INVESTIGATION OF BODY ASSISTED REACHES AND MOVES

by

Alfred Shih-Ou York

Thesis submitted to the Graduate Faculty of the

Virginia Polytechnic Institute

in candidacy for the degree of

MASTER OF SCIENCE

in

INDUSTRIAL ENGINEERING

APPROVED:

Director of Graduate Studies

Dean of Engineering

APPROVED:

Head of Department

Major Professor

1951

Blacksburg, Virginia

157216

TABLE OF CONTENTS

ILLUSTRATIONS

FREQUENCY DISTRIBUTION CHARTS

TABLES

GRAPHS

I

INTRODUCTION

Despite the progress and perfection of mechanical equipment in replacing the physical work of human beings, there remains considerable activity that will continue to be performed manually. There is no doubt that men and their work methods are still the key to efficiency and productivity in many important industries. The present trend toward increased efficiency in all kinds of work has increased interest in motion and time study. Enlightened management understands that accurate work measurement of industrial operations is an economic necessity; a part of normal industrial growth. Thus there has been a recognized need for scientific measurement of manual work; upon which equitable compensation for both management and labor can be built. Within recent years progressive industrial engineers have been approaching this problem by developing predetermined time standards for basic manual work. Several independent attempts and detailed studies have resulted in several sets of standard time data. Among these systematic plans for manual work measurement, the Methods-Time Measurement method has had wide acceptance and success in a variety of work situations. Methods-Time Measurement, as defined by its originators, "is a procedure which analyzes manual work 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 conditions under which it is made". This method was developed by H. B. Maynard, G. J. Stegemerten and J. L. Schwab. After the public announcement of

Methods-Time Measurement in 1948, interest in this subject has been rising rapidly ever since. It is considered to be an outstandlingly effective dualpurpose tool for work measurement and method analysis.

The originators of Methods-Time Measurement made no claim as to its completeness. It is being subjected to public scrutiny and impartial investigation. Several investigations of this system have already been conducted, and it is felt that certain motions should be broken down more finely, classified into sub-groups, and additional new classifications of body movement will doubtless be found. It is the purpose and objective of this study to evaluate the consistency and reproductibility of standard data and to justify the classification of those Reaches and Moves accompanied by body movement. The presentation of certain time values for these complicated motions is also a principal approach of this investigation.

There is probably no end to the wealth of knowledge to be had from further study along these lines. It is hoped that this work will spur contribution to further research on Methods-Time Measurement system, and others will accept the challenge of finding a scientific and adequate method of measuring manual operation.

II

REVIEW OF LITERATURE

A great deal of literature has been published on the subject of motion and time study, but little of it applies directly to the problem investigated in this study.

The publication of Methods-Time Measurement (1) by Maynard, Stegemerten and Schwab, disclosed that during the development of data bearing on the two predominant basic motions of Reach and Move, it was found that the most difficult information to determine accurately was the length of longer motions, primarily because the longer arm motions involved body movement. In Chapter 5, Treatment of Reach (also applicable to Move) motions involving body movements, when the body is rotated, is outlined in detail as: "To determining the time for a Reach accompanied by a body pivot, the length of the Reach motion is considered to be the distance moved by the hand minus four times the distance moved by the shoulder when the arm is partly extended to the normal working position. In all the cases of combined body and hand movement described above, it is assumed that the movement of the hand attributable to arm motion requires more time than the movement of the hand attributable to body motion. It is assumed that when body movement and arm movement are combined, the operator will instinctively accomplish the major part of the movement with the faster moving member and will use the body motion only as a means of assisting arm motion". In Chapter 14, Treatment of the same arm motions, when accompanied by body displacement is outlined as: "The case of complex simultaneous motions of the arms and the other body members are handled and evaluated in a manner that the motion group is analyzed, the motions occuring are identified, and the time value for the limiting motion is considered to be the time value for the group".

S. M. Lowry, H. B. Maynard and G. J. Stegemerten, in Time and Motion Study and Formula for Wage Incentives (2), stated that the movement of the body about hips or ankles as a pivot are not as easy to recognize, classify and measure as are the movements of the arm and leg. They explained that these body assistance motions, in most cases, are employed in reaching for material or machine control level outside the maximum working area, and the time for making the body movement depend upon the resistance against which the movement is made, the length of the movement, and the strength and muscular coordination of the operator. They also disclosed that the combination motions are varied and they have not yet been definately classified and studied.

In Applied Time and Motion Study (3) by W. G. Holmes, some of the body members have been defined. The times in the Body Member Movement Chart listed the standard time value for the body member detailed with type of movements, the extent of the movement together with the distance. In its discussion of Economy in Use of Movements, consideration has been given to the point that no type of motion for any body member can be used to the exclusion of other movements and there are varius factors involved on the reasonable and justness of time allowed to complete the combined bodily movements. It was believed that the accuracy of alignment, or precision of these movements and each sequence of movements must be considered and proper allowance made for each movement of any appreciable length must be determined and time allowed for its accomplishments.

In Work Content of Manual Operation (4), a summary of three basic research projects published by the University of Alabama Research Committee, some information has been found helpful for the investigation. The major purpose of their investigation was to determine a method to permit accurate measurement of body member displacement to convert the curvilinear motion paths to straight line displacement.

Another approach by Dr. G. Nadler, in a series of articles in the Advanced Management adapted from his "A Priori Procedure for Bio-mechanical Determination of Optimum Motion Pattern" (5), outlined phys-iological information bearing the problem of this investigation. The conclusion of that experimental procedure, explained that there seem to be a relationship between the amount of time used to perform a task at a given pace level and energy expenditure and it would appear feasible to extend the biomechanical approach to cover more complex activities. It also predicted, however, in a broad sense, that the entire concept of time study could be possibly changed by the biomechanical approach to work, and time in itself, would be no longer the basis of industrial standard. But it was pointed out that the study was limited in its development. In that it was restricted by experimental limitation to the application to arm movements under unloaded state, and the assumption that the shoulder remains at one point during the movement.

R. L. Morrow, in Time Study and Motion Economy (6), illustrated the standard data for parts handled by hand with some curves giving allowance for handling light weights and heavier weights where either only finger, wrist and arm movement or body are involved. These curves are based on minimum distances in both cases and value obtained from the curve must be multiplied by the distance factor given with each set of curves. Mr. Morrow stated that these data are the results of the studies which were carried on in the Westinghouse Electric & Manufacturing Company. No comment was being made to describe the amount and characteristics of these body movements so involved.

Several research reports published by the Special Devices Center of the Office of Naval Research (7), made some comment dealing with work efficiency and motion economy. Through the principle of distribution, principle of least effort and the principle of smoothness of motion, they indicated that there are exceptions to the principle of motion economy in the hand motion. It would be best to begin with gross physical factors and movements and proceed, step by step, to the more precise and more confined body motions.

The "Motion-Time Standard of Work Factor Analysis" (8) originated by J. H. Quick, W. J. Shea and R. E. Koehler of RCA, Victor Division, Radio Corporation of America and the Philco Corporation presents standards classified by body members involved, in contrast to the object of the motion performed, i.e. Therblig. Thus finer time values are obtained, but more detailed analysis is required. The originators presented a new and significant concept which has been described as the Work Factor—essentialy a device for rapid, simplified classification of the variables which exist in manual work as they influence time. It was by listing the motions of operation and analyzing each in terms of the number of control and weight factors involved, that the correct time value can be selected according to the distance and body member used. In this system, a motion-time table has been established, and among their basic motions the trunk movement measured at shoulder has been also included in its corresponding work factors, weight, and the relative distance moved ranging from one to twenty inches. But no claim is made to the nature and characteristics of this trunk movement.

This review of the literature reveals that most authors on the subject of motion and time study recognize the hand and arm motion are predominate in industrial operations. Much data has been obtained from the situations where the distance of hand travel has been small—within twenty inches approximately, but no detailed reasoned information is available on the movement of body to complement the arm and hand movements that could add to our knowledge the characteristics of such complex activities. It is evident that no thorough investigation has been ever made to those motions involving simultaneous body motion.

III

THE INVESTIGATION

A. Objective of Investigation

In performing certain long Reach and Move motions, various body movements will assist the arm and hand to accomplish the motion. The various types of these assisting body movements will probably have an affect on method and time required to make long Reach and Move motions. The Research Group of the Industrial Engineering Deaprtment at this Institute, under the supervision of Professor H. L. Manning, has been pursuing several projects to explore these body assisted hand motions. The scope of this particular investigation will be devoted to studying those Reach and Move motions of the following nature; using only one hand:

1. Reaching for an object from a normal working level of forty inches above floor to a supply height in excess of fifty-seven inches above floor (above shoulder height).
2. Moving an object from a supply height in excess of fifty-seven inches above floor to the same height of forty inches above floor. Where some piling was necessary this height was increased by two inches increments to approximately forty-four inches height.
3. Reach and Move Motions are accompanied by two types of body movement: "Body-Rotation" and "Turn-Body-case 1". These two body movements may be distinguished as:

a. Body-Rotation: The motion of twisting or rotating the body about the ankles and waist, with no stepping of the feet.

b. Turn-Body-case 1: It is defined as the turning of the entire body by one step of the foot. This motion is an MTM classification.

4. The degree which the body twisted or turns is approximately 90° (ranging from 80° to 110°).

The objective of this investigation is to analyze the application and relationship of body motion to hand and arm motion when the latter is assisted by "Body-Rotation and "Turn-Body-case 1" motions. The characteristics of these body motions as regards the effect on work method, and the time required for such motions will be investigated. It is also the purpose of this study to attempt to validate the present Methods-Time Measurement classification and derivation time standards for body assisted motions, and further, to develop more adequate measurement for the application of those assisted motions.

B. Plan of Procedure

1. Apparatus:

Two solid hard wood tables were built. The working platform surface of each is thirty-six inches by twenty-four inches (36" x 24"). The supply table is of fifty-seven inches height above the floor, and the dispose table is of forty inches above the floor. The space between these two tables is thirty-six inches apart. The work place layout is illustrated in Figure 1.

2. Materials:

The material or object used in this experimentation are to possess the same general rectangular shape as shown in Figure 2. The detailed information and physical property are illustrated in the following table:

Material Number	Description	Average Weight in Oz.	Dimensions in Inches		
			L.	W.	H.
1	Cardboard Box	1	4	4	1 1/32
2	Wood Block	13	8	3 5/8	1 5/8
3	"Soap" Fire Brick	40	8	2 3/16	1 7/8
4	Fire Brick	120	9	4 1/2	2 1/2

Their number of items used in supply stack and total height of the stack are as follows:

Material Number	Number of Items	Height of Stack in Inches
1	25	27 3/4
2	17	28
3	15	28 1/2
4	11	27 3/4

3. Operator:

The five operators or subjects selected are all instructors in laboratories of the Industrial Engineering Department at V. P. I. All are experienced mechanics. The personal data of their physical structure is outlined as below:

Operator	A	B	C	D	E
Sex	Male	Male	Male	Male	Male
Age	27	39	29	38	25
Weight (in Pounds)	172	163	205	113-1/2	120
Height (In Inches)	68-7/8	69-7/8	72-1/4	67-7/8	66-15/16
Knee Height (From Floor-In.)	21	21-3/4	21-1/4	18	18-3/4
Waist Height (From Floor-In.)	43-7/16	41-7/8	43-1/4	40-1/2	38-3/4
Elbow Height (From Floor-In.)	41-1/2	44-1/4	44	41-1/4	39-1/2
Shoulder Height (From Floor-In.)	57-1/8	57-5/16	60-1/4	55-7/8	54
Arm Length (To Knuckle-In.)	28	25	27-1/2	26	25
Forearm Length (To Knuckle-In.)	14	13-3/4	13-3/4	13	13
Shoulder Width (End of Collar Bone-In.)	14	14-1/2	15	13	13

From the Subject Data Sheet, it may be noted that there is not much difference, except height, between these five operators so far as their physical build is concerned. As they are all mechanics, they possess shop work experience. We have considered these five operators as being fairly representative of the average industrial worker. It is believed that the variance of these operators from the average industrial worker will not materially affect the results of this investigation.

4. Operating Conditions:

The operating conditions under which the operators performed the Reaches and Moves were considered as normal and average. There were no unfavorable conditions (which could be detected) while the motion pictures were taken. They were set up as representative of average conditions for performing manual shop operations, which are usually highly repetitive but do not necessarily require visual concentration or predominantly mental demand.

5. Reaching and Moving

In addition to the above mentioned procedure, we also note that simplicity of the Reach and Move motions have been maintained. Figures 3-8 illustrate the motion in process with operator and material in place.

