AN INVESTIGATION OF THE VALIDITY OF SYNTHETIC RATING

Thesis for the Degree of M. S.
MICHIGAN STATE UNIVERSITY
Lloyd G. Ritzema
1958

THESIS

This is to certify that the

thesis entitled

AN INVESTIGATION OF THE VALIDITY
OF SYNTHETIC RATING

presented by

LLOYD G. RITZEMA

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of the requirements for

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Dale Jones
Major professor

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By

Lloyd G. Ritzema

AN ABSTRACT

Submitted to the College of Engineering
Michigan State University of Agriculture and
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requirements for the degree of

MASTER OF SCIENCE

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ABSTRACT

Virtually all industrial firms require time standards for scheduling work and determining the effectiveness with which it is accomplished. Since production time standards directly affect the employee's performance measure, the validity of such standards is constantly being challenged. This thesis was intended to contribute toward improvement of the science of setting time standards.

Under present rating methods time standards are subject to various criticisms. To eliminate some of these criticisms a new rating technique called "synthetic rating" was developed. The specific object of this thesis is to test the validity of synthetic rating under certain typical manufacturing conditions.

To test the validity of synthetic rating the prime consideration is the determination of whether or not there is any significant difference in the change of rating in performance of skilled elements as compared with unskilled elements as operator motivation level increases from low to high.

In testing the validity of synthetic rating, two typical short cycle industrial assembly operations were studied. The operations were timed by an automatic electric timer developed by Dr. Dale Jones in connection with the Fair Day's Work Research Program.

Two experimental subjects with industrial experience were used. Each experimental subject performed each operation at six different motivation levels increasing from low to high. At each motivation level the experimental subjects performed each operation for five

cycles. It was intended that the various experiments for each operation differ only in respect to the degree of operator motivation. All other motion time determinants were maintained as constant as possible.

Under the conditions of this study, the following conclusions are suggested:

1. The experimental results obtained indicate that there is no significant difference in the change of rating in performance of skilled elements as compared with unskilled elements as operator motivation level increases from low to high.

2. The experimental results obtained therefore tend to support the validity of synthetic rating as an improved means of establishing better time standards.

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Grateful acknowledgment of generous encouragement and assistance is made to the following persons: Dr. W. Dale Jones, Professor, Department of Mechanical Engineering, Michigan State University; Harrison Wadsworth, Assistant Professor, Department of Mechanical Engineering, Michigan State University; the two experimental subjects; and my wife.

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INTRODUCTION

Virtually all industrial firms require time standards for scheduling work and determining the effectiveness with which it is accomplished. Since production time standards directly affect the employee's performance measure, the validity of such standards is constantly being challenged. This thesis was intended to contribute toward improvement of the science of setting time standards.

In establishing a time standard through direct stop watch time study, the time study man determines the select (usually the average) time the operator actually spends in performing the various divisions (elements) of the work cycle. Then he multiplies these select times by his estimate of the rating at which the work was accomplished, to arrive at the estimated normal time for the work elements. These estimated normal element times are totaled to obtain the estimated normal cycle time, to which is added allowances for personal fatigue, and delay requirements, to arrive at the standard time for the operation.

Time study men can rate unskilled elements more easily than skilled elements. However, it has been suggested that skilled elements may be synthetically rated with accuracy, under certain conditions, by merely using the average rating assigned to unskilled elements preceding and following the skilled movements.

Review of Prior Research:

From a review of the literature many authors mention synthetic rating, but no mention is made regarding the validity of synthetic rating with the exception of one author.

B. W. Niebel,[1] W. Swanson,[2] William Gomberg,[3] Adam Abruzzi,[4] and M. E. Mundel[5] are the authors that mention synthetic rating without presenting evidence of evaluation of its soundness.

P. W. Schwab[6] investigated the basic assumptions of synthetic rating as proposed by Robert L. Morrow[7] in his book, Time Study and Motion Economy. These assumptions are that within limits all manually controlled elements of a time study are affected equally by variations in operator skill, aptitude, pace, exertion, attitude, etc. He investigated these assumptions by photographing six different, light, manually controlled, industrial operations using six different operators. Every operator performed but one operation. Each operator performed

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1 Niebel, B. W., Motion and Time Study. Homewood, Illinois: Richard D. Irwin Inc., 1955.

2 Swanson, W. and Niebel, B. W., Stops and Go's in Time Study. Clinic Proceedings, Industrial Management Society, 1956.

3 Gomberg, W., A Trade Union Analysis of Time Study, 2nd Edition. New York: Prentice-Hall, Inc., 1955.

4 Abruzzi, Adam, Work Measurement. New York: Columbia University Press, 1952.

5 Mundel, M. E., Motion and Time Study, 2nd Edition. New Jersey: Prentice-Hall, Inc., 1957.

6 Schwab, P. W., An Investigation to Determine the Proportionality of Element and Therblig Times at Typical Levels of Factory Activity. Lafayette, Indiana: M. S. Thesis, Purdue University, 1948.

7 Morrow, Robert L., Time Study and Motion Economy. New York: Ronald Press Co., 1946.

his operation for five complete cycles at six different speeds of performance ranging from medium slow to medium fast. The data was obtained by analyzing the film by frame counting. Each cycle was analyzed and broken down into therbligs for the right and left hand. After completing the frame counting of each cycle by therbligs, all similar therbligs for each operation were reduced to a common base for purposes of comparison.

Schwab's comparison was based on the use of correlation coefficients using rate of activity and therblig time as the two variables. He took as a common base for each distribution of therbligs, the time for the therblig at 100 percent rate of activity, and using this corrected value, he obtained an index of proportion for every distribution of similar therbligs. Then he obtained correlation coefficients for the right and left hand and compared these correlation coefficients to the correlation coefficients of a hypothetical time study developed by statistical means using three standard deviations equal to 15 percent. The 15 percent was used since it was assumed that in general practice a time study could be in error by plus or minus 15 percent.[8] The comparison of these correlation coefficients was done by the use of "t-tests".

Schwab concluded that the assumptions made by Morrow were not even remotely tenable and that the residual error with such a procedure had limits too wide for acceptance.

Several questions arise from Mr. Schwab's presentation, and they are:

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8 Barnes, R. M., <u>Motion and Time Study</u>. New York: John Wiley & Sons, 1949.

1. How could he know the degree of effect of the variations previously mentioned on either the unskilled or skilled therbligs since they were considered together.

2. How could he know that the operator was performing the operation at the requested speed since no mention was made of any control mechanisms to insure this.

3. Time study experiments suggest that it is more difficult for the operator to work uniformly throughout the work cycle at speeds slower than the operator's usual work speed than it is at speeds which are greater. Many operators find it difficult to work at a requested slower pace during the time study. Thus, had he any assurance that the operator maintained the requested slower pace since, again, there are no such controls mentioned.

4. How could he know what caused the variations he encountered, i.e., the difference between operators, the difference between operations, and/or the difference between the unskilled and skilled therbligs since no controls to determine this were mentioned.

Robert L. Morrow[9] when developing synthetic rating supervised the experiments testing the validity of his recommended synthetic rating method. At present he is doing more research, particularly in defining and limiting the valid applications of synthetic rating.

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9 Morrow, Robert L., Op Cit

OBJECTIVE

Since the rating (judgment) process is the least accurate determinant of many time standards, it is understandable that the validity of the time study man's ratings are most vulnerable to challenge and criticism. Accordingly, this thesis was intended to test the validity of the aforementioned synthetic rating procedure under certain typical manufacturing conditions.

Further understanding of the synthetic rating technique can be affected through use of an example. Assume an operation cycle consists of four work divisions: two unskilled, easily rated elements, and two skilled elements which would be quite difficult to rate accurately. After determining the average actual performance time of each of the four elements, the time study man assigns rating factors of 120 percent to one of the unskilled elements and 125 percent to the other. Then, he averages these two ratings to obtain 122½ percent, which is applied to each of the two skilled elements to synthetically rate them. As previously noted, the select element times (average times in this case) are multiplied by the respective ratings, factorially expressed, to obtain estimated normal or 100 percent times for the elements.

As pointed out by Morrow, synthetic rating is most valid when:

1. The operator is highly trained,
2. The operator has the same degree of motivation throughout all phases of the work cycle,
3. The operator is applying the same relative degree (rating) of skill in behalf of both unskilled and skilled elements.

The time study man can, through observation, determine with reasonable accuracy whether the operator is highly trained (point 1) and whether the operator is equally motivated in the performance of both unskilled and skilled elements (point 2). However, determining whether the operator is performing skilled elements at the same rating as unskilled elements (point 3), a requirement for valid synthetic rating, is difficult to determine by observation. It is this problem which prompted this thesis. The specific objective of this thesis is to determine, for typical production conditions involving trained operators, motivated equally in behalf of performance of both unskilled and skilled elements, whether there is any significant difference in the change of rating in performance of skilled elements as compared with unskilled elements, as operator motivation level gradually increases from low to high. Stated in another way, it is desired to determine if there is any significant change of the portion of the total cycle time spent in performing unskilled (or skilled) elements as the operator decreases cycle time by increasing his work speed.

Assume that a cycle is composed of one-half minute skilled work and one-half minute unskilled work when performed at a slow pace. If the performance is then observed at a greater degree of motivation and the time spent on the skilled portion of the cycle is found to be significantly greater than that spent on the unskilled portion of the cycle, there is evidence that at the original slow pace, the skilled portion of the cycle was performed at a higher rating than the unskilled portion of the cycle. (See Figure 1, Case I). If this difference of rating was significant, it would not be correct to synthetically rate the skilled portion of the cycle through use of the estimated rating of the unskilled portion of the cycle: to do so would result in unequal earning opportunities for the time spent on the unskilled work elements as compared to the time spent on the skilled work elements.

On the other hand, if the performance is observed at a greater degree of motivation and the time spent on the unskilled portion of the cycle is found to be significantly greater than that spent on the skilled portion of the cycle, there is evidence that at the original slow pace the unskilled portion of the cycle was performed at a higher rating than the skilled portion of the cycle. (See Figure 1, Case II). If this difference of rating was significant, again it would not be correct to synthetically rate the skilled portion of the cycle through use of the estimated rating of the unskilled portion of the cycle.

If the performance is observed at a greater degree of motivation and the ratio of cycle time spent on the unskilled (or skilled) portions of the cycle is not significantly greater than that spent on the skilled (or unskilled) portions of the cycle, there is evidence that at the original slow pace, the unskilled (or skilled) portion of the cycle was performed at the same relative rating as the skilled (or unskilled) portion of the cycle. (See Figure 1, Case III). If this difference of rating was not significant, it would be correct to synthetically rate the skilled portion of the cycle through use of the estimated rating of the unskilled portion of the cycle: to do so would result in equal earning opportunities for the time spent on the unskilled or skilled work elements. This would indicate the validity of the synthetic rating technique.

