POSTURAL DATA INCORPORATED INTO TRADITIONAL WORK MEASUREMENT

by
Walthea V. Yarbrough

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Approved by:

Dr. C. Patrick Koelling, Chairperson

Professor Paul T. Kemmerling

Dr. Vincent K. Omachonu

Dr. Paul E. Torgersen

Dr. Jeffrey C. Woldstad

Blacksburg, Virginia

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Dr. C. Patrick Koelling, Chairperson

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(ABSTRACT)

Research was conducted that culminated in the merging of the objectives of two tools: predetermined motion time systems and posture recording. This dissertation reports the development and testing of a computerized tool—the Work and Posture Analysis Sequence Technique (WAPAST)—used to collect methods, postural, and work measurement data. From the data collected, one can determine the method used to complete an activity by task identification, the time it takes to complete each task, as well as the time to complete an entire activity, and the postural considerations for each task and for the overall activity.

The tool is based on the Maynard Operations Sequence Technique (MOST) with some characteristics of the Ovako Working Posture Analysis System (OWAS). Criteria established were speed of completion, accuracy, and reliability. A validation study was conducted to assess the data collected with WAPAST against data collected with known, validated tools. The study was an experiment that had several subjects use WAPAST to analyze videotaped work activities while several other subjects used MOST or OWAS to analyze the same videotaped activities. The data collected with WAPAST were compared with the data collected with MOST and OWAS. The work measurement data collected with WAPAST were found to be both accurate and reliable, but the postural data were not. Times to complete applications were extensive. Recommendations are given for improving the tool, which include a different way of recording postural data and expanding the limitations of the tool.

Dedicated in loving honor to

my parents,

Reverend and Mrs. Walter Yarbrough.

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CHAPTER 1. INTRODUCTION

1.1. The Purpose of This Research

Since the beginning of recorded history there has been a quest for a better way to do things. The inventor of the wheel was probably motivated by the desire to eliminate some of the effort required to move objects from one place to another (Karger and Bayha, 1987). This desire occurs in many of life's arenas. In the auto industry, continuous changes are made to existing vehicles to meet the customers' and government regulating agencies' ideas of improvement. In competitive, team sports, new plays are continuously devised so that, if executed properly, the game would be won more easily. In the workplace, the desire is to improve the tasks that comprise work.*

Improvement often results from change efforts that materialize with use of the systems approach. Using the systems approach, consideration is given to three components: the current status of the system*, the desired status to be achieved at a future point in time, and alternative methods for reaching the desired status from the current status. Prior to any change effort, the systems approach should be incorporated by developing a map or plan to guide the system from its current status to some desired future status. To construct this map, a detailed description of the current status must first be developed, along with a list of the desired goals of the system. The map should be a preliminary plan for reaching the defined goals from the current status of the system. Each component of the systems approach is important for successful change and can be studied intensely. This research, however, studied the first component—

* Denotes those terms that are listed in the Glossary of Terms (Appendix A).

identifying the system's current status. Its purpose was to develop a tool that helps one to identify the current status of B-Work.* Beruvides and Koelling (1993) define B-Work as "all work of a manual or physical nature whose output is clearly definable or tangible, and whose inputs are clearly definable and directly influential in the output produced with no discretion (or little) permitted in the job task. Job task pursuits and tool use needs can best be described as process and project levels on the uncertainty scale; endeavors are functional and operational; decisions are structured; and stages of maturity can be described in the visibility to control level."

Consider B-Work in the context of moving boxes from a table to the floor in a repetitive, continuous manner. In identifying the current status of this task with the intent of future improvement, one should consider three components: the method used to complete the task, the time that it takes to complete the task, and the posture assumed while completing the task. These components are inter-related and affect one another not only in this task, but in other tasks that compose B-Work as well. In this task, the method used was probably developed as a result of time constraints. The objective was to move as many boxes as possible, as quickly as possible. However, development of the method may or may not have considered the effects of the assumed posture on the body. For example, the method may involve extensive bending of the back and/or lifting using muscles of the back. Studies have shown that these types of activities can cause damage to the back if performed repeatedly (Chaffin and Andersson, 1991; Chapel, 1987; and Farnham, 1990). One cannot address these and other posture related problems without considering the method <u>and</u>

considering the time component. Therefore, data for each of these components should be collected simultaneously.

Several tools and techniques have been employed to document and measure various components of B-work. Work measurement* has been established to determine time requirements for individual tasks. Methods engineering* is used to identify the individual elements of tasks. Predetermined motion time systems (PMTS)* use predetermined times* to meet the objectives of work measurement simultaneously with the objectives of methods engineering. Finally, posture recording is used to record postures assumed while performing tasks, so that future improvements can be made to those postures that are potentially harmful to one's body. This chapter briefly introduces each of the tools and techniques mentioned and culminates with a discussion of the research problem and objective.

1.2. Tools and Techniques For Documenting and Measuring the Components of B-Work

In the 19th and early part of the 20th centuries, Taylor, Gantt, Emerson, the Gilbreths, and others developed the concept of scientific management. New principles and techniques for management were introduced that were designed to systemize and standardize the planning, control, and operation of industry. An essential part of implementing these steps was the establishment of an adequate basis for work measurement to exert corrective control.

