FURTHER INVESTIGATION
OF BODY TWIST ASSISTED REACHES AND MOVES

Body Twist Assisted Reaches and Moves
Where the Supply Level is of Normal Height

BY

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PREFACE

This thesis is based on one of the research projects on Methods-Time Measurement, a new advanced technique in motion and time study, conducted by the Research Group of the Industrial Engineering Department at Virginia Polytechnic Institute, and is a part of an investigation on Body Assisted Reaches and Moves. It consists of critical studies of Body Twist Assisted Reaches and Moves where blocks of varying weights were transferred from a supply bench of normal height to another bench of approximately the same height. It presents some new concepts in the method of approach to the whole problem of motion and time study as conceived by the author, with the hope of making a small contribution toward establishing a new course of scientific research in this field. Sincere discussions and criticisms always help find the true answer to problems, and the author welcomes any arguments or suggestions made toward any part of this thesis.

In conducting his research work, the author received help and encouragement from many people, to all of whom a deep sense of appreciation is extended. Special mention is made of Professor H. L. Manning for his kind encouragement and guidance throughout the work, of Dr. M. E. Terry and Dr. D. B. Duncan for their guidance and instructions in

the statistical methods used, and to former Instructor F. A. Beebe, Jr., for his design of the experiment and the preliminary work done by him. The author's colleagues, Hale C. Sweeny and Alfred S. York, also aided him with many suggestions and discussions, and it was a sincere pleasure to have been able to associate with them in this study. Messrs. R. E. Dillon, R. W. Henderson, S. C. Lafon, Jr., G. K. McCauley, and M. K. Smith all co-operated willingly as the operators for the preliminary part of the investigation conducted by Instructor F.A. Beebe, Jr. The author also wishes to express his appreciation to the Burlington Mills Corporation for granting funds for research, which made it possible for him to complete his graduate studies, and therefore this thesis, at Virginia Polytechnic Institute.

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INTRODUCTION

1.1 Introduction

The object of production has been described as "to produce a required quality by the best and cheapest method at the required time". In order to accomplich this aim, the use of scientific methods has become so common and extensive a practice in industry that it is now considered the basis of modern industrial development. Many developments have been made in the several fields to which this principle has been applied, among which is motion and time study. At first, time study, originated by Frederick W. Taylor, the father of scientific management, and motion study, developed by Frank B. and Lillian M. Gilbreth, each more or less made separate and independent progress--time study being used mainly for determining time standards, while motion study was used for improving methods. However, it has gradually been realized that motion study and time study not only supplement each other, but are actually inseparable; and it is becoming common practice to combine the two together as Motion and Time Study, or as it is sometimes called, Methods Engineering.

Although there are definite advantages and there have been many improvements in Motion and Time Study along the classical line, there still exist certain inherent defects in the methods employed, especially in the stop watch method of determining standard time. These defects can be divided into four general classes, namely:

1. Errors of sampling; which include
    a) lack of meeting the prior requirements to sampling (i.e. the standardization of methods, existence of proper conditions, etc.)
    b) improper selection of the number of observations so that there is nothing to insure the desired precision and accuracy of results.
2. Errors of definition; which include the following:
    a) The motion elements are not properly selected and defined so as to be as accurate and yet universal as possible.
    b) The inadequate definitions of standard (or normal) conditions, skill, workers, effort, etc.
3. Errors of measurement; which include
    a) indifference toward the accuracy and precision of stop watch readings.
    b) the improper selection of observed data (eg. throwing away certain values without scientifically valid reasons.)
    c) subjective errors in converting observed data into standard time (i.e. rating, leveling, etc.).

4. Limitation of usage, which means that the standard time obtained can be applied to that certain operation only, and cannot even be applied to similar operations.

In order to solve some of the weaknesses mentioned above, several improvements have been made recently, which can be divided into three main categories:

1. The effort rating approach. Although improved and much publicized, the technique of effort rating requires skill, and is contrary to the principle of transfer of skill. Although a skillful rating may increase the reliability or consistency of an observer's values, there is no way of verifying that his results will be valid or accurate.
2. The statistical approach. This will reduce the errors of sampling and measurement and will clarify the limits of usage, but little has been done along this line.
3. Motion-element-standard-data approach. There are already several methods proposed, among which are:
    a) Time standards for certain operations as published by Ralph M. Barnes.

b) Standard data as developed by Harold Engstrom.

c) Motion-Time Standards as developed by J.H. Quick, W. J. Shea, and R. E. Koehler, at the R. C. A. Victor Division, Radio Corporation of America, Camden, New Jersey.

d) Methods-Time Measurement as developed by the Methods Engineering Council, headed by Harold B. Maynard.

e) Elemental Time Standard for Basic Manual Work developed by the Western Electric Company.

These overcome much of the weaknesses of the traditional stop watch time study, and it is the author's belief that this approach combined with the application of statistics will prove to be the best means of finding and establishing a more scientifically reliable technique of motion and time study.

Among these motion-element-standard-data techniques, Methods-Time Measurement was originated by the Methods Engineering Council, headed by Harold B. Maynard, in 1940, their results being published in book form in 1948. It is defined as "a procedure which analyzes any manual operation or method into the basic motions required to perform it and assigns to each motion a predetermined time standard which is determined by the nature of the motion and the conditions under which it is made". Originally developed as a means of method improvement, it can also be used for establishing time standards, estimating, and other phases of production planning, as well as settling grievances and training personnel in becoming method conscious. It eliminates the necessity for rating or leveling, therefore increasing the objectivity of the standard time obtained. It is also easy to use if well understood and properly applied.

Although Methods-Time Measurement is a great advancement over the stop watch time study method, it is yet by no means perfect and has certain weak points. The main weakness being not in its basic aim or concept of approach, but rather in the crudeness of the procedure employed in the development of the data, due mainly to the infancy of the idea. This is acknowledged by the originators of the Methods-Time Measurement in their book, in which they ask for corrections, additions, and refinements. The main points that this author believes need to be further studied can be classified as follows:

1. Scope of the data

The present data are mainly restricted to manual motions within a limited magnitude of motions. It has been found by actual applications in certain industries that the Methods-Time Measurement technique fits very well to small operations involving simple motions, but there is much to be done in the field of combined motions, motions involving body movements as well as hand movements, and other complicated motions. If the Methods-Time Measurement technique finds itself into wider usage among various fields where human labor is used, there would undoubtedly be a necessity for the study of new motions not yet covered by the present data.

2. Compilation of data

A study of the procedure followed in collecting the data shows that many of the defects of the classical stop watch time study still exist in M.T.M. One of the main objections in the procedure is the non-systematic methods taken in sampling, i.e., the selection of the operators, the operations, the conditions, the number of operators and motions, etc., and because of this, some time standards were obtained from smaller samples than other, so that we have no uniform measure of the precision of the results. It is felt that a sound application of modern statistical methods, coupled with a thorough understanding of methods engineering, is the only solution to this problem.

3. Analysis of data

We find that rating and leveling were used in obtaining the Methods-Time Measurement data. This is a serious drawback when M.T.M. is supposed to have eliminated all subjective judgement; this is merely hiding subjectivity behind the stage. We also do not know how distinct the various classifications of motions differ from each other, and there seems to be room for statistical analysis to justify the classification chosen. The curves seem to have been fitted by eye, without much mathematical or statistical treatment, and the author mentions cases where some data were reanalyzed so as to fit the curve. Such *a posteriori* correction of data has a danger of introducing bias into the results and is subject to criticism.

With the aim of making improvements in Methods-Time Measurement, both basic and supplementary, the Research Group of the Industrial Engineering Department at Virginia Polytechnic Institute, under the direction of Professor Herbert L. Manning, has taken up a research project of making a critical investigation on some of the more complicated motions and fields not well covered by Methods-Time Measurement. The investigation was mainly conducted in the laboratory, establishing standard data whenever possible, and later checking the results with actual industrial cases. The experiments so far conducted are the following:

1. Professor Cecil A. Horst on Investigation of

Cranking Motions.

2. Professor Jacob D. Cantor on An Investigation of the Effect of Varying Diameters on the Time Required for Cranking Motions.

3. Frank A. Beebe, Jr., former research instructor of the Industrial Engineering Department at Virginia Polytechnic Institute, started the investigation of Body Assisted Reaches and Moves by designing the experiment, setting up the equipment, selecting the operators, and taking micromotion pictures of the motions to be studied. Later, Alfred S. York, Hale C. Sweeny, and the author divided the investigation into three parts according to the height of the supply from which the operators took materials of various weights and transferred them to a table of normal height by using body assisted motions. The investigation by Alfred S. York was completed in October, 1951, as his thesis for the Master of Science Degree in Industrial Engineering.

This particular thesis dealt with Body Twist Assisted Reaches and Moves where the objects were picked up from a supply bench of normal height (thirty-three inches) and moved to another bench of ordinary height (forty inches). Since the experiment set-up was made and pictures taken by Instructor Frank A. Beebe, Jr., the work done by this author was mainly the analysis of the films, analysis of the data, and interpretation of results. The main part of the study was devoted to statistical treatments of the data with such purpose in mind as finding the important factors involved in determining standard-data, forming some basis for obtaining the best classification of motions, and attaining a rough trend of the quantitative relationships between the assumed factors and the time values. It was also in the mind of the author to introduce some new means of approach to the problems now faced in motion and time study, through such examples of some application of statistical analysis as mentioned above. The positive result obtained in this thesis was a conceptual one rather than any definite and valid numerical values or formulas. But since most of the standard-data systems and values published thus far look very dubious when viewed under the light of concepts and procedures discussed in this investigation, it is believed that some forward steps have been taken in the right direction.

1.2 Bibliography

Many literatures read and experiences gained in the general field of Industrial Engineering helped toward formulating the ideas and procedures used in this thesis, but only those literatures directly consulted for specific purposes will be quoted here.

Since this whole field of standard-data techniques is a rather new one, not many references were found available. Among them (1) Methods-Time Measurement, by H. B. Maynard, G. J. Stegemerten, and J. L. Schwab; New York, McGraw-Hill Book Company, Inc., (1948), was used constantly as the fundamental reference on which to base this whole work.

The arguments presented in an article by L. E. Davis on (2) A Proposal for the Improvement of Time Study, Mechanical Engineering, May 1949, (Vol. 71, Number 5) was considered to fit well with the ideas of the author and were quoted directly in this thesis.

(3) Statistical Methods in Research and Production, by O. L. Davies; London: Oliver and Boyd, and (4) Experimental Designs, by W. G. Cochran and G. M. Cox, New York; John Wiley and Sons, Inc. (1950), were consulted to design the statistical techniques used in this thesis. (5) Statistical Tables by R. A. Fisher and F. Yates, New York:

Hafner Publishing Company, Inc., (1949) was used in connection with the two references mentioned above.

The opening statement of the Introduction was quoted from the (6) Production Handbook, by L. P. Alford and J. R. Bangs, New York: The Ronald Press Company, (1950).

The following side references will be found to be of value in connection with the subject matter of this thesis:

(7) J. H. Quick, W. J. Shea, and R. E. Koehler: Motion-Time Standards; Factory Management and Maintenance, Vol. 103, May (1945).

