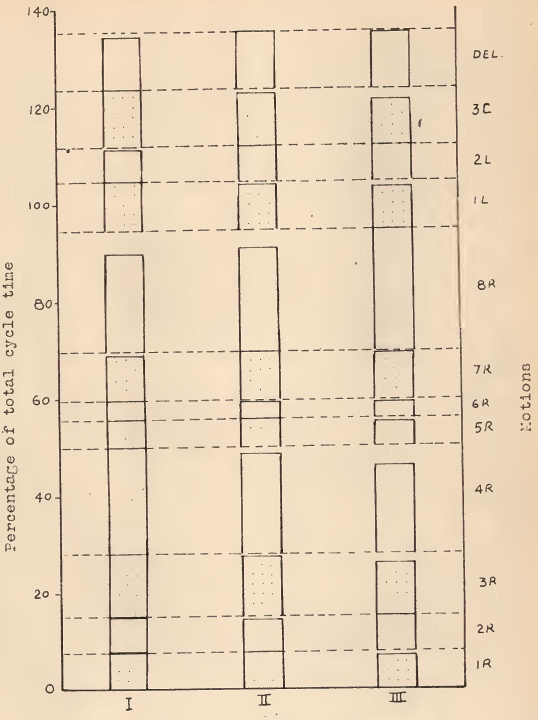


Fig. 15. Histogram: Group comparison of time percentage per motion.

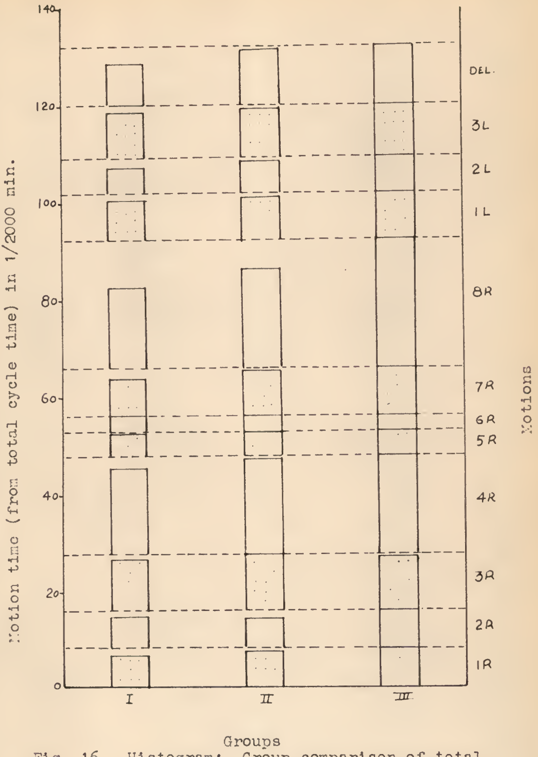


Fig. 16. Histogram: Group comparison of total cycle time per motion.

This may be a psychological effect or human nature that if the operator starts any operation, like an assembly job of this project at a high rate, he cannot slow down speed for some operations and again return to the original speed. In other words, it can be said that it is very difficult to perform some motions within the cycle at high rate and some motions at slow rate.

Out of the 504 points calculated for the control charts, 31 points fell outside the control limits. In other words, 6.15% of the total points were out of control. Out of these 31 points, 27 were $\bar{X}$ chart points, while the remaining 4 were range chart points. The analysis of the data leads to the following remarks.

The percentage of total cycle time values of the operators definitely lacked in homogeneity between one another because too many points fell outside the control limits of $\bar{X}$ charts. If the operators had been performing the assembly in a homogeneous manner, all points would have fallen within the control limits of $\bar{X}$ charts.

Even though there were 27 points out of control on $\bar{X}$ charts, there were only 4 points out of control on R charts and all of these points were above the upper control limit. Since there were 4 points out of control, it is obvious that there was variability, but as the number of points out of control on the R charts was few in comparison with the $\bar{X}$ charts, this provides a point that probably should be investigated further in a later study.

Even though a great deal of variation was present between operators, the time values of any particular motion of any operator were not found to be big or small with any regularity. In other words, it is safe to conclude that in any forced pace operation where the operators always need to try harder to achieve the rate, the time value of any motion would seldom be too big or small, even though variability was present.

As mentioned previously, Tables 3 and 4 were constructed in an attempt to check whether any one operator or any one motion within a group contained more points out of control than the other operators or motions.