Work measurement is rooted in the desire and the need of humankind to continuously improve the performance of the tasks that comprise work (Karger and Bayha, 1987). Much of the origin of work measurement is credited to

Frederick Taylor. He studied the reduction of tasks into elements that could be managed to produce more efficient, more productive, and less fatiguing work than before. The elements were studied individually to determine the value of their components, i.e. whether the components were useful or useless. After identifying the useful or productive components, a stopwatch was used to determine the time for each. Since this timing process yielded the actual time for a particular task under certain conditions, and it needed to be generalized to all workers, the concept of performance rating* was developed (Niebel, 1993).

Concurrently, Frank and Lillian Gilbreth studied methods of work by identifying all manual operations as combinations of basic elements. They isolated these elements and identified them with the intention of explaining and improving methods. The hypothesis of their research was that effort and time to perform a task could be reduced by reducing the motion content of the task (Niebel, 1993). Taylor's followers practiced time study, while the Gilbreths' followers practiced motion study. The best of these two techniques were joined to form Predetermined Motion Time Systems (PMTS) (Zandin, 1980).

PMTS use time study and micro motion techniques to determine and assign times to specified basic motions. According to Zandin (1980), the motions and associated times are catalogued, reducing work measurement to the process of establishing the best basic motion pattern to perform a particular task and assigning the appropriate, predetermined time from the catalog for each basic motion in that pattern. PMTS are used in many of the same capacities as traditional work measurement; these systems merely provide faster, more consistent means for analyzing the motion and the time of a task.

Another component of the current status of B-Work that should be considered is the posture assumed while performing a task. This component has not often been considered in conjunction with methods improvement and work measurement, however its affect on the body is an important ergonomics concern. Before one can assess the effects of a posture on the body, it is necessary to develop a data base of working postures for future analysis and comparison, thus creating the need for posture recording. Several posture recording methods, whose primary purpose is to identify postures that are potentially hazardous to the body's well-being, have been developed and applied in the workplace. There are four characteristics that are necessary for the accuracy and comprehensiveness of posture recording: the relationship between the recording method and the actual human form, the sensitivity and range of the measurement scale used in the method, the relationship between the technique of the method and the analysts cognitive ability, and the ability of the method to recreate the original posture, if used properly (Malone, 1991).

1.3 The Importance Of Postural Data In Job Analysis Systems

In past work environments, both work measurement and methods engineering were important techniques for identifying the current status of a work task; thus they were meshed into one tool—PMTS. While these techniques are still important, in today's work environment, postural considerations are also important. Poor posture affects many parts of the body; however, injuries in three body parts are often studied: the lower back, the hand and wrist, and the shoulder and neck (Armstrong et al., 1986; Gabor, 1990). Armstrong et al. (1986) identify one of the major causes of lost time and workers' compensation as repetitive trauma disorders (RTD), also known as cumulative trauma disorders (CTD). RTDs result from assuming unnatural postures when performing repetitive tasks. The body may not be affected if these tasks are performed a small number of times, but with the increase in repetition is an increase in the potential damage to the body. Examples include: carpal tunnel syndrome, tendonitis, bursitis, and back injuries.[1]

Many of the tasks that comprise work today involve constant repetitive motion that, over time, can stress tendons and damage nerves in the hand, wrist, shoulder, neck, and/or back. RTDs are the most frequently reported on-the-job ailment. The American Academy of Orthopedic Surgeons estimates RTD related injuries cost $27 billion a year in medical bills and lost work days (Gabor, 1990). In addition, back pain alone accounts for 40% of all lost workdays, and is second only to the common cold as a reason for seeking a doctor's care. It is the largest component of workers' compensation (Chapel, 1987; Farnham, 1992). According to Chaffin and Andersson (1991), a large portion of RTDs are caused by overexertion of the body's muscles. Overexertion results from both the external load placed on these body parts and from performing tasks using unnatural postures (Armstrong et al. 1987; Chapel, 1987; Farnham, 1992; Kroemer, 1989; and LaBar, 1991c).

Although predetermined motion time systems are a means of simplifying job analysis*, they do not include in them the postural data that have become increasingly more important in today's work environment (Chaffin and Andersson, 1991). Current job analysis systems are designed to aid in work

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[1]There is controversy concerning the classification of back injuries as repetitive trauma disorders. Some authors (Farnham, 1992; Chapel, 1987) consider back injury separate from other RTDs. LaBar (1991c), however, notes that these injuries are often due to repetitive motions that overexert the disc and the spine by fatiguing the back, which can result in injury.

improvements by recording the method for tasks performed and the time required to complete these tasks. They neglect to consider, however, the posture assumed while performing tasks. Simultaneous use of postural data in job analysis could aid in identifying postures that are potentially harmful to the operator's body, so that more comprehensive improvements can be made.

1.4. The Research Problem and Objective

With the recent increase in reported cases of RTDs, ergonomics has become an important industrial consideration (LaBar, 1990). Many managers have opted to design out problems instead of attempting to fit operators to jobs as has been done in the past (Shumacher, 1990). The increased focus on ergonomics does not, however, lessen the importance of work measurement and methods engineering. On the contrary, it strengthens the value of these techniques in industry because of their importance in ergonomics improvements.