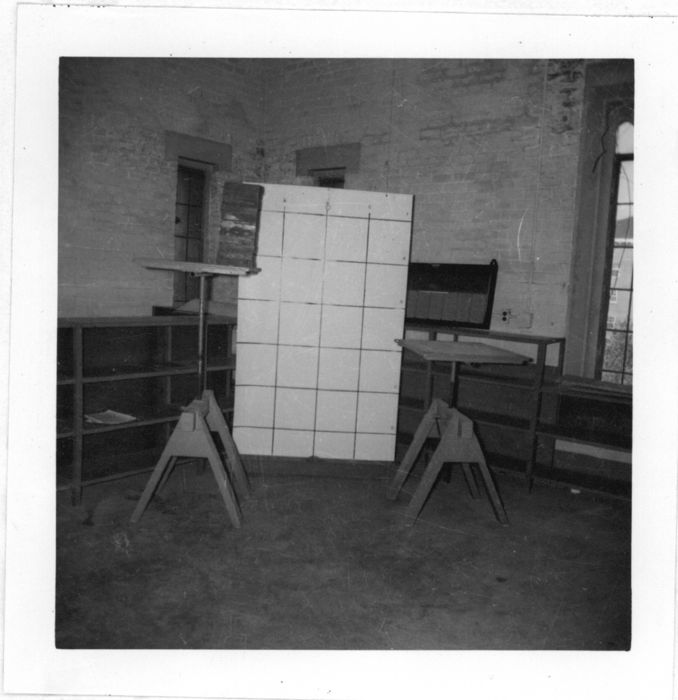


Figure 1

Work Place Layout

(Material #2 on Dispose Table)

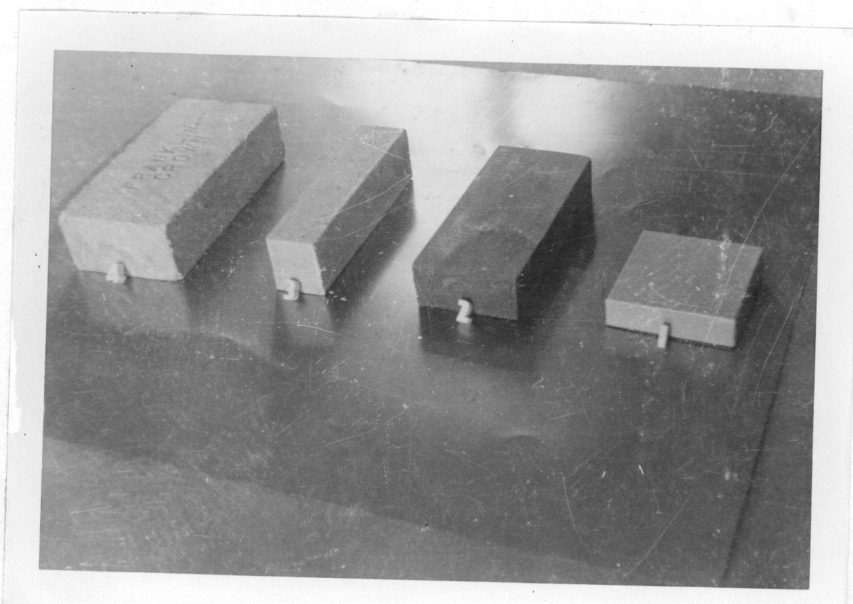


Figure 2

Four Materials

Figure 3

Reach in Process

(Operator D - Material #1)

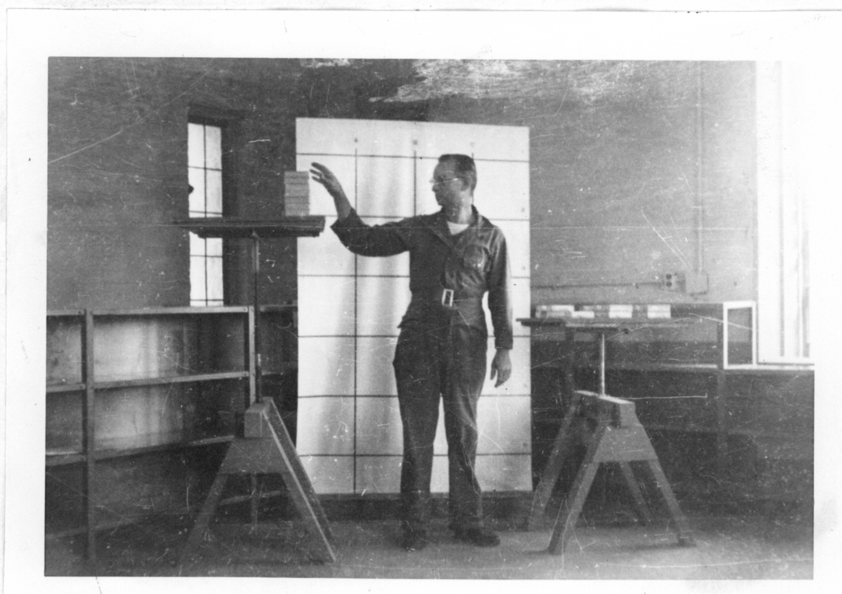


Figure 4

Reach in Process

(Operator B - Material #1)

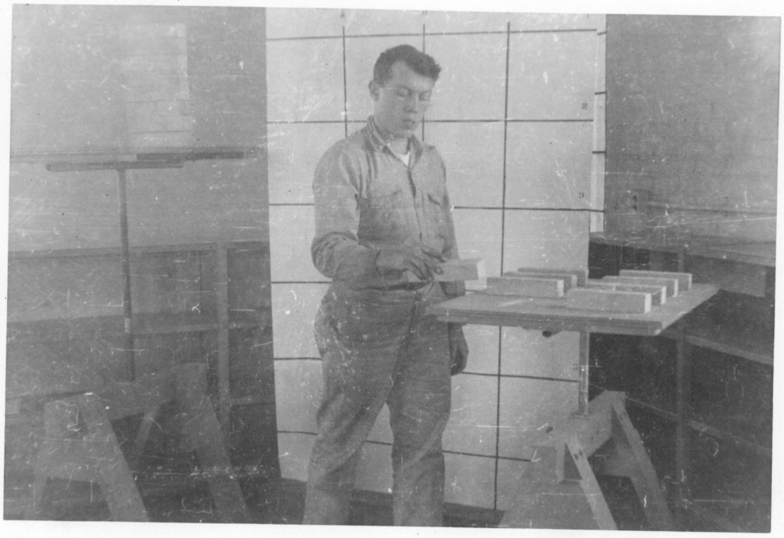


Figure 5

Move in Process

(Operator A, Material #3)

Figure 6

Move in Process

(Operator A, Material #1)

Figure 7

Move in Process

(Operator B - Material #3)

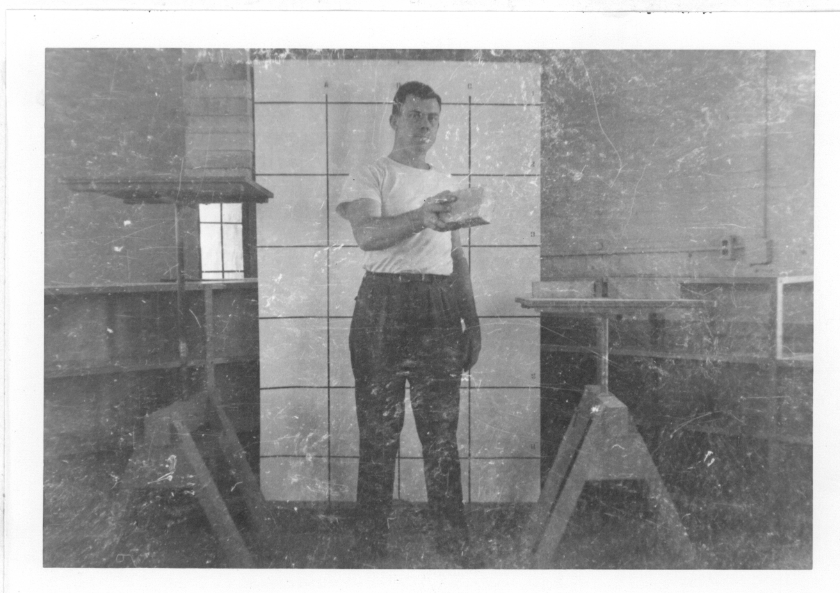


Figure 8

Move in Process

(Operator C - Material #4)

C. Method of Investigation

1. Preliminary Method:

About one thousand feet of 8-mm motion picture film was exposed in recording the Reach and Move motions performed by five subjects. They obtained and moved four different objects of the same general shape whose weight ranged from one to one-hundred-twenty ounces. Items were obtained from heights ranging from fifty-seven inches height above the floor up to eighty-five inches above the floor. Two runs were photographed for each of the five subjects in reaching and moving the four different objects. One run was to record the Reaches and Moves accompanied by Body-Rotation, while the other was recorded for Reaches and Moves accompanied by Turn-Body-case 1 motion.

These motion pictures were taken at the laboratory using a 8-mm Measurement Cine-Kodak Camera running at a constant speed of one thousand frames per minute (1000 FPM). It should be noted that these laboratory experiments set up with the following characteristics:

a. Subjects were to work at their normal path.

b. One handed (perferred hand) work was performed.

c. Grasp characteristics were made as simple and similar as possible.

d. Positioning of the objects was kept to the minimum.

2. Collection of Data:

Micromotion study technique was used for analyzing these manual operations recorded on the loops of film. Loops were projected on a measurement desk screen with a 8-mm Model K-68 Keystone Projector equipped with a frame counter. An electric control box was connected for the ease of controlling forward and reverse projection. The data were thus accumulated through detailed studies of these films on the basis of Methods-Time Measurement analysis. The observed time value of various motions were recorded. The distance (motion length), which was determined by measurement, was also posted in the respective column on loop analysis sheets.

3. Tabulation of Data and Results:

By collecting and combining all the recorded data on the loop analysis sheet, the summary data sheets for each of the various motions were tabulated as shown in the Appendix. (Table 1-4)

D. Statistical Treatment of Data and Results

1. Frequency Distribution:

By grouping the necessary data on the Summary Data Sheets, the Frequency Distribution Charts for each motion were made. The Average Time column appearing on each chart is the arithemetic average of the observed times available. The Frequency Distribution Charts were tabulated as shown on the following pages. (Chart 1 - Chart 4-D)

2. Equations and Fitted Curves:

The data of Average Time vs. Straight Line Distance listed on each frequency distribution chart were treated by statistical method (10). With these two variates (Average Time as dependent variable and Straight Line Distance as independent variable). We derive the regression equation for each motion as summarized on Chart 5. The Adjusted Time column on the frequency distribution chart is the time values obtained from computing these derived equations. Plot the Adjusted Time against the Straight Line Distance and we obtain the Time Trend Curves (Regression Lines) as shown on Graph 1, 2, and 3. The Average Time was plotted showing the variations about the regression.

Chart 1

Frequency Distribution

of

Reaches Accompanied by Body-Rotation

St. Line Distance in Inches	Time in .001 Minute												Adjusted Time in .001 Minute
	Observed Time for Five Operators											Average Time	
	11	12	13	14	15	16	17	18	19	20	21		
42	1		1			1	1					14.2	14.2
43		1			1	1						14.3	14.2
44			2	2	1	1						14.2	14.2
45	1		3	4		2	1	1				14.4	14.2
46	1	3	1	1	2	1	1	2				14.4	14.2
47		1	2		1	1						14.0	14.3
48		1	5	2	4	3						14.2	14.3
49	1				1	1	1					14.8	14.4
50				2	4	2		1				14.3	14.5
51			2	3	1		1	1				14.8	14.7
52		2	2	2	3	2	1					14.3	14.8
53			5	5	5	5		2		1		14.5	14.9
54			5	3	3	4	1	1				14.8	15.1
55			1	4	2				3	3		16.2	15.3
56			2	3	7	4	1		1		2	15.8	15.5
57			1	5	7	4	2	1	1		1	15.6	15.7
58			1	4	1	7	3	1	1			14.8	15.9
59			1	1	2		4	1		1		16.3	16.1
60			1	2	1	1	3	2	1			16.2	16.3
61				4	1	3	3	1	1		2	16.7	16.6
62				1	1	1	2	4				16.8	16.8
63				1	3	1	2	1		1		17.3	17.0
64					1	2	3	1				16.6	17.3
65			1			1	2		2		2	17.7	17.5
66					1	1	2	1			1	17.3	17.7
67								2				18.0	18.0
68						1		1	2		1	18.6	18.2

Chart 2

Frequency Distribution

of

Reaches Accompanied by Turn-Body-case 1

St. Line Distance in Inches	Time in .001 Minute: Observed Time for Five Operators 12	13	14	15	16	17	18	19	20	21	22	23	24	Average Time	Adjusted Time in .001 Minute
42			1											14.0	14.2
43	1			3										14.3	14.5
44		2				2								15.0	14.8
45	1	1	1	3	1	4	2	1						15.8	15.1
46		1	2	1	3		1	1						15.7	15.3
47			2	1	3									15.2	15.3
48		2	7	4	2	3	1	1						15.2	15.7
49		1		1	1			1						15.8	15.9
50			5	2	1	1		1		1				15.7	16.0
51			3		2	3								15.7	16.2
52		1	2		3	2	1		1					16.1	16.3
53			2	4	5	3	3	7						16.9	16.4
54		2	2	2	7	3		1		3				16.5	16.5
55				5	4	2	1		2					16.5	16.6
56			1	2	4	7	1	5	3					17.3	16.7
57		1	1	4	4	2	1	2	1	1	2			17.2	16.9
58			3	2	6	1	5	4	2	1				17.2	17.0
59					5	1	1		1					17.0	17.2
60				2	5	2	2	1				1		17.1	17.4
61				3	4	1	3	3					1	17.4	17.6
62				1	1		6	3	2					18.1	17.8
63				1	1		2			1				17.6	18.1
64				1	2		2	1	1	1		1		18.4	18.4
65			1			1		3	1	1	1	1		19.3	18.8
66							1		1	1				19.6	19.2
67						1	1				1			19.0	19.7
68								1	1		1			20.3	20.2

Chart 3-A

Frequency Distribution

of

Moves Accompanied by Body-Rotation

(for Moving an Object of 1 Ounce)

St. Line Distance in Inches	Time in .001 Minute												Adjusted Time in .001 Minute
	Observed Time for Five Operators											Average Time	
	14	15	16	17	18	19	20	21	22	23	24		
45		1										15.0	15.6
46		1	1	1								16.0	15.8
47			2	1								16.3	15.8
48		1		1								16.0	16.0
49		1	1									15.5	16.1
50		2	2	1								15.8	16.2
51		1	1	1								16.0	16.3
52	1	1	2		1							15.8	16.4
53			1	3								16.7	16.6
54	1		3		1	1						16.5	16.7
55			1	1		1						17.3	16.9
56			1	3	2							17.2	17.0
57		2	1	1		1	1					17.0	17.2
58		1			2		1					17.8	17.4
59			1	1	1	2	1					18.1	17.7
60					4	1						18.3	17.9
61			1	1	2	1			1			18.3	18.2
62			1	2	1	1	1			1		18.6	18.5
63					2							18.0	18.7
64						1						19.0	19.1
65			1			1				1		19.3	19.5
66							1					20.0	19.8
67								1				21.0	20.3
68						1					1	21.0	20.7

Chart 3-B

Frequency Distribution

of

Moves Accompanied by Body-Rotation

(Weight 13 Ounces)