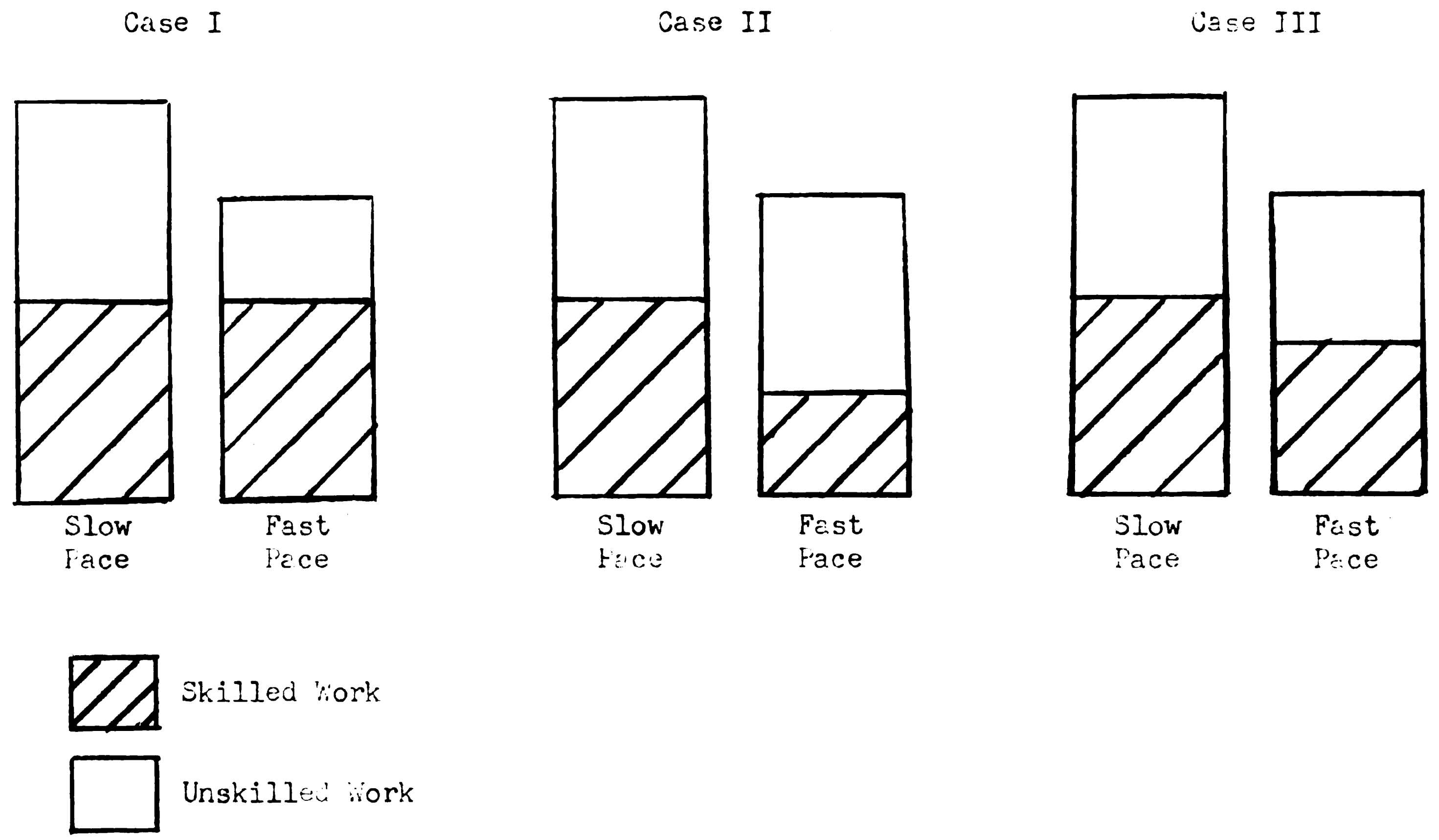

Figure 1 Graphical Representation of Hypothetical Cases.

EXPERIMENT PROCEDURE

Two typical short cycle industrial assembly operations were studied. Operation A, the clevis assembly illustrated in Figure 2, consists of a clevis assembled to a base through use of two pins and a machine screw; and a pivoting bar assembled in the throat of the clevis through use of a pin. Operation B, the worm and gear assembly illustrated in Figure 3, consists of a worm, one end of which is assembled in a hole of the housing and the other end to which is assembled first a ball bearing assembly and then a flange, after which a spur and worm gear cluster is assembled to the worm. The following explanation of the experiment procedure applied to both Operations A and B.

The Operation Motion Patterns

The experimental motion pattern was established. Each operation was divided into four elements. These elements are listed on right and left hand charts shown in Tables I and II. Each operation consists of four elements: two elements that were considered the least skilled of the four elements and two elements that were considered the most skilled of the four elements.[10] For Operation A the least skilled elements were elements 1 and 3, and the most skilled elements were elements 2 and 4. For Operation B, the least skilled elements were elements 1 and 2, and the most skilled elements were elements 3 and 4.

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[10] The relative degrees of dexterity and eye-hand coordination requirements of the four elements, as judged by the writer and Dr. Dale Jones, was the criterion for ranking the elements in reference to skill.

Figure 2 The Workplace Layout for the Clevis Assembly.

Figure 3 The Workplace Layout for the Gear Assembly.

TABLE I

RIGHT AND LEFT HAND CHART FOR OPERATION A

Element	Left Hand	Right Hand	End Points
1	Get and position base	Aside finished assembly	When both hands start reach for base pins
2	Get and position base pin	Get and position base pin	When both hands start reach for clevis and machine screw
3	Get and position clevis	Get and position machine screw	When both hands start reach for pivoting bar and pivoting bar pin
4	Get and position pivoting bar pin	Get and position pivoting bar	As left hand starts to reach for base and as right hand starts to aside finished assembly

All grasps are "see" type grasps.

All transport distances are 15 inches.

TABLE II

RIGHT AND LEFT HAND CHART FOR OPERATION B

Element	Left Hand	Right Hand	End Points
1	Aside completed assembly and get flange	Get and assemble bearing to flange	When right hand starts reach for worm
2	Hold	Get and assemble worm to flange and bearing	When right hand starts reach for housing
3	Hold	Get and assemble housing to flange and bearing and worm	When right hand starts reach for spur and worm gear cluster
4	Hold	Get and assemble spur and worm gear cluster to housing	As left hand starts to aside complete assembly

All grasps are "see" type grasps.

All transport distances are 15 inches.

All transport (empty and loaded) motions were 15 inches distant. The bins used for the experiments were standard industrial bins, sizes A-10 and A-12. The work table which was used was approximately 30 inches from the floor. The experimental subjects used a chair with provision for height adjustment. Figure 4 illustrates the position of the experimental subject in reference to the work table and the work layout.

The Motion Timer

An automatic motion timer shown in Figure 5, developed by Dr. Dale Jones for the Fair Day's Work Research Program, was used to time the motions during the experiments. The timer consists, fundamentally, of a drum having a circumference of 100 inches driven by a 10 r.p.m. synchronous motor. When in use, paper is wrapped and taped about the circumference of the drum, each lineal inch of the paper representing 0.001 minute. Dots are posted to the revolving paper through use of a relay-actuated ball point pen, either automatically as in the case when the switch button or switch buttons are integrated with the operation motion pattern or manually, as is the case when an observer visually discerns the element or motion endings and depresses a switch button. In these experiments the writer manually controlled the motion timing. The standard deviation inherent in the machine and the writer's sensory reactions were carefully established in the manner described in Appendix A, and the effects of same are discussed later in this thesis.

Selection of Experimental Subjects

Two experimental subjects fulfilling the following criteria were selected:

1. Experienced female bench work employees;

Figure 4 The Position of the Experimental Subject in reference to the Workplace Table and the Work Layout.

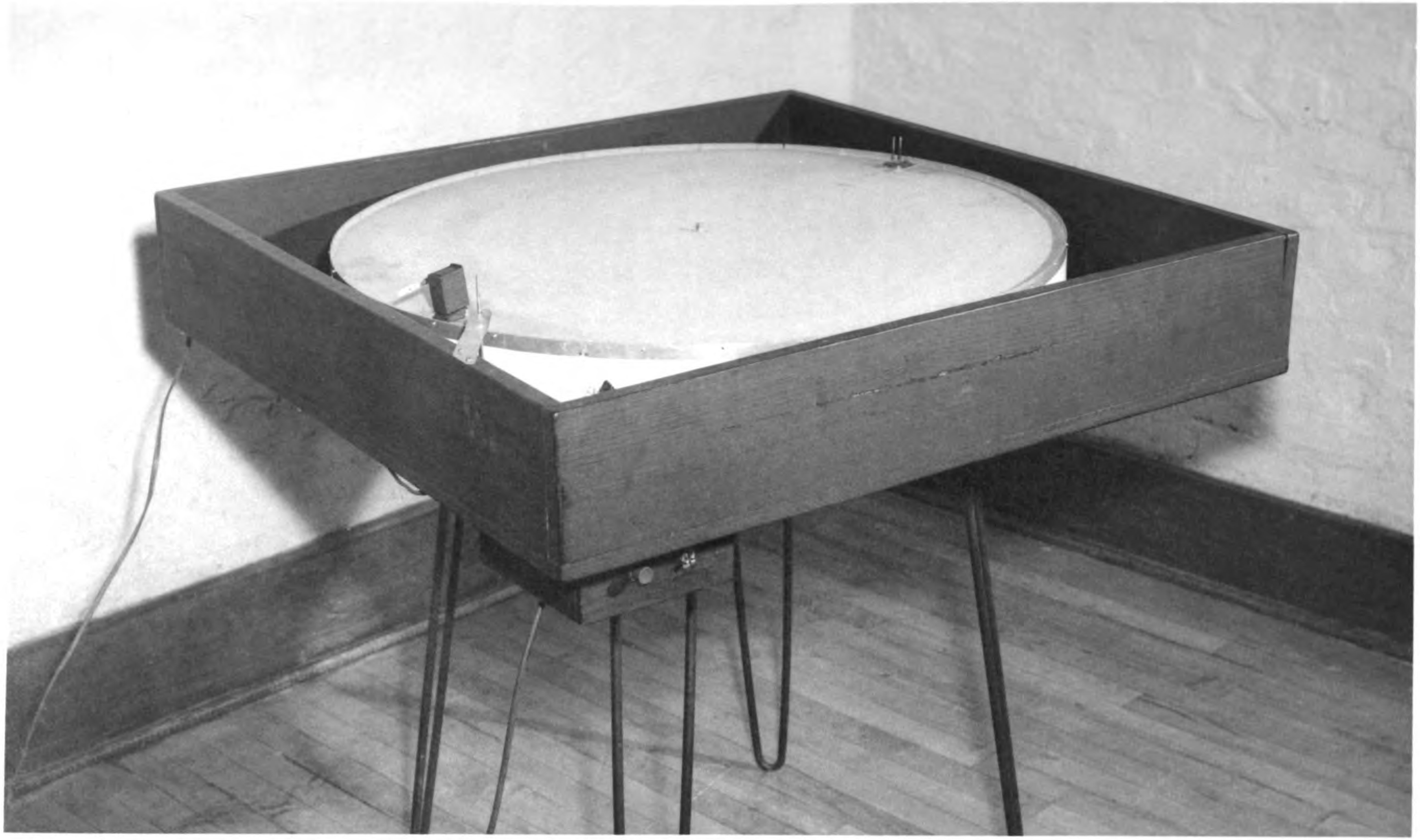

Figure 5 The Automatic Timer Developed by Dr. Dale Jones.