There are a variety of industrial engineering tools for data collection and analysis. While each of these tools has its own purpose, some of the data collected by these tools can be used simultaneously with the data collected using other tools to solve problems. For example, the variety of predetermined motion time systems and posture recording methods are separate industrial engineering tools for data collection and analysis. The existing problems are: 1) the current use of separate tools to collect these data make it necessary to combine them before they become useful in addressing the inter-related issues concerning methods improvement, time constraints, and posture assumed in work tasks; or 2) the use of separate tools can cause an analyst to have a myopic view of the current status of the work task.

1.4.1. The Research Environment

Figure 1.1 depicts the environment for this research endeavor. Part a of this figure represents the environment before completing this research, i.e. PMTS and posture recording as separate tools. With the culmination of this research, however, the objectives of the two tools are met in one tool; i.e. a job analysis technique is developed that records the time, the method, and the posture required to perform a task (Figure 1.1b).

1.4.2. The Research Scope

In this research, a computerized tool was developed that is used to collect methods, work measurement, and postural data. From the data collected, one can determine the method used to complete an activity by task identification, the time it takes to complete each task, as well as the time to complete the entire activity, and the posture assumed by the worker for each task and for the overall activity.

The new tool is constrained by several things, however. First, only a portion of B-Work activities are considered—those in which object movement is freely through the air or in contact with a surface. These work activities comprise approximately 80% if all B-Work (Zandin, 1980). In this novel attempt to combine the data collection for work measurement, methods engineering, and postural data, it was thought best to perfect the application using only a portion of B-Work activities. After achieving this, the tool could be expanded to the remainder of B-Work activities.

Additionally, the work measurement data are reported in time measurement units (TMUs). Although this is not a common measurement of time in everyday life, it is common for work measurement applications. Many of the existing predetermined motion time systems use TMUs to measure the time

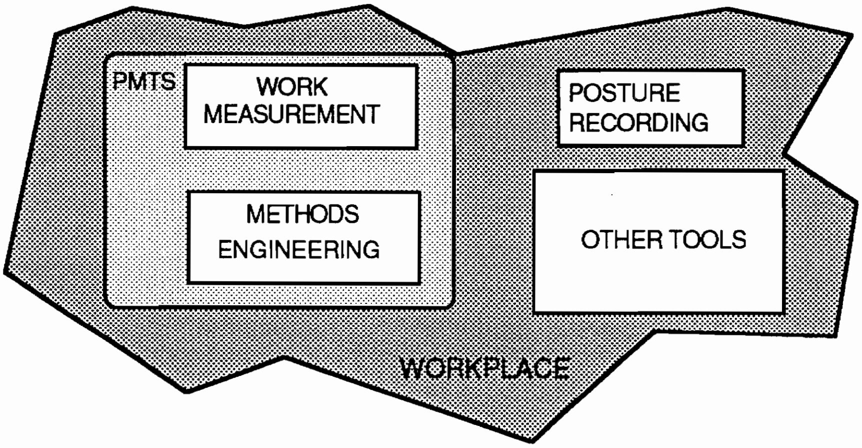


Figure 1.1a. The pre-existing environment (before research)

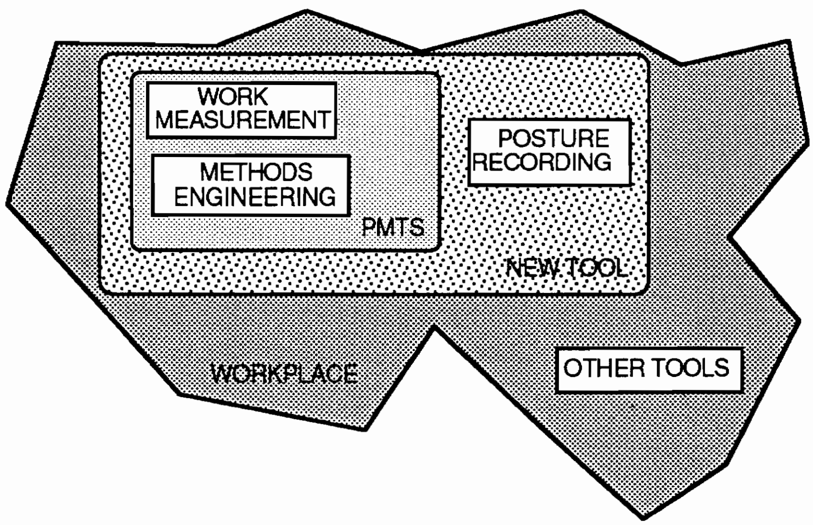


Figure 1.1b. The current environment (after research)

for activities. Since the tool developed in this research combines an existing PMTS with an existing posture recording tool, it was thought easier to use time measurement units than to convert data.

Finally, there are limitations on the postural considerations, i.e. the tool developed in this research only considers the postures of the back and the extremities—both upper and lower. The postures of the hand and the wrist are not considered. The planned usage of this tool was to analyze activities that have whole body usage. In these type of activities, primary consideration is given to the extremities and the back, because injuries frequently occur there. Injuries to the hand and wrist occur more frequently in activities whose main body movement is in the hands and the wrists. Examples include functional operations, such as typing.