St. Line Distance in Inches	Time in .001 Minute											Adjusted Time in .001 Minute
	Observed Time for Five Operators										Average Time	
	16	17	18	19	20	21	22	23	24	25		
42											–	15.5
43											–	16.6
44	1	2	1								17.0	16.8
45		1									17.0	16.9
46		1	1								17.5	17.1
47	1			1							17.5	17.3
48	1	2		1							17.3	17.4
49	1	2									16.7	17.6
50		2									17.0	17.8
51		2	1								17.3	18.0
52		1	1		1						18.3	18.1
53		1		2							18.3	18.3
54		1	1	1							18.0	18.5
55			1	1		1	1				20.0	18.7
56			1			1	1				20.3	18.9
57			1	1	3		1				19.8	19.2
58		2	2	3	2	2	1				19.3	19.4
59				1	1						19.5	19.6
60					1						20.0	19.9
61					3						20.0	20.1
62					1						20.0	20.4
63			1		1			1			20.3	20.7
64				1			1				20.5	21.0
65					1	1					20.5	21.3
66							2				22.0	21.6
67					1				1		22.0	22.0
68						1				1	23.0	22.3

Chart 3-C

Frequency Distribution

of

Moves Accompanied by Body-Rotation

(Weight 40 Ounces)

St. Line Distance in Inches	Time in .001 Minute												Adjusted Time in .001 Minute
	Observed Time for Five Operators											Average Time	
	18	19	20	21	22	23	24	25	26	27	28		
42												-	19.6
43		1										19.0	19.8
44				1								21.0	19.9
45												20.0	20.0
46	2		2									19.0	20.1
47	2	2		1								19.0	20.1
48		1		1								20.0	20.2
49				1								21.0	20.3
50		1		1								20.0	20.4
51		1		1	1							20.6	20.5
52				1	1							21.5	20.6
53			1	1		1						21.3	20.7
54		2	1	1	1	1	1					21.1	20.8
55			1	1	2	1						21.6	21.1
56				1	3	1						22.0	21.4
57			1	1	1	1	1					21.6	21.7
58					2			1				22.0	22.0
59				1	1	2						22.3	22.4
60				1		1		1				23.0	22.9
61						1						23.0	23.5
62				1		2				1		23.5	24.1
63						2	1			1		24.3	24.9
64									1			26.0	25.9
65												26.5	26.6
66									1		1	27.0	27.6
67												-	28.8
68												-	30.4

Chart 3-D

Frequency Distribution

of

Moves Accompanied by Body-Rotation

(Weight 120 Ounces)

St. Line Distance in Inches	Time in .001 Minute														Adjusted Time in .001 Minute
	Observed Time for Five Operators													Average Time	
	19	20	21	22	23	24	25	26	27	28	29	30	31		
42	1			1	1									21.3	21.4
43				1										22.0	21.7
44				1										22.0	22.0
45			1			1								22.5	22.3
46				1										22.0	22.6
47			1		1	1								22.6	22.9
48				1			1							23.5	23.1
49			1			1	1							23.3	23.4
50				1				1						24.0	23.7
51							1							25.0	24.0
52			1	1		1				1				24.0	24.3
53				1		1		1						24.0	24.6
54					1	2	1							24.0	24.9
55							1							25.0	25.2
56								1						26.0	25.6
57						1	1				1			26.0	25.9
58								1						26.0	26.3
59							1				1			27.0	26.8
60										1				28.0	27.3
61									1	1				27.5	27.8
62										1				28.0	28.3
63									1			2	1	29.0	28.9
64														29.7	29.6
65														30.5	30.2
66													1	31.0	31.0
67														-	31.8
68														-	32.6

Chart 4-A

Frequency Distribution

of

Moves Accompanied by Turn-Body-case 1

(Weight 1 Ounce)

St. Line Distance in Inches	Time in .001 Minute												Adjusted Time in .001 Minute
	Observed Time for Five Operators											Average Time	
	16	17	18	19	20	21	22	23	24	25	26		
42												—	—
43												—	—
44	2	1										16.3	16.4
45												17.2	17.1
46		1	2	1								18.0	17.2
47	1		1		1							18.0	17.5
48												17.8	17.7
49	1			1								17.5	17.9
50		2	4									17.6	18.1
51	1		1		1							18.0	18.3
52		1	2	1								18.0	18.5
53		1		3	1		1					19.3	18.7
54			2	1	2	1						19.3	18.9
55		1	1		2							18.8	19.1
56	1	2	1	4	3							18.6	19.3
57			1	1	1	1						19.5	19.5
58			1	1	2	2	1					19.8	19.7
59				2	2	5						20.5	19.9
60				2	2	1		1				20.3	20.1
61				2	2	2	2					20.5	20.3
62		1		1	3	2			1			20.3	20.5
63				1				1				21.0	20.7
64	1						1	1				20.3	20.9
65					2		1					20.7	21.1
66												21.0	21.3
67						2	1					21.3	21.5
68					1	1					1	22.3	21.7

Chart 4-B

Frequency Distribution

of

Moves Accompanied by Turn-Body-case 1

(Weight 13 Ounces)

Distance Range	Distance in Inches	Time in .001 Minute — Observed Time for Five Operators: 16	17	18	19	20	21	22	23	24	25	26	27	Average Time	Adjusted Time in .001 Minute
43-44	44	1	1	1	1	1								18.0	17.8
44-45	46	1			2	1								18.5	18.2
47-48	48	2		1		1								17.5	18.6
49-50	50	1	1	2	1	2	1							18.6	18.9
51-52	52		1	1			1	2						20.0	19.3
53-54	54	1				2	1	1						19.8	19.6
55-56	56				2	2	1	1	1					20.6	19.9
57-58	58		2	2	2	2	4	1	1			1		19.6	20.3
59-60	60		1	1	1			1	2					20.3	20.6
61-62	62		1		3			1	1				1	20.8	21.1
63-64	64					1		2	1					21.7	21.6
65-66	66			1	1		1		3		1	1	1	22.3	22.2
67-68	68					1								23.0	22.9

Chart 4-C

Frequency Distribution

of

Moves Accompanied by Turn-Body-case 1

(Weight 40 Ounces)

Dist. Range	Dist. in Inches	Time in .001 Minute — Observed Time for Five Operators: 19	20	21	22	23	24	25	26	27	28	29	30	Average Time	Adjusted Time in .001 Minute
43-44	44													-	-
45-46	46	1		2	1									20.8	20.5
47-48	48	2	1	2	3	1		1						21.0	21.6
49-50	50				3	1	1							22.6	22.0
51-52	52													22.4	22.5
53-54	54	2	2		6	1		1	2					22.1	22.7
55-56	56					7	1	1						23.3	22.9
57-58	58			3		1	1		1	1		1		24.0	23.2
59-60	60		1		1	2		1						23.2	23.6
61-62	62					1	1	1	1					24.5	24.4
63-64	64						1	1	1					25.0	25.7
65-66	66							1				1	1	28.0	27.6
67-68	68													-	-

Chart 4-D

Frequency Distribution

of

Moves Accompanied by Turn-Body-case 1

(Weight 120 Ounces)

Dist. Range	Dist. in Inches	Time in .001 Minute																Adjusted Time in .001 Minute
		Observed Time for Five Operators															Average Time	
		22	23	24	25	26	27	28	29	30	31	32	33	34	35	36		
43-44	44	1	2					1									24.0	24.1
45-46	46			1		1	2										26.0	25.4
47-48	48			1	1	1		1									25.6	26.0
49-50	50						1										27.0	26.8
51-52	52				1	1	1	1	2								27.3	27.3
53-54	54				2	1	1		1								26.4	27.7
55-56	56				1		2	1		2	1				1		29.1	28.0
57-58	58			1					1							1	29.6	28.6
59-60	60								1								29.0	29.2
61-62	62					1			2					1			29.5	30.2
63-64	64							1		1						1	31.3	31.6
65-66	66																33.6	33.4
67-68	68															1	36.0	35.9

Chart 5
Summary of Equations

Reach Accompanied by Body-Rotation:

$$Y = 15.6330 + 0.1634\,(x-55) + 0.0057\left[(x-55)^2 - 60.66\right] - 0.000194\left[(x-55)^3 - 109\,(x-55)\right]$$

Reach Accompanied by Turn-Body-case 1:

$$Y = 16.2111 + 0.1918\,(x-55) + 0.0032\left[(x-55)^2 - 60.66\right] + 0.00068\left[(x-55)^3 - 109\,(x-55)\right]$$

Move Accompanied by Body-Rotation (Weight of Object Moved - 1 Ounce):

$$Y = 17.3740 + 0.1986\,(x-56) + 0.0075\left[(x-56)^2 - 44\right] + 0.00027\left[(x-56)^3 - 79\,(x-56)\right]$$

Move Accompanied by Body-Rotation (Weight of Object Moved - 13 Ounces):

$$Y = 19.1640 + 0.2262\,(x-56) + 0.0043\left[(x-56)^2 - 52\right] + 0.0001\left[(x-56)^3 - 93.4\,(x-56)\right]$$

Move Accompanied by Body-Rotation (Weight of Object Moved - 40 Ounces):

$$Y = 21.7260 + 0.2693\,(x-54) + 0.0091\left[(x-54)^2 - 44\right] + 0.0010\left[(x-54)^3 - 79\,(x-54)\right]$$

Move Accompanied by Body-Rotation (Weight of Object Moved - 120 Ounces):

$$Y = 25.3560 + 0.3764\,(x-54) + 0.0094\left[(x-54)^2 - 52\right] + 0.00055\left[(x-54)^3 - 93.4\,(x-54)\right]$$

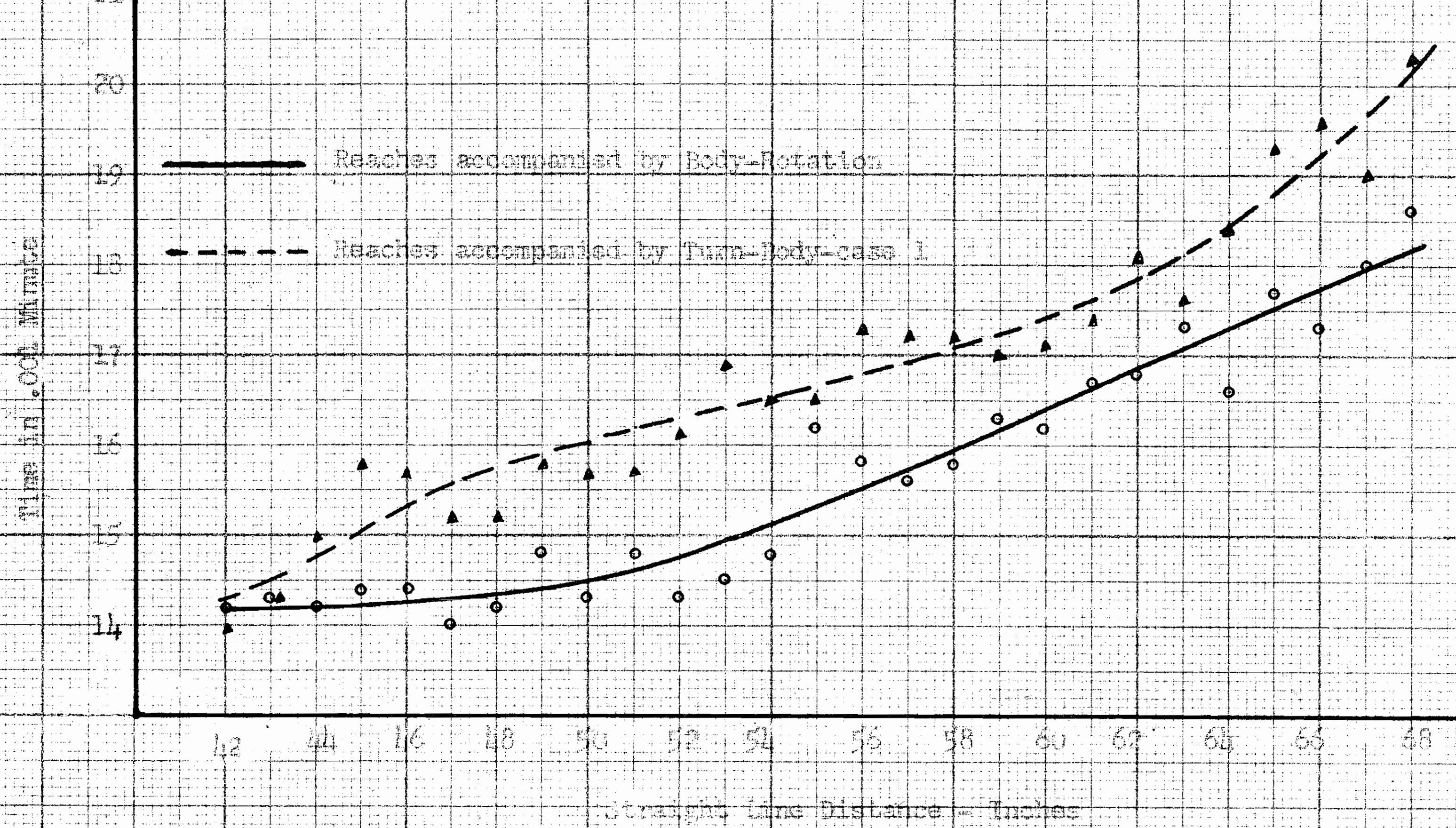
Move Accompanied by Turn-Body-case 1 (Weight of Object Moved - 1 Ounce):

$$Y = 19.2760 + 0.2000\,(x-56) + 0.0002\left[(x-56)^2 - 52\right] + 0.00007\left[(x-56)^3 - 93.4\,(x-56)\right]$$

Chart 5 (Continued)
Summary of Equations

Move Accompanied by Turn-Body-case 1 (Weight of Object Moved - 13 Ounces): $Y = 20.0770 + 0.4016 \left(\frac{x-56}{2}\right) + 0.0123 \left[\left(\frac{x-56}{2}\right)^2 - 14\right] + 0.0028 \left[\left(\frac{x-56}{2}\right)^3 - 25 \left(\frac{x-56}{2}\right)\right]$
Move Accompanied by Turn-Body-case 1 (Weight of Object Moved - 40 Ounces): $Y = 23.3545 + 0.5563 \left(\frac{x-56}{2}\right) + 0.0459 \left[\left(\frac{x-56}{2}\right)^2 - 19\right] + 0.0204 \left[\left(\frac{x-56}{2}\right)^3 - 17.8 \left(\frac{x-56}{2}\right)\right]$
Move Accompanied by Turn-Body-case 1 (Weight of Object Moved - 120 Ounces): $Y = 28.8000 + .8071 \left(\frac{x-56}{2}\right) + 0.0542 \left[\left(\frac{x-56}{2}\right)^2 - 14\right] + 0.0194 \left[\left(\frac{x-56}{2}\right)^3 - 25 \left(\frac{x-56}{2}\right)\right]$
Where: Y = Time in .001 Minute; x = Straight Line Distance in Inches