2. Minimum of six months' experience in bench work;

3. Average or better scores for industrial norm qualification on the Purdue Peg Board test taken by each subject at the Michigan State University Testing Center. The results of these tests are shown in Table III.

Orientation of Experimental Subjects

1. The experiment procedure was explained.

2. The specific motion patterns for each of the two assembly operations were demonstrated.

3. The experimental subjects practiced at slow pace to learn the motion patterns.

4. When completely familiar with the motion pattern the experimental subjects worked at increasingly rapid speed until it appeared they had completely mastered the motion pattern. The cycle times were posted to obtain the learning curves illustrated in Figures 6, 7, 8, and 9. The fact that the learning curves entail different numbers of cycle performances is due to differences in ability to master the operations, as suggested by general leveling of cycle performance times. After the asymptotes of the learning curves had been established by the experimental subjects, the experiments were begun.

Standardization of Experiment Conditions

It was intended that the various experiments for each operation differ only in respect to the degree of operator motivation. Thus, it was very important to keep all other motion time determinants as constant as possible. The conditions which were standardized and closely controlled throughout the experiments were:

1. Consistency of motion path from cycle to cycle

2. Relative positions of objects assembled

3. Position of experimental subject

4. Light

5. Sound

6. Ventilation

TABLE III

RESULTS OF PURDUE PEG BOARD TEST
TAKEN BY OPERATORS 1 AND 2

Operator	Test Procedure	Raw Score	Percentile	Conversion to Industrial Norm
1	Right hand	22	99	
	Left hand	19	97	
	Both hands	14	62	
	Total	55	96	Good
	Assembly	12	96	Good
2	Right hand	18	68	
	Left hand	16	54	
	Both hands	13	37	
	Total	47	47	Average
	Assembly	10 3/4	82	Average

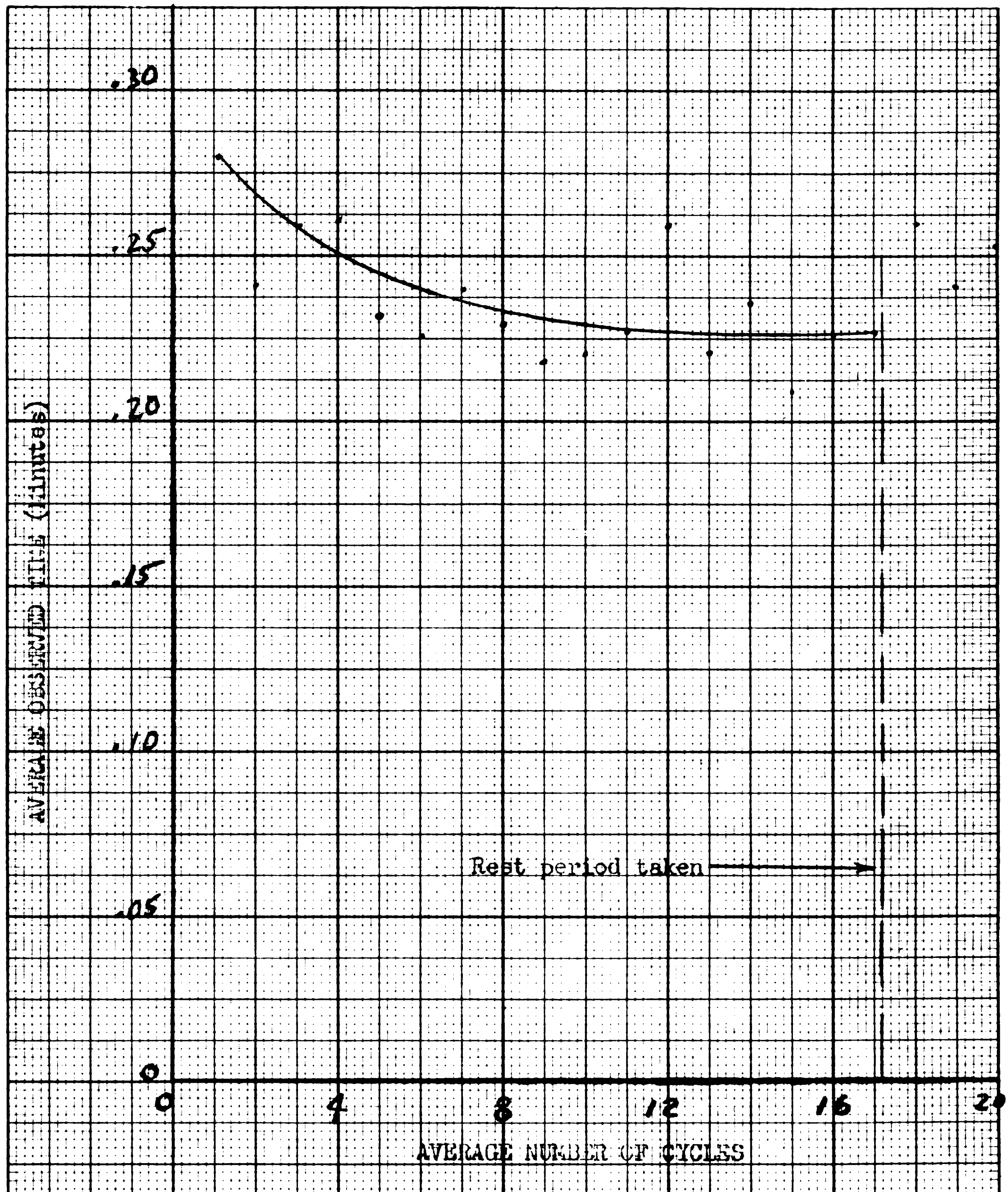

Figure 6 The Learning Curve for Operator 1 and Operation A.

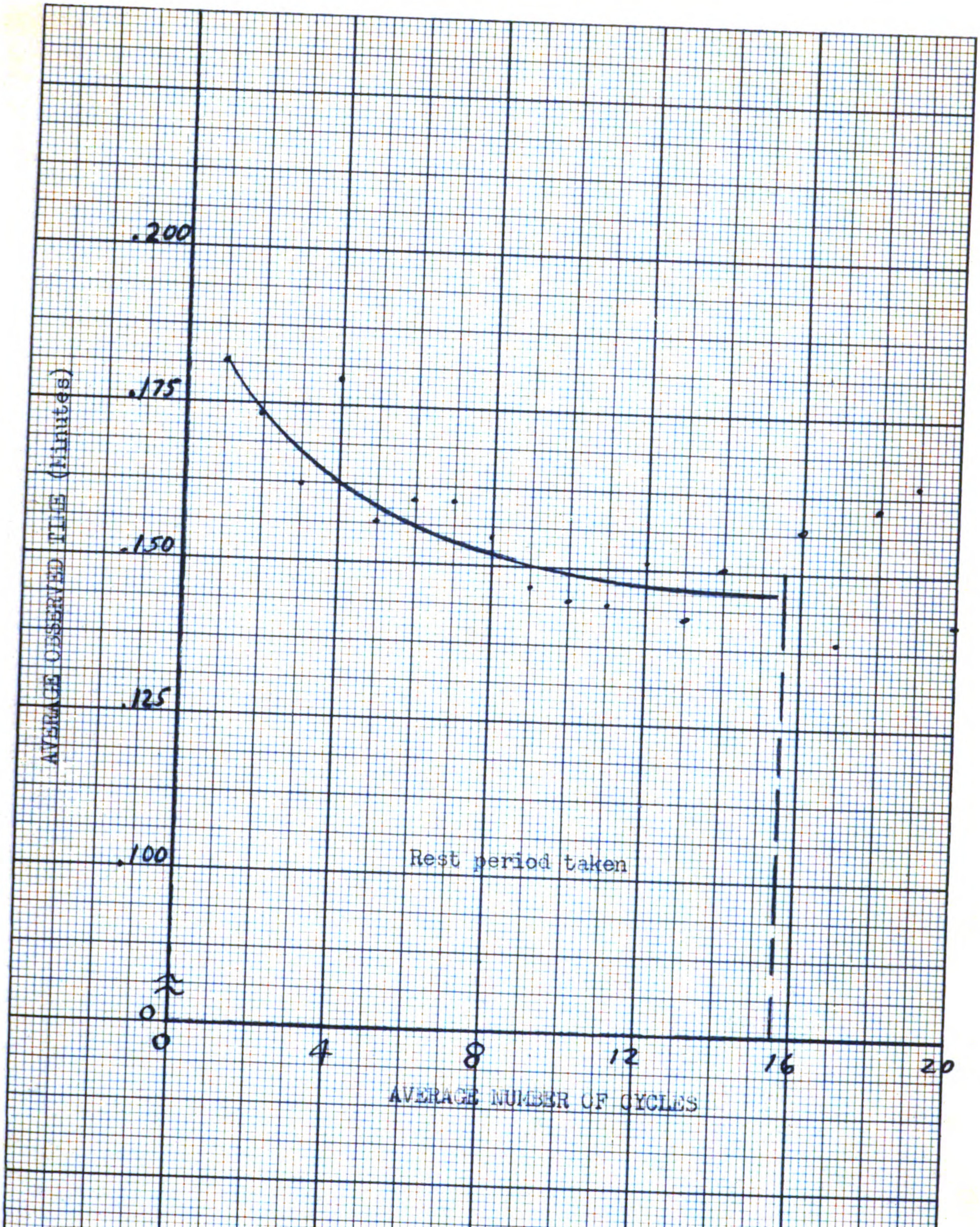

Figure 7 The Learning Curve for Operator 1 and Operation B.

7. Distractions

The Experiment Performance

Prior to each experiment the experimental subject was instructed in the desired level of motivation, and the importance of consistent adherence to this level throughout the period of experimentation.

The experiments started at a very slow motivation level and increased to a fast level. In reference to motivation levels and their order of performance, the experiments involving both Operations A and B were performed as follows:[11]

1. Very slow motivation
2. Medium slow motivation
3. Natural motivation of an average worker
4. Experimental subjects' own natural motivation which was felt to be a little higher than that of an average production employee
5. Medium fast motivation
6. Fast motivation

The Experiment Timing

Each experiment was timed by the writer, as illustrated in Figure 10, by tapping a sensitive microswitch connected to a relay-actuated ballpoint pen. The writer actuated the switch at the end of each element of the cycle.