(8) H. Engstrom: Development and Use of Standard Data for Setting Time Standard, Proceedings of National Motion and Time Study Clinic, Industrial Management Society (1942).

(9) Elemental Time Standard for Basic Manual Work; Western Electric Company.

(10) R. M. Barnes: Motion and Time Study, New York, John Wiley and Sons, Inc., (1949).

(11) M. E. Mundel: Motion and Time Study; New York, Prentice-Hall, Inc. (1950), Chapters 17 - 21.

(12) W. A. Nordhoff: Machine-Shop Estimating, New York, McGraw-Hill Book Company, Inc., (1947)

II

EXPERIMENTAL PROCEDURE

2.1 Preliminary Experiment

The idea was to set up a series of motion patterns necessitating the use of the body in moving objects from one table to another. The body motion studied in this thesis was "Body Twist", which is the twisting of the body while keeping both feet in place on the floor.

Benches used were that of the adjustable height type as in Figures 1, 2, and 3. The main dimensions were as follows:

Table 1

Bench Dimensions

	Supply Bench	Dispose Bench
Height	33"	40"
Length	36"	36"
Width	23 3/4"	23 7/8"

Four box shaped materials of varying weights were used as shown in Table 2 and Figure 4.

Table 2

Materials Data

Materials Used No.	Average Weight*	Dimensions (L x W x H)
1 Cardboard Box	1 oz.	4"x4" x 1 1/32"
2 Wood Block	13 oz.	8"x3 5/8"x1 5/8"
3 "Soap" Fire Brick	2.7 lbs.	8" x2 3/16"x 1 7/8"
4 Fire Brick	7.5 lbs.	9" x4 1/2"x 2 1/2"

* From weighing 10 items

Five laboratory instructors in the Industrial Engineering Department were selected as operators for the experiment. The physical characteristics were as follows:

Table 3

Data of Operators

Operator	#1	#2	#3	#4	#5
Sex	Male	Male	Male	Male	Male
Age	27	25	39	38	29
Weight (lbs.)	172	120	163	113½	205
Height (in.)	69	67	70	68	72¼
Knee Height (in.)	21	19	22	18	21¼
Waist Height (in.)	43½	39	42	40½	43¼
Elbow Height (in.)	41½	39½	44¼	41¼	44
Shoulder Height (in.)	57¼	54	57¼	56	60¼
Arm Length (in.) (to knuckle)	28	25	25	26	27½
Forearm Length (in.) (to knuckle)	14	13	14	13	13½
Shoulder Width (in.) (end of collar bone)	14	13	14½	13	15

The two benches were set thirty-six inches apart with the operator standing between them. The materials were laid near the edge of the supply bench and transferred to an evenly distributed pattern of two to three layers on the other bench. These are illustrated in Figures 1, 2, and 3. All the operations were performed by the right hand alone. Grasp was made as simple and similar as possible; that is, the fingers were closed normally with the objects fully enclosed within the hand. Positioning of the objects was kept at a minimum, and the operators were told to work at their normal pace. The above descriptions were not clear enough to objectively measure the conditions, but by standardizing the method and by removing any restrictions other than the direct factors to be considered, it was hoped that the operators would work according to what each thought to be "normal", under what was hoped would be "normal" conditions.

The movie cameras used were Bell and Howell D-70A 16mm cameras, motorized to run at 1000 and 4000 frames per minute, and a Bedeaux Measurement Camera, made by the Eastman Kodak Company, which is an 8mm camera also made to run at 1000 and 4000 frames per minute. Each were used with the camera speed of 1000 frames per minute.

All the preliminary experiment up to this point was done by former Instructor Frank A. Beebe, Jr.

2.2 Analysis Procedure

Analysis of films taken above were done by the Model K-68 Keystone Projector, fitted with Porter Micromotion Conversion. This conversion consisted of a Veeder-Root

Counter, which counted the number of frames, and an electric control box which made it possible to vary the speed, stop, and reverse the projection of the films. A desk projection booth was used.

In the analysis of the films, the method of analysis mentioned in the Methods-Time Measurement was followed whenever possible. Notes were kept of all other observed facts to help analyze the data at a later time. The definitions of the classifications of the Reaches and Moves, as well the definition of the starting and ending points of a motion, were in accordance with those set up in "Methods-Time Measurement", by H.B. Maynard, G.J. Stegemerten, and J.L. Schwab.

Definitions and notations peculiar to this thesis are found in Appendix 1.

The raw data obtained as the result of the analysis of the films are found in Appendix 2. The films should be considered a part of this thesis and as the final source of investigation for any arguments to be made for or against any of the results attained in this thesis.

Fig. 1 Experimental Setup
Showing Supply Stack

Fig. 2 Experimental Setup
Showing Layout Pattern

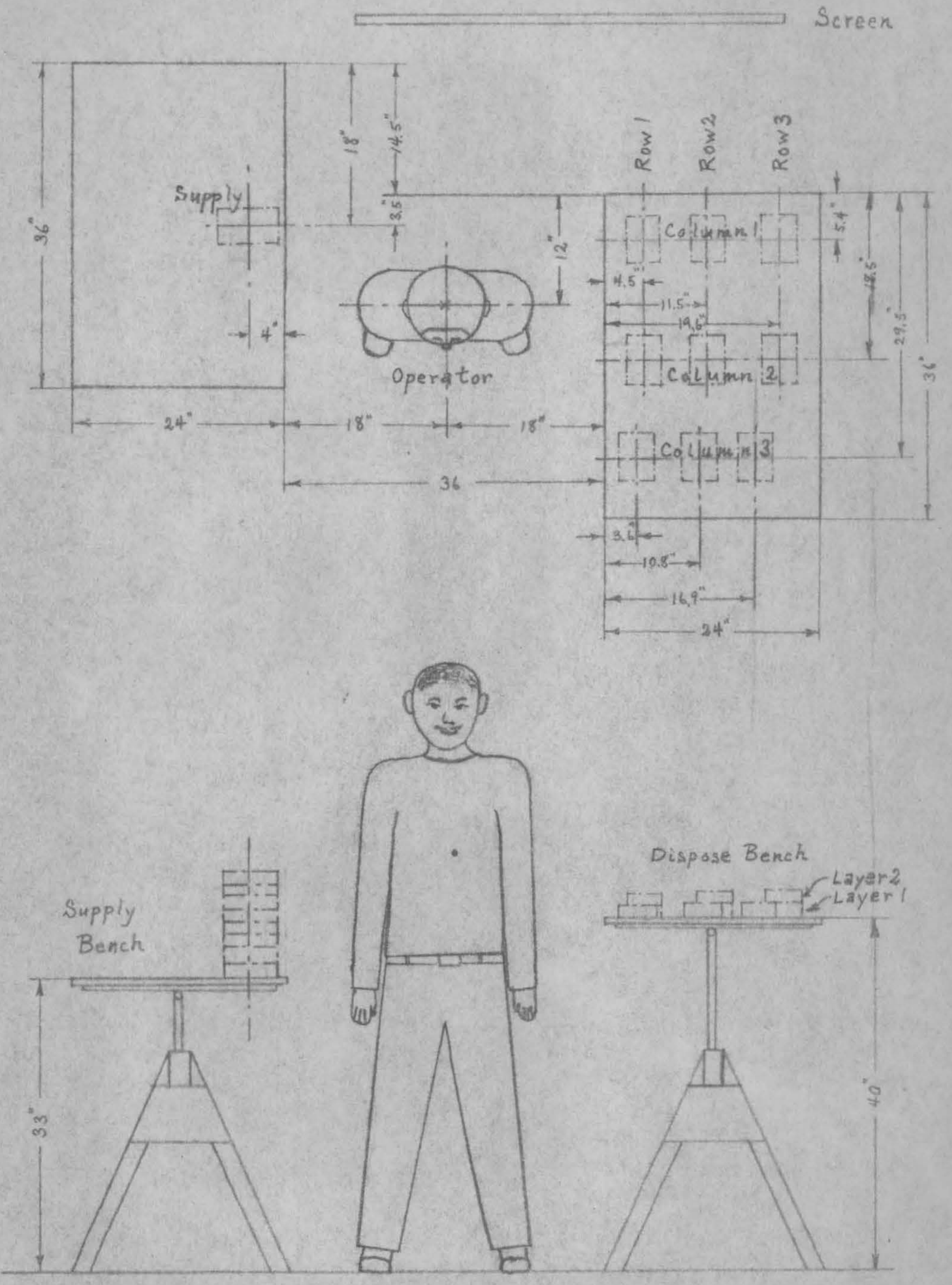

Fig. 3 Experimental Setup---Showing Dimensions

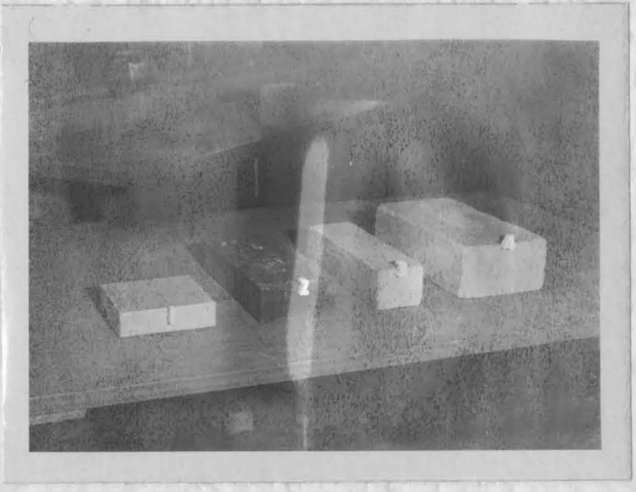

Fig. 4

The Four Materials Used

III

ANALYSIS OF DATA

3.1 Introduction

In a research project, the standard approach to a problem would be first to consider the factors affecting the experiment, establishing correlations among such factors qualitatively, and then to find quantitative relationships among the variables associated with measurable factors. Hence, in this investigation, all possible factors involved in determining the standard time of Reaches and Moves Assisted by Body Twist were first considered in order to form the basis of the analysis as follows:

A. Concerning the path of the motion

  1. Distance of hand moved a) Distance of actual path

  2. Angle a) of actual body rotation by the operator

     b) made by the starting and ending positions of the hand and the axis of the operator (i.e., by the set-up)

  3. Type of path of the motion (e.g., straight line, smooth, unrestricted curve, sudden change of direction, guided path, etc.)

B. Concerning the type of motion

  1. Amount of control required (i.e., necessity of carefulness, ease of location, skill required, effort required, object of motion, etc.)

  2. Combination of motions

C. Concerning materials

1. Weight of material
2. Size of material
3. Shape of material (i.e., flat, sharp corners, etc.)
4. Surface of material (i.e., smoothness)

D. Concerning operators

1. Physical characteristics of operators (i.e., strength, age, weight, height, health, fatigue, etc.)
2. Other characteristics of operators (i.e., skill, effort, training, intelligence, mental awareness, feeling, liking of work, adaptability, etc.)

E. Concerning conditions

1. Environment (e.g., temperature, humidity, brightness of light, floor conditions--slipperiness, etc.--space, safety, etc.)