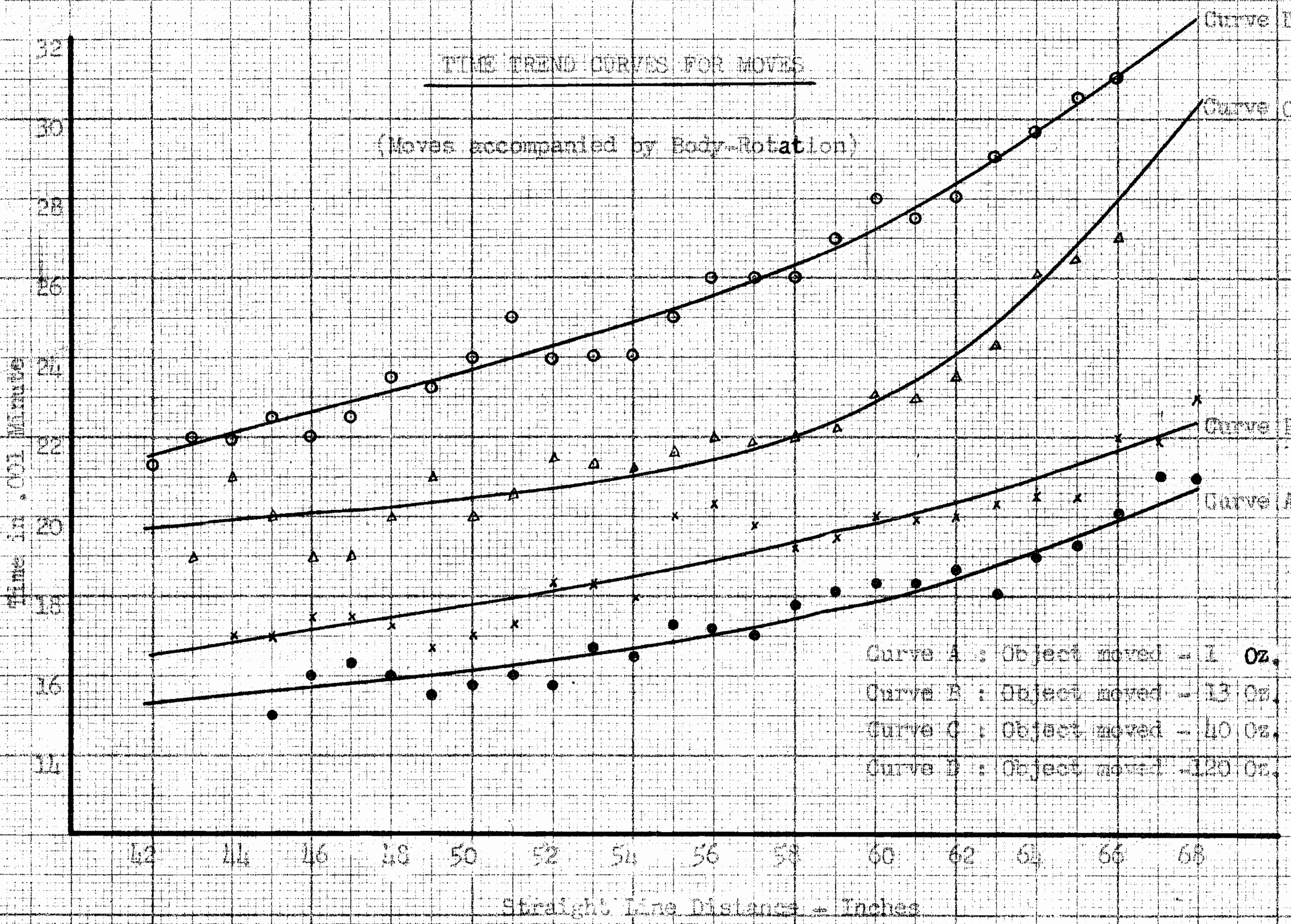
TIME TREND CURVES FOR REACHES



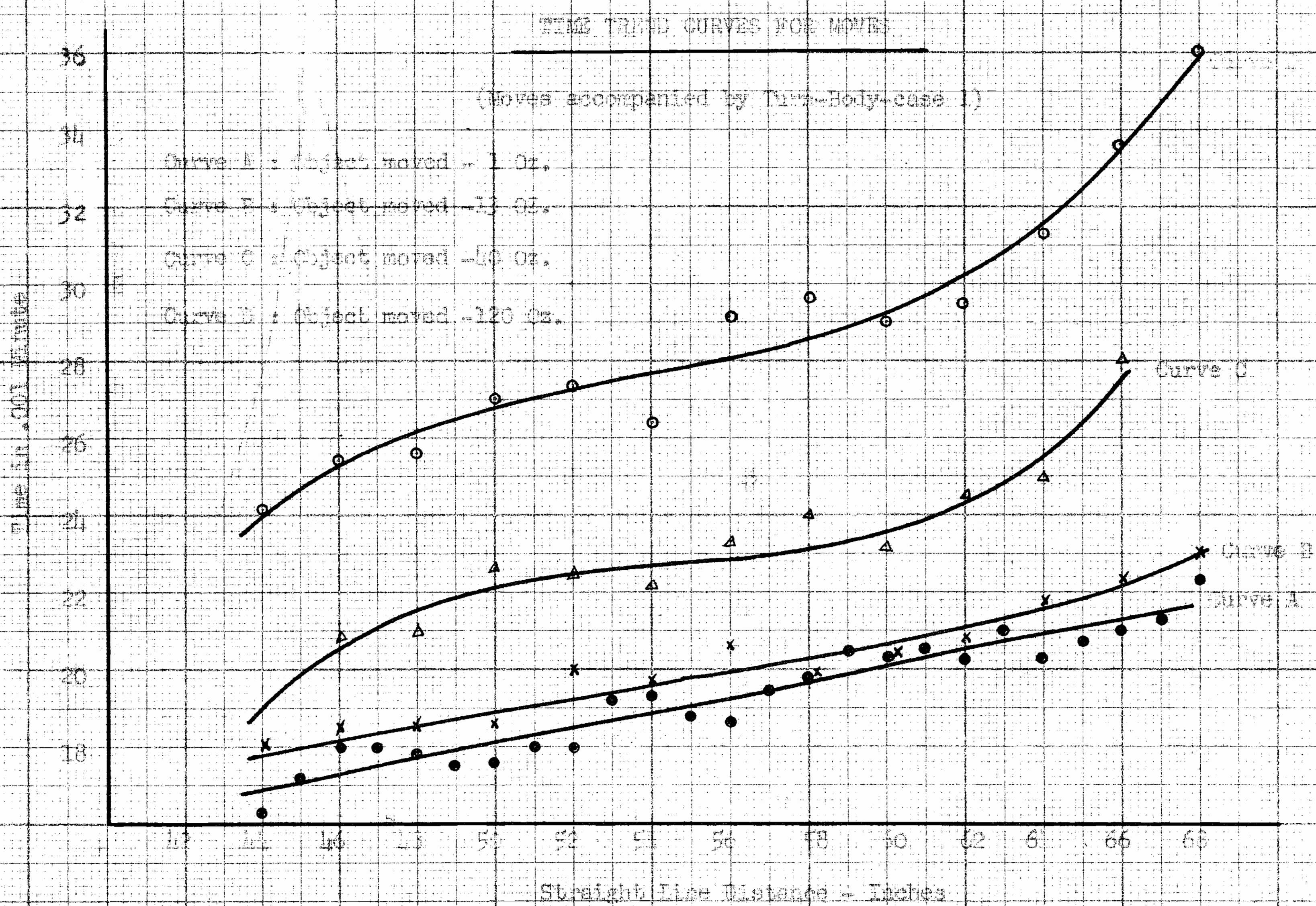
Graph 1

TIME TREND CURVES FOR MOVES

(Moves accompanied by Body-Rotation)



Graph 2


TIME TREND CURVES FOR MOVES
(Moves accompanied by Turn-Body-case 1)
Curve A : Object moved - 1 Oz.
Curve B : Object moved -13 Oz.
Curve C : Object moved -60 Oz.
Curve D : Object moved -120 Oz.
Time in .001 Minute
36
34
32
30
28
26
24
22
20
18
Curve C
Curve B
Curve A
Straight Line Distance - Inches

Graph 3

IV

DISCUSSION OF RESULTS

A. Body Assisted Reaches

The investigation of time required to perform Reach motion accompanied by a Body-Rotation and a Turn-Body-case 1 indicate that there is a definite trend of difference. The Adjusted Time value for these type of Reaches were tabulated in the Adjusted Time column on each of the Frequency Distribution Charts. They were also summarized in Table 5 and graphically represented in Graph 1. It clearly shows that the operator will take more time to make a Reach if accompanied by a Turn-Body-case 1 motion.

B. Body Assisted Moves

The investigation of time required to perform Moves accompanied by a Body-Rotation and a Turn-Body-case 1 motion also indicate that there is a difference. The adjusted time value for these motions is tabulated on Table 6. The comparison of the time trend is also graphically represented in Graph 2 and 3. Moves accompanied by a Turn-Body-case 1 motion are greater in time than Moves accompanied by a Body-Rotation.

The results of the investigation also reveal that the weight of the object moved does have an effect on the time required to make the move. It shows that increasing the weight will result in an increase of time for the Move. It also indicates that the heavier weight of the object will have a particularily significant effect on the time required to perform a Move of extreme distance. An appreciable increase in time value would be noticed if both the weight and distance of the Move are increased.

C. Comparison of Time Trend for Reaches and Moves

In this section, the comparison of time trend has been made only for those Reaches and Moves that are accompanied by a Body-Rotation. Those Reaches and Moves accompanied by a Turn-Body motion (case 1) will be discarded from further analysis because of the inefficient method of making the motion.

One method of combining the four experimental curves of Move considers the time for moving an object of one ounce to be the basic time for the Move, and yields the multiple factor for each weight. The average multiple factor is listed in Table 7. And then we obtain by the least squares method (10) the relation of weight to time as a multiple factor (see bottom column of Table 7). We note that the estimate of this common multiple factor is only fair because the experimental curves for each different weight do not conform to a pattern. It was possibly due to excessive variability in a portion of the experiment. Also, insufficient data has been obtained to yield a result of the desired accuracy. However, we still believe that the estimate of this multiple factor does give some reliable indication of the relationship involved.

Another method to obtain the multiple factor is to break the distance range into arbitrary classes, (e.g. 40" to 50", 51" to 60", and 61" to 70"). The multiple factors for each class are listed in Table 8. Using the least squares method as above, we obtain the relation of weight to time as a multiple factor for each class of the distance range. The estimate of these computed multiple factors (Table 9) will result in a closer fit to the experimental curves of move.

A summary is outlined in Table 10 for the comparison of time trend. We could also conclude that the basic time for Move is about 10% higher than that of Reach (Graph 4 is a graphic representation of the difference). A possible reason for this difference might be due to the manual control involved in making the Move.

Further, the use of these multiple factors should be made cautiously until more experimentation is available for estimation of the forms and values of the factor.

D. Comparison of Results to Methods-Time Measurement Data

1. Method of Determining Length of Motion:

Methods-Time Measurement data explains that the most accurate method of determining the length of Reach and Move is to measure the actual path of the motion and that the measurement is made at the same part of the hand at the beginning and the end of the motion. Furthermore, under the MTM system, to determine the time for a Reach motion accompanied by a body rotation, the length of the Reach motion is considered to be the distance moved by the hand minus four times the distance moved by the shoulder when the arm is partly extended to the normal working position. By applying this method of measurement to the experimental data regarding Reaches, the results, as shown in Table 11, were plotted on Graph 5a and 5b. In Graph 5a the time values obtained from MTM Tables for the equivalent distance (distance the hand moved minus four times the distance moved by the shoulder) were plotted as Curve A, B, C, D, (representing four different operators). The Curve E is the average of these four curves, and is most irregular. The Curve F in the same graph is the fitted curve of the adjusted time values (from this investigation) plotted against the total distance the hand moved. In Graph 5b, the Curve G represents the adjusted time value vs. distance. By comparing Curve G and E, it was observed that Curve G has shown a strong degree of association between time and distance.

2. Principles of Definition of Length:

The above comparison of time data has shown that it is not practical to measure the actual curvilinear path of the motion in determining its length since the error introduced from such measurement is quite appreciable. From logical consideration, it was found that a better determination of the motion length of Reach or Move is to obtain the straight line distance between the starting and the terminal point of the hand motion, and further, it possesses the merit of simplicity in measuring the motion performed by different operators. Therefore, in the case of Reaches or Moves accompanied by a body rotation, it will be better to determine the length of motion by measuring the straight line distance between the starting point of the hand and the object to which this type of body assisted Reach or Move is made.