The effects of the writer's sensory reactions were obtained to correct for any reaction time delay in actuating the switch at the

[11] The word motivation as used here is not synonomous with speed. Rather, it denotes the "will to work". In other words, motivation would be the cause of an operator working at a certain pace and speed would be the effect of that motivation or incentive.

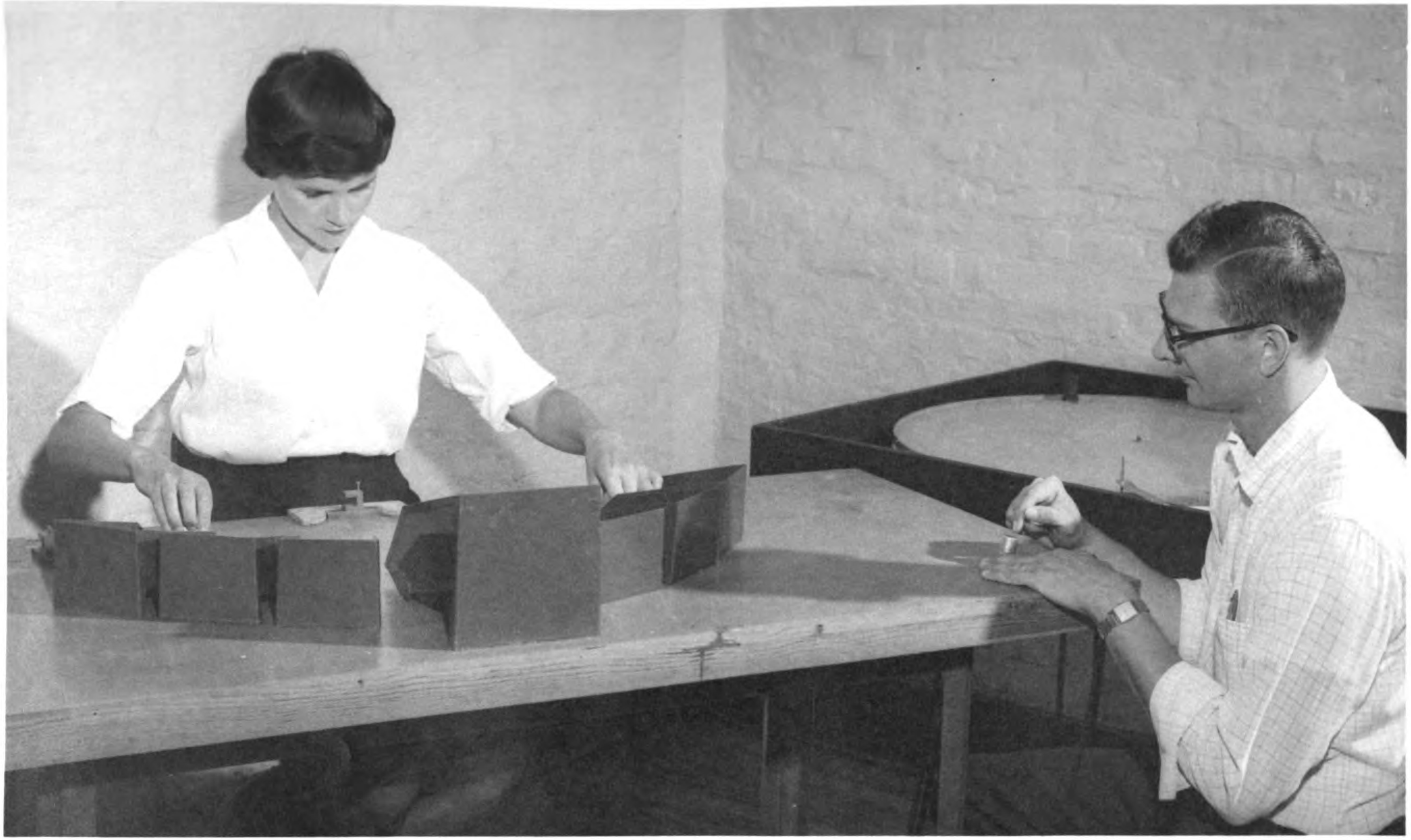

Figure 10 Timing the Experiment.

proper moment.[12] The writer's reaction time was calculated as 0.00179 minute.[13] This value was adjusted to correspond to the data as presented in this thesis by calculating the standard deviation of averages of twenty observations. This value of σ is 0.00040 minute, and is so much smaller than the difference between the observations as shown in Tables Ia and IIa that it had negligible effect on the results.

Analysis of Experiment Time

Each level of motivation was performed for five complete, uninterrupted cycles and recorded on the tape of the previously described timer. The individual times for each element were obtained from this tape by means of a special scale which converted the distance between dots to time in minutes.

For each of the four elements (two unskilled and two skilled) the five performance times were averaged to obtain a representative time for the degree of motivation reflected in the experiment. Also, the representative total cycle time for each experiment was established by totaling the cycle's four representative element times.

For purposes of graphic analysis it was necessary to express the various levels of operator motivation factorially, in reference to a

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12 To establish the writer's reaction time, a piece of piano wire, 0.013 in diameter by 12 feet 9 inches long was used with a 4-ounce plumb bob fastened on the end of the wire. The wire was fastened to the ceiling in order to serve as a pendulum. A cardboard marker was secured to the floor to serve as a guide in determining the change of direction on the pendulum. As soon as the pendulum started to change direction, the writer tapped the sensitive microswitch as described above. The results were posted to the paper taped on the drum of the timer. The time values were then obtained from this tape by means of a special scale which converted the distance between dots to time in minutes.

13 See Appendix A for calculation of reaction time.

base. This was done by taking the greatest representative cycle time (representing the slowest motivation level) as unity and dividing into this time value the other representative cycle times.

The relationship between element time and motivation level, as applied to Operator 2 performing Operation A, is illustrated in Figures 11, 12, and 13. The relationship between the unskilled element performance time and the degree of motivation is shown in Figure 11. The relationship between the skilled element performance and the degree of motivation is shown in Figure 12. Figure 13 presents the curves of Figures 11 and 12, showing the resultant curves representing average slopes of these curves.

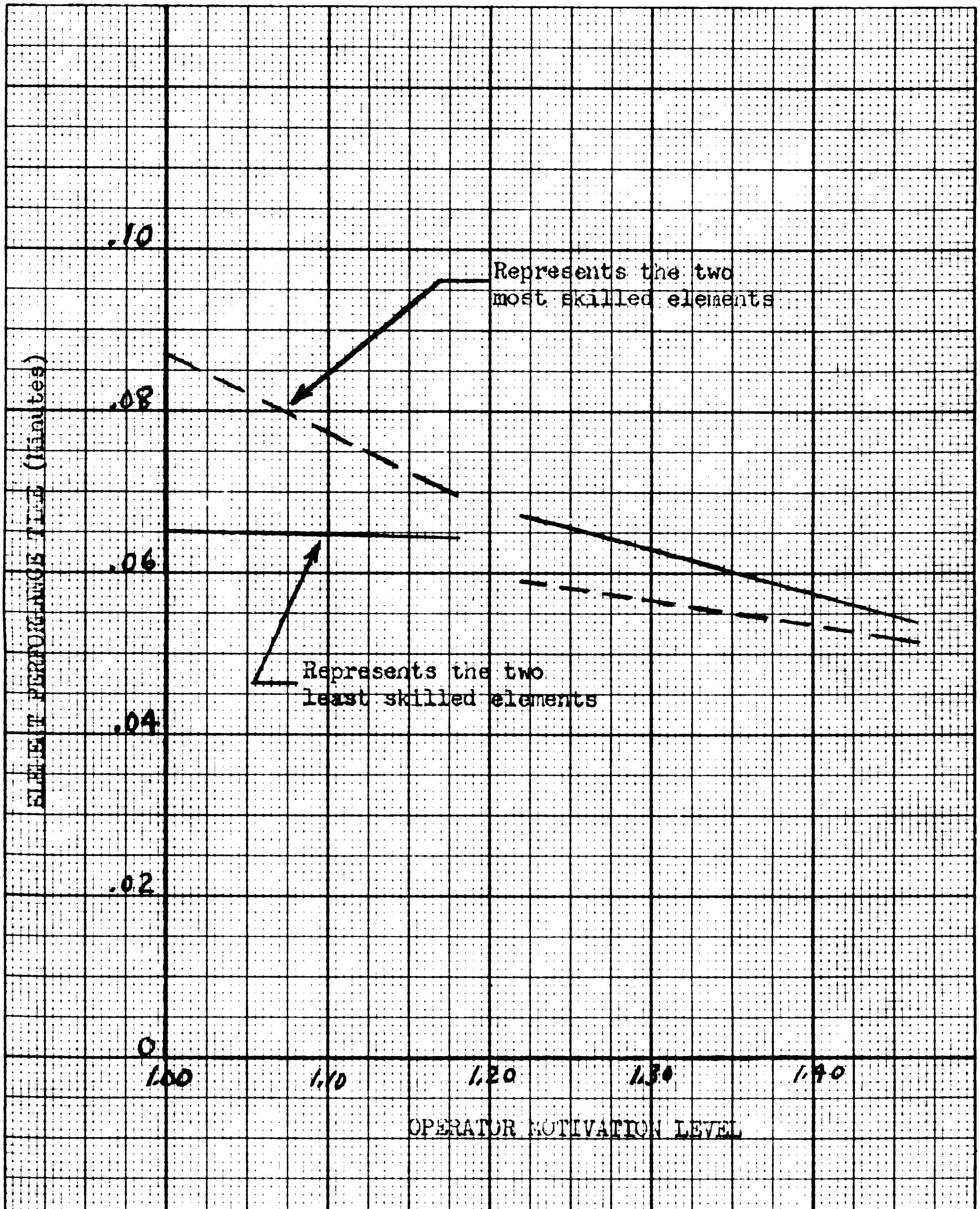

Figure 13 Experiment results from Operator 2 and Operation A, showing the relationship between Operator Motivation Level and respective Element Performance Time.

EXPERIMENT RESULTS

The experiment results of only Operator 1 performing Operation A will be explained. The interpretation of the other results, which are presented in Appendix B, should be guided by this explanation.

For the purpose of making two comparisons, the data was arranged in two ways. First, the total performance times of the two least skilled elements were compared with the total performance times of the two most skilled elements for the first three levels of motivation (the slower working speeds). Second, the total performance times of the two least skilled elements were compared with the total performance times of the two most skilled elements for the last three levels of motivation (the faster working speeds).

The first comparison relates the degree of motivation and respective element performance time for the lower three levels of motivation, as illustrated in Table IVa, and the second comparison relates the degree of motivation and respective element performance time for the higher three levels of motivation, as illustrated in Table Va.