In determining the way in which we handle these numerous factors, either separately or as a combination, we must consider the object of motion and time study, the accuracy of results desired, and the ease of applying the method chosen. With this in mind the above factors mentioned may be classified into two groups as follows:

1. The object of standardization

   Operators

   Environment

2. Observable variables

   a) Measurable: Distance

   Angle

   Weight of material

(Observable variables, continued)

Size of material
Surface of material

b) Non-measurable:

Type of path
Amount of control required
Combination of motions
Shape of material

The main purpose of studying number 1 would be to find the requirements and the distribution characteristics of the operators and environments in order to find what may be called "normal". The purpose of studying number 2, on the other hand, will be to find the relation between these factors and the standard time data. The proper treatment of the non-measurable factors would be to classify various possible cases by clear definitions.

Regarding operators, it would be a project in itself to determine the distribution of the various characteristics of people, and perhaps by the use of psychological and physiological tests determine certain correlations, if any, among such results and the standard-time data. Therefore, the operator, as a factor in standard time determination, will be treated only very generally and roughly in this thesis.

As for environments, this is quite a complicated and extensive field to be covered by this thesis, and therefore it is assumed, as mentioned in the chapter of Experimental Procedures, that the environment was normal in that nothing special existed to prevent the operators from doing the operations smoothly and comfortably.

Among the observable variables, the following can be said of the measurable factors:

Distance of actual path: This is the variable used in Methods-Time Measurement, but it was impossible to measure the actual distance of the hand moved, from the pictures taken, with any degree of accuracy. It might be added that it is also very difficult to make this measurement accurately when used in practical applications.

Straight line distance: Neither was this measurement so easy to make from the pictures, but it was possible to measure them from a reproduction of the original set-up. This is an easy measurement to take in actual applications.

Actual angle of body rotation: Although these measurements were not easy to take from the pictures, a rough approximation was made from observation.

Angle by set-up: This was made from the reproduction of the original set-up. One of the intents of using this variable was to overcome the inaccuracy of the observation made of the actual angle of body rotation.

Weight and size of the material: The materials were weighed and measured, but since it was not possible to make separate investigations of the two factors because of the design of this experiment, consideration of the size was dropped because of the comparative similarity of the sizes, all within the scope of easy grasp.

As for the non-measurable variables, the type of path was considered as a smooth, unrestricted curve, with no special control required. The combination of motions was made of Body Twist and Reaches (defined as "the basic element employed when the predominant purpose is to move the hand to a destination or general location) and Moves (defined as "the basic element employed when the predominant purpose is to transport an object to a destination) according to the Methods-Time Measurement classification.

Reaches were of classification R-b: Reach for single object in location that may vary slightly from cycle to cycle.

Moves were of classification M-b: Move object to approximate location.

The materials were box shaped with a surface of medium roughness, suitable for easy grasp. It is hoped that this is a normal condition, although a critical study may be made in the future as desired.

3.2 Graph Plotting

First of all, the data were plotted on a graph to help see the overall picture. The results turned out to be a widespread scattering of points with seemingly no systematic relation at all, as shown in Figures 5 to 12. It is expected that a wide variation among measured values will occur wherever human factors exist, and more samples must be taken to find accurate and precise results.

A somewhat rough guess can be made from the graph that weight has some effect on the results, but that seems to be about all that is anywhere near being clear, as obtained from this method.

3.3 Frequency Distribution

Looking at the graph obtained above, one would ordinarily be discouraged from going any further, if not for the techniques developed in statistics.

Leveling is a popular technique used among motion and time study men where such wide variation exists, but even though this may bring a more consistent result, which is not always the case, a serious bias may enter into the values so obtained, thus destroying the accuracy of the results, as mentioned in the Introduction.

Finding the frequency distribution and average values is the first step in using statistics, which was done without much success of deriving any additional information. Since the graphs in the previous section were plotted in a way to get a rough idea of the frequency distribution, separate distribution tables were not made. It seems clear that, for this investigation, a more advanced technique is necessary to obtain any distinct results, if any.

3.4 Analysis of Variance

In the foregoing sections no attention was paid to the difference among the operators, nor to that between the first and the second layers. In designing the experiment, the assumption must have been that the placing of the blocks on top of another could be treated the same as the placing of the block directly on the table in the same position. Since such an *a priori* assumption seemed doubtful because of the positioning effect, the layers were considered as a factor. To see clearly which assumed factors, or combinations of factors, really contributed to the time values, a technique known in statistics as analysis of variance was employed. In order to use simple techniques, there must be a balanced combination among the values of the factors involved, which requires a special design of the experiment, called factorial design. Since the experiment for this investigation was not planned by the author, and since it was designed without any intent of being subjected to such an analysis, the result as a whole was an unbalanced and imperfect one for this statistical analysis, which necessitated the deletion of some of the data. Since, as a result of the experimental design, a breakdown of the factors into the basic variables of distance and angles overthrew the balance of the design completely, the factors *Rows* and *Columns* (according to the pattern of the layout, as explained in Section 2.1) were substituted as a convenience toward obtaining results. From the experimental data, it was then possible to estimate the variation among operators, difference between first and second layers, and the effect of columns, rows, and weights on the time values.(3)(4)[*] Since the main purpose of this analysis was to detect any effect of the assumed factors upon the time values, the two extremes of the factors were chosen for analysis, which, except for a few missing values, fortunately made up a well balanced design with three operators. By taking weights numbers 3 and 4, it was possible to consider four operators instead of three and see the effect of a smaller difference in weights for Move.

Two methods of overcoming the unbalance of the design caused by a few missing values were used for Move. One was to use the average value of the other operators for that

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[*] See reference (3) of Bibliography, Chapter 5; and Reference (4), Chapter 5.

position, which assumed the homogeneity or the randomness of the operators, while another was to use the same value as that of the other layer, assuming no significant difference between the two layers. Since the effect of the layers turned out to be negligible, the second method was perhaps preferable; incidentally there was no great difference in the results obtained from both cases.

The tabulated results of the analysis are shown in Tables 4 to 9.

To make sure further whether or not the layers had any effect on the resulting time values, a separate test was made for each weight as shown in Tables 10 and 11.

The results of this analysis show that:

A. For Reach: it is most probable that the contributing factors are mainly the Row effect, which implies the effect of distance, and weight, while the operators may show an essential difference among themselves. It is obvious that there should be no difference with respect to layers, but the non-significance of columns is rather surprising. This, in a sense, implies that the angle of body movement has no essential effect on the time values, although it must be cautioned that we cannot make a positive conclusion because the joint effect of both the angle and distance is included in the column, even though the angle effect may be dominant.

The significant result of rows indicate that distance and perhaps some angle effect are probable factors, and that further studies should be made along these lines.

The significant result for weight is another surprising fact, since Reach is a motion apparently independent of the object, to say nothing of its weight. There must be some psychological effect of the weight on the operators, or else some dependence of the motions on preceding ones (such as Release, Move), or maybe even on those following as the result of anticipation.

B. For Move: it may be said with a small probability of error that there is a wide variation among operators, and that the columns, rows, and weights should be considered as factors. Layer turned out to be a possible factor according to Plan II, while it gave no effect in Plan I. Since the difference between the two plans was in operators and weights, there must have been some difference in some of the operators' reaction to weights in placing the materials to different layers. This can be substantiated by the significant result obtained for (Operator x Layer x Weight), which is the interaction among the three factors. The interaction is a measure of the influence of one factor on the effect of the other.(3)* The F-test given for each

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* See Reference (3), pp. 89, 90, and 248.

weight showed that there was no significant effect of layers up to weight number 3, but in weight number 4 the difficulty of positioning due to heavy weight became apparent. This shows that the kind of experimental design, as used in this thesis, where an operator places the materials on top of another, should not be employed to investigate heavy weights.

Since the Rows and Columns include the angle and distance effects, it may safely be concluded that a study of these latter effects should be made to establish any relationships between these factors and the time values. The results also show that the different weights should be treated separately in our investigations.

Had the experiment been more accurate and precise, it would have been very interesting, and probably very important, to study the results of the interactions of the factors, but it seems safe to disregard them in this thesis, except to publish the results for those wishing to obtain some rough inferences from them. The main purpose for the breakdown was to obtain the value of the higher interactions (third and fourth interactions combined) to be used as the error term, (which was assumed to have been stripped of significant factors by this time), rather than to make use of the individual terms by interpreting them.(3)*

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*See Reference (3), pp. 90, 93.

3.5 Regression

In order to follow up the results obtained by the factorial analysis, and make a more detailed study of the relationships between these factors and the time values, a statistical treatment called regression was employed. This is a mathematical method of curve fitting, using the theory of least squares. No attempt was made, however, to make any detailed study of the relationships, since it seemed a waste of effort to go beyond the bounds of accuracy and precision of the data used. Therefore, a study of the data was made by using only the simple linear regression technique, to see if some sort of relation existed between the factors and the time values, and to obtain a rough approximation of the magnitude and trend of any such relationships. Since the analysis indirectly showed the distance, angle, and weight to be the main contributing factors, the first two were taken both independently and combined, while the analysis was made separately for the different weights. The results are shown in Tables 12 to 14.

Some discussion on the results are made below, according to the factors analyzed.

A. Actual Angle of Body Rotation:

Weight number 3 showed a high significance in both

Reach and Move, but weight number 4 did not. This unconvincing result indicates that nothing definite can be said of this factor. A third camera angle of the experiments, or some other ingenious device to measure the actual body rotation angles, is definitely needed to obtain the accurate measurements necessary for this investigation.

B. Measured Angle of the Setup

The results for Reach definitely show that this is not a factor, while the result for Move is insufficient to reach any definite conclusions. At any rate, this factor in itself seems to be an unimportant factor within the range of magnitude studied, which was rather narrow.

C. Straight Line Distance

The results showed a significant effect of this factor in both Reach and Move, except for one case in Reach, which showed non-significance for weight number 2. Since the number of samples was the smallest for this weight, a further investigation will probably show a positive result for this case also. This result is nothing new since distance has been used as the independent variable in all cases of motion and time study for intuitively obvious reasons. The object of the regression analysis was rather to go a little further and make a rough measurement of the magnitude of the relation and the variation of the dependent variable, to be used in judging the effectiveness of using this factor, especially in comparison with any other factors or combinations of factors. In other words, it may be used as a criterion for the selection of the best classification.

D. (Straight Line Distance) x (Measured Angle of the Setup)

The result for significance was about the same as for (C), weight number 2 being the exceptional case. This was expected from the combined results of (B) and (C); that is, since the angle was not a factor for Reach (within the limits of our range), the combination of angle and distance should approximately be the same as for distance alone.

The comparison of (C) and (D), though it may not be too accurate, is worth mentioning here. It may be seen from the results that the straight line distance shows a better fit with Reach, while the (Straight Line Distance) x (Measured Angle of Setup) seems to be a better basis for the independent variable with respect to Move. However, nothing definite can be said of the comparison, which showed no statistically significant difference according to the F-test, as shown in Table 15. It seems advisable, though, to consider both factors in future experiments, especially for Move, for extended ranges of angles and distances.

In such a case, the form of combination should be:

$$T = B_o + B_1 d + B_2 \theta_s + B_3 d \theta_s$$

Where: B_o, B_1, B_2, and B_3 are constant coefficients

T : Time Value

d : Straight Line Distance

θ_s : Measured Angle of Setup

instead of a simple $T = B_o + B_1 d \, \theta_s$ as used in this thesis.