Table 5

Comparison of Time Trend

for

Body Assisted Reaches

Straight Line Distance in Inches	Time in .001 Minute		
	Reaches Accompanied by Body-Rotation	Reaches Accompanied by Turn-Body-case 1	Difference
42	14.2	14.3	0.1
43	14.2	14.5	0.3
44	14.2	14.8	0.6
45	14.2	15.1	0.9
46	14.2	15.3	1.1
47	14.3	15.5	1.2
48	14.3	15.7	1.4
49	14.4	15.9	1.5
50	14.5	16.0	1.5
51	14.7	16.2	1.5
52	14.8	16.3	1.5
53	14.9	16.4	1.6
54	15.1	16.5	1.4
55	15.3	16.6	1.3
56	15.5	16.7	1.2
57	15.7	16.9	1.2
58	15.9	17.0	1.1
59	16.1	17.2	1.1
60	16.3	17.4	1.1
61	16.6	17.6	1.0
62	16.8	17.8	1.0
63	17.0	18.1	1.1
64	17.3	18.4	1.1
65	17.5	18.8	1.3
66	17.7	19.2	1.2
67	18.0	19.7	1.7
68	18.2	20.2	1.8

Table 6

Comparison of Time Trend for Body Assisted Moves

St. Line Distance in Inches	Time for Body Assisted Moves in .001 Minute							
	Wt. 1 Oz.		Wt. 13 Oz.		Wt. 40 Oz.		Wt. 120 Oz.	
	BR	TB	BR	TB	BR	TB	BR	TB
42	15.3	16.5	16.5	17.2	19.6	18.8	21.4	22.5
43	15.4	16.7	16.6	17.4	19.8	18.9	21.7	23.5
44	15.5	16.9	16.8	17.8	19.9	19.0	22.0	24.1
45	15.6	17.1	16.9	17.9	20.0	19.8	22.3	24.8
46	15.8	17.3	17.1	18.2	20.1	20.5	22.6	25.4
47	15.8	17.5	17.3	18.4	20.1	21.1	22.9	25.8
48	16.0	17.7	17.4	18.6	20.2	21.6	23.1	26.2
49	16.1	17.9	17.6	18.8	20.3	21.8	23.4	26.5
50	16.2	18.1	17.8	18.9	20.4	22.2	23.7	26.9
51	16.3	18.3	18.0	19.1	20.5	22.3	24.0	27.1
52	16.4	18.5	18.1	19.3	20.6	22.5	24.3	27.3
53	16.6	18.7	18.3	19.4	20.7	22.6	24.6	27.5
54	16.7	18.9	18.5	19.6	20.9	22.7	25.9	22.7
55	16.9	19.1	18.7	19.7	21.1	22.8	25.2	27.9
56	17.0	19.3	18.9	19.9	21.4	22.9	25.6	28.0
57	17.2	19.5	19.2	20.1	21.7	23.1	25.9	28.4
58	17.4	19.7	19.4	20.3	22.0	23.2	26.3	28.6
59	17.7	19.9	19.6	20.5	22.4	23.4	26.8	29.0
60	17.9	20.1	19.9	20.6	22.9	23.6	27.3	29.2
61	18.2	20.3	20.1	20.9	23.5	24.0	27.8	29.7
62	18.5	20.5	20.4	21.1	24.1	24.4	28.3	30.2
63	18.7	20.7	20.7	21.3	24.9	25.0	29.0	30.8
64	19.1	20.9	21.0	21.6	25.7	25.7	29.6	31.6
65	19.5	21.1	21.3	21.9	26.6	26.6	30.2	32.3
66	19.8	21.3	21.6	22.2	27.6	27.6	31.0	33.4
67	20.3	21.5	22.0	22.6	28.8	28.7	31.8	34.4
68	20.7	21.7	22.3	22.9	30.4	30.1	32.6	35.9

BR: Moves Accompanied by Body-Rotation

TB: Moves Accompanied by Turn-Body-case 1

Table 7

Average Multiple Factor

Weight of Object Moved (in ounce)	Average Multiple Factor
1	1.00
13	1.09
40	1.29
120	1.48
Common Multiple Factor = 0.9856 + 0.0092 W-0.000042W^2 Where W = Weight of Object Moved in Ounces	

Table 8

Multiple Factors for Each Class of Distance Range

Distance Range in Inches	Multiple Factors			
	1 Oz. Object	13 Oz. Object	40 Oz. Object	120 Oz. Object
41" to 50"	1.00	1.08	1.27	1.43
51" to 60"	1.00	1.10	1.26	1.49
61" to 70"	1.00	1.09	1.36	1.54

Table 9

Computed Multiple Factor for Each Class of Distance Range

Distance Range in Inches	Multiple Factor
41" to 50"	0.9846 + 0.0086W-0.000041W^2
51" to 60"	0.9959 + 0.0079W-0.000031W^2
61" to 70"	0.9724 + 0.0117W-0.000058W^2
W = Weight of Object Moved in Ounces	

Table 10

Summary of Time Data

for

Body Assisted Reaches & Moves

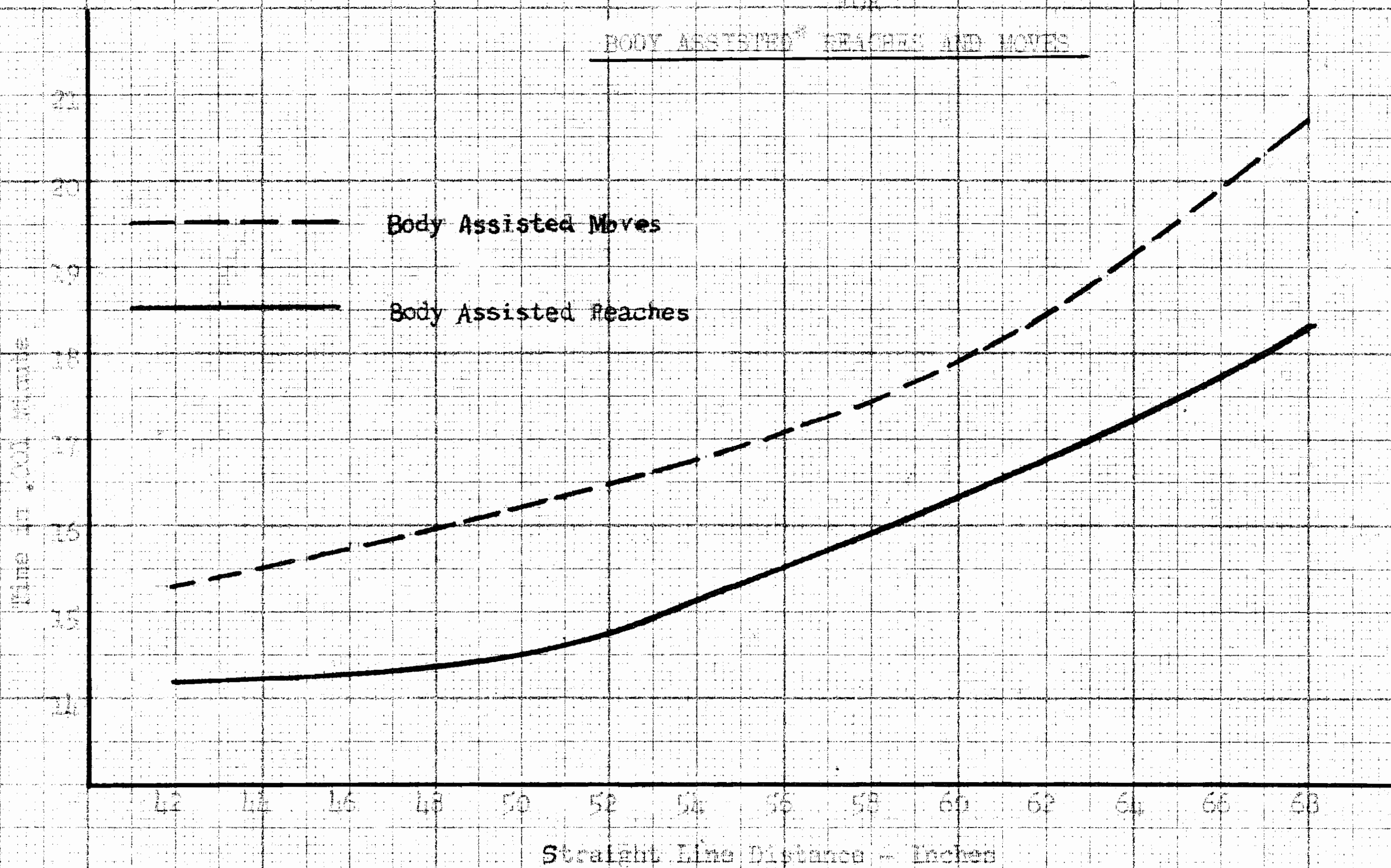
Distance in Inches	Time in .001 Minute		Multiple Factor W = Weight in Ounce	Common Multiple Factor
	Reaches	Moves		
42	14.2	15.3		
43	14.2	15.4		
44	14.2	15.5		
45	14.2	15.6		
46	14.2	15.8	$0.9846+0.0086W-0.000041W^2$	
47	14.3	15.8		
48	14.3	16.0		
49	14.4	16.1		
50	14.5	16.2		
51	14.7	16.3		
52	14.8	16.4		
53	14.9	16.6		
54	15.1	16.7		
55	15.3	16.9	$0.9959+0.0079W-0.000031W^2$	$0.9856+0.0092W-0.000042W^2$
56	15.5	17.0		
57	15.7	17.2		
58	15.9	17.4		
59	16.1	17.7		
60	16.3	17.9		
61	16.6	18.2		
62	16.8	18.5		
63	17.0	18.7		
64	17.3	19.1	$0.9724+0.0117W-0.000058W^2$	
65	17.5	19.5		
66	17.7	19.8		
67	18.0	20.3		
68	18.2	20.7		

Table 11

Resulting Time Data Obtained by MTM Method

Distance in Inches	Time in .001 Minute				Mean Time Values
	Operator A	Operator B	Operator C	Operator D	
42	8.6	5.2	5.2	4.7	5.9
43	5.6	-	5.6	-	5.6
44	7.7	9.5	11.2	-	9.5
45	9.9	7.6	4.7	7.5	7.4
46	10.8	10.3	11.2	8.6	10.2
47	9.1	-	7.3	9.1	8.5
48	11.2	9.5	6.1	7.7	8.8
49	9.9	9.9	-	6.5	8.8
50	-	12.1	10.3	-	11.2
51	9.9	7.3	9.1	7.2	8.4
52	10.7	11.2	10.6	7.7	10.1
53	11.0	7.3	7.2	8.2	8.4
54	12.0	10.3	6.2	10.3	9.7
55	12.5	7.1	7.3	9.0	9.0
56	10.3	12.1	10.3	8.9	10.4
57	9.5	12.2	8.2	8.2	9.5
58	12.9	9.2	9.8	11.0	10.7
59	9.1	10.7	9.9	14.2	11.0
60	12.0	11.2	8.3	8.6	10.0
61	9.7	11.3	4.3	9.1	8.6
62	12.1	8.6	8.6	11.2	10.1
63	9.1	9.9	11.7	8.2	9.6
64	12.9	14.2	12.9	7.8	11.9
65	7.7	-	10.7	9.1	9.2
66	12.9	8.6	6.9	5.2	8.4
67	-	-	5.6	-	5.6
68	14.6	9.5	7.7	8.8	10.2

COMPARISON OF TIME TREND
FOR
BODY ASSISTED* REACHES AND MOVES

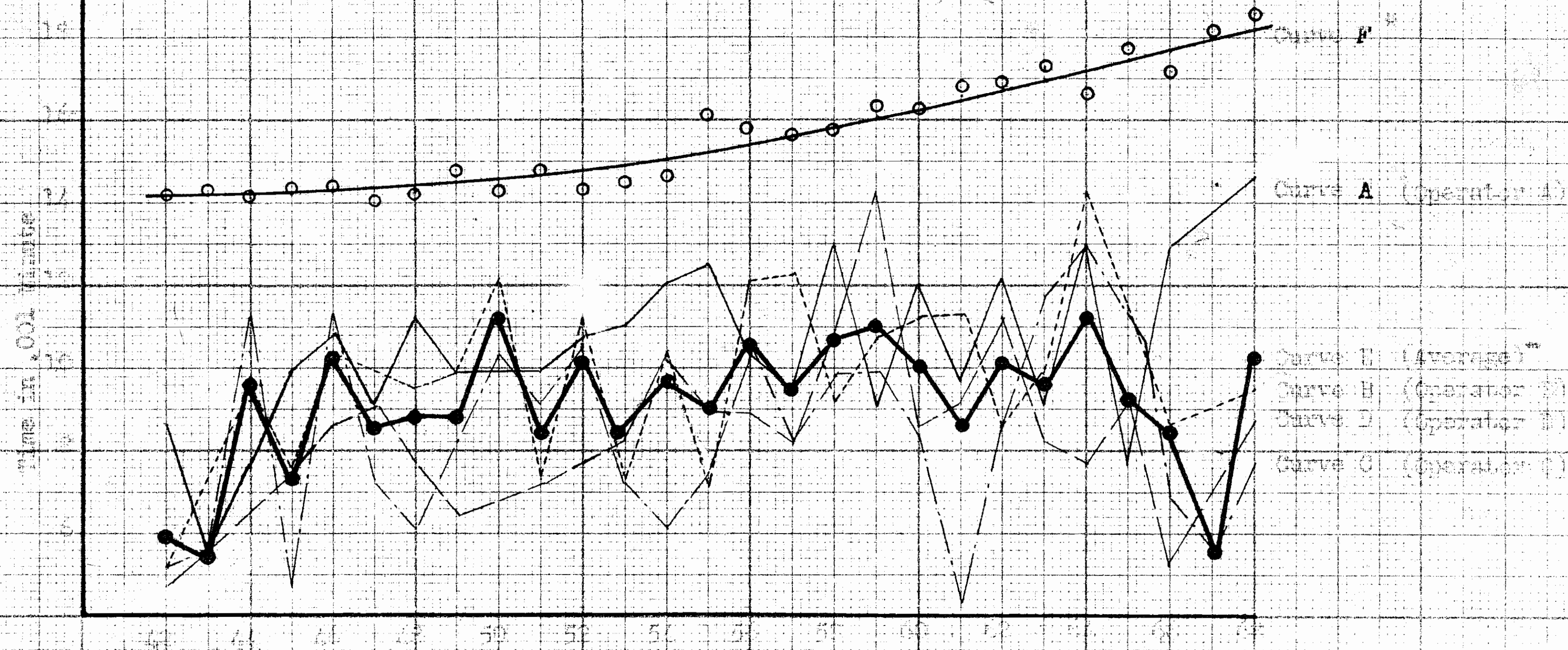


* Body Assistance : By Rotation of Trunk and Ankles, but no movement of Feet.