Table 3 comparing operators against groups, shows a fairly even range of values of data that was analyzed. However, operator No. 2 had more points out of control than the trend of the others. For operator No. 2, all points of the $\bar{X}$ chart which were out of control fell above the upper control limit. For the other operators there was no specific trend. It appears that each operator attained a certain level at which he was producing his percentage of total cycle time values and, in general, this level was different from the other operators.

Table 4, comparing motions against the groups, showed two motions with more points out of control than any other motions.

The motions out of control were 2R and 2L. This was an interesting point as both these motions were grasps that were performed simultaneously by the right and left hands. An explanation for this might be that the part being grasped was not picked up securely and the operator may have temporarily lost control of the part. Consequently, the operator had to regrasp it which caused a great deal of variability. These slips could happen because the two pieces were being picked up simultaneously by both hands. It was observed that while picking up two pieces, the operators looked directly at one piece even though both pieces were being picked up together. This often led to poor grasping of the piece which was not viewed. The explanation was backed by the fact that motion 6R, which is also a grasp by the right hand while the left hand simply holds the first two assembled parts, did not contain any points out of control.

Motions 1R and 1L also contained a large number of points which were out of control. The reason for this could be because of the different reaction time of the operators. In this motion, the operator had to press the two switches simultaneously and then start the cycle, so after pressing the switches, some of the operators were slightly slower to start the cycle which caused this variability.

While disposing of the complete assembly, some operators used a slightly different way which caused some of these points to fall outside the control limits.

Even though motions 4R and 8R were the assembly operations, they did not contain a significant number of points out of control. This was an interesting point, that these motions which were variable between groups and operators, were not variable within a group of given motions.

Tables 5 and 6 were condensed and tabulated, as shown in Table 7 and 8, according to the types of motions. The main purpose of condensing the summary was to check the characteristics of similar motions within the cycle.

A study of the four tables points out some specific trends followed during the motions. The percentage of the total cycle time spent on the reach motions from the different Tables 5 through 8, seemed to be a significant source of variation for the operators at the 5% level, but at 1%, there was no significant variation. There was a split in the significance at the 5% level and no significance at the 1% level for group to group comparison. This indicates that even though there was significant variance between the percentage values of the operators, there was very little variability between the percentage values of the operators.

Similarly, the percentages of the total cycle time spent on all other motions were studied. It was found that each motion had significant variance at the 5% level and little variability at the 1% level for the operator to operator comparison.

Table 7. A condensation of the summary of the analysis of variance according to the types of motions in Form No. 1.

Motion Type	Number of Motion Types	Comparison of	Significant Variance ?	
			5%	1%
Reach	3	Operators	Yes	Split
		Groups	Split	No
Return	3	Operators	Split	No
		Groups	No	No
Grasp	3	Operators	Split	Split
		Groups	No	No
Assembly	2	Operators	No	No
		Groups	Split	Split
Delivery	1	Operators	Yes	Yes
		Groups	Yes	Yes

Table 8. A condensation of the summary of the analysis of variance according to the types of motion in Form No. 2.

Motion Type	Number of Motion Types	Comparison of	Significant Variance ?	
			5%	1%
Reach	3	Operators	Yes	Split
		Groups	Split	No
Return	3	Operators	No	No
		Groups	Split	No
Grasp	3	Operators	Split	No
		Groups	No	No
Assembly	2	Operators	Yes	Split
		Groups	Yes	No
Delivery	1	Operators	No	No
		Groups	No	No

The amount of cycle time spent on the grasp showed no significant variance at either the 5% or the 1% levels for the group to group comparison. All other motions showed a split in the significant variance at the 5% and very little variability at 1% for the group to group comparison.

In other words, it could be said that the variability was present, randomly scattered, in all the motions of this assembly operation.

Some interesting relations were noted from Fig. 15, the "Group Comparison of Total Cycle Time per Motion" and Fig. 16, the "Group Comparison of Time Percentage per Motion".

It was a noticeable point that the assembly motions, 4R and 8R, took the greatest percentage of total cycle time and showed the greatest over-all change from Group 1 to Group 3. Even though the motion 4R was most variable from group to group, it was the most consistant with respect to its change from one group to another. The same was true for the less complex assembly motion 8R. It was clear from the histograms that nearly all of the increase in the total cycle time from Group 1 to Group 3 was because of these assembly operations.

When comparing the remaining motions, they showed nearly the same relative change from one group to another. However, the changes did not increase in proportion to the analysis of variance. These changes varied randomly from one group to the next. So, even though the change in percentage of total cycle time taken by the motion was nearly the same when comparing the motions, it was still variable in its relative change when compared to the total cycle time change between groups.