In this way more general conclusions may be obtained.

The idea of selecting a standard-data system (including its classification of motions, factors considered, method of analysis, time value assignment procedure, and the values themselves) as most effective by testing its variance (the smaller the variance the better), as used briefly above, seems to be a valid and powerful one for our purpose. In any system of measurements, there would exist errors caused by:

1. the measuring device
2. the measuring procedure.

Any departure from the requirements of precision and accuracy of either of these two items would result in excessive variance of the data obtained. The first item, as applied to our problem, would mean an accurate and detailed choice and classification of the true factors and motion elements involved, accurate devices, or techniques, for measuring such factors, and an accurate standard-time value, which should give results with the required accuracy and precision. The second item in our case would be an unerring assignment of the correct classification of motion elements and factors, accurate measurement of the measurable factors, and the correct use of the standard-data tables, charts, or formulas. Now in some cases, the increase in accuracy and precision of the first item would cause difficulty in making such detailed and precise measurements or assignments as required in the second item, which, on the whole, might not give the expected results. Such was our case when we tried to measure the actual distance of the path taken by the hand. Although it might be that the actual hand path would be a true factor, and therefore a better one from the viewpoint of the first item, it is felt that the difficulty of accurate measurements would cause the final values to leave larger errors, and therefore, a wide variance. It might also be noted that an improvement of the first item would tend to increase the cost of the measurements, although an overall economy might be obtained in some cases. At any rate, the minimum variance comparison is an effective criteria in appraising any standard-data system.