Graph 4

COMPARISON OF TIME DATA

(a)



Straight Line Distance – Inches

(Straight Line Distance between the Starting and Terminal Point of the Hand Movement)

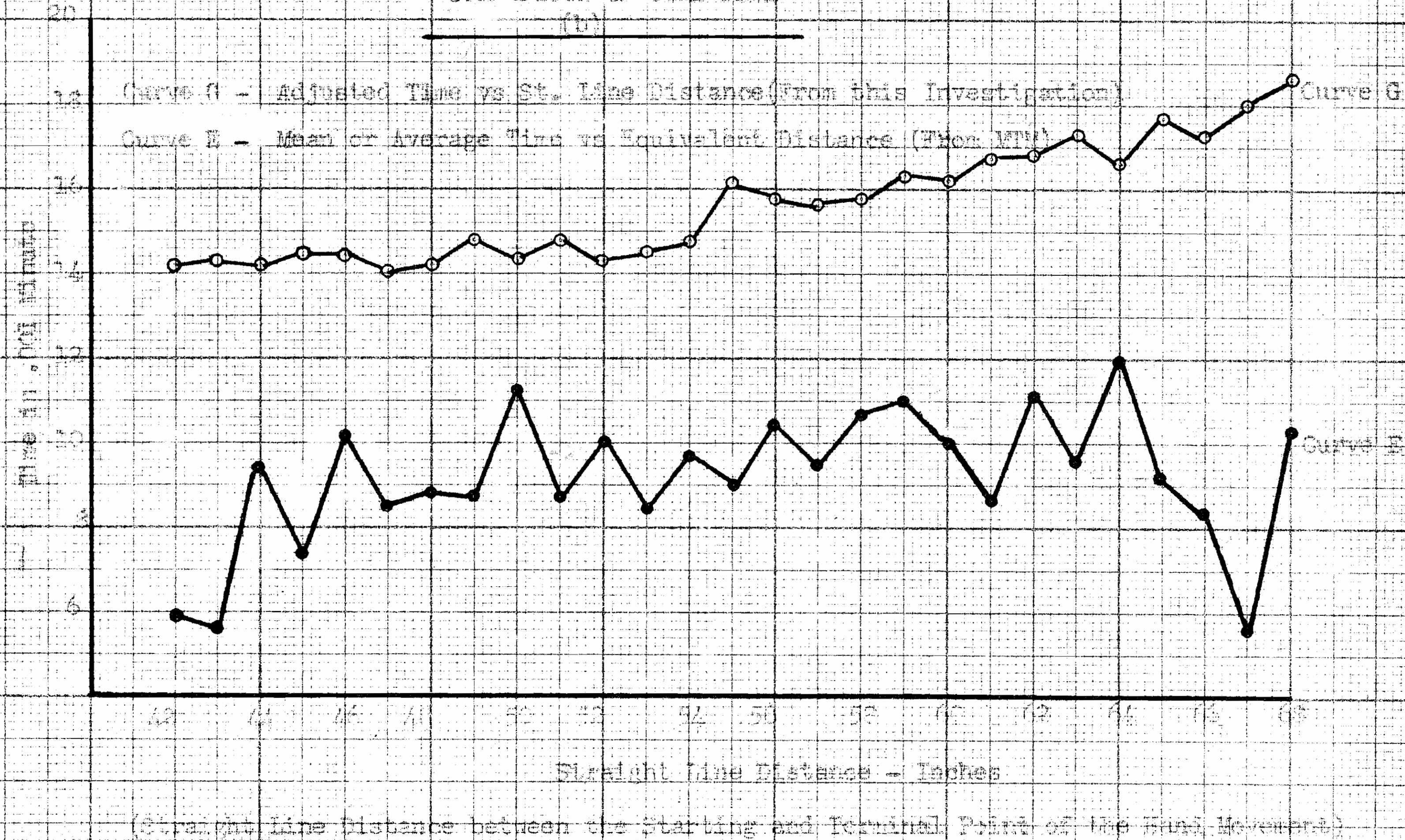
Graph 5a

* Curve F : Fitted Curve of Adjusted Time vs Straight Line Distance

** Curve E : Mean or Average Time vs Equivalent Distance (From MTM)

COMPARISON OF TIME DATA

(b)



Graph 5b

V

CONCLUSIONS

From the results of this investigation, the following conclusions could be drawn:

1. When it is necessary to reach or move long distance, requiring body displacement, it is faster to rotate the trunk than to displace the body by the use of the leg (Turn-Body). This assumes, of course, that no walking is required to reach the proximity of the terminal point.
2. The results of this study have revealed that the weight of an object does have an effect on the time required to make a Move motion. It was also found that the time required to make a Move of extremely long distance will be considerably increased if the object moved is of heavier weight.
3. The experimental results appear to indicate that the MTM method of determining the time and length of a Reach or Move motion accompanied by a body pivot is inconsistent and unsatisfactory. This investigation has found a better method of determining the length of such type of motion is to measure the straight line distance between the starting and terminal points of the hand motion.
4. It is believed that the time trend for Reaches and Moves bear a definate relationship to each other. Further it is believed that there is a fixed relationship between the time trend for Moves for objects of different weight.
5. No direct comparison of time data could be made for Move with MTM Tables because the MTM Tables do not extend beyond a thirty inch

Move and this study was limited to Move beyond forty-two inches.

6. A comparison was made of the time values to Reach given fixed distance with the published MTM Tables. It was found that the time values obtained by means of MTM method were not as consistent as the experimental data. It is believed that the method derived from this investigation has the merit of simplicity and probably greater accuracy.
7. It is felt that, insufficient data has been obtained through this investigation upon which to establish time standards for these body assisted Reaches and Moves, but the author believes the time values obtained from this investigation will serve as a guide for other studies which may be made of such types of Reaches and Moves.

VI

SUMMARY

Since time and motion study was developed, the necessity for standard times for motions has been recognized to be very useful in many industrial applications. Among many attempts to set up predetermined times for manual motions, the Methods Engineering Council has established certain workable standard data known as Methods-Time Measurement which is applicable throughout industry.

With the purpose to appraise the value of this new work-measurement technique of MTM, this study was conducted and it was devoted to investigating their data on the Reach and Move motions involving body rotation movements.

The findings of this investigation do indicate that the MTM method of determining the time of Reach motion has inconsistencies and thus is weak. As a result, a suggested method of measuring the length of motion is made and the time values obtained may serve as a guide for further study on industrial operations by which they can be conclusively verified. Also, it was found that time data can be derived for Moves in the area above forty-two inches and that further study should be made to supplement this data for industrial use.

VII

SUGGESTIONS FOR FURTHER STUDY

The time values found in this investigation, for the body-assisted Reaches and Moves are limited to experimental operations performed in the laboratory. Therefore further investigation should be made on industrial operations to check these time values.

Further study is indicated to determine what effect, if any, there may be upon the time values when two hands are necessary to move the object. Also, further study is indicated to determine the effect upon time values of shape, surface texture and other elements of "grip".

No attempt was made during this study to determine the relative amount of fatigue produced by the two body motions. The Body-Rotation is new motion which is not yet classified - in itself - by the published MTM data, but it is in reality a variation of the Turn-Body. Therefore it is suggested that an extended investigation of the relative difference between Body-Rotation and Turn-Body motion (case 1) might produce useful information.

VIII

ACKNOWLEDGEMENT

The author wishes to acknowledge the valuable advice rendered by Professor Herbert L. Manning, Head of the Industrial Engineering Department, Virginia Polytechnic Institute in the writing of this thesis.

He also wishes to express his greatest appreciation to Research Instructor Frank A. Beebe, Jr., a former member of the research staff of the Industrial Engineering Department at Virginia Polytechnic Institute, for without his assistance this study could not have been carried to a successful conclusion.

The Industrial Engineering Department staff, Messrs. Mark L. Smith, Charles E. Bodell, Ralph E. Dillon, Rudolph A. Henderson, Alexander S. Henderson, Kenneth G. McCauley and Marshall K. Smith, assisted in procuring data representative of a normal average, and their willing cooperation is highly valued.

The guidance of the members of the staff of the Department of Statistics at Virginia Polytechnic Institute, and in particular Dr. Milton E. Terry, II, in making the statistical treatment of data and results is fully appreciated.

IX

BIBLIOGRAPHY

1. Maynard, H. B., J. L. Schwab, G. J. Stegmerten. Methods-Time Measurement. New York: McGraw-Hill Book Company, Inc. (1948)

2. Lowry, S. M., H. B. Maynard, G. J. Stegmerten. Time and Motion Study and Formula for Wage Incentives. New York: McGraw-Hill Book Company, Inc. (1940)

3. Holmes, W. G. Applied Time and Motion Study. New York: The Ronald Press Company. (1945)

4. Smalley, H. E. "Work Content of Manual Operations". A Summary of Three Basic Research Projects. University of Alabama Research Committee, University of Alabama. (1949)

5. Nadler, G. "A Priori Procedure for Biomechanical Determination of Optimum Motion Pattern". Advanced Management, Vol. XV, No. 6-8, June-August 1950). New York: Society for Advancement of Management.

6. Morrow, R. L. Time Study and Motion Economy. New York: The Ronald Press Company. (1946)

7. "Work and the Work-Place". Special Devices Center, Office of Naval Research, U. S. Navy. Systems Research Laboratory, John Hopkins University.

8. Quick, J. H., W. J. Shea, R. E. Koehler. "Motion-Time Standards", Factory Management and Maintenance, Vol. 103, No. 5, May 1945. New York: McGraw-Hill Publishing Company. (1945)

9. Fisher, R. A., F. Yates. Statistical Tables for Biological Agricultural and Medical Research. London: Oliver and Boyd Ltd. (1943)

10. Davies, O. L. Statistical Methods in Research and Production. London: Oliver and Boyd Ltd. (1949)

X

VITA

Alfred S. York was born in Chekiang, China, on June 7, 1926. After receiving the Degree of Bachelor of Science in Industrial Management at the Chiao-Tung University, Shanghai, China, in June 1948, he was employed as a junior industrial engineer by the Hwainan Mining and Railway Company in Shanghai. After nine months of service, he resigned from his position. Following this, he went to Formosa and joined the Keelung Harbour Bureau. In February 1950, he came to the United States. He entered the Virginia Polytechnic Institute in April of the same year for graduate study in Industrial Engineering.

XI

APPENDIX

SYMBOLS, ABBREVIATIONS, AND TERMS

Time:	observed time value in .001 minute
Distance:	distance, or motion length, in inches
S. L.:	straight line distance between the starting point of the hand and the object to which the motion is made, or the straight line distance between the starting and terminal points of the hand motion.
M. P.:	distance determined by measuring the motion path
S:	shoulder movement
H - 4S:	distance moved by the hand minus four times the distance moved by the shoulder
MTM Time:	time value obtained in MTM Table
x:	film data lacking
*:	data not available

Table 1

Summary Data Sheet

for

Reaches Accompanied by Body-Rotation

Operator A						Operator B					
Time	Distance S.L.	Distance M.P.	S	H-4S	M.T.M. Time	Time	Distance S.L.	Distance M.P.	S	H-4S	M.T.M. Time
17	66	63	11	22	12.06	21	68	67	13	16	9.48
17	61	58	10	21	11.61	17	58	57	13	6	5.16
19	56	54	8	24	12.90	17	64	63	9	28	14.64
15	64	61	10	21	12.90	16	56	55	7	28	14.64
14	53	50	9	17	9.90	20	63	63	9	27	14.19
18	62	60	10	22	12.06	16	54	54	9	18	10.32
19	57	53	8	25	13.32	17	60	64	9	24	12.90
15	52	46	8	20	11.16	17	51	52	10	11	7.32
17	60	58	9	24	12.90	18	58	61	9	22	12.06
16	54	52	8	22	12.06	15	48	51	8	16	9.48
16	49	46	8	17	9.90	15	57	58	9	21	11.61
16	58	55	10	18	10.32	13	48	48	7	20	11.16
16	53	51	8	21	11.61	15	55	59	13	3	3.54
18	46	44	7	18	10.32	16	45	46	10	5	4.68
17	58	55	9	22	12.08	16	48	51	9	12	7.74
16	53	48	8	21	11.61	15	53	56	11	9	6.48
15	46	43	7	18	10.32	21	66	66	13	14	8.64
16	56	53	10	16	9.48	18	57	58	8	25	13.32

Table 1 (Continued)

Summary Data Sheet

for

Reaches Accompanied by Body-Rotation

Operator A						Operator B					
Time	Distance S.L.	Distance M.P.	S	H-4S	M.T.M. Time	Time	Distance S.L.	Distance M.P.	S	H-4S	M.T.M. Time
19	68	67	10	28	14.64	18	63	61	14	7	5.58
18	62	60	10	22	12.08	17	54	51	9	18	10.32
16	54	55	8	25	13.32	18	61	60	9	25	13.32
16	66	65	10	26	13.74	14	52	51	8	20	11.16
15	59	60	11	15	9.06	19	58	58	10	18	10.32
15	53	50	9	17	9.90	15	48	50	8	16	9.48
15	63	64	12	15	9.06	17	57	55	9	21	11.61
14	57	58	10	17	9.90	17	46	45	7	18	10.32
13	51	49	8	19	10.74	18	56	54	10	16	9.48
16	60	49	10	20	11.16	17	45	45	6	21	11.61
16	53	54	9	17	9.90	15	53	55	11	9	6.48
15	47	46	8	15	9.06	17	42	46	9	6	5.16
17	52	48	9	16	9.48	18	62	63	12	14	8.64
15	51	49	9	15	9.06	18	53	55	10	13	8.19
15	44	42	8	12	7.74	18	60	60	11	16	9.48
15	56	54	9	20	11.16	17	50	50	7	22	12.06
21	65	64	13	12	7.74	18	59	58	10	19	10.74
21	57	64	14	1	9.06	17	49	54	8	17	9.90

Table 1 (Continued)

Summary Data Sheet

for

Reaches Accompanied by Body-Rotation

Operator A.					
Time	Distance S.L.	Distance M.P.	S	H-4S	M.T.M. Time
17	63	60	12	15	13.74
15	54	50	7	26	13.74
16	61	60	14	5	4.68
16	52	52	8	20	11.16
14	58	61	8	26	13.74
16	48	52	7	20	11.16
17	57	56	10	17	9.90
16	46	44	6	22	12.06
17	56	56	11	12	7.74
15	54	46	9	18	10.32
15	43	55	9	7	5.58
15	53	51	7	25	13.32
18	54	55	8	22	12.06
21	61	63	9	25	13.32
18	51	50	8	19	10.74
21	56	55	8	24	12.94
18	46	46	7	18	10.32
18	55	48	8	23	12.48