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APPENDIX A

The Nature of Employment as Operators

Eleven operators were employed for this project from the staff members, students, and workshop personnel. The time schedules were fixed at their convenience. Each operator was called four times, first time for dexterity test and remaining three times for filming. Each time it took nearly thirty minutes to finish the operation.

On the first call, a peg board test was given to each operator as a dexterity test, and then some practice on the work surface to give some idea what they were supposed to do.

Each time while filming an operator, 100 feet of film was used. The operator filled out a Personal Conditions Form as shown in Fig. 17. The purpose of this form was to check the general conditions of the operator while he was operating.

Complete Setup of the Equipment

The work surface was fixed to the floor by bolts after leveling. The camera mount was also fixed in the position as shown in the schematic diagram, Fig. 18.

Summary of Analysis of Variance

While doing calculations for analysis of variance, the data were divided into two parts as discussed in the thesis, and the separate summaries are presented in Tables 5 and 6. An attempt

PERSONAL CONDITIONS FORM

Date________________

Hour________________

Personnel Code________

Approximate hours of sleep last night_________

Have you any unusual personal worries at the moment? Yes___No___

Check any of the following which may apply to you at this time

_____Sleepy

_____Have Indigestion

_____Have a Cold

_____Physically tired

_____Mentally Fatigued

_____Headache

_____Stuffy (too much food)

_____Nervous

_____Other ailments (specify)_________

____

____

Note: All information on this questionnaire will be held strictly confidential and will be available in coded form only.

Fig. 17. Personal conditions form.

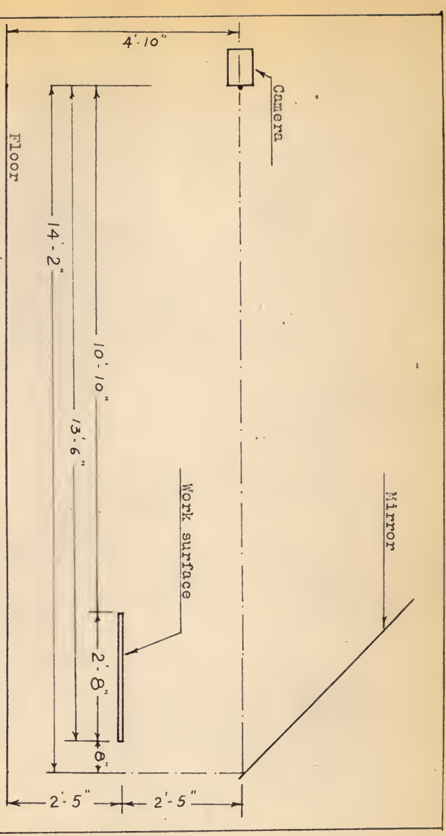

Fig. 18. The schematic diagram of the equipment.

was made to combine these summaries into one table and condensed summaries into another table to see whether some special characteristics was present. The combined summaries did not give any better result, so, it is not included in the thesis.

APPENDIX B

Computer Program for Control Chart Limits

This program calculated the upper and lower limits of $\bar{X}$ and R charts. The Input and Output for this program were in the form of floating point numbers. For this program the IBM 650 computer and SOAP language were used. The input to the program consisted of the following seven words:

Word 1	1 to 10	$\bar{\bar{X}}$
Word 2	11 to 20	$\bar{X}$
Word 3	21 to 30	$\sigma X'$
Word 4	31 to 40	R
Word 5	41 to 50	D_2
Word 6	51 to 60	D_1
Word 7	61 to 70	A

Since one data card gave full data to calculate the required limits for $\bar{X}$ and R charts for one motion, it was not necessary to store any data. Each card was read and the answer was punched out before the next card was read in.