In order to evaluate probable significance of difference of the experimental subjects' ability to shorten the most skilled element times as compared with the least skilled element times, in going from least to highest levels of motivation, it was necessary to calculate correlation and regression coefficients, as illustrated in Tables IVb and Vb. A correlation coefficient is the result of a problem which considers the joint variation of two measurements, neither of which is restricted by the experimenter. In these experiments the

TABLE IVa

Degree of Motivation versus Performance Time for the Three Lower Levels of Motivation for Operator 1 Operation A

Motivation Level	Least Skilled Elements: Degree of Representative (or Average) Motivation (x)	Least Skilled Elements: Performance Time for the Two Elements (y)	Most Skilled Elements: Degree of Representative (or Average) Motivation (x)	Most Skilled Elements: Performance Time for the Two Elements (y)
1	1.00	.050068	1.00	.076272
		.100256		.097824
2	1.13	.049784	1.13	.099360
		.082068		.055596
3	1.23	.047668	1.23	.053140
		.072816		.089036
Sums (S)	6.72	.402660	6.72	.471228
$Sx^2 \cdot Sy^2$	7.58	.029356	7.58	.039112
Sxy		.447522		.524083

TABLE Va

Degree of Motivation versus Performance Time for the Three Higher Levels of Motivation for Operator 1 Operation A

	Least Skilled Elements		Most Skilled Elements	
Motivation Level	Degree of Representative (or Average) Motivation (x)	Performance Time for the Two Elements (y)	Degree of Representative (or Average) Motivation (x)	Performance Time for the Two Elements (y)
4	1.24	.036708	1.24	.052032
		.086968		.084792
5	1.29	.029148	1.29	.053712
		.078796		.089708
6	1.34	.026564	1.34	.053792
		.078592		.082540
Sums (S)	7.74	.336776	7.74	.416576
Sx^2 Sy^2	9.99	.022852	9.99	.030536
Sxy		.433515		.537358

TABLE IVb

Regression and Correlation Data for the Three Lower Degrees of Motivation for Operator 1 Operation A

Adj. Sums of Squares and Products

$$S\underline{x}^2 = Sx^2 - \frac{(Sx)^2}{6} \qquad S\underline{y}^2 = Sy^2 - \frac{(Sy)^2}{6}$$

$$S\underline{xy} = Sxy - \frac{(Sx)(Sy)}{6}$$

Elements	Degrees of Freedom	$S\underline{x}^2$	$S\underline{xy}$	$S\underline{y}^2$	Correlation Coeff.(See 1)	Regression Coeff.(See 2)	Sums of Squares (See 3)	Degrees of Freedom
Least Skilled	5	.05	-.003458	.002332	-.307	-.069	.00209265	4
Most Skilled	5	.05	-.003694	.002101	-.344	-.074	.00182801	4
Sum	10	.10	-.007152	.004433	-.340	-.072	.00392149	9
				Sum of Least and Most Skilled Elements			.00392066	8
						Difference	.00000083	1

1 $\dfrac{S\underline{xy}}{\sqrt{(S\underline{x}^2)(S\underline{y}^2)}}$ 2 $\dfrac{S\underline{xy}}{S\underline{x}^2}$ 3 $S\underline{y}^2 - \dfrac{(S\underline{xy})^2}{S\underline{x}^2}$

In each row in Table IVb the deviations whose sums of squares and products are listed are measured from the group mean, not from the experiment mean.

TABLE Vb

Regression and Correlation Data for the Three Higher Degrees of Motivation for Operator 1 Operation A

Adj. Sums of Squares and Products

$$S\underline{x}^2 = Sx^2 - \frac{(Sx)^2}{6} \qquad S\underline{y}^2 = Sy^2 - \frac{(Sy)^2}{6}$$

$$S\underline{xy} = Sxy - \frac{(Sx)(Sy)}{6}$$

Elements	Degrees of Freedom	$S\underline{x}^2$	$S\underline{xy}$	$S\underline{y}^2$	Correlation Coeff. (See 1)	Regression Coeff. (See 2)	Sums of Squares (See 3)	Degrees of Freedom
Least Skilled	5	.005	-.000926	.003949	-.207	-.185	.00376771	4
Most Skilled	5	.005	-.000025	.001614	-.009	-.005	.00161388	4
Sum	10	.010	-.000951	.005563	-.127	-.095	.00547256	9
				Sum of Least and Most Skilled Elements			.00538159	8
						Difference	.00009097	1

1 $\dfrac{S\underline{xy}}{\sqrt{(S\underline{x}^2)(S\underline{y}^2)}}$ 2 $\dfrac{S\underline{xy}}{S\underline{x}^2}$ 3 $S\underline{y}^2 - \dfrac{(S\underline{xy})^2}{S\underline{x}^2}$

In each row in Table Vb the deviations whose sums of squares and products are listed are measured from the group mean, not from the experiment mean.

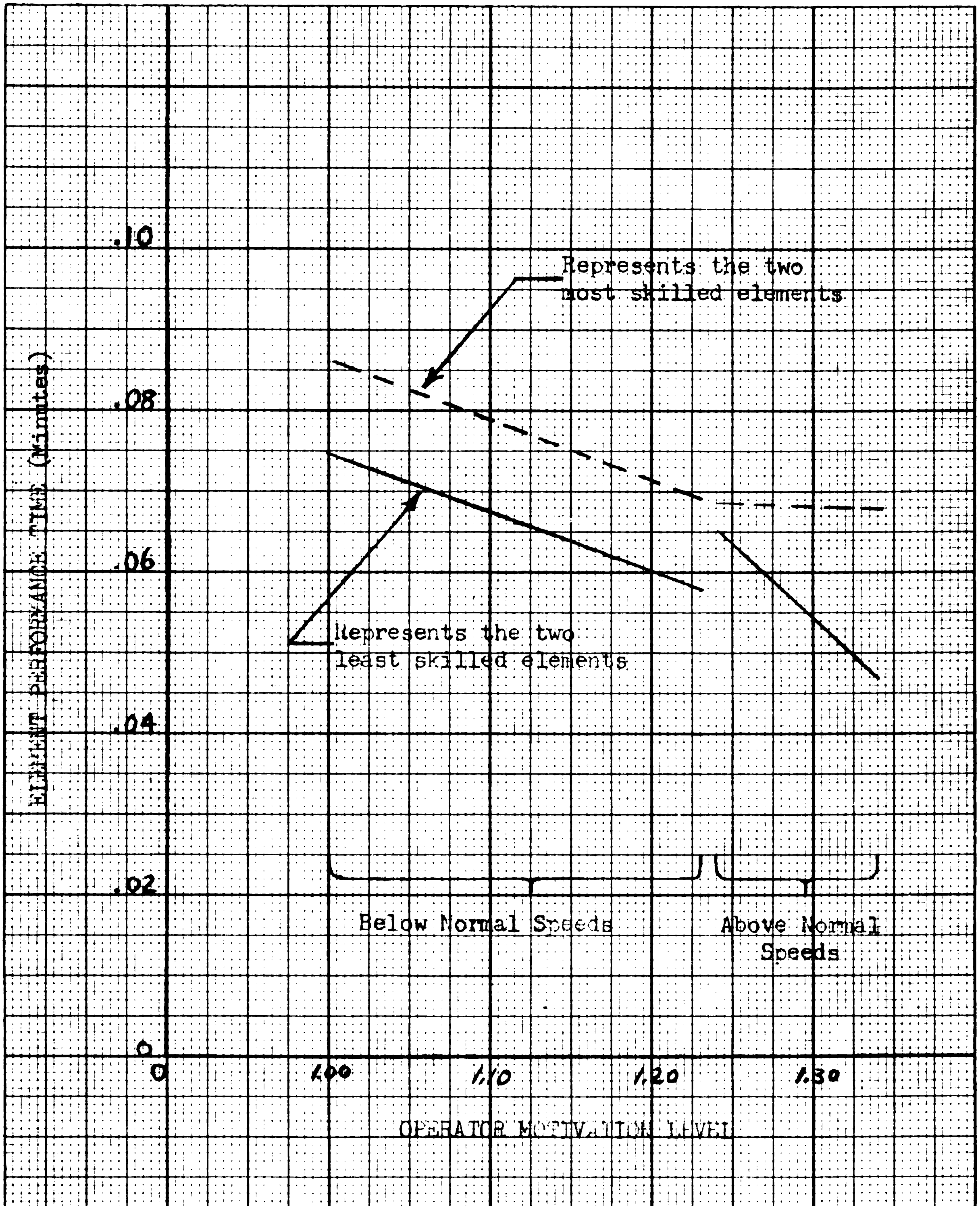

Figure 14 Experiment results from Operator 1 and Operation A, showing the relationship between Operator Motivation Level and respective Element Performance Time.

two measurements are the degree of motivation and the element performance time. A regression coefficient is the result of a problem which considers the variation of one variable when another is held fixed at each of several levels. In these experiments the element performance time is the variable while the degree of motivation is held fixed at each of several levels.

The values of each set of coefficients differ considerably among themselves. The problem was to learn if these differences were significant or if they represented merely sampling variations. To obtain a clearer picture, the regression curves illustrated in Figure 14 were plotted. When regression curves are straight or approximately straight lines, as is the case of those obtained, they are generally called linear regression curves.[14]

The regression equation used to obtain the curves shown in Figure 14 is:

$$\hat{Y} = \bar{Y} + b(X - \bar{X})$$

where:

X is the observed motivation time values

$\bar{X}$ is the mean of the observed motivation values

b is the slope of the line

$\bar{Y}$ is the mean of the observed performance time values

$\hat{Y}$ is the estimate of the mean $\bar{Y}$

The mean values $\bar{X}$ and $\bar{Y}$ used in the above equation were obtained from Table IVa and Va. The line drawn by the above equation has the property that the sum of squares of vertical deviations of values from

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14 Dixon, Wilfred J. and Massey, Frank J. Jr., Introduction to Statistical Analysis. New York: McGraw-Hill, 1957, p 191.

this line is smaller than the corresponding sum of squares of vertical deviations from any other line. This is called a least square property.

The regression equations for the least skilled and the most skilled elements are:

Least Skilled Elements	Most Skilled Elements
$\hat{Y} = .067110 - .069(X - 1.120000)$	$\hat{Y} = .078538 - .074(X - 1.120000)$
Simplifying	Simplifying
$\hat{Y} = .144390 - .069X$	$\hat{Y} = .161418 - .074X$

Having established the slope of these lines, the problem was to determine if their slopes were significantly different. This requires that the mean square deviation from individual group regressions be compared as illustrated in Tables IVc and Vc.[15] This method of comparison involved the use of the F distribution test. The F distribution test is a variance ratio used to test the significance of difference between two values. A straight forward explanation of the use of the F test is presented in R. A. Fisher's book, <u>Statistical Methods for Research Workers</u> published by Oliver & Boyd, Edinburgh: Tweeddale Court, London; 1938. If the slopes do not differ significantly it means that Y increases at the same rate as X.