Operator B					
Time	Distance S.L.	Distance M.P.	S	H-4S	M.T.M. Time
19	55	65	9	19	10.74
16	45	57	9	9	6.48
18	53	60	10	13	8.19
16	44	51	7	16	9.48

Operator A					
Time	Distance S.L.	Distance M.P.	S	H-4S	M.T.M. Time
18	45	49	7	17	9.90
17	52	53	8	20	11.16
16	42	47	7	14	8.64

Table 1 (Continued)

Summary Data Sheet

for

Reaches Accompanied by Body-Rotation

Operator C						Operator D					
Time	Distance S.L.	Distance M.P.	S	H-4S	M.T.M. Time	Time	Distance S.L.	Distance M.P.	S	H-4S	M.T.M. Time
19	68	70	14	12	7.74	18	68	67	13	16	9.48
16	61	65	13	9	6.48	19	61	61	11	17	9.90
16	68	69	14	12	7.74	18	66	69	15	6	5.16
17	59	57	11	15	9.06	16	58	58	9	22	12.06
21	67	70	15	7	5.58	17	64	69	14	8	6.06
20	59	59	10	19	10.74	17	58	59	10	18	10.32
15	60	64	12	12	7.74	18	62	60	11	18	10.32
14	61	67	15	1	1.26	19	55	58	12	7	5.58
17	64	53	10	24	12.90	17	62	61	13	10	6.90
20	53	56	9	17	9.90	16	54	52	8	22	12.06
15	52	58	9	16	9.48	18	60	60	10	20	11.16
15	62	62	12	14	8.64	16	54	55	9	18	10.32
14	56	56	9	20	11.16	19	60	58	10	20	11.16
13	50	50	7	22	12.06	14	51	57	12	3	3.54
14	61	65	15	1	1.26	17	59	48	8	27	14.19
14	55	57	12	7	5.58	15	50	61	13	-2	-
14	50	51	9	14	8.64	15	57	60	11	13	8.19
14	59	58	10	19	10.74	15	49	51	10	9	6.48

Table 1 (Continued)

Summary Data Sheet

for

Reaches Accompanied by Body-Rotation

Operator C						Operator D					
Time	Distance S.L.	Distance M.P.	S	H-4S	M.T.M. Time	Time	Distance S.L.	Distance M.P.	S	H-4S	M.T.M. Time
15	53	55	10	13	8.19	16	56	59	10	16	9.48
15	46	47	6	22	12.06	16	47	51	8	15	9.06
15	57	59	11	13	8.19	14	55	58	9	19	10.74
13	51	51	9	15	9.06	15	46	47	8	14	8.64
14	50	50	8	18	10.32	16	54	60	12	6	5.16
14	44	44	6	20	11.16	14	45	46	7	17	9.90
16	56	52	10	16	9.48	17	65	64	14	9	6.48
18	67	-	-	-	-	16	58	54	10	18	10.32
16	61	-	-	-	-	16	64	61	12	16	9.48
12	58	60	10	18	10.32	15	56	55	9	20	11.16
13	65	66	11	21	11.61	17	62	60	10	22	12.06
12	56	64	9	20	11.16	14	54	52	9	18	10.32
15	63	62	11	19	10.74	17	60	60	13	8	6.06
13	55	56	10	15	9.06	14	51	52	9	15	9.06
13	60	60	10	20	11.16	16	58	56	9	22	12.06
15	57	59	12	9	6.48	14	48	50	8	16	9.48
15	57	55	11	13	8.19	14	57	61	11	13	8.19
14	58	58	11	14	8.64	15	48	48	10	8	6.06

Table 1 (Continued)

Summary Data Sheet

for

Reaches Accompanied by Body-Rotation

Operator C						Operator D					
Time	Distance S.L.	Distance M.P.	S	H-4S	M.T.M. Time	Time	Distance S.L.	Distance M.P.	S	H-4S	M.T.M. Time
12	46	48	7	18	10.32	14	55	54	9	19	10.74
13	54	58	13	2	2.58	14	45	52	8	13	8.19
12	43	47	9	7	5.58	14	48	52	10	8	6.06
13	54	57	11	10	6.09	15	53	53	10	13	8.19
17	65	67	12	17	9.90	19	65	62	11	21	11.61
15	57	55	10	17	9.90	16	57	54	11	13	8.19
16	63	61	10	23	12.48	15	63	60	12	15	9.06
13	54	51	9	18	10.32	14	54	50	10	14	8.64
14	61	60	12	13	8.19	17	61	60	12	13	8.19
12	52	52	8	20	11.16	14	52	54	10	12	7.74
14	58	58	10	18	10.32	16	58	56	10	18	10.32
12	48	48	10	8	6.06	13	48	48	8	16	9.48
13	57	57	12	9	6.48	14	57	56	11	13	8.19
12	46	48	9	10	6.90	13	46	47	8	14	8.64
14	56	56	9	20	11.16	14	56	57	11	12	7.74
11	45	50	10	5	4.68	14	45	48	9	9	6.48
14	53	57	11	9	6.48	14	53	55	11	9	6.48
13	53	52	11	9	6.48	13	53	51	10	13	8.19

Table 1 (Continued)

Summary Data Sheet

for

Reaches Accompanied by Body-Rotation

Operator C						Operator D					
Time	Distance S.L.	Distance M.P.	S	H-4S	M.T.M. Time	Time	Distance S.L.	Distance M.P.	S	H-4S	M.T.M. Time
17	66	64	14	10	6.90	17	63	63	13	11	7.32
15	56	53	10	16	9.48	14	62	51	8	30	15.48
13	54	60	12	6	5.16	13	52	53	10	12	7.74
12	52	52	8	20	11.16	14	51	49	9	15	9.06
14	60	60	13	8	6.06	15	56	58	10	16	9.48
14	57	57	10	17	9.90	15	56	53	9	20	11.16
13	47	46	9	11	7.32	13	45	56	10	5	4.68
13	53	57	12	5	4.68	13	45	49	8	13	8.19
11	42	47	9	6	5.16	16	52	52	10	12	7.74
13	53	56	12	7	5.58	13	42	46	9	5	4.68

Table 1 (Continued)

Summary Data Sheet

for

Reaches Accompanied by Body-Rotation

Operator E					
Time	St. Line Distance	Time	St. Line Distance	Time	St. Line Distance
16	58	14	50	15	58
18	67	13	45	13	48
17	61	19	65	14	57
14	55	14	58	12	46
18	64	16	64	13	56
15	59	14	50	14	44
14	54	15	55	13	47
16	62	16	57	13	47
16	57	11	46	17	62
15	50	13	48	13	53
15	61	19	55	14	60
15	54	13	44	13	50
15	48	14	46	13	59
17	59	14	53	11	49
16	53	16	65	18	55
13	48	15	57	13	44
17	59	14	63	16	48
16	53	13	54	14	53
14	45	14	61	-	-
15	56	13	52	-	-

Table 2

Summary Data Sheet

for

Reaches Accompanied by Turn-Body-case 1

Operator A				Operator B				Operator C				Operator D			
Time	Distance S.L.	M.P.	S	Time	Distance S.L.	M.P.	S	Time	Distance S.L.	M.P.	S	Time	Distance S.L.	M.P.	S
20	66	62	12	19	58	58	12	19	68	70	15	20	68	67	18
19	61	57	11	19	53	54	14	18	62	65	14	18	61	60	14
20	56	52	11	18	63	63	11	16	58	64	14	18	66	60	13
18	64	60	11	18	58	58	12	17	67	70	16	18	58	56	11
21	58	54	11	18	53	50	9	18	61	64	14	19	64	70	16
17	53	50	8	23	64	63	13	18	55	57	13	19	58	61	14
19	62	58	10	17	56	56	10	20	64	70	15	18	62	65	15
22	57	50	8	16	50	51	11	18	59	60	13	15	55	56	16
20	52	48	8	17	59	60	13	16	54	56	13	18	60	65	15
23	60	57	10	15	60	56	13	18	62	70	16	13	53	56	11
19	54	51	10	16	48	46	10	17	57	62	15	16	60	64	14
19	49	48	8	18	60	58	13	16	51	57	13	16	54	57	11
19	58	54	10	15	43	52	10	17	56	56	12	17	60	63	17
18	53	51	8	14	47	46	11	14	50	51	11	17	51	49	10
18	46	45	8	18	60	56	9	16	61	65	15	15	50	52	11
18	58	56	9	15	50	49	9	17	55	59	14	15	57	59	12
17	52	49	8	19	65	67	13	14	50	49	11	15	49	56	11
19	56	43	9	16	58	60	16	16	59	63	14	16	56	60	11

Table 2

Summary Data Sheet

for

Reaches Accompanied by Turn-Body-case 1

Operator A				Operator B				Operator C				Operator D			
Time	Distance S.L.	M.P.	S	Time	Distance S.L.	M.P.	S	Time	Distance S.L.	M.P.	S	Time	Distance S.L.	M.P.	S
20	56	53	12	19	64	64	18	14	53	55	12	16	47	48	10
21	50	41	9	17	56	57	9	16	46	49	11	15	55	56	12
20	65	62	16	18	62	62	15	16	57	59	16	14	54	57	12
18	58	56	15	15	54	53	10	13	49	52	12	15	45	51	11
21	64	61	18	17	60	63	13	14	45	45	12	17	65	64	14
19	56	54	17	16	51	52	12	22	67	64	13	16	58	58	11
18	62	60	17	16	58	57	13	14	58	58	12	15	56	54	11
21	54	51	16	14	44	44	10	15	66	67	13	15	64	62	13
18	60	57	19	19	56	57	10	14	65	65	12	15	62	59	11
17	51	52	17	16	55	48	8	14	56	54	14	12	54	54	12
20	58	56	17	17	45	60	10	16	63	64	14	16	60	59	11
17	48	46	16	13	44	48	8	15	55	54	15	14	51	51	11
18	57	57	19	15	43	51	9	16	60	61	13	16	58	52	11
17	48	45	16	19	53	56	9	14	50	54	12	14	48	47	9
20	55	54	18	19	65	65	14	15	57	60	13	15	57	52	11
18	45	44	13	16	57	57	15	15	48	49	11	14	48	49	9
15	48	43	16	18	63	62	13	14	57	58	12	15	55	50	9
19	53	53	17	17	54	52	9	12	45	47	11	14	45	46	10

Table 2 (Continued)

Summary Data Sheet

for

Reaches Accompanied by Turn-Body-case 1

Operator A				Operator B				Operator C				Operator D			
Time	Distance S.L.	M.P.	S	Time	Distance S.L.	M.P.	S	Time	Distance S.L.	M.P.	S	Time	Distance S.L.	M.P.	S
23	65	70	18	19	61	60	10	14	58	58	13	14	48	46	10
20	57	61	14	16	52	49	8	15	46	48	14	15	53	55	12
21	63	64	15	20	58	59	12	15	61	65	15	21	65	62	14
17	54	54	13	19	48	48	8	14	52	54	15	19	57	55	11
16	61	63	18	21	57	55	12	16	58	58	13	15	65	61	13
16	52	52	15	16	46	45	9	13	48	53	12	16	54	56	11
19	58	64	16	19	56	55	12	13	57	60	16	17	61	61	12
18	48	53	14	17	45	44	7	13	46	48	16	16	52	52	11
24	57	55	13	19	53	56	12	16	56	60	14	17	58	61	14
19	46	49	11	20	62	64	12	13	45	50	16	16	48	51	9
12	56	57	14	19	53	54	9	16	53	58	18	16	57	57	11
19	45	48	12	19	60	59	11	21	66	67	13	16	47	49	9
20	53	60	18	17	50	50	9	17	56	58	13	16	56	57	12
20	42	48	14	16	53	43	8	14	53	58	17	17	45	50	10
24	61	63	10	20	59	59	9	16	54	65	15	18	53	50	10
21	54	54	14	19	50	49	8	13	52	54	12	17	53	51	10
19	61	60	12	17	55	62	10	16	60	60	14	16	61	60	12
17	51	51	9	18	45	54	8	14	50	53	11	15	54	-	10

Table 2 (Continued)

Summary Data Sheet

for

Reaches Accompanied by Turn-Body-case 1

Operator A				Operator B				Operator C				Operator D			
Time	Distance S.L.M.P.		S	Time	Distance S.L.M.P.		S	Time	Distance S.L.M.P.		S	Time	Distance S.L.M.P.		S
19	56	59	10	19	53	59	11	19	57	60	17	14	51	50	10
16	46	48	8	17	44	51	8	14	47	50	14	15	56	57	12
20	55	60	10	-	-	-	-	16	53	56	17	14	46	47	10
21	54	40	8	-	-	-	-	15	43	46	13	16	55	51	11
18	52	60	11	-	-	-	-	15	53	53	16	15	45	54	12
-	-	-	-	-	-	-	-	-	-	-	-	14	52	51	10
-	-	-	-	-	-	-	-	-	-	-	-	14	42	46	10

Table 2 (Continued)

Summary Data Sheet

for

Reaches Accompanied by Turn-Body-case 1

Operator E					
Time	St.Line Distance	Time	St.Line Distance	Time	St.Line Distance
22	68	17	56	17	52
20	62	16	56	15	58
18	58	22	65	15	48
18	67	14	58	15	57
16	61	16	64	14	46
16	55	17	56	17	56
18	64	19	62	17	44
16	59	16	54	19	62
16	54	16	60	16	53
16	62	15	51	16	47
16	57	15	58	15	60
15	61	14	48	14	50
13	54	17	57	16	59
15	48	14	48	16	49
16	59	16	55	16	55
16	53	17	45	13	44
17	48	14	48	13	48
17	53	19	53	15	53
16	45	18	61	-	-