1.4.3. Research Validation

The tool developed in this research was tested and compared with existing tools to determine if it can be used effectively to simultaneously collect postural, work measurement, and methods engineering data. Specifically, the tests compare the application time of the new tool with that of an existing tool, the data collecting using the new tool with the data collected using other tools for accuracy, and the data collected using the new tool among users and between applications for reliability. These tests are described and their results reported in Chapter 5.

CHAPTER 2. LITERATURE REVIEW

The importance of work measurement, methods engineering, and postural considerations in today's work environment has fostered various methods for data collection and analysis. Predetermined motion time systems integrate the best of work measurement and methods engineering—the data collected using these two techniques are more useful collected simultaneously. In addition, posture recording methods were developed to address the need for postural data in job analysis. There are many variations of these methods, each of which was developed to address a need present at the time of its development. This chapter reviews the literature on predetermined motion time systems and posture recording methods. The methods are listed and briefly described, and the advantages and disadvantages of each method listed are discussed.

2.1. Types of Predetermined Motion Time Systems

Work measurement has been an important industrial consideration since Frederick Taylor introduced the stopwatch to job analysis in the late 1800s. Prior to that time, historical data and estimation were the only forms of work measurement. Since that time, other tools for work measurement have been developed, including predetermined motion time systems (PMTS) (Brisley and Eady, 1982; Zandin, 1980).

PMTS have gained popularity as tools for work measurement. Brisley and Eady (1982) note the following reasons for this increase in popularity.

"1. The systems generally provide a practical vehicle for analyzing and improving methods for performing work.

2. The work methods may be designed prior to the initiation of production.
3. The predetermined time values associated with precisely described motions provide for greater consistency in the establishment of standards than is possible with other work measurement techniques.
4. When used for developing standard multi-use elements, PMTS are generally faster."

Three of the most prominent PMTS are Methods Time Measurement, Maynard Operation Sequence Technique, and Modular Arrangement of Predetermined Time Standards. The following sections discuss each of these systems in detail, culminating with a brief description of some historical systems.

2.1.1. Methods time measurement (MTM)

Of the predetermined motion time systems, the most commonly used is Methods Time Measurement (MTM), developed by H. B. Maynard, G. J. Stegemerten, and J. L Schwab and published in 1948 (Chaffin and Andersson, 1991; Zandin, 1980). MTM was developed through precise analysis of motion pictures taken of workers performing a variety of manual tasks. The motion pictures were analyzed by dividing the motions into fundamental groups and subgroups and by determining the time required to perform each variation of subgroup (Ricks, 1980). MTM should be used for short-cycle (not longer than five to ten seconds), highly repetitive operations that are identically repeated from cycle to cycle (Zandin and Weiss, 1977). The metric for MTM is the time measurement unit (TMU) and is equivalent to one-one-hundred-thousandths of an hour (0.00001 hr.). This fraction of an hour was chosen as the basic unit of measure because production rates in industry are often quoted in units per hour (Chaffin and Andersson, 1991).

The MTM system has a detailed card of basic data motions that represents work elements used in manual motion. The data card consists of ten tables, each detailing the time to perform a work element based on certain characteristics, such as distance, weight, and special cases. (See Table 2.1). For manual work, basic motions are identified, and the appropriate times are chosen from the data card with consideration of the variables (Niebel, 1993; Zandin, 1980).

The time and the method for any manual task can be analyzed using MTM. An example is given below and analyzed by MTM in Table 2.2.

Activity Description: Move a book from one place on a desk to another place 20 inches away.

By summing the elements in the TMU column of Table 2.2, one can determine the time it takes to move a book from one place on a desk to another place 20 inches away—42.3 TMU (or 1.5228 seconds). Four work elements are used to code this task: reach (R), grasp (G), move (M), and release (RL). The additional characters in the codes represent information found in the elements' respective data cards, (shown in Table 2.1). In the code for reach to the book, R20B, the R represents the "reach" element, 20 represents the distance traveled, and B represents the case description. Other codes are developed similarly. Though the example given here is not always a repetitive task as would be found in many work environments, the same procedure would be used for determining cycle time for those repetitive tasks. After one has determined the total cycle time in TMUs, it can be converted to hours, minutes, or seconds for information purposes.

Table 2.1 Methods Time Measurement Data Card (Nieble, 1993)