To determine if the value obtained for the F ratio is significantly different, the F distribution tables were used. The tables were entered with one degree of freedom in the numerator and with eight degrees of freedom in the denominator. In order for the F ratio to be significant at the 5 percent level, the value for the

15 Snedecor, George W., <u>Statistical Methods</u>. Ames, Iowa: The Iowa State College Press, 1940.

TABLE Vc

Test of Significance of Adjusted Group Means for the Three Higher Degrees of Motivation for Operator 1 Operation A

Source	Sum of Squares	Degrees of Freedom	Mean Square
Common Slope	.00009097	1	.00009097
Residual	.00538159	8	.00067270

$$F = \frac{.00009097}{.00067270} = 0.13500$$

ratio would have to be 5.32 or greater. Since the value of the F ratio obtained for the first and second comparison was 0.00169 and 0.13500 respectively, the conclusion was that the slopes were not significantly different.

The F ratio values for all the experiments are shown in Table XII.

TABLE XII

F Ratio Values for all the Experiments

Operator	Operation	Comparison	F Ratio Value
1	A	First	0.00169
		Second	0.13500
1	B	First	2.05850
		Second	0.05825
2	A	First	0.43250
		Second	0.03595
2	B	First	0.37999
		Second	0.84950

As already noted the F ratio value to be significantly different would have to be 5.32 or greater.

SUMMARY AND CONCLUSIONS

Summary

Since time standards are important to all industrial firms for scheduling work and determining the effectiveness with which it is accomplished, this thesis was intended to contribute toward improvement of the science of setting time standards.

Time standards consist of two important parts: one is the estimated normal time for the operation, and the other is the allowance times for personal, fatigue, and delay requirements. Estimated normal times consist of the actual performance time for the operation multiplied by the speed or rate at which the operator accomplishes the operation. To enable a time study man to improve the setting of time standards much research has been done to enable him to better time the job and also to arrive at the allowance times with more accuracy; but very little has been done to improve the rating techniques that he uses.

Time study men agree that skilled elements are more difficult to rate than unskilled elements. Because of this fact time standards are subject to much criticism. To combat this area of criticism a new rating technique called "synthetic rating" was developed to enable the time study man to rate the skilled elements he encounters during a study, but very little has been done to determine the validity of this technique. The research that has been done to determine the validity of synthetic rating leaves much to be answered. Therefore, the purpose of this thesis is to test the validity of synthetic rating under certain typical manufacturing conditions.

To test the validity of synthetic rating the prime consideration is the determination of whether or not there is any significant difference in the change of rating in performance of skilled elements as compared with unskilled elements as operator motivation level increases from low to high.

The procedure used for determining if any significant difference in the change of rating of skilled elements as compared with unskilled elements was as follows:

Two typical short cycle industrial assembly operations were studied. Each operation consisted of four elements: two elements that were considered the least skilled of the four and two elements that were considered the most skilled of the four. The operations were timed by an automatic timer developed by Dr. Dale Jones in connection with the Fair Day's Work Research Program. Two experimental subjects with industrial experience were used. Each experimental subject performed each operation at six different motivation levels increasing from low to high. At each motivation level the experimental subject performed each operation for five cycles. It was intended that the various experiments for each operation differ only in respect to the degree of operator motivation. All other motion time determinants were maintained as constant as possible.

Conclusions

Under the conditions of this study, the following conclusions are suggested:

The experimental results obtained indicate that there is no significant difference in the change of rating in performance of skilled elements as compared with unskilled elements as operator motivation levels increase from low to high.

These findings therefore suggest that unskilled elements are performed at about the same speed rating as skilled elements, when these elements are performed by qualified, well trained, and well motivated operators.

The experimental results obtained, therefore, tend to support the validity of synthetic rating as an improved means of establishing better time standards.

Implications

One result of this pilot study is that the concept of synthetic rating appears valid. Further research is needed to firmly establish the validity of synthetic rating.

Once this validity is established, the applications of its use would have the following results:

1. Better labor relations will be established because of the improved accuracy and consistency of time standards set on jobs by this method of rating.

2. There would be the possibility of reducing judgment to such an extent that it will no longer play an important part in the final determination of the rate at which an operator performs a job.

3. When using this method of rating, it is not essential to have data for all elements of an operation being analyzed. Thus, there is the ease of application and savings in time.

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APPENDIX A

Inherent Error of the Automatic Timer

The inherent error of the automatic timer was calculated in the following manner:

The sensitive microswitch which controls the posting relay of the timer was actuated every 0.020 minute by a synchronous driven cam. The synchronous drive for the Mechanical Engineering Department's 16 m.m. Cine Special Movie camera was used in conjunction with the cam. Twenty time intervals were obtained from the timing paper used in the automatic timer. Of these twenty time values, one was discarded because it was out of control from the rest of the time values. These readings were made to the nearest 0.00001 minute. See Table XIII for the readings and the method of calculating the standard deviation.

The standard deviation for the average of 16 postings is 0.00001 minute. Therefore, we can be statistically 99.73 percent sure that the tabulated averages of the 16 postings are within plus or minus 0.00003 minute of the true average times for the 16 postings.

TABLE XIII

Calculation of the Mechanical
Inherent Error of the Timer

Trials	X	$(X - \overline{X})$	$(X - \overline{X})^2$
1	.01990	.00002	.0000000004
2	.01991	.00001	.0000000001
3	.01986	.00006	.0000000036
4	.01987	.00005	.0000000025
5	.01986	.00006	.0000000036
6	.01993	.00001	.0000000001
7	.01990	.00002	.0000000004
8	.01994	.00002	.0000000004
9	.01990	.00002	.0000000004
10	.01999	.00007	.0000000049
11	.02000	.00008	.0000000064
12	.01997	.00005	.0000000025
13	.01990	.00002	.0000000004
14	.01994	.00002	.0000000004
15	.01997	.00005	.0000000025
16	.01997	.00005	.0000000025
18	.01988	.00004	.0000000016
19	.01991	.00001	.0000000001
20	.01994	.00002	.0000000004
Sum	.37854	Sum	.0000000332

$$\overline{X} = \frac{.37854}{19} = 0.01992$$

$$\sigma_{est} = \sqrt{\frac{.0000000332}{19}} = 0.000042 \text{ minutes}$$

Determining the mechanical inherent error in the timer:

$$\sigma_{\overline{X}_{n=3}} = \frac{\sigma_{est}}{\sqrt{n}}$$

$$\sigma_{\overline{X}_{n=3}} = \frac{.000042}{\sqrt{3}} = 0.0000243 \text{ minutes}$$

TABLE XIV

The Calculations of the Writer's Reaction Time

Trials	X	(X - $\bar{X}$)	(X - $\bar{X}$)^2
1	.06640	.00033	.0000001089
2	.06566	.00041	.0000001681
3	.06696	.00089	.0000007921
4	.06370	.00237	.0000056169
5	.06892	.00285	.0000081225
6	.06330	.00277	.0000076729
7	.06784	.00177	.0000031329
8	.06506	.00101	.0000010201
9	.06952	.00345	.0000119025
10	.06500	.00107	.0000011449
11	.06556	.00051	.0000002601
12	.06694	.00087	.0000007569
13	.06632	.00025	.0000000625
14	.06250	.00357	.0000127449
15	.06922	.00315	.0000099225
16	.06596	.00011	.0000000121
17	.06656	.00049	.0000002401
18	.06548	.00059	.0000003481
19	.06494	.00113	.0000012769
20	.06376	.00231	.0000053361
21	.06416	.00191	.0000036481
22	.06758	.00151	.0000022801
23	.06788	.00181	.0000032761
24	.06584	.00023	.0000000529
25	.06676	.00069	.0000004761
Sum	1.65182		Sum .0000803753

$$\bar{X} = \frac{1.65182}{25} = 0.06607$$

$$\sigma_{est} = \sqrt{\frac{.0000803753}{25}} = 0.00179$$

$$\sigma_{\bar{X}_{n=20}} = \frac{\sigma_{est}}{\sqrt{n}}$$

$$\sigma_{\bar{X}_{n=20}} = \frac{.00179}{\sqrt{20}} = 0.000400$$

TABLE XV

Element Times and Cycle Times for Operator 1

Operation A

Motivation Level	Element #1	Element #2	Element #3	Element #4	Total Cycle Time
1	.050068	.076272	.100256	.097824	.32442
2	.049784	.099360	.082068	.055596	.28681
3	.047668	.053140	.072816	.089036	.26266
4	.036708	.052032	.086968	.084792	.26050
5	.029148	.053712	.078796	.089708	.25136
6	.026564	.053792	.078592	.082540	.24149

Operation B

Motivation Level	Element #1	Element #2	Element #3	Element #4	Total Cycle Time
1	.049214	.070320	.059964	.034248	.213766
2	.054248	.038108	.058420	.041500	.192242
3	.047148	.033700	.062304	.045040	.188172
4	.039056	.030400	.039768	.055248	.164672
5	.034372	.040008	.049140	.037712	.161232
6	.027844	.022248	.034920	.036296	.121308

TABLE XVI

Element Times and Cycle Times for Operator 2

Operation A

Motivation Level	Element #1	Element #2	Element #3	Element #4	Total Cycle Time
1	.039620	.100964	.092000	.076228	.308816
2	.051012	.078244	.075304	.090764	.295304
3	.035132	.056524	.093648	.076602	.261906
4	.052388	.057784	.079564	.063568	.253304
5	.047572	.042232	.075292	.052008	.217084
6	.029308	.041344	.070720	.068940	.210312

Operation B

Motivation Level	Element #1	Element #2	Element #3	Element #4	Total Cycle Time
1	.051676	.049876	.075132	.032100	.208784
2	.038232	.040256	.048604	.047420	.174512
3	.042456	.027596	.051136	.045240	.166428
4	.038992	.034996	.040688	.038168	.152844
5	.031244	.030788	.031992	.050124	.144148
6	.035628	.029680	.031580	.029756	.126544