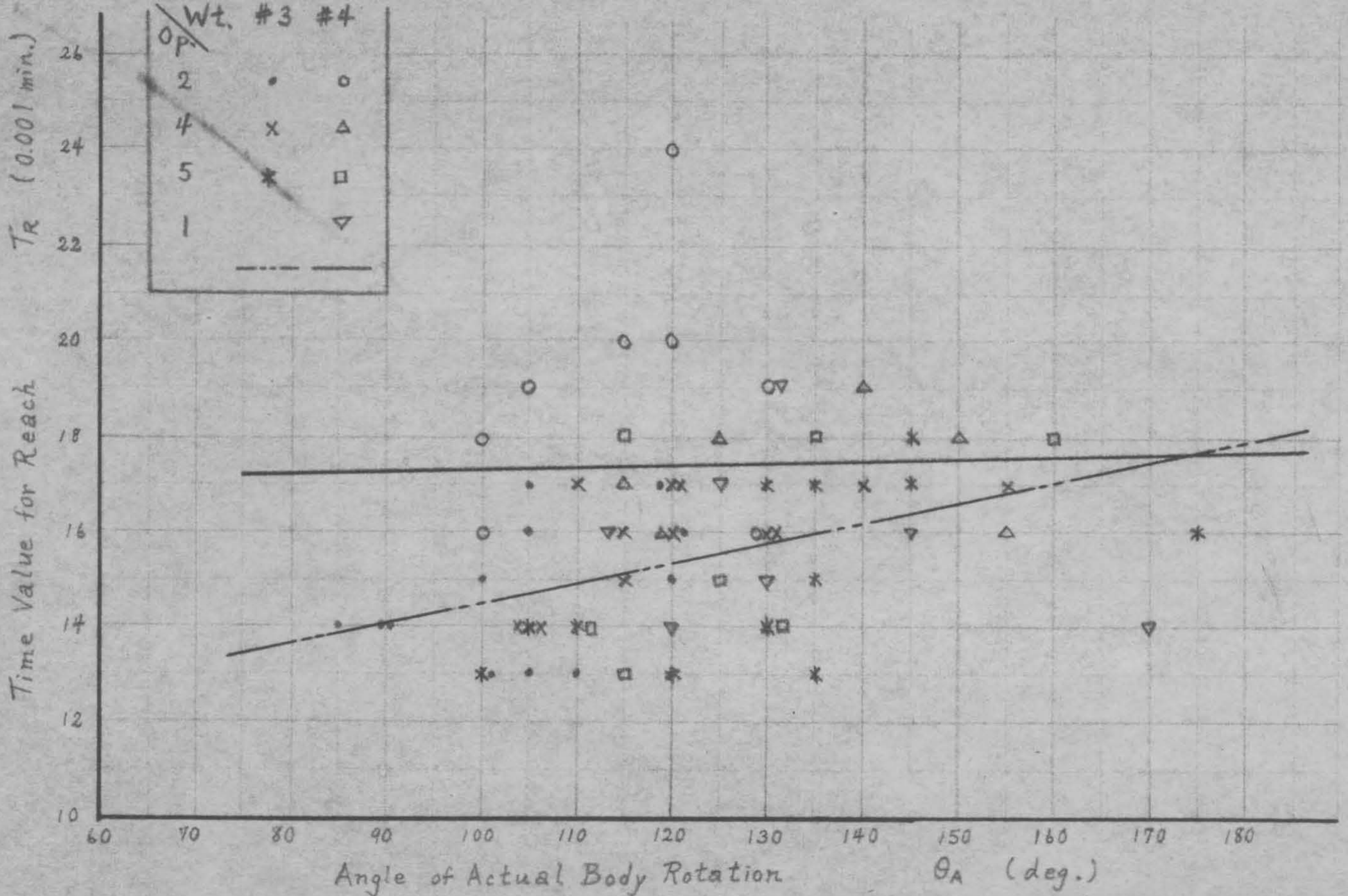

Fig.5 Graph of T_R and θ_A

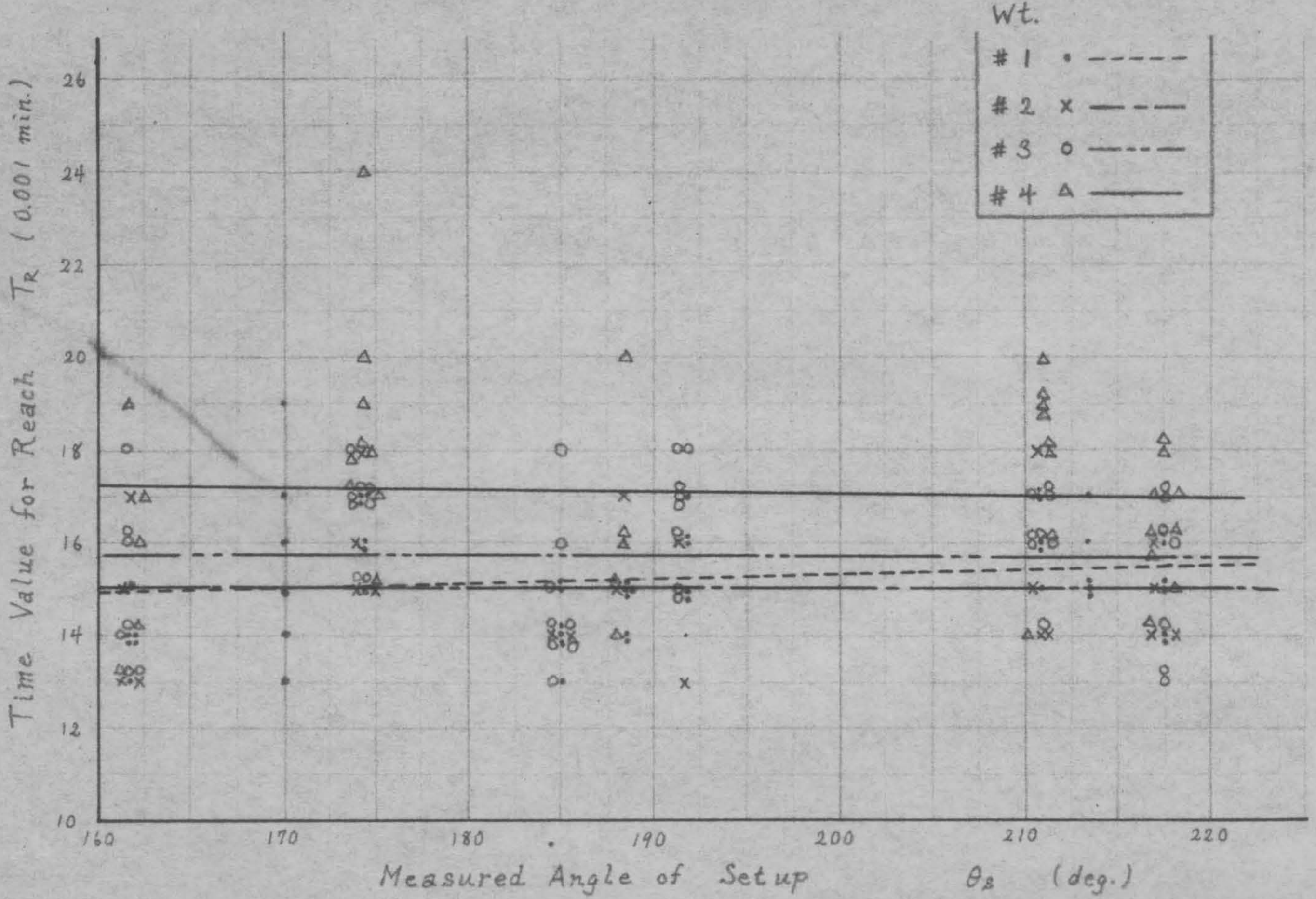

Fig. 6 Graph of T_R and θ_s

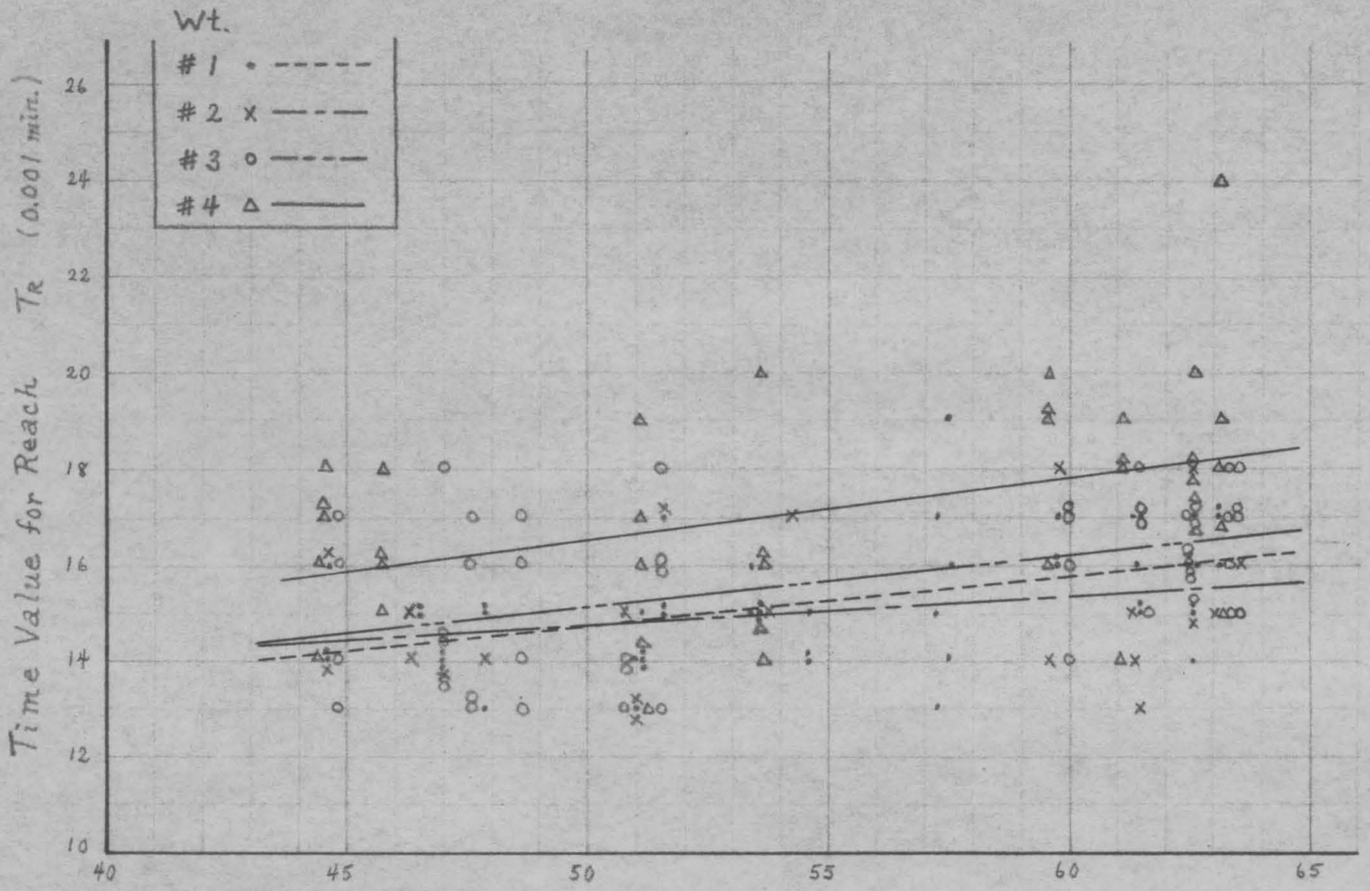

Fig. 7 Graph of T_R and d

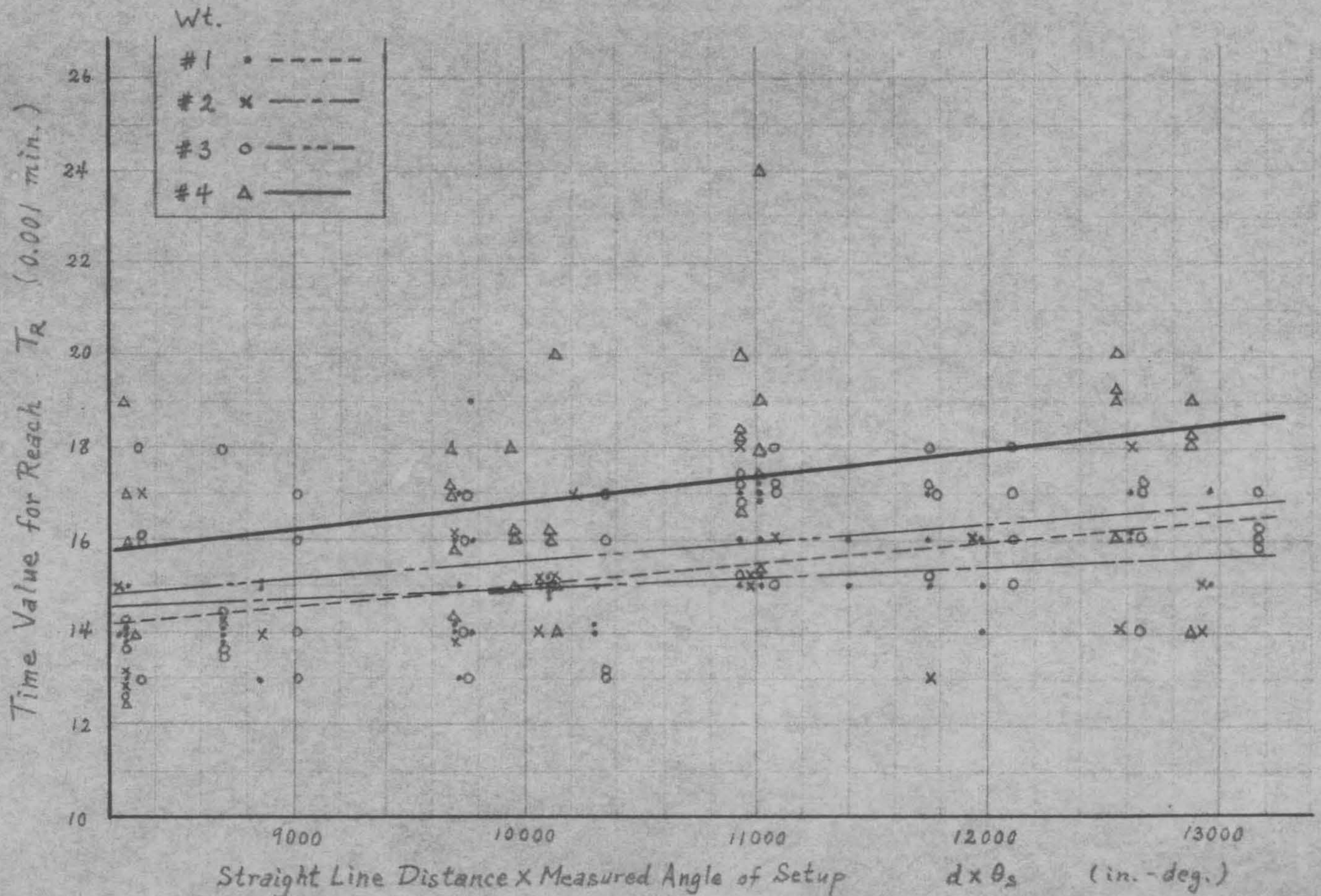

Fig. 8 Graph of T_R and $d \times \theta_s$

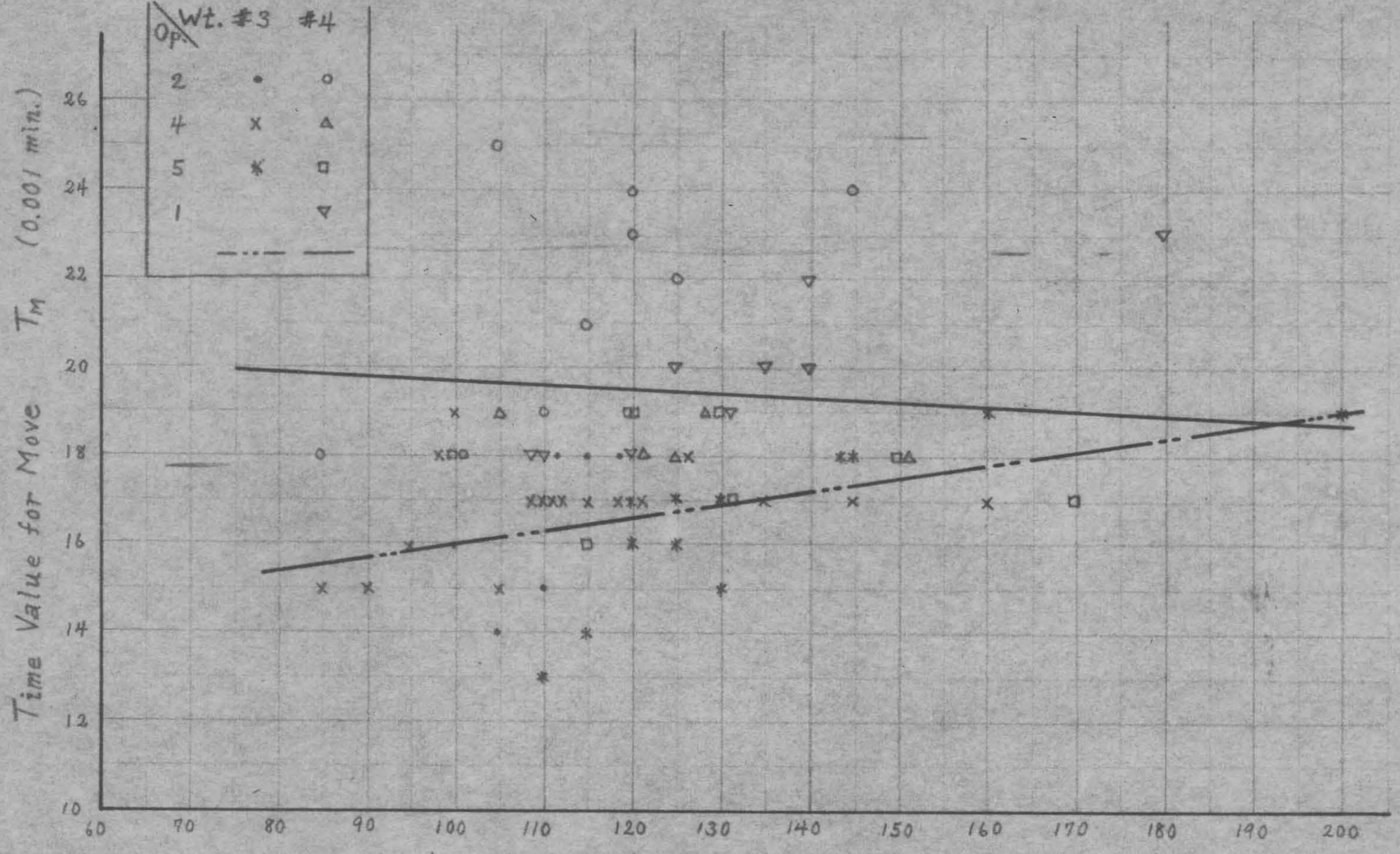

Fig. 9 Graph of T_M and θ_A

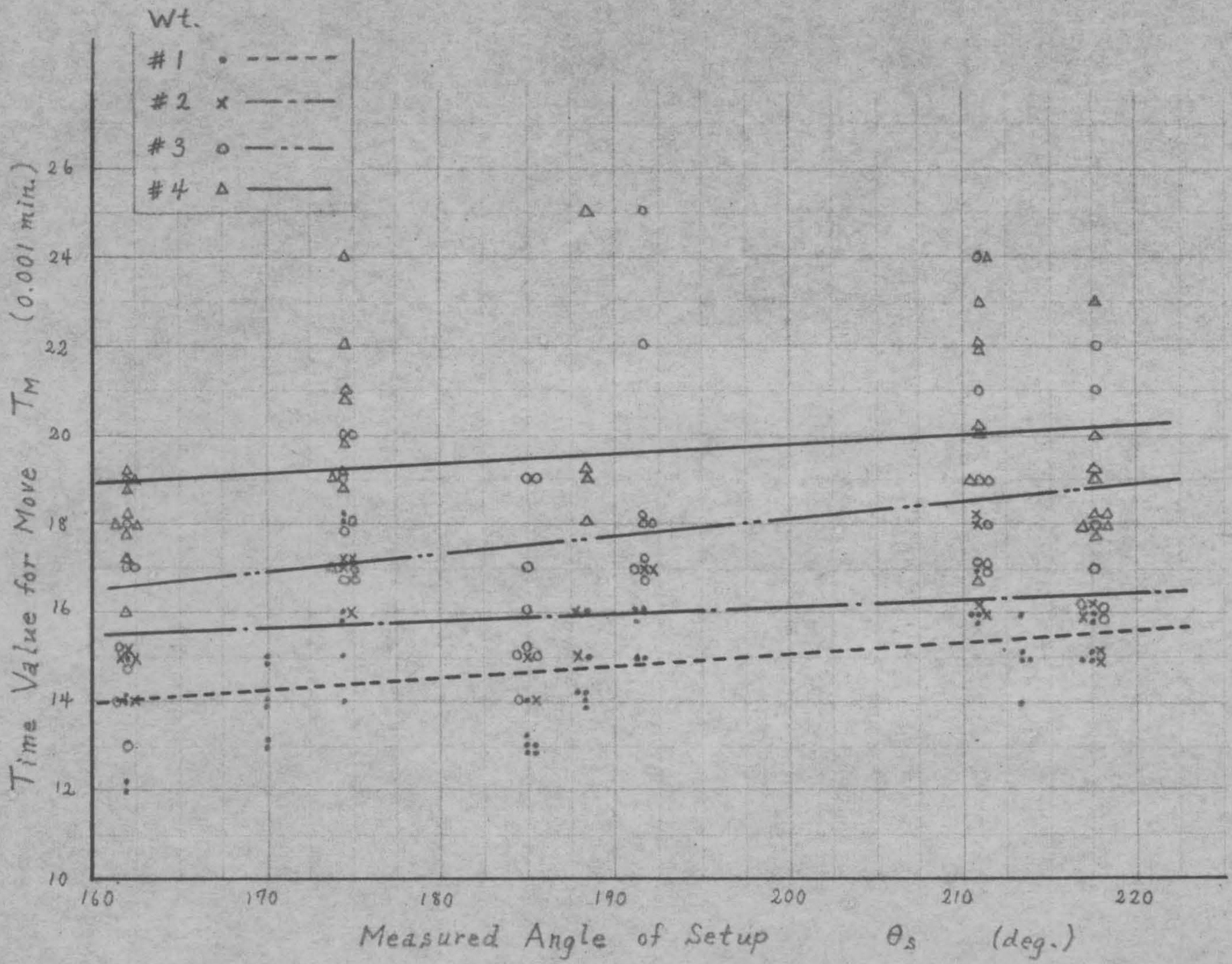

Fig. 10 Graph of T_M and θ_s

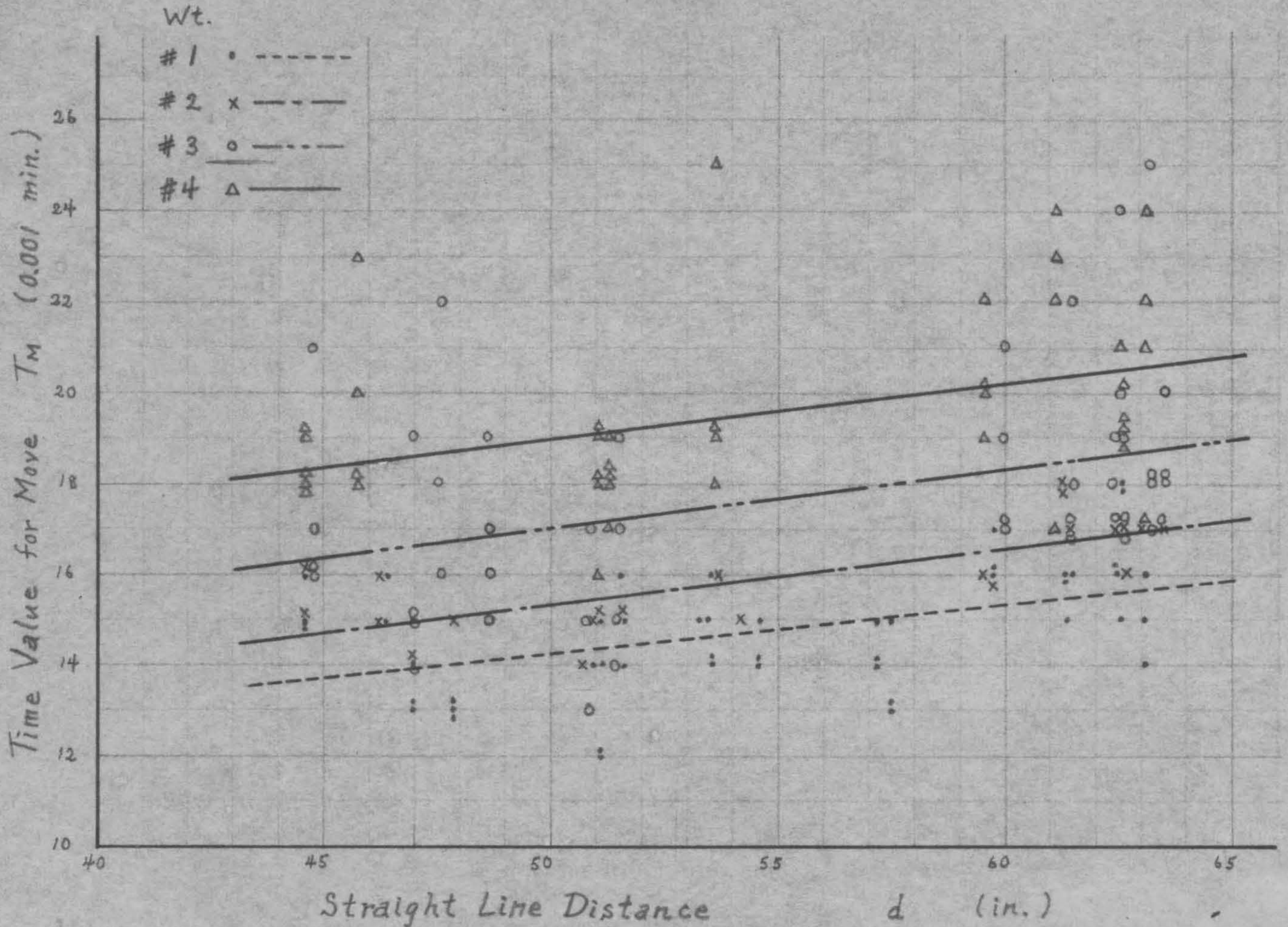

Fig. 11 Graph of T_M and d

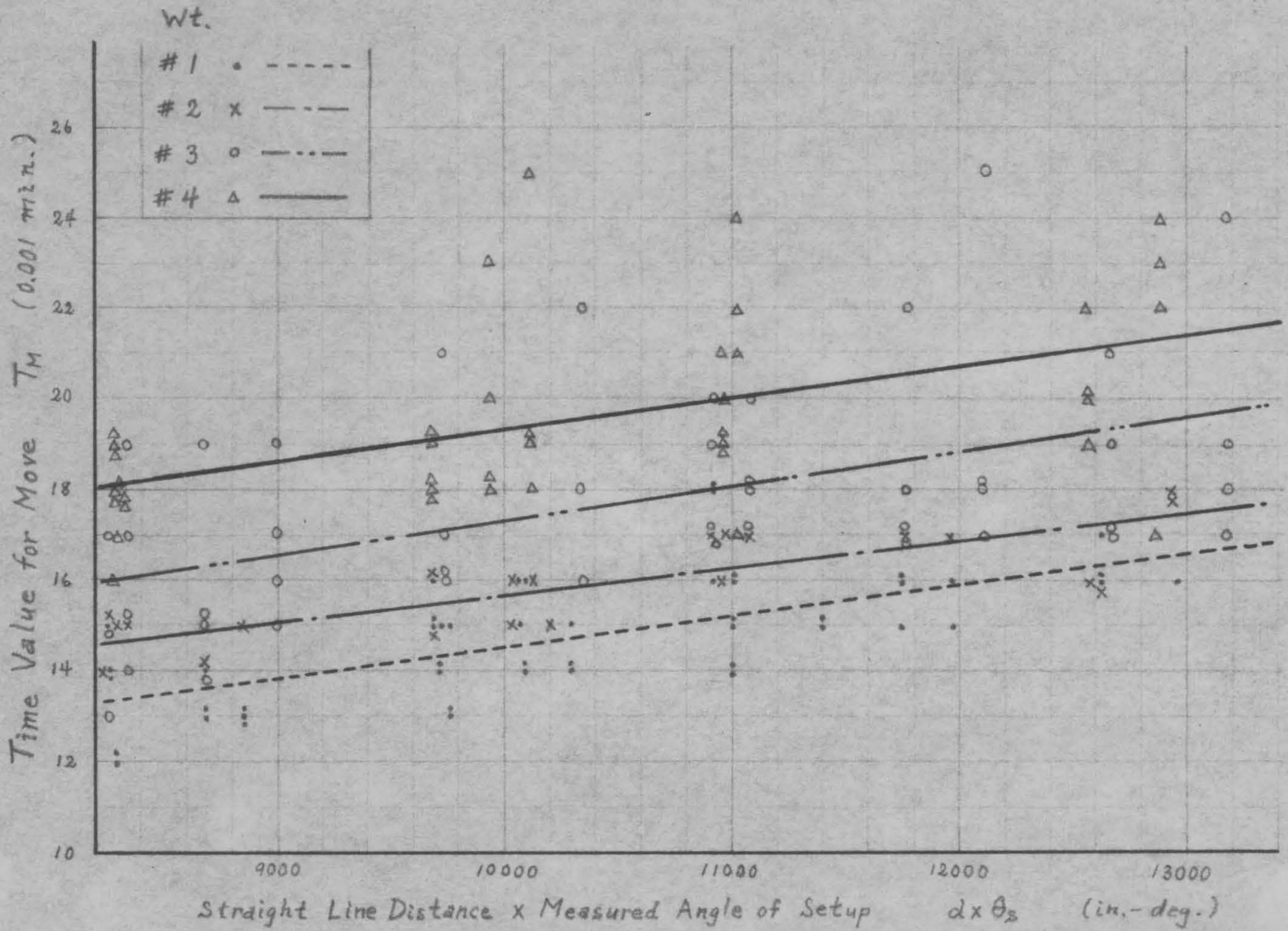

Fig. 12 Graph of T_M and $d \times \theta_s$

Table 4--Factorial Design for Reach

Factor	Number of Sample	Sample Description	Abbreviation
Operator	3	#1, #3, #5	O
Layer	2	#1, #2	L
Column	2	#1, #3	C
Row	2	#1, #3	R
Weight	2	#1, #4	W

Table 5--Factorial Design for Move

Plan I

Factor	Abbreviation	Number of Sample	Sample Description
Operator	O	3	#1, #3, #5
Layer	L	2	#1, #2
Column	C	2	#1, #3
Row	R	2	#1, #3
Weight	W	2	#1, #4

Plan II

Factor	Abbreviation	Number of Sample	Sample Description
Operator	O	4	#2,#3, #4,#5
Layer	L	2	#1, #2
Column	C	2	#1, #3
Row	R	2	#1, #3
Weight	W	2	#3, #4

Table 6.