TABLE I – REACH – R

Distance Moved Inches	Time TMU A	Time TMU B	Time TMU C or D	Time TMU E	Hand In Motion A	Hand In Motion B	CASE AND DESCRIPTION
3/4 or less	2.0	2.0	2.0	2.0	1.6	1.6	A Reach to object in fixed location, or to object in other hand or on which other hand rests.
1	2.5	2.5	3.6	2.4	2.3	2.3	
2	4.0	4.0	5.9	3.8	3.5	2.7	
3	5.3	5.3	7.3	5.3	4.5	3.6	B Reach to single object in location which may vary slightly from cycle to cycle.
4	6.1	6.4	8.4	6.8	4.9	4.3	
5	6.5	7.8	9.4	7.4	5.3	5.0	
6	7.0	8.6	10.1	8.0	5.7	5.7	
7	7.4	9.3	10.8	8.7	6.1	6.5	C Reach to object jumbled with other objects in a group so that search and select occur.
8	7.9	10.1	11.5	9.3	6.5	7.2	
9	8.3	10.8	12.2	9.9	6.9	7.9	
10	8.7	11.5	12.9	10.5	7.3	8.6	
12	9.6	12.9	14.2	11.8	8.1	10.1	D Reach to a very small object or where accurate grasp is required.
14	10.5	14.4	15.6	13.0	8.9	11.5	
16	11.4	15.8	17.0	14.2	9.7	12.9	
18	12.3	17.2	18.4	15.5	10.5	14.4	
20	13.1	18.6	19.8	16.7	11.3	15.8	
22	14.0	20.1	21.2	18.0	12.1	17.3	E Reach to indefinite location to get hand in position for body balance or next motion or out of way.
24	14.9	21.5	22.5	19.2	12.9	18.8	
26	15.8	22.9	23.9	20.4	13.7	20.2	
28	16.7	24.4	25.3	21.7	14.5	21.7	
30	17.5	25.8	26.7	22.9	15.3	23.2	
Additional	0.4	0.7	0.7	0.6			TMU per inch over 30 inches

TABLE II – MOVE – M

Distance Moved Inches	Time TMU A	Time TMU B	Time TMU C	Hand In Motion B	Wt. Allowance: Wt. (lb.) Up to	Dynamic Factor	Static Constant TMU	CASE AND DESCRIPTION
3/4 or less	2.0	2.0	2.0	1.7				A Move object to other hand or against stop.
1	2.5	2.9	3.4	2.3	2.5	1.00	0	
2	3.6	4.6	5.2	2.9				
3	4.9	5.7	6.7	3.6	7.5	1.06	2.2	
4	6.1	6.9	8.0	4.3				
5	7.3	8.0	9.2	5.0	12.5	1.11	3.9	
6	8.1	8.9	10.3	5.7				B Move object to approximate or indefinite location.
7	8.9	9.7	11.1	6.5	17.5	1.17	5.6	
8	9.7	10.6	11.8	7.2				
9	10.5	11.5	12.7	7.9	22.5	1.22	7.4	
10	11.3	12.2	13.5	8.6				
12	12.9	13.4	15.2	10.0	27.5	1.28	9.1	
14	14.4	14.6	16.9	11.4				
16	16.0	15.8	18.7	12.8	32.5	1.33	10.8	
18	17.6	17.0	20.4	14.2				
20	19.2	18.2	22.1	15.6	37.5	1.39	12.5	
22	20.8	19.4	23.8	17.0				C Move object to exact location.
24	22.4	20.6	25.5	18.4	42.5	1.44	14.3	
26	24.0	21.8	27.3	19.8				
28	25.5	23.1	29.0	21.2	47.5	1.50	16.0	
30	27.1	24.3	30.7	22.7				
Additional	0.8	0.6	0.85		TMU per inch over 30 inches			

TABLE III A – TURN – T

Weight	30°	45°	60°	75°	90°	105°	120°	135°	150°	165°	180°
Small – 0 to 2 Pounds	2.8	3.5	4.1	4.8	5.4	6.1	6.8	7.4	8.1	8.7	9.4
Medium – 2.1 to 10 Pounds	4.4	5.5	6.5	7.5	8.5	9.6	10.6	11.6	12.7	13.7	14.8
Large – 10.1 to 35 Pounds	8.4	10.5	12.3	14.4	16.2	18.3	20.4	22.2	24.3	26.1	28.2

(Time TMU for Degrees Turned)

TABLE III B – APPLY PRESSURE – AP

FULL CYCLE SYMBOL	TMU	DESCRIPTION	COMPONENTS SYMBOL	TMU	DESCRIPTION
APA	10.6	AF + DM + RLF	AF	3.4	Apply Force
			DM	4.2	Dwell, Minimum
APB	16.2	APA + G2	RLF	3.0	Release Force

TABLE IV – GRASP – G

TYPE OF GRASP	Case	Time TMU	DESCRIPTION	
PICK-UP	1A	2.0	Any size object by itself, easily grasped	
	1B	3.5	Object very small or lying close against a flat surface	
	1C1	7.3	Diameter larger than 1/2"	Interference with Grasp on bottom and one side of nearly cylindrical object.
	1C2	8.7	Diameter 1/4" to 1/2"	
	1C3	10.8	Diameter less than 1/4"	
REGRASP	2	5.6	Change grasp without relinquishing control	
TRANSFER	3	5.6	Control transferred from one hand to the other.	
SELECT	4A	7.3	Larger than 1" x 1" x 1"	Object jumbled with other objects so that search and select occur.
	4B	9.1	1/4" x 1/4" x 1/8" to 1" x 1" x 1"	
	4C	12.9	Smaller than 1/4" x 1/4" x 1/8"	
CONTACT	5	0	Contact, Sliding, or Hook Grasp	

EFFECTIVE NET WEIGHT			
Effective Net Weight (ENW)	No. of Hands	Spatial	Sliding
	1	W	$W \times F_c$
	2	W/2	$W/2 \times F_c$

W = Weight in pounds
F_c = Coefficient of Friction

TABLE V – POSITION* – P

CLASS OF FIT		Symmetry	Easy To Handle	Difficult To Handle
1–Loose	No pressure required	S	5.6	11.2
		SS	9.1	14.7
		NS	10.4	16.0
2–Close	Light pressure required	S	16.2	21.8
		SS	19.7	25.3
		NS	21.0	26.6
3–Exact	Heavy pressure required.	S	43.0	48.6
		SS	46.5	52.1
		NS	47.8	53.4

SUPPLEMENTARY RULE FOR SURFACE ALIGNMENT	
P1SE per alignment: >1/16 ≤1/4"	P2SE per alignment: ≤1/16"

*Distance moved to engage–1" or less.