APPENDIX B

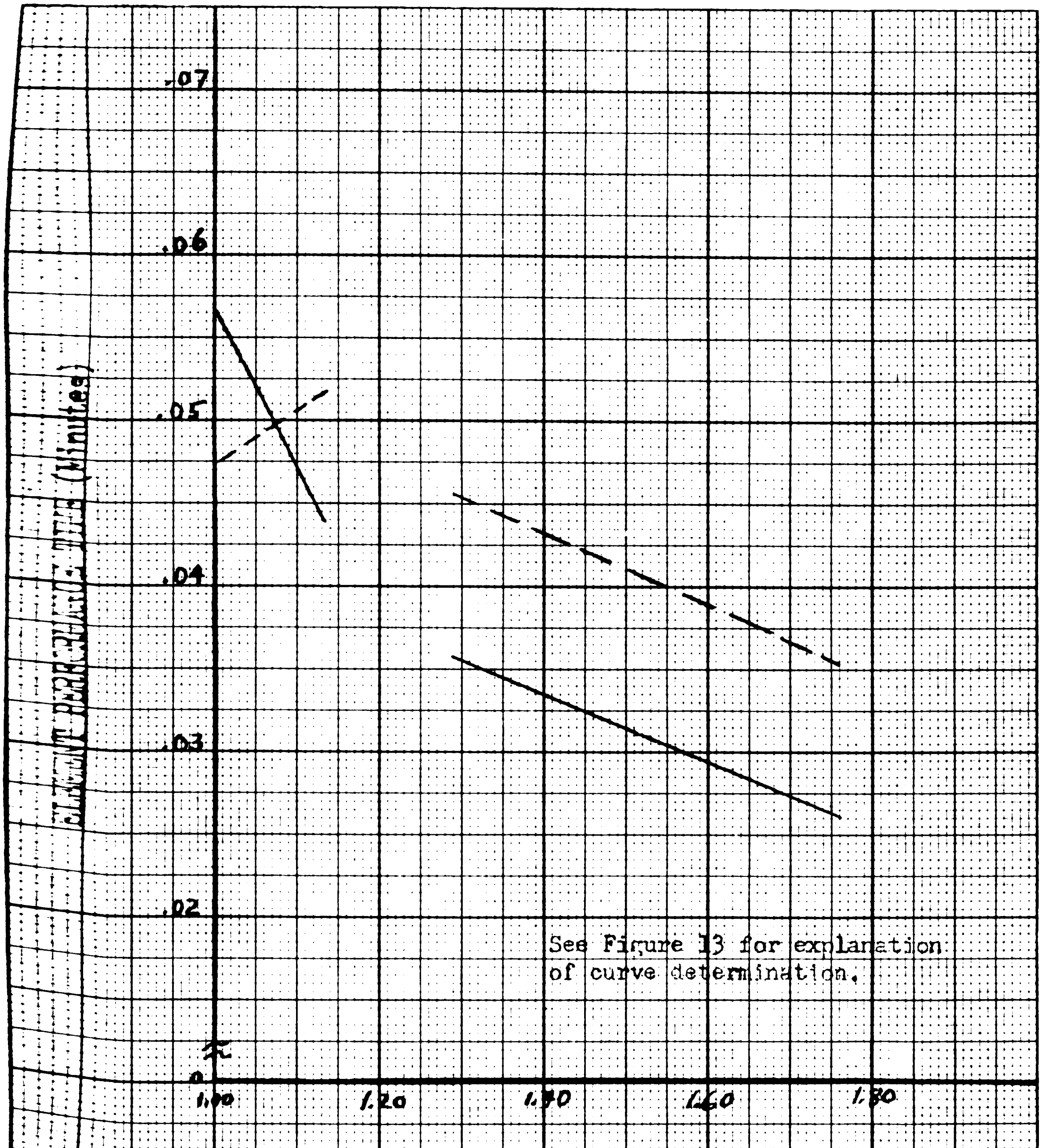

Figure 15 Experiment results from Operator 1 and Operation B, showing the relationship between Operator Motivation Level and respective Element Performance Time.

TABLE VIa

Degree of Motivation versus Performance Time for the Three Lower Levels of Motivation for Operator 1 Operation B

	Least Skilled Elements		Most Skilled Elements	
Motivation Level	Degree of Representative (or Average) Motivation (x)	Performance Time for the Two Elements (y)	Degree of Representative (or Average) Motivation (x)	Performance Time for the Two Elements (y)
1	1.00	.049214	1.00	.059964
		.070320		.034248
2	1.11	.054248	1.11	.058420
		.038108		.041500
3	1.13	.047148	1.13	.062304
		.033700		.045040
Sums (S)	6.48	.292738	6.48	.301476
Sx^2 Sy^2	7.02	.015121	7.02	.015814
Sxy		.313407		.326422

* See Figure 15

TABLE VIIa

Degree of Motivation versus Performance Time for the Three Higher Levels of Motivation for Operator 1 Operation B

	Least Skilled Elements		Most Skilled Elements	
Motivation Level	Degree of Representative (or Average) Motivation (x)	Performance Time for the Two Elements (y)	Degree of Representative (or Average) Motivation (x)	Performance Time for the Two Elements (y)
4	1.29	.039056	1.29	.039768
		.030400		.055248
5	1.32	.034372	1.32	.049140
		.040008		.037712
6	1.76	.027844	1.76	.034920
		.022248		.036296
Sums (S)	8.74	.193928	8.74	.253084
Sx^2 Sy^2	13.01	.006502	13.01	.011008
Sxy		.275942		.362555

* See Figure 15

TABLE VIb

Regression and Correlation Data for the Three Lower Degrees of Motivation for Operator 1 Operation B

Adj. Sums of Squares and Products

$$S\underline{x}^2 = Sx^2 - \frac{(Sx)^2}{6} \qquad S\underline{y}^2 = Sy^2 - \frac{(Sy)^2}{6}$$

$$S\underline{xy} = Sxy - \frac{(Sx)(Sy)}{6}$$

Elements	Degrees of Freedom	$S\underline{x}^2$	$S\underline{xy}$	$S\underline{y}^2$	Correlation Coeff. (See 1)	Regression Coeff. (See 2)	Sums of Squares (See 3)	Degrees of Freedom
Least Skilled	5	.022	-.002750	.000839	-.648	-.125	.00049510	4
Most Skilled	5	.022	.000828	.000667	.214	.038	.00063581	4
Sum	10	.044	-.001922	.001506	-.237	-.044	.00142201	9
				Sum of Least and Most Skilled Elements			.00113091	8
						Difference	.00029110	1

1 $\dfrac{S\underline{xy}}{\sqrt{(S\underline{x}^2)(S\underline{y}^2)}}$ 2 $\dfrac{S\underline{xy}}{S\underline{x}^2}$ 3 $S\underline{y}^2 - \dfrac{(S\underline{xy})^2}{S\underline{x}^2}$

In each row in Table VIb the deviations whose sums of squares and products are listed are measured from the group mean, not from the experiment mean.

* See Figure 15

TABLE VIIb

Regression and Correlation Data for the Three Higher Degrees of Motivation for Operator 1 Operation B

Adj. Sums of Squares and Products

$$S\underline{x}^2 = Sx^2 - \frac{(Sx)^2}{6} \qquad S\underline{y}^2 = Sy^2 - \frac{(Sy)^2}{6}$$

$$S\underline{xy} = Sxy - \frac{(Sx)(Sy)}{6}$$

Elements	Degrees of Freedom	$S\underline{x}^2$	$S\underline{xy}$	$S\underline{y}^2$	Correlation Coeff. (See 1)	Regression Coeff. (See 2)	Sums of Squares (See 3)	Degrees of Freedom
Least Skilled	5	.28	-.006546	.000234	-.812	-.023	.00007909	4
Most Skilled	5	.28	-.006104	.000333	-.633	-.022	.00019989	4
Sum	10	.56	-.012650	.000567	-.710	-.023	.00028100	9
				Sum of Least and Most Skilled Elements			.00027898	8
						Difference	.00000202	1

1 $\dfrac{S\underline{xy}}{\sqrt{(S\underline{x}^2)(S\underline{y}^2)}}$ 2 $\dfrac{S\underline{xy}}{S\underline{x}^2}$ 3 $S\underline{y}^2 - \dfrac{(S\underline{xy})^2}{S\underline{x}^2}$

In each row in Table VIIb the deviations whose sums of squares and products are listed are measured from the group mean, not from the experiment mean.

* See Figure 15

TABLE VIIc

Test of Significance of Adjusted Group Means for the Three Higher Degrees of Motivation for Operator 1 Operation B

Source	Sum of Squares	Degrees of Freedom	Mean Square
Common Slope	.00000202	1	.00000202
Residual	.00027898	8	.00003485

$$F = \frac{.00000202}{.00003485} = 0.05825$$

* See Figure 15

TABLE VIIIa

Degree of Motivation versus Performance Time for the Three Lower Levels of Motivation for Operator 2 Operation A

	Least Skilled Elements		Most Skilled Elements	
Motivation Level	Degree of Representative (or Average) Motivation (x)	Performance Time for the Two Elements (y)	Degree of Representative (or Average) Motivation (x)	Performance Time for the Two Elements (y)
1	1.00	.039620	1.00	.100964
		.092000		.076228
2	1.05	.051012	1.05	.078244
		.075304		.090764
3	1.18	.035132	1.18	.056524
		.093648		.076602
Sums (S)	6.46	.386716	6.46	.479326
Sx^2 Sy^2	6.99	.028311	6.99	.039427
Sxy		.416212		.511739

* See Figure 13

TABLE IXa

Degree of Motivation versus Performance Time for the Three Higher Levels of Motivation for Operator 2 Operation A

	Least Skilled Elements		Most Skilled Elements	
Motivation Level	Degree of Representative (or Average) Motivation (x)	Performance Time for the Two Elements (y)	Degree of Representative (or Average) Motivation (x)	Performance Time for the Two Elements (y)
4	1.22	.052388	1.22	.057784
		.079564		.063568
5	1.42	.047572	1.42	.042232
		.075292		.052008
6	1.47	.029308	1.47	.041344
		.070720		.068940
Sums (S)	8.22	.354844	8.22	.325876
Sx^2 Sy^2	11.33	.022867	11.33	.018330
Sxy		.482489		.443988

* See Figure 13

TABLE VIIIb

Regression and Correlation Data for the Three Lower Degrees of Motivation for Operator 2 Operation A

Adj. Sums of Squares and Products

$S\underline{x}^2 = Sx^2 - \frac{(Sx)^2}{6} \qquad S\underline{y}^2 = Sy^2 - \frac{(Sy)^2}{6}$.

$S\underline{xy} = Sxy - \frac{(Sx)(Sy)}{6}$

Elements	Degrees of Freedom	$S\underline{x}^2$	$S\underline{xy}$	$S\underline{y}^2$	Correlation Coeff. (See 1)	Regression Coeff. (See 2)	Sums of Squares (See 3)	Degrees of Freedom
Least Skilled	5	.04	-.000152	.003387	-.013	-.004	.00338642	4
Most Skilled	5	.04	-.004335	.001135	-.646	-.108	.00066520	4
Sum	10	.08	-.004487	.004522	-.236	-.056	.00427034	9
				Sum of Least and Most Skilled Elements			.00405162	8
						Difference	.00021872	1

1 $\frac{S\underline{xy}}{\sqrt{(S\underline{x}^2)(S\underline{y}^2)}}$ 2 $\frac{S\underline{xy}}{S\underline{x}^2}$ 3 $S\underline{y}^2 - \frac{(S\underline{xy})^2}{S\underline{x}^2}$

In each row in Table VIIIb the deviations whose sums of squares and products are listed are measured from the group mean, not from the experiment mean.