Analysis of Variance for Reach

Source of Variation[*]	Sum of Squares	Degree of Freedom	Mean Square	F-Ratio	Significance Level[**]
O	14.29	2	7.15	3.32	?
L	0.00	1	0.00	0.00	-
C	0.75	1	0.75	0.35	-
R	44.08	1	44.08	20.45	* * *
W	12.00	1	12.00	5.57	*
OxL	4.63	2	2.31	1.07	-
OxC	1.63	2	0.81	0.38	-
OxR	0.79	2	0.40	0.18	-
OxW	4.63	2	2.31	1.07	-
LxC	0.00	1	0.00	0.00	-
LxR	1.33	1	1.33	0.62	-
LxW	0.75	1	0.75	0.35	-
CxR	6.75	1	6.75	3.13	-
CxW	0.00	1	0.00	0.00	-
RxW	0.00	1	0.00	0.00	-
OxLxC	6.13	2	3.06	1.42	-
OxLxR	1.29	2	0.65	0.30	-
OxLxW	1.63	2	0.81	0.38	-
OxCxR	1.13	2	0.56	0.26	-
OxCxW	6.13	2	3.06	1.42	-
OxRxW	0.13	2	0.06	0.03	-
LxCxR	0.00	1	0.00	0.00	-
LxCxW	2.08	1	2.08	0.97	-
LxRxW	0.75	1	0.75	0.35	-
CxRxW	1.33	1	1.33	0.62	-
ERROR	23.71	11	2.16		
TOTAL	135.92	47			

[*] See Table 4 for abbreviations.

[**] The notations are as follows:

* * *	Significant, less than 0.1% level.
* *	Significant, between 0.1% and 1.0% levels.
*	Significant, between 1.0% and 5.0% levels.
?	Possibly significant, between 5.0% and 10.0% levels.
-	Non-significant, higher than 10.0% level.

Table 7.

Analysis of Variance for Move

Plan I
(Missing Variate = Average of Other Operators)

Source of* Variation	Sum of Squares	Degree of Freedom	Mean Square	F-Ratio	Significance Level**
O	11.63	2	5.81	8.55	* *
L	1.33	1	1.33	1.96	-
C	8.33	1	8.33	12.26	* *
R	35.02	1	35.02	51.51	* * *
W	165.02	1	165.02	242.70	* * *
OxL	7.29	2	3.65	5.36	*
OxC	0.54	2	0.27	0.40	-
OxR	6.29	2	3.15	4.63	*
OxW	6.29	2	3.15	4.63	*
LxC	3.52	1	3.52	5.18	*
LxR	0.08	1	0.08	0.12	-
LxW	6.75	1	6.75	9.93	* *
CxR	4.08	1	4.08	6.01	*
CxW	0.08	1	0.08	0.12	-
RxW	0.02	1	0.02	0.03	-
OxLxC	1.54	2	0.77	1.13	-
OxLxR	0.29	2	0.15	0.21	-
OxLxW	7.63	2	3.81	5.61	*
OxCxR	3.04	2	1.52	2.24	-
OxCxW	0.54	2	0.27	0.40	-
OxRxW	1.79	2	0.90	1.32	-
LxCxR	0.02	1	0.02	0.03	-
LxCxW	2.52	1	2.52	3.71	?
LxRxW	1.33	1	1.33	1.96	-
CxRxW	1.33	1	1.33	1.96	-
ERROR	7.48	11	0.68		
TOTAL	283.81	47	6.04		

* See Table 5 for Abbreviations.

** The notations are as follows:

* * *	Significant, less than 0.1% level.
* *	Significant, between 0.1% and 1.0% level.
*	Significant, between 1.0% and 5.0% level.
?	Significance possible, between 5.0% and 10.0% levels.
-	Non-significant, higher than 10.0% level.

Table 8.

Analysis of Variance for Move

(Plan I $L_1 = L_2$)

Source of* Variation	Sum of Squares	Degree of Freedom	Mean Square	F-Ratio	Signifi-** cance Level
O	15.17	2	7.16	12.06	* *
L	0.33	1	0.33	0.53	-
C	12.00	1	12.00	19.08	* *
R	40.33	1	40.33	64.14	* * *
W	168.75	1	168.75	268.37	* * *
OxL	4.67	2	2.33	3.71	?
OxC	1.50	2	0.75	1.19	-
OxR	4.67	2	2.33	3.71	?
OxW	4.50	2	2.25	3.58	?
LxC	3.00	1	3.00	4.77	?
LxR	0.00	1	0.00	0.00	-
LxW	4.08	1	4.08	6.49	*
CxR	5.33	1	5.33	8.48	*
CxW	0.75	1	0.75	1.19	-
RxW	0.08	1	0.08	0.13	-
OxLxC	1.50	2	0.75	1.19	-
OxLxR	0.50	2	0.25	0.40	-
OxLxW	10.67	2	5.33	8.48	* *
OxCxR	5.17	2	2.58	4.11	*
OxCxW	1.50	2	0.75	1.19	-
OxRxW	2.67	2	1.33	2.12	-
LxCxR	0.33	1	0.33	0.53	-
LxCxW	2.08	1	2.08	3.31	?
LxRxW	2.08	1	2.08	3.31	?
CxRxW	2.08	1	2.08	3.31	?
ERROR	6.92	11	0.63		
TOTAL	300.67	47	(6.40)		

* See Table 5 for Abbreviations.

** The notations are as follows:

* * * : Significant, less than 0.1% level.
* * : Significant, between 0.1% and 1.0% level.
* : Significant, between 1.0% and 5.0% level.
? : Possibly significant, between 5.0% and 10.0% levels.
\- : Non-significant, higher than 10.0% level.

Table 9.

Analysis of Variance for Move

Plan II $L_1 = L_2$

Source of* Variation	Sum of Squares	Degree of Freedom	Mean Square	F-Ratio	Significance Level**
O	61.30	3	20.43	28.74	* * *
L	5.64	1	5.64	7.93	*
C	17.02	1	17.02	23.93	* * *
R	47.27	1	47.27	66.48	* * *
W	37.52	1	37.52	52.77	* * *
OxL	10.17	3	3.39	4.77	*
OxC	12.05	3	4.02	5.65	* *
OxR	13.30	3	4.43	6.23	* *
OxW	61.54	3	20.52	28.86	* * *
LxC	0.39	1	0.39	0.55	-
LxR	0.02	1	0.02	0.02	-
LxW	0.14	1	0.14	0.20	-
CxR	3.52	1	3.52	4.95	*
CxW	2.64	1	2.64	3.71	?
RxW	0.14	1	0.14	0.20	-
OxLxC	2.17	3	0.72	1.02	-
OxLxR	2.05	3	0.68	0.96	-
OxLxW	16.92	3	5.64	7.93	* *
OxCxR	2.30	3	0.77	1.08	-
OxCxW	7.67	3	2.56	3.60	*
OxRxW	5.67	3	1.89	2.66	?
LxCxR	0.02	1	0.02	0.02	-
LxCxW	0.02	1	0.02	0.02	-
LxRxW	0.39	1	0.39	0.55	-
CxRxW	0.77	1	0.77	1.08	-
ERROR	11.37	16	0.71		
TOTAL	321.98	63	(5.11)	(7.19)	(* * *)

* See Table 5 for Abbreviations.

** The notations are as follows:

- * * * : Significant, less than 0.1% level.
- * * : Significant, between 0.1% and 1.0% levels.
- * : Significant, between 1.0% and 5.0% levels.
- ? : Possible significance, between 5.0% and 10.0% levels.
- \- : Non-significant, higher than 10.0% levels.

Table 10

F-Test for Significance Between Layers for Reach

Weight	#1	#2	#3	#4
S.S.	21.85	9.50	40.18	23.33
Layer 1 d/F*	15	4	14	6
M. S.	1.46	2.38	2.87	3.89
S.S.	18.68	16.50	25.18	15.33
Layer 2 d/F*	18	4	10	6
M. S.	1.04	1.13	2.52	2.56
F-Ratio	1.40	1.74	1.14	1.52
Significance**	-	-	-	-

Table 11

F-Test for Significance Between Layers for Move

Weight	#1	#2	#3	#4
S.S.	9.01	0.50	119.00	111.70
Layer 1 d/F*	13	4	18	17
M. S.	0.69	0.13	6.61	6.57
S.S.	11.19	1.50	75.25	12.40
Layer 2 d/F*	17	4	18	16
M. S.	0.66	0.38	4.18	0.78
F-Ratio	1.05	3.00	1.58	8.48
Significance**	-	-	-	* * *

* d/F : Degrees of Freedom

** The notations are as follows:

* * * : Significant, less than 0.1% level.

* * : Significant, between 0.1% and 1.0% level.

* : Significant, between 1.0% and 5.0% level.

? : Possibly significant, between 5.0% and 10.0% levels.

\- : Non-significant, higher than 10.0% level.

Table 12

Operator List for the Regression Analysis

For Regression (A)

Operator	Op.#1	Op. #2	Op. #3	Op. #4	Op. #5
Weight #3		x		x	x
#4		x		x	x

For Regression (B), (C), and (D)

Operator	Op. #1	Op. #2	Op. #3	Op. #4	Op. #5
Weight #1	x		x		x
#2	x		x		
#3		x	x	x	x
#4	x	x	x	x	x

Table 13 - Regression Analysis for Reach
(Operators are listed in Table 12)

A. Actual Angle of Body Rotation as the Independent Variable.

Weight No.	B_1	B_o	Total S.S.	S.S. due to Linearity	Dev. from Linearity	(n-2) d/F*	M.S.	F-Ratio	Significance**
3	0.0421	10.27	85.22	22.78	62.45	34	1.84	12.40	* *
4	0.0044	16.88	123.14	0.11	123.04	19	6.48	0.02	-

B. Measured Angle of the Setup as the Independent Variable

1	0.0101	13.29	80.04	1.77	78.28	49	1.60	1.11	-
2	-0.0008	15.20	46.95	0.01	46.95	20	2.35	0.00	-
3	-0.0012	15.93	119.81	0.02	119.81	45	2.66	0.01	-
4	-0.0031	17.70	173.56	0.18	173.37	34	5.10	0.04	-

C. Straight Line Distance as the Independent Variable.

1	0.105	9.42	80.04	20.04	60.00	49	1.22	16.37	* * *
2	0.059	11.79	46.95	3.59	43.36	20	2.17	1.66	-
3	0.106	9.83	119.83	27.25	92.58	45	2.06	13.25	* * *
4	0.127	10.11	173.56	28.59	144.77	34	4.26	6.71	*

D. (Straight Line Distance) x (Measured Angle of the Setup) as the Independent Variable.

1	0.00048	10.21	80.04	21.62	58.41	49	1.19	18.14	* * *
2	0.00020	12.95	46.95	2.13	44.82	20	2.24	0.95	-
3	0.00039	11.63	119.83	18.50	101.33	45	2.25	8.21	* *
4	0.00055	11.26	173.56	21.93	151.62	34	4.46	4.92	*

* d/F : Degrees of Freedom. ** See Table 6 for notations.