TABLE VI – RELEASE – RL

Case	Time TMU	DESCRIPTION
1	2.0	Normal release performed by opening fingers as independent motion.
2	0	Contact Release

TABLE VII – DISENGAGE – D

CLASS OF FIT	HEIGHT OF RECOIL	EASY TO HANDLE	DIFFICULT TO HANDLE
1–LOOSE–Very slight effort, blends with subsequent move.	Up to 1"	4.0	5.7
2–CLOSE–Normal effort, slight recoil.	Over 1" to 5"	7.5	11.8
3–TIGHT–Considerable effort, hand recoils markedly.	Over 5" to 12"	22.9	34.7

SUPPLEMENTARY

CLASS OF FIT	CARE IN HANDLING	BINDING
1–LOOSE	Allow Class 2	——
2–CLOSE	Allow Class 3	One G2 per Bind
3–TIGHT	Change Method	One APB per Bind

TABLE VIII – EYE TRAVEL AND EYE FOCUS – ET AND EF

Eye Travel Time = $15.2 \times \frac{T}{D}$ TMU, with a maximum value of 20 TMU.

where T = the distance between points from and to which the eye travels.
D = the perpendicular distance from the eye to the line of travel T.

Eye Focus Time = 7.3 TMU.

SUPPLEMENTARY INFORMATION

– Area of Normal Vision = Circle 4" in Diameter 18" from Eyes

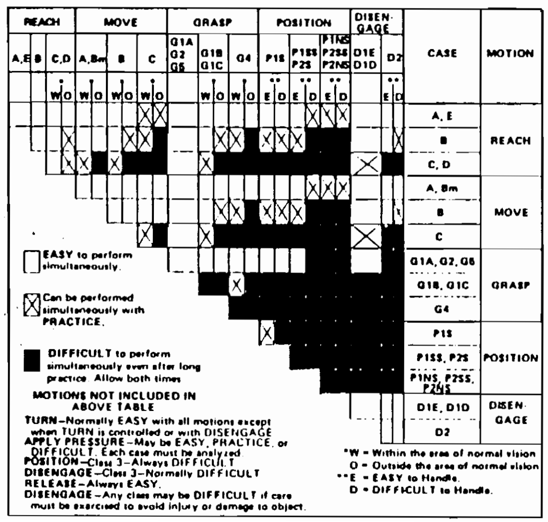
– Reading Formula = 5.05 N Where N = The Number of Words.

Table 2.1. (continued) Methods Time Measurement Data Card (Nieble, 1993)

TABLE IX – BODY, LEG, AND FOOT MOTIONS

TYPE		SYMBOL	TMU	DISTANCE	DESCRIPTION
LEG–FOOT MOTION		FM	8.5	To 4"	Hinged at ankle.
		FMP	19.1	To 4"	With heavy pressure.
		LM__	7.1	To 6"	Hinged at knee or hip in any direction
			1.2	Ea. add'l inch	
HORIZONTAL MOTION	SIDE STEP		*	≤12"	Use Reach or Move time when less than 12". Complete when leading leg contacts floor.
		SS__C1	17.0	12"	
			0.6	Ea. add'l inch	
		SS__C2	34.1	12"	Lagging leg must contact floor before next motion can be made.
			1.1	Ea. add'l inch	
	TURN BODY	TBC1	18.6	—	Complete when leading leg contacts floor.
		TBC2	37.2	—	Lagging leg must contact floor before next motion can be made
	WALK	W__FT	5.3	Per Foot	Unobstructed.
		W__P	15.0	Per Pace	Unobstructed.
		W__PO	17.0	Per Pace	When obstructed or with weight.
VERTICAL MOTION		SIT	34.7	—	From standing position.
		STD	43.4	—	From sitting position.
		B,S,KOK	29.0	—	Bend, Stoop, Kneel on One Knee.
		AB,AS,AKOK	31.9	—	Arise from Bend, Stoop, Kneel on One Knee
		KBK	69.4	—	Kneel on Both Knees.
		AKBK	76.7	—	Arise from Kneel on Both Knees.

TABLE X – SIMULTANEOUS MOTIONS



SUPPLEMENTARY MTM DATA

TABLE 1 – POSITION – P

Class of Fit and Clearance	Case of † Symmetry	Align Only	Depth of Insertion (per ¼") 0 >0≤1/8"	2 >1/8≤¾	4 >¾≤1¼	6 >1¼≤1¾
21 .150" – .350"	S	3.0	3.4	6.6	7.7	8.8
	SS	3.0	10.3	13.5	14.6	15.7
	NS	4.8	15.5	18.7	19.8	20.9
22 .025" – .149"	S	7.2	7.2	11.9	13.0	14.2
	SS	8.0	14.9	19.6	20.7	21.9
	NS	9.5	20.2	24.9	26.0	27.2
23* .005" – .024"	S	9.5	9.5	16.3	18.7	21.0
	SS	10.4	17.3	24.1	26.5	28.8
	NS	12.2	22.9	29.7	32.1	34.4

*BINDING—Add observed number of Apply Pressures.
DIFFICULT HANDLING—Add observed number of G2's.