* See Figure 13

TABLE IXb

Regression and Correlation Data for the Three Higher Degrees of Motivation for Operator 2 Operation A

Adj. Sums of Squares and Products

$$S\underline{x}^2 = Sx^2 - \frac{(Sx)^2}{6} \qquad S\underline{y}^2 = Sy^2 - \frac{(Sy)^2}{6}$$

$$S\underline{xy} = Sxy - \frac{(Sx)(Sy)}{6}$$

Elements	Degrees of Freedom	$S\underline{x}^2$	$S\underline{xy}$	$S\underline{y}^2$	Correlation Coeff. (See 1)	Regression Coeff. (See 2)	Sums of Squares (See 3)	Degrees of Freedom
Least Skilled	5	.07	-.003647	.001882	-.317	-.052	.00169199	4
Most Skilled	5	.07	-.002462	.000631	-.371	-.035	.00054441	4
Sum	10	.14	-.006109	.002513	-.385	-.044	.00224643	9
				Sum of Least and Most Skilled Elements			.00223640	8
						Difference	.00001003	1

1 $\dfrac{S\underline{xy}}{\sqrt{(S\underline{x}^2)(S\underline{y}^2)}}$ 2 $\dfrac{S\underline{xy}}{S\underline{x}^2}$ 3 $S\underline{y}^2 - \dfrac{(S\underline{xy})^2}{S\underline{x}^2}$

In each row in Table IXb the deviations whose sums of squares and products are listed are measured from the group mean, not from the experiment mean.

* See Figure 13

TABLE VIIIc

Test of Significance of Adjusted Group Means for the Three Lower Degrees of Motivation for Operator 2 Operation A

Source	Sum of Squares	Degrees of Freedom	Mean Square
Common Slope	.00021872	1	.00021872
Residual	.00405162	8	.00050645

$$F = \frac{.00021872}{.00050645} = 0.43250$$

* See Figure 13

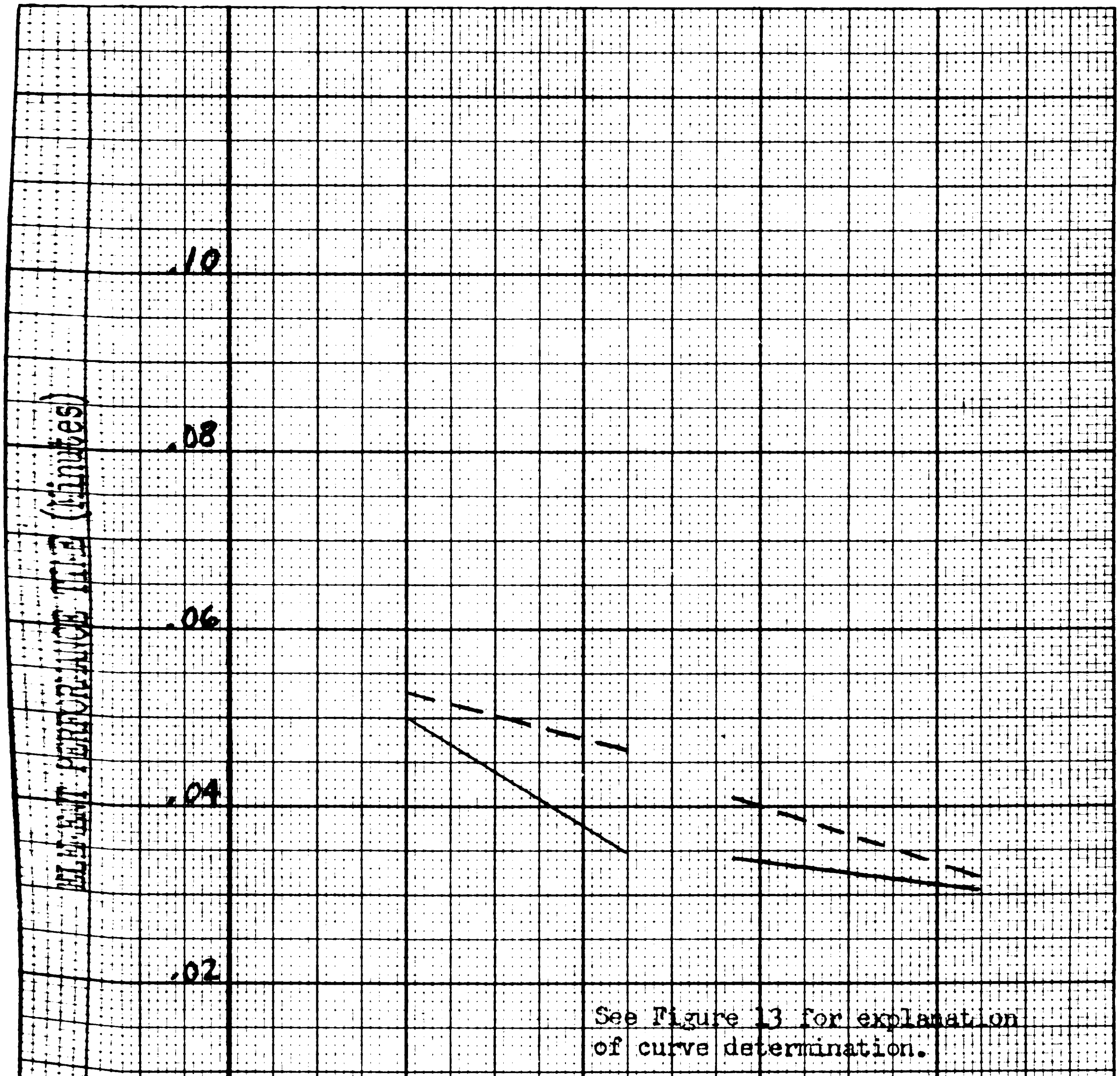

Figure 16 Experiment results from Operator 2 and Operation B, showing the relationship between Operator Motivation Level and respective Element Performance Time.

TABLE Xa

Degree of Motivation versus Performance Time for the Three Lower Levels of Motivation for Operator 2 Operation B

Motivation Level	Least Skilled Elements: Degree of Representative (or Average) Motivation (x)	Least Skilled Elements: Performance Time for the Two Elements (y)	Most Skilled Elements: Degree of Representative (or Average) Motivation (x)	Most Skilled Elements: Performance Time for the Two Elements (y)
1	1.00	.051676	1.00	.075132
		.049876		.032100
2	1.20	.038232	1.20	.048604
		.040256		.047420
3	1.25	.042456	1.25	.051136
		.027596		.045240
Sums (S)	6.90	.250092	6.90	.299632
Sx^2 Sy^2	8.00	.010804	8.00	.015948
Sxy		.283303		.342931

* See Figure 16

TABLE XIa

Degree of Motivation versus Performance Time for the Three Higher Levels of Motivation for Operator 2 Operation B

Motivation Level		Least Skilled Elements: Degree of Representative (or Average) Motivation (x)	Least Skilled Elements: Performance Time for the Two Elements (y)	Most Skilled Elements: Degree of Representative (or Average) Motivation (x)	Most Skilled Elements: Performance Time for the Two Elements (y)
4		1.37	.038992	1.37	.040688
			.034996		.038168
5		1.45	.031244	1.45	.031992
			.030788		.050124
6		1.65	.035628	1.65	.031580
			.029680		.029756
Sums	(S)	8.94	.201328	8.94	.222308
Sx^2	Sy^2	13.40	.006819	13.40	.008531
Sxy			.299068		.328305

* See Figure 16

TABLE Xb

Regression and Correlation Data for the Three Lower Degrees of Motivation for Operator 2 Operation B

Adj. Sums of Squares and Products

$S\underline{x}^2 = Sx^2 - \frac{(Sx)^2}{6}$ $\quad S\underline{y}^2 = Sy^2 - \frac{(Sy)^2}{6}$

$S\underline{xy} = Sxy - \frac{(Sx)(Sy)}{6}$

Elements	Degrees of Freedom	$S\underline{x}^2$	$S\underline{xy}$	$S\underline{y}^2$	Correlation Coeff. (See 1)	Regression Coeff. (See 2)	Sums of Squares (See 3)	Degrees of Freedom
Least Skilled	5	.07	-.004302	.000380	-.828	-.061	.00011561	4
Most Skilled	5	.07	-.001645	.000985	-.198	-.023	.00094634	4
Sum	10	.14	-.005947	.001365	-.430	-.042	.00111238	9
				Sum of Least and Most Skilled Elements			.00106195	8
						Difference	.00005043	1

1 $\dfrac{S\underline{xy}}{\sqrt{(S\underline{x}^2)(S\underline{y}^2)}}$ $\qquad$ 2 $\dfrac{S\underline{xy}}{S\underline{x}^2}$ $\qquad$ 3 $S\underline{y}^2 - \dfrac{(S\underline{xy})^2}{S\underline{x}^2}$

In each row in Table Xb the deviations whose sums of squares and products are listed are measured from the group mean, not from the experiment mean.

* See Figure 16

TABLE XIb

Regression and Correlation Data for the Three Higher Degrees of Motivation for Operator 2 Operation B

Adj. Sums of Squares and Products

$S\underline{x}^2 = Sx^2 - \frac{(Sx)^2}{6}$ $\quad S\underline{y}^2 = Sy^2 - \frac{(Sy)^2}{6}$

$S\underline{xy} = Sxy - \frac{(Sx)(Sy)}{6}$

Elements	Degrees of Freedom	$S\underline{x}^2$	$S\underline{xy}$	$S\underline{y}^2$	Correlation Coeff. (See 1)	Regression Coeff. (See 2)	Sums of Squares (See 3)	Degrees of Freedom
Least Skilled	5	.08	-.000910	.000064	-.407	-.011	.00005365	4
Most Skilled	5	.08	-.002933	.000295	-.599	-.037	.00018747	4
Sum	10	.16	-.003843	.000359	-.509	-.024	.00026670	9
				Sum of Least and Most Skilled Elements			.00024112	8
						Difference	.00002558	1

1 $\frac{S\underline{xy}}{\sqrt{(S\underline{x}^2)(S\underline{y}^2)}}$ $\quad$ 2 $\frac{S\underline{xy}}{S\underline{x}^2}$ $\quad$ 3 $S\underline{y}^2 - \frac{(S\underline{xy})^2}{S\underline{x}^2}$

In each row in Table XIb the deviations whose sums of squares and products are listed are measured from the group mean, not from the experiment mean.

* See Figure 16

TABLE Xc

Test of Significance of Adjusted Group Means for the Three Lower Degrees of Motivation for Operator 2 Operation B

Source	Sum of Squares	Degrees of Freedom	Mean Square
Common Slope	.00005043	1	.00005043
Residual	.00106195	8	.00013274

$$F = \frac{.00005043}{.00013274} = 0.37999$$

* See Figure 16