Table 14 - Regression Analysis for Move
(Operators are listed in Table 12)

A. Actual Angle of Body Rotation as the Independent Variable.

Weight No.	B_1	B_o	Total S.S.	S.S. due to Linearity	Dev. from Linearity	(n-2) d/F*	M.S.	F-Ratio	Significance**
3	0.0304	13.01	73.64	15.78	57.86	34	1.70	9.28	* *
4	-0.0090	20.61	134.24	0.82	133.42	23	5.80	0.14	-

B. Measured Angle of the Setup as the Independent Variable.

1	0.0277	9.53	88.48	12.45	76.03	46	1.65	7.53	* *
2	0.0160	12.86	27.82	2.28	25.53	20	1.8	1.79	-
3	0.0408	9.98	276.87	27.32	249.55	44	5.67	4.82	*
4	0.0208	15.58	177.98	8.76	169.21	38	4.45	1.97	-

C. Straight Line Distance as the Independent Variable.

1	0.106	8.99	88.48	18.83	69.65	46	1.51	12.44	* * *
2	0.123	9.15	27.82	15.49	12.33	20	0.62	25.11	* * *
3	0.132	10.43	276.87	40.88	235.98	44	5.36	7.62	* *
4	0.120	13.00	177.98	25.99	151.98	38	4.00	6.50	*

D. (Straight Line Distance) x (Measured Angle of the Setup) as the Independent Variable.

1	0.00071	7.49	88.48	39.65	48.83	46	1.06	37.35	* * *
2	0.00060	9.65	27.82	19.05	8.76	20	0.44	43.48	* * *
3	0.00076	9.70	276.87	72.02	204.85	44	4.66	15.47	* * *
4	0.00068	12.47	177.98	44.35	133.62	38	3.52	12.61	* *

* d/F : Degrees of Freedom.

** See Table 6 for notations.

Table 15 - Comparison of Factors (C) and (D) (d and dxθ_s)

A. For Reach

Weight No.	M.S. due to linearity		d/F*	F Ratio	Sig.**	M.S. due to dev. from linearity		d/F*	F Ratio	Sig.**
	(C)	(D)				(C)	(D)			
1	20.04	21.62	1	1.08	-	1.22	1.19	49	1.03	-
2	3.59	2.13	1	1.66	-	2.17	2.24	20	1.03	-
3	27.25	18.50	1	1.47	-	2.06	2.25	45	1.09	-
4	28.59	21.93	1	1.30	-	4.26	4.46	34	1.05	-

B. For Move

1	18.83	39.65	1	2.11	-	1.51	1.06	46	1.43	-
2	15.49	19.05	1	1.23	-	0.62	0.44	20	1.41	-
3	40.88	72.02	1	1.76	-	5.36	4.66	44	1.15	-
4	25.99	44.35	1	1.71	-	4.00	3.52	38	1.14	-

* d/F : Degrees of Freedom

** See Table 6 for notation.

IV

SUMMARY

4.1 Results and Suggestions

One of the main purposes of this thesis was to set up a new approach in both concept and methodology of experimentation in trying to solve the problems of motion and time study scientifically. Because of the crudeness of the experimental set-up, no definite results or conclusions are claimed to have been obtained, but it is believed that something of a new course has been set for future investigations along those lines.

One of the basic viewpoints expressed in this thesis is that the classical stop watch time study method and the rating approach will eventually give way to the motion-element-standard-data techniques after the latter has been revised and implemented thoroughly with sound applications of statistics, psychology, and physiology. Even when rating is perfected to an ideal stage, it is consistency and not accuracy which is attained, the system still retaining its subjectivity and the necessity of skill. This is essentially a throwback to the days of skilled craftsmen before the Industrial Revolution.

Next to be considered is the thorough restudy of all possible factors and their combinations, making separate treatments of those factors which are the objects of standardization and those variables which have some relationship with the standard-time data, (although they may be combined together into one experiment, if more efficient that way.).

The use of statistics should be extended to many techniques other than those used in this thesis. Physiology should help in the study of motions and of operators, while psychology should help give some means of measurement of operators, as well as the effect of environment on operators.

Although a detailed study of all possible factors and their relationships to time values is necessary to form a scientifically accurate and precise standard-data system, it must not be forgotten that the ease of application is essential for the system to have any practical value. The minimum variance method should help find an optimum system with both accuracy and convenience in mind. Also a measure of precision and reliability should accompany all systems if they are to be used wisely. It would be good to have several alternate systems of varying precision and complexity, so that engineers will have a choice between accuracy and simplicity, according to the purpose for which it is to be used.

Nothing definite can be said of the results obtained by the analysis of the data, because of the crude experimental set-up, but a few points will be repeated here. First of all, there was a wide variation among operators, which tells us that great care must be taken in choosing enough operators in such a way as to be representative of the population to which we are going to apply the results.

Distance and weight showed to be contributable factors to the time values of both Reach and Move, while angle showed a slight effect on Move only. Unless some accurate means of measuring the angle of actual body rotation is found, it seems better to use the angle of the set-up as the variable. A similar statement can be made for distance, where straight line distance seems to be a good substitute for the actual distance of the hand path with its ease of accurate measurement. The combination of angle and distance seemed to show the best fit for Move, while distance alone was the likely factor for Reach; the adjustment for weight, of course, has to be made for both cases.

4.2 Concluding Remarks

With all its imperfections, this investigation is believed to have served its purpose by pointing out the need of a change in approach to the present problems of motion and time study, from that standpoint taken by the majority of engineers. It also showed some rough examples of how statistical methods help obtain important information from seemingly disorganized data. It is hoped that this thesis will serve as a useful guide in opening a new field of research in motion and time study and in conducting the investigations effectively in the future.

Appendix I

Definitions and Notations

Words and phrases peculiar to Motion and Time Study and Statistics have the same meaning generally accepted in those respective fields. For details please consult Motion and Time Study, by R. M. Barnes(10) for terminologies in the general Motion and Time Study field, and Methods-Time Measurement, by H. B. Maynard, G. J. Stegemerten, and J. L. Schwab(1) for those concerned with Methods-Time Measurement. Most of the recently published textbooks on mathematical or engineering statistics give explanations on the statistical terminologies used.

Words and notations peculiar to this thesis are as follows:

Angle of Actual Body Rotation: The angle of body rotation as actually taken by the operators to perform a Reach or Move as measured at the shoulder level.

B_o and B_1 : Constant coefficients in the equation

$T = B_o + B_1 x$

where T : Either T_R or T_M

x : Any of the assumed factors (independent variable)

Body Twist; The twisting motion of the body while keeping both feet in place on the floor.

Body Twist Assisted Move : Move (defined by the Methods-Time Measurement as "the basic element employed when the predominant purpose is to transport an object to a destination") combined with Body Twist. The classification of Move studied was case B: Move object to approximate location.

Body Twist Assisted Reach: Reach (defined by the Methods-Time Measurement as "the basic element employed when the predominant purpose is to move the hand to a destination or general location") combined with Body Twist.

d ; Notation for Straight Line Distance

d/F : Degrees of Freedom

L1, L2 : Layer 1 and Layer 2

Measured Angle of Setup : The angle made between the two lines connecting the starting and the terminal points of the hand motions with the central position of the operator.

Move: as used throughout this thesis, this term will mean Body Twist Assisted Move.

M. T. M. : Methods-Time Measurement

Reach : As used throughout this thesis, this term will mean Body Twist Assisted Reach.

Straight Line Distance : The shortest distance between the starting and terminal points of the hand motions.

T_M : Time value for Move (in 0.001 minute units)

T_R : Time value for Reach (in 0.001 minute units)

Time : Observed time value in 0.001 minute units.

θ : Notation for angle in general.

θ_A : Notation for Actual Angle of Body Rotation.

θ_s : Notation for Measured Angle of Setup.

* * * : Very Highly Significant; less than 0.1% significance level, which means that there is less than 0.1% probability that the factor has no effect on the time values.

* * : Highly Significant; between 0.1% and 1.0% significance level

* : Significant, between 1.0% and 5.0% significance levels.

? : Possibly Significant, between 5.0% and 10.0% significance levels.

- : Non-significant, more than 10.0% significance level.

Appendix Table II - 1

Raw Data for Reach

Material No.	Operator No.	Column 1						Column 2						Column 3					
		Row 1		Row 2		Row 3		Row 1		Row 2		Row 3		Row 1		Row 2		Row 3	
		L1	L2	L1	L2	L1	L2	L1	L2	L1	L2	L1	L2	L1	L2	L1	L2	L1	L2
1 1 oz.	1	15	14	16	15	17	16	15	14	15	15	14	16	14	14	16	15	16	15
	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	3	15	16	15	17	15	17	15	14	14	15	16	17	15	13	14	17	17	17
	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	5	-	14	-	15	-	16	13	14	14	15	15	15	14	14	19	13	17	16
2 13 oz.	1	14	14	-	-	14	14	14	14	-	-	16	13	13	13	-	-	15	15
	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	3	15	16	-	-	15	18	-	-	17	15	-	-	17	15	-	-	16	18
	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3 43 oz.	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	13	14	-	-	16	16	13	14	-	-	15	17	13	14	-	-	17	15
	3	17	16	-	-	16	17	17	18	-	-	18	18	16	-	-	-	18	17
	4	16	17	-	-	17	17	16	14	-	-	16	17	16	14	-	-	15	17
	5	13	13	-	-	16	14	14	14	-	-	17	15	18	13	-	-	17	17
4 120 oz.	1	16	16	-	-	14	16	-	-	15	-	-	-	14	-	-	-	19	17
	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	3	15	17	-	-	18	19	-	-	16	-	-	-	17	-	-	-	17	20
	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	5	18	14	-	-	18	16	-	-	14	-	-	-	13	-	-	-	15	18

Appendix Table II - 2

Raw Data for Move

Material No.	Operator No.	Column 1						Column 2						Column 3					
		Row 1		Row 2		Row 3		Row 1		Row 2		Row 3		Row 1		Row 2		Row 3	
		L1	L2	L1	L2	L1	L2	L1	L2	L1	L2	L1	L2	L1	L2	L1	L2	L1	L2
1 1 oz.	1	16	15	15	14	16	16	13	13	15	14	15	15	12	14	13	14	16	18
	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	3	15	15	15	15	-	17	13	14	14	14	16	16	14	15	13	15	14	18
	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	5	-	16	-	16	-	16	13	13	14	16	-	16	12	-	15	14	15	16
2 13 oz.	1	15	16	-	-	18	16	15	14	-	-	17	17	15	15	-	-	17	16
	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	3	15	16	-	-	18	16	-	-	15	16	-	-	15	14	-	-	17	17
	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3 43 oz.	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	16	16	-	-	18	17	15	15	-	-	18	18	14	15	-	-	18	19
	3	22	21	-	-	24	21	19	19	-	-	25	22	19	16	-	-	20	20
	4	17	17	-	-	17	17	17	15	-	-	17	17	17	17	-	-	18	17
	5	18	16	-	-	19	19	16	14	-	-	18	17	15	13	-	-	17	17
4 120 oz.	1	20	18	-	-	23	20	-	-	19	-	-	-	18	18	-	-	22	20
	2	23	18	-	-	24	22	-	-	25	-	-	-	19	18	-	-	24	21
	3	18	19	-	-	22	20	-	-	19	-	-	-	19	17	-	-	21	19
	4	-	18	-	-	-	19	-	-	18	-	-	-	18	19	-	-	19	19
	5	18	19	-	-	17	19	-	-	-	-	-	-	16	18	-	-	17	19