†Determine symmetry by geometric properties, except use S case when object is oriented prior to preceding Move.

TABLE 1A – SECONDARY ENGAGE – E2

CLASS OF FIT	DEPTH OF INSERTION (PER 1/4") 2	4	6
21	3.2	4.3	5.4
22	4.7	5.8	7.0
23	6.8	8.2	11.5

TABLE 2 – CRANK (LIGHT RESISTANCE) – C

DIAMETER OF CRANKING (INCHES)	TMU (T) PER REVOLUTION	DIAMETER OF CRANKING (INCHES)	TMU (T) PER REVOLUTION
1	8.5	9	14.0
2	9.7	10	14.4
3	10.6	11	14.7
4	11.4	12	15.0
5	12.1	14	15.5
6	12.7	16	16.0
7	13.2	18	16.4
8	13.6	20	16.7

FORMULAS:

A. CONTINUOUS CRANKING (Start at beginning and stop at end of cycle only)

TMU = [(N×T)+5.2]·F+C

B. INTERMITTENT CRANKING (Start at beginning and stop at end of each revolution)

TMU = [(T+5.2) F+C]·N

C = Static component TMU weight allowance constant from move table
F = Dynamic component weight allowance factor from move table
N = Number of revolutions
T = TMU per revolution (Type III Motion)
5.2 = TMU for start and stop

Table 2.2 MTM Analysis of Retrieving a Book

Hand Description*	Hand Motion*	TMU
Retrieve Book		
Reach to Book	R20B	18.6
Grasp book	G1B	3.5
Move book to desk	M20B	18.2
Release	RL1	2.0

*If both hands are used, then description and hand motion columns should be developed for both hands separately.

Although MTM is one of the most widely used predetermined motion time systems, it has several drawbacks, including: extensive studies and calculations, a large amount of paperwork, limited application, and difficulty in understanding complex analysis techniques by workers and unions (Zandin, 1980; Zandin and Weiss, 1977). However, it does provide an accurate estimate of time to perform manual tasks.

Several levels of MTM have been developed to address some of its inadequacies. Upon development of these variations, standard MTM became known as MTM-1. The levels of MTM include:

MTM-2 and MTM-3 - developed to reduce applicator error and the time for analysis (Zandin, 1980).

MTM-C - a high-level system for setting clerical standards (Karger and Bayha, 1987).

MTM-V - a high level system for setting manual labor standards in machine shop environments (Karger and Bayha, 1987).

MTM-M - a very specialized, functionally oriented system for setting labor standards on work involving magnification for part or all of the work (Karger and Bayha, 1987).

While levels of MTM were developed to address deficiencies in the system, other systems based on MTM were developed to meet other needs of work measurement. Two of these MTM-based PMTS are Maynard Operation Sequence Technique and Modular Arrangement of Predetermined Time Sequence.

2.1.2. Maynard Operation Sequence Technique (MOST)

Maynard Operation Sequence Technique (MOST) is a work measurement technique that was derived from MTM. It was developed in Sweden by Maynard Co. in the 1960s to address some of the drawbacks of MTM listed in the previous section. After installation in European companies, MOST was introduced in the United States. Advantages of MOST over MTM and other techniques currently in use include: speed, accuracy of estimation times for setups, simplicity, and reduction in variation among analysts. Though these advantages exist, MOST does not replace MTM. MTM is used to analyze highly repetitive operations that are identical from cycle to cycle and have cycle times less than ten seconds. MOST, however, does not account for the precision and detail needed to analyze these tasks and is better suited for other tasks with little or no repetition and cycle times greater than 10 seconds (Zandin, 1980).

MOST's inception was preceded by careful analysis of MTM patterns, which revealed a consistent repetition of certain motion sequences in manual work. These sequences were modified and reduced in number to form the basis for MOST systems. MOST is composed of three sequence models that represent ways in which objects are handled: the General Move Sequence, the

Controlled Move Sequence, and the Tool Use Sequence. Each of these sequences will be discussed in detail.

2.1.2.1. The general move. The General Move is used for unrestricted object handling, i.e., moving an object freely through the air. If an object is in contact with, or restrained by, another object during movement, the General Move Sequence is not applicable. The General Move follows a set of sub-activities that are identified by the following steps.