The program was as follows:

```
1        CALCULATE CONTROL LIMITS
1
                REG     P0027     0036     PUNCH AREA
                REG     R1951     1960     READ AREA
      START     RCD      1951              READ CARD
                LDD     R0001              TRANSFER
                STD     P0002              X BAR
                LLD     R0004              TRANSFER
                STD     P0005              R
                RAU     R0007              BRING A
```

```
FMP     R0003              A SIGMA XP
STU     R0007              SIGA
FAD     R0002              UCL X
STU     P0001              STOR UCL X
RAU     R0002              X 2 BAR
FSB     R0007              LCL X
STU     P0003              STOR LCL X
RAU     R0005              D2
FMP     R0003              UCL R
STU     P0004              STOR UCL R
RAU     R0006              D 1
FMP     R0003              LCL R
STU     P0006              STOR LCL R
PCH     P0001     START    PUNCH CARD
```

Output was also in floating point and consisted as follows:

Word 1	1 to 10	Upper Limit for $\bar{X}$ Chart.
Word 2	11 to 20	$\bar{X}$
Word 3	21 to 30	Lower Limit for $\bar{X}$ Chart.
Word 4	31 to 40	Upper Limit for R Chart.
Word 5	41 to 50	R.
Word 6	51 to 60	Lower Limit for R Chart.

In the IBM 533, the General Purpose 80-80 Input-Output board was used. After getting the output from IBM 533, some changes were made before printing the results on the accounting machine. The first three words of the answer cards were transferred to other blank cards in the first thirty spaces. Then, a special code word was punched on each card to identify the motion. It was coded as follows:

Digits 31-32 indicates the operator number.

Digits 33-34 indicates the motion number.

Digit 35 indicates the Group number.

Digit 36 indicates the type of chart
(1 indicates $\overline{X}$ chart)
(2 indicates R chart)

Example: Suppose the code number is 110231

This means that these are the limits of the eleventh operator second motion in the third group for the $\overline{X}$ chart.

In the same way the remaining three words for the R chart were also transferred to blank cards in the first thirty spaces and the code words were punched.

The last operation after printing the answers was to check the points which were out of control. All points which were out of control were marked.

All the answers for the control limits are printed and shown on the following pages.

	8771196051	7620000051	7028804051	010111
*	9642392051	9680000051	6157608051	020111
*	1003372652	1029000052	5766274051	040111
	8810430051	7320000051	6989570051	060111
	8578472051	6010000051	5301528051	010211
*	1021694452	1163000052	3663056051	020211
	1095293252	1029000052	2927068051	040211
	8652260051	8470000051	5227740051	060211
	1439904652	1330000052	1140095452	010311
	1589809252	1200000052	9901908051	020311
	1657145152	1213000052	9228549051	040311
	1446655552	1263000052	1133344552	060311
	2428315052	2324000052	1947685052	010411
	2668630052	1976000052	1707370052	020411
	2776577552	1695000052	1599422552	040411
	2439137552	2243000052	1936862552	060411
	7071078051	5300000051	4848922051	010511
	8182156051	5430000051	3737844051	020511
	8681243051	7320000051	3238757051	040511
	7121115051	6490000051	4798885051	060511

4165808051	3450000051	2974192051	010611
4761616051	3480000051	2378384051	020611
5029248051	3640000051	2110752051	040611
4192640051	3840000051	2947360051	060611
1022509852	9660000051	8054902051	010711
1131019652	7760000051	6969804051	020711
1179761352	9080000051	6482387051	040711
1027396552	8370000051	8006035051	060711
2297697052	2026000052	1770303052	010811
2561394052	2054000052	1506606052	020811
2679844552	2298000052	1388155552	040811
2309572552	2059000052	1758427552	060811
1078758652	1007000052	9192414051	010911
* 1158517252	1200000052	8394828051	020911
1194344152	1029000052	8036559051	040911
1082350552	9520000051	9156495051	060911
8503750051	5340000051	5256250051	011011
* 1012750052	1162000052	3632500051	021011
1085687552	1033000052	2903125051	041011
8576875051	7040000051	5183125051	061011

```
1333043252 1153000052 9949568051 011111
1502086452 9680000051 8259136051 021111
1578019252 1210000052 7499808051 041111
1340656052 1187000052 .9873440051 061111

1300244852 1111000052 8277552051 011211
1536489652 1046000052 5915104051 021211
1642608852 7320000051 4853912051 041211
1310884052 9820000051 8171160051 061211
```

5625552051	2690000051	9295440050	010112
438414805 1	2230000051		20112
3708116051	5800000050		40112
5567204051	4340000051	8168720050	060112
1058006452	4060000051	1748208051	010212
8245336051	4810000051		20212
6973912051	5800000050		40212
1047032852	9410000051	1536304051	060212
9679752051	4040000051	1599444051	010312
7543698051	5700000051		20312
6380466051	7400000050		40312
9579354051	5270000051	1405572051	060312
1551780052	8680000051	2564100051	010412
1209345052	2100000051		20412
1022865052	1390000051		40412
1535685052	1049000052	2253300051	060412
7174536051	3190000051	1185492051	010512
5591314051	1230000051		20512
4729138051	2870000051		40512
7100122051	2790000051	1041796051	060512