Table 3

Summary Data Sheet

for

Moves Accompanied by Body-Rotation

Weight 1 Ounce									
Operator A		Operator B		Operator C		Operator D		Operator E	
Time	St. Line Distance	Time	St. Line Distance	Time	St. Line Distance	Time	St. Line Distance	Time	St. Line Distance
16	61	x		17	62	18	68	20	66
15	58			18	60	18	62	18	61
15	65			24	68	21	67	18	56
18	58			22	61	18	60	23	65
14	54			23	62	19	64	18	60
18	63			18	62	16	59	16	56
15	57			19	65	18	63	19	62
14	52			17	53	17	56	19	57
18	61			16	57	17	62	17	61
19	55			20	62	16	54	16	55
17	50			15	57	19	60	15	45
19	59			15	51	16	54	18	60
16	53			18	62	19	60	16	64
17	48			17	56	17	52	15	48
18	59			15	50	20	59	14	59
16	52			17	59	16	50	17	53
15	46			17	53	20	58	16	46
18	56			16	47	16	50	20	57

Table 3 (Continued)

Summary Data Sheet

for

Moves Accompanied by Body-Rotation

Weight 1 Ounce									
Operator A		Operator B		Operator C		Operator D		Operator E	
Time	St. Line Distance	Time	St. Line Distance	Time	St. Line Distance	Time	St. Line Distance	Time	St. Line Distance
15	50	x		18	58	17	56	16	51
-	-			16	52	16	47	15	45
-	-			17	51	17	55	16	49
-	-			17	46	17	47	-	-
-	-			17	57	18	54	-	-
-	-			-	-	18	52	-	-
-	-			-	-	19	54	-	-

Table 3 (Continued)

Summary Data Sheet

for

Moves Accompanied by Body-Rotation

Weight 13 Ounces									
Operator A		Operator B		Operator C		Operator D		Operator E	
Time	St. Line Distance	Time	St. Line Distance	Time	St. Line Distance	Time	St. Line Distance	Time	St. Line Distance
21	68	22	66	25	68	22	66	21	58
23	63	22	58	22	64	20	58	20	65
18	58	19	64	24	67	21	65	22	57
20	67	20	57	17	58	20	57	22	55
20	60	18	63	17	58	20	63	21	58
19	54	21	55	20	61	19	55	18	56
19	58	20	61	20	52	20	61	19	47
18	52	18	51	19	58	17	51	19	53
20	62	19	59	17	49	20	59	16	44
18	54	17	50	18	57	16	49	-	-
18	58	19	48	19	57	17	48	-	-
17	48	20	58	16	48	19	58	-	-
17	52	22	56	16	47	21	56	-	-
17	45	17	46	18	55	18	46	-	-
20	57	17	50	17	44	17	49	-	-
17	51	17	53	17	55	19	53	-	-
-	-	18	44	-	-	17	44	-	-

Table 3 (Continued)

Summary Data Sheet

for

Moves Accompanied by Body-Rotation

Weight 40 Ounces									
Operator A		Operator B		Operator C		Operator D		Operator E	
Time	St. Line Distance	Time	St. Line Distance	Time	St. Line Distance	Time	St. Line Distance	Time	St. Line Distance
26	64	26	66	28	66	27	62	23	57
25	60	24	57	24	58	24	63	22	55
27	63	23	63	23	63	22	55	23	62
20	55	23	55	21	55	23	62	20	53
21	60	23	61	21	62	19	51	22	59
21	52	21	53	21	51	21	59	22	52
23	59	23	59	23	60	21	50	20	57
21	49	22	51	21	58	21	58	18	47
21	57	22	57	18	47	19	47	20	56
19	47	21	47	23	56	21	56	18	46
22	56	22	56	20	46	18	46	21	48
19	55	20	46	21	54	24	54	19	48
19	43	23	54	19	50	23	53	-	-
19	54	-	-	20	54	22	54	-	-
21	44	-	-	-	-	-	-	-	-

Table 3 (Continued)

Summary Data Sheet

for

Moves Accompanied by Body-Rotation

Weight 120 Ounces									
Operator A		Operator B		Operator C		Operator D		Operator E	
Time	St. Line Distance	Time	St. Line Distance	Time	St. Line Distance	Time	St. Line Distance	Time	St. Line Distance
28	62	30	63	31	66	32	62	32	63
22	52	29	57	29	59	-	-	29	61
24	57	28	60	27	63	24	47	24	52
21	47	25	59	24	54	24	49	26	58
22	50	25	51	27	61	24	53	26	50
22	46	26	56	21	49	22	42	29	57
23	53	24	45	25	57	22	48	25	49
23	42	25	54	23	47	-	-	24	54
26	53	22	44	25	55	-	-	22	43
-	-	25	48	21	45	-	-	-	-
-	-	28	52	23	54	-	-	-	-
-	-	-	-	19	42	-	-	-	-
-	-	-	-	21	52	-	-	-	-

Table 4

Summary Data Sheet

for

Moves Accompanied by Turn-Body-case 1

Weight 1 Ounce									
Operator A		Operator B		Operator C		Operator D		Operator E	
Time	St. Line Distance	Time	St. Line Distance	Time	St. Line Distance	Time	St. Line Distance	Time	St. Line Distance
20	61	19	59	20	68	21	68	26	68
21	58	21	54	20	62	17	62	24	62
22	65	22	64	19	59	22	67	21	59
20	58	20	58	21	67	19	60	21	67
19	54	19	53	19	61	23	64	21	61
23	63	16	64	17	56	20	59	19	56
21	57	18	56	20	65	19	63	20	65
17	52	18	50	20	60	20	58	21	60
20	61	22	61	17	56	21	62	16	56
17	55	19	60	20	62	18	54	21	62
18	49	18	55	19	57	22	61	19	57
21	59	21	61	16	51	18	54	18	51
19	53	18	56	19	62	20	60	19	61
18	46	20	57	16	49	19	52	21	55
21	59	18	58	20	62	21	59	23	60
22	53	18	50	19	56	17	50	20	54
17	46	17	44	17	50	21	58	22	59
20	56	-	-	20	59	18	50	20	53

Table 4 (Continued)

Summary Data Sheet

for

Moves Accompanied by Turn-Body-case 1

Weight 1 Ounce									
Operator A		Operator B		Operator C		Operator D		Operator E	
Time	St. Line Distance	Time	St. Line Distance	Time	St. Line Distance	Time	St. Line Distance	Time	St. Line Distance
18	50	-	-	17	53	19	56	19	46
16	44	-	-	16	47	18	47	19	56
-	-	-	-	17	52	20	47	20	51
-	-	-	-	19	58	20	55	-	-
-	-	-	-	16	44	20	54	-	-
-	-	-	-	20	56	-	-	-	-

Table 4 (Continued)

Summary Data Sheet

for

Moves Accompanied by Turn-Body-case 1

Weight 13 Ounces									
Operator A		Operator B		Operator C		Operator D		Operator E	
Time	St. Line Distance	Time	St. Line Distance	Time	St. Line Distance	Time	St. Line Distance	Time	St. Line Distance
22	58	18	66	26	67	25	66	27	66
21	65	21	58	17	61	20	58	23	65
21	57	23	65	20	67	23	65	21	57
23	63	19	57	17	59	20	57	27	62
23	55	22	63	19	66	22	63	22	55
23	61	20	55	20	64	20	55	21	61
22	51	19	61	17	58	19	61	22	51
23	59	21	51	19	61	18	51	22	59
20	49	19	59	17	52	18	59	20	49
26	58	19	49	18	58	16	49	23	58
23	60	19	58	17	49	20	58	21	56
21	49	19	55	18	57	18	48	20	46
-	-	19	46	16	48	21	56	18	49
-	-	20	54	17	57	19	46	21	53
-	-	19	44	16	47	18	49	18	44
-	-	20	53	19	55	22	53	-	-
-	-	16	45	17	44	20	44	-	-
-	-	-	-	16	54	-	-	-	-
-	-	-	-	16	43	-	-	-	-

Table 4 (Continued

Summary Data Sheet

for

Moves Accompanied by Turn-Body-case 1

Weitht 40 Ounces									
Operator A		Operator B		Operator C		Operator D		Operator E	
Time	St. Line Distance	Time	St. Line Distance	Time	St. Line Distance	Time	St. Line Distance	Time	St. Line Distance
30	65	25	65	20	53	29	65	23	55
24	57	27	57	20	59	29	57	25	62
25	63	25	63	24	49	24	63	20	53
23	55	24	55	21	57	23	55	23	59
26	62	24	62	19	47	23	62	23	49
26	53	23	53	23	56	22	53	23	57
25	59	22	59	19	46	23	59	22	47
22	49	22	49	22	54	22	49	23	56
26	57	21	57	19	54	21	57	21	46
23	48	22	47	-	-	21	47	21	48
25	56	23	56	-	-	23	56	20	48
25	49	21	46	-	-	22	46	19	48
26	54	22	54	-	-	22	54	-	-
24	42	22	53	-	-	22	53	-	-
22	47	19	54	-	-	25	54	-	-

Table 4 (Continued)

Summary Data Sheet

for

Moves Accompanied by Turn-Body-case 1

Weight 120 Ounces									
Operator A		Operator B		Operator C		Operator D		Operator E	
Time	St. Line Distance	Time	St. Line Distance	Time	St. Line Distance	Time	St. Line Distance	Time	St. Line Distance
30	62	36	63	36	67	34	61	30	63
28	52	35	55	30	56	36	57	31	55
39	57	39	61	38	63	25	47	29	61
24	47	26	52	25	54	27	56	29	52
28	56	25	59	26	61	26	46	29	59
24	46	27	51	25	52	26	53	29	51
29	53	27	56	24	57	28	47	30	56
-	-	27	45	24	47	-	-	27	45
-	-	25	54	25	55	-	-	27	49
-	-	23	44	22	44	-	-	27	54
-	-	26	48	23	44	-	-	28	43

SAMPLE OF CALCULATING REGRESSION EQUATION

The sample calculation shown here is for equation of Reaches accompanied by Body-Rotation. The data are as follows:

x	y.	ξ_1'	ξ_2'	ξ_3'	$\xi_1'y$	$\xi_2'y$	$\xi_3'y$
42	14.2	-13	+325	-130	-184.6	+4165.0	-1846.0
43	14.3	-12	+250	-70	-171.6	+3575.0	-1001.0
44	14.2	-11	+181	-22	-156.2	+2570.2	-312.4
45	14.4	-10	+118	+15	-144.0	+1699.2	+216.0
46	14.4	-9	+61	+42	-129.6	+878.4	+604.8
47	14.0	-8	+10	+60	-112.0	+140.0	+840.0
48	14.2	-7	-35	+70	-99.4	-497.0	+994.0
49	14.8	-6	-74	+73	-88.8	-1095.2	+1080.4
50	14.3	-5	-107	+70	-71.5	-1530.1	+1001.1
51	14.8	-4	-134	+62	-59.2	-1983.2	+917.6
52	14.3	-3	-155	+50	-42.9	-2216.5	+715.0
53	14.5	-2	-170	+35	-29.0	-2465.0	+507.5
54	14.8	-1	-179	+18	-14.8	-2649.2	+266.4
55	16.2	0	-182	0	0	-2948.4	0
56	15.8	+1	-179	-18	+15.8	-2828.2	-284.4
57	15.6	+2	-170	-35	+31.2	-2652.0	-546.0
58	15.8	+3	-155	-50	+47.4	-2449.0	-790.0
59	16.3	+4	-134	-62	+65.2	-2184.2	-1010.6
60	16.2	+5	-107	-70	+81.0	-1733.4	-1134.0
61	16.7	+6	-74	-73	+100.2	-1235.8	-1219.1
62	16.8	+7	-35	-70	+117.6	-588.0	-1176.0
63	17.3	+8	+10	-60	+138.4	+173.0	-1038.0
64	16.6	+9	+61	-42	+149.4	+1012.6	-697.2
65	17.7	+10	+118	-15	+177.0	+2088.6	-265.5
66	17.3	+11	+181	+22	+190.3	+3131.3	+380.6
67	18.0	+12	+250	+70	+216.0	+4500.0	+1260.0
68	18.6	+13	+325	+130	+241.8	+6045.0	+2418.0
K		1638	712530	101790	Σ=267.7	Σ=1372.9	Σ=-118.9
J		1	3	1/6			

Denote the two variates (distance and time) by x and y respectively. We require to fit a higher order equation to the data. Let the regression equation be :

$$Y = A + BX_1 + CX_2 + DX$$

where $X_1 = (x - \bar{x})$

$X_2 = \left[(x - \bar{x}) - (n^2 - 1)/12\right]$

$X_3 = (x - \bar{x})^3 - \frac{3n^2 - 7}{20}(x - \bar{x})$

n = Number of observations.

We obtain :

$$\begin{cases} \bar{x} = 55 \\ \bar{y} = 15.6330 \end{cases}$$

$\bar{y}$ gives the constant A of the regression

To calculate constants B, C, D we refer to Table XXIII of Statistical Tables (9) under n = 27 and obtain ξ_1', ξ_2', ξ_3' of the above table. The letters K and J have been introduced at the bottom of the table for reference.

The procedure for calculating the constant B, C, D is as follows :

(i) Multiple each y by the corresponding ξ_1', and add. Repeat the process for ξ_2' and ξ_3'.

(ii) Multiple (i) by the corresponding value of K.

(iii) Divide (ii) by the corresponding value of J.

Following out this procedure we obtain :

$$\begin{cases} \Sigma \xi_1' y = 267.7 \\ \Sigma \xi_2' y = 1372.9 \\ \Sigma \xi_3' y = -118.9 \end{cases}$$

Then $B = \Sigma \xi_1' y \times \frac{K}{J} = 0.1634$

$C = \Sigma \xi_2' y \times \frac{K}{J} = 0.0057$

$D = \Sigma \xi_3' y \times \frac{K}{J} = -0.000194$

As shown above, $A = 15.6330$.

Using the values derived above for A, B, C, D, we substituted those values in the regression equation, We obtain :

$$Y = 15.6330 + 0.1634\,(x - 55) + 0.0057\left[(x-55)^2 - 60.66\right] - 0.000194\left[(x-55)^3 - 108\,(x-55)\right]$$

where: $\begin{cases} x = \text{Distance in Inches} \\ Y = \text{Time in .001 Minute.} \end{cases}$