3847296051	1200000051	6357120050	010612
2998304051	2250000051		20612
2535968051	2200000050		40612
3807392051	2720000051	5586560050	060612
7006776051	5120000051	1157772051	010712
5460574051	2520000051		20712
4618558051	6600000050		40712
6934102051	4340000051	1017436051	060712
1702764052	5640000051	2813580051	010812
1327011052	3750000051		20812
1122387052	3450000051		40812
1685103052	1642000052	2472540051	060812
5150232051	1160000051	8510040050	010912
4013718051	3330000051		20912
3394806051	5800000050		40912
5096814051	2680000051	7478520050	060912
1048500052	8860000051	1732500051	011012
8171250051	2700000050		21012
6911250051	1840000051		41012
1037625052	9490000051	1522500051	061012

1091558452	5110000051	1803648051	011112
8506816051	4740000051		21112
7195072051	1690000051		41112
1080236852	6150000051	1585024051	061112

1525497652	1008000052	2520672051	011212
1188862452	3590000051		21212
1005540852	2870000051		41212
1509675252	1000000052	2215136051	061212

	9147000051	7540000051	7253000051	010121
*	9098703051	9610000051	7301297051	020121
	9360075051	9300000051	7039925051	030121
	9020102051	8920000051	7379898051	040121
	9204767051	7380000051	7195233051	050121
*	9360075051	6010000051	7039925051	060121
	9470874051	7880000051	6929126051	070121
	9098703051	7480000051	7301297051	090121
	9147000051	8730000051	7253000051	100121
	9840204051	8330000051	6559796051	110121
	8641000051	5670000051	4539000051	010221
	8536399051	8270000051	4643601051	020221
*	9102475051	3940000051	4077525051	030221
*	8366166051	8950000051	4813834051	040221
	8766111051	4540000051	4413889051	050221
	9102475051	8190000051	4077525051	060221
	9342442051	9100000051	3837558051	070221
	8536399051	6240000051	4643601051	090221
*	8641000051	3070000051	4539000051	100221
	1014233252	9330000051	3037668051	110221

1460900052	1213000052	1001100052	010321
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SOME WORK CYCLE CHARACTERISTICS OF A
SIMPLE, HIGH RATE, FORCED-PACE
ASSEMBLY OPERATION

by

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AN ABSTRACT OF A MASTER'S THESIS

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Manhattan, Kansas

1962

The purpose of this thesis was to study the characteristics of some work cycles in a simple, high rate, forced-pace assembly operation. The data obtained from micromotion films, were analyzed by using statistical and graphical methods. Certain conclusions regarding the source of variability present in the work cycles and the possible causes of this variability were drawn. The writer feels that the implications found from this project are just and valid.

By comparing and combining the experimental conclusions of the project, certain general conclusions were drawn as follows:

(1) One of the conclusions of this project was the large amount of variability that was present in the time values of different motions and even in the percentages of these times based on total cycle time. It was found that the operators produced variable over-all cycle times consisting of variable times for motions within the cycles.

As this study was carried out for only one type of assembly work, these conclusions should not be interpreted as necessarily being true for other types of assembly work. Because of these limitations of this project, it was felt that the conclusions do not prove the hypercritical feelings that have appeared in most Time and Motion Study books regarding the reliability of pre-determined time standards.

(2) Next, it was realized that each operator produced the over-all cycle time and the component motion time in his own way which was usually different from the other operators. Some operators were producing the assemblies in such a way that there was not a single reading in Group I, while some were following a different pattern and they did not have any reading in Group III. This was the reason why the data were divided into two parts while analyzing for analysis of variance.

(3) It was noted that one of the principle causes of cycle variability was speed with which some of the operators worked. The assembly motions were the most variable of the motions and also accounted for the largest percentage of the total cycle time. So, it appears that the most significant motion to be considered for improving the over-all cycle time would be the assembly motion.

(4) In all general cases the path of travel during the motion 3R, 7R, and 3L was a straight line or slightly curved, but, during motion 7R, an interesting path was noted for some operators. When the grasping of the third part and rising of the obstruction took place at the same time, some operators were afraid of the pacer. As a result of this, the path was distorted. In such cases, instead of straight travel, the hand went straight upward and then the operator tried to bring it back for assembly operation. Even though the pacer was safe, and this was known to all operators, they changed the usual path unconsciously.