"1. Reach with one or two hands a distance to the object(s), either directly or in conjunction with body motions.
2. Gain manual control of the object.
3. Move the object a distance to the point of placement, either directly or in conjunction with body motions.
4. Place the object in a temporary or final position.
5. Return to the workplace." (Zandin 1980, p. 15)

These five sub-activities are the basis of the activity sequence model that describes the manual displacement of an object freely through space—the General Move Sequence model. The General Move Sequence model, used to guide the analyst through the operation, is a series of letters that represent the various sub-activities of the General Move. It follows the same steps identified above, with the exception of an additional parameter for body motions. The General Move Sequence model is:

A B G A B P A

where:	A	=	action distance*
	B	=	body motion*
	G	=	gain control*
	P	=	place*

The model is often divided into three phases: get, put, and return. The first three letters of the model above comprise the "get" phase, the second three letters of the model comprise the "put" phase, and the final A represents the "return" phase.

Numerical subscripts are used to indicate the time required for each of the parameters of the sequence model. These numerical subscripts have been developed through extensive research and are catalogued in a data card (Table 2.3). The analysts use the data card in conjunction with preprinted calculation sheets to determine the time of an activity. Each subscript, multiplied by 10, yields the total time of that parameter in TMUs.

Table 2.3 General Move Data Card (Zandin, 1980, p. 19)

GENERAL MOVE ABGABPA				
INDEX	**A Action Distance**	**B Body Motion**	**G Gain Control**	**P Place**
0	≤ 2 in ≤ 5 cm			hold toss
1	within reach		light object light objects simo	lay aside loose fit
3	1 - 2 steps	bend and arise (50% occurrence)	non simo heavy or bulky blind or obstructed disengaged interlocked collect	adjustments light pressure double
6	3 - 4 steps	bend and arise		care or precision heavy pressure blind or obstructed intermediate moves
10	5 - 7 steps	sit or stand		
16	8 - 10 steps	through door climb on or off		

An example of the use of the General Move Sequence model follows.

Activity Description A man walks four steps to a small suitcase, picks it up from the floor, and without moving further places it on a table located within reach.

This activity is a general move, because the suitcase is being moved freely through the air.

General Move Sequence A_6 B_6 G_1 A_1 B_0 P_1 A_0

In the "get" phase of the sequence model, the subscript for action distance (A) is 6, because the man walks 4 steps. He must bend and arise to get the suitcase, thus the subscript of B is 6. The G parameter for gaining control of the suitcase, a light object, has a subscript of 1.

The "put" phase can be analyzed similarly. The subscript for A in the "put" phase is 1, since the table on which the suitcase is placed is within reach. There is no vertical body motion, corresponding to a 0 subscript of B. The subscript of P is 1, because the suitcase is laid aside.

Finally, an A_0 is used because there is no return motion. The total time to perform this activity is 150 TMUs, which is equivalent to 5.3571 seconds.

__2.1.2.2. The controlled move.__ The Controlled Move Sequence model is used when an object retains contact with another object during movement. Examples include, but are not limited to, a lever, a push button, and a crank. As with the General Move Sequence, there are a fixed sequence of sub-activities that identify the Controlled Move. They are listed below.

"1. Reach with one or two hands a distance to the object, either directly or in conjunction with body motions.
2. Gain manual control of the object.
3. Move the object over a controlled path.

4. Allow time for a process to occur.
5. Align the object following the controlled move or at the conclusion of the process time.
6. Return to workplace" (Zandin, 1980, p. 36).

These six activities form the basis for the Controlled Move Sequence model that describes manual displacement of an object over a controlled path. The Controlled Move Sequence model is:

A B G M X I A

where:	A	=	action distance
	B	=	body motion
	G	=	gain control
	M	=	move controlled*
	X	=	process time*
	I	=	align*

There are also three phases for the Controlled Move Sequence—get, move or actuate, and return. The "get" and "return" phases of the Controlled Move phases are identical to the "get" and "return" phases of the General Move. The "move or actuate" phase is the only different phase. The "move or actuate" phase describes actions to either move an object over a controlled path or actuate a control device. Usually, move requires use of the M and I parameters, while actuate requires the M and the X parameters. This is not always the case; thus all parameters should be considered.

Numerical subscripts also complete the Controlled Move Sequence model. The subscripts are catalogued in the data cards found in Tables 2.3 and 2.4. Since the "get" and "return" phases of the Controlled Move are identical to those of the General Move, the data card in Table 2.3 is used to obtain subscripts for these two phases of the Controlled Move Sequence model. Table 2.4 is used for the "move or actuate" phase.

An example of the use of the Controlled Move Sequence model is taken from Zandin (1980, p. 48) and is listed below.

Activity Description Using the foot pedal to activate the machine, a sewing machine operator makes a stitch requiring 3.5 seconds process time. (The operator must reach the pedal with the foot.)

This activity is a controlled move, because the pedal is a control device to be activated.

Controlled Move Sequence

$A_1 \quad B_0 \quad G_1 \quad M_1 \quad X_{10} \quad I_0 \quad A_0$

Table 2.4 Controlled Move Data Card (Zandin, 1980, p. 38)

CONTROLLED MOVE ABGMXIA						
INDEX	**M**		**X**			**I**
	Move Controlled		**Process Time**			**ALIGN**
	push/pull/ pivot	**Crank (revs)**	**sec.**	**min.**	**hr..**	**OBJECT**
1	≤ 12 inches (30 cm) button /switch/ knob		.5	.01	.0001	To one point
3	> 12 inches (30 cm) resistance, seat or unseat high control 2 stages ≤ 12 inches (30 cm)	1	1.5	.02	.0004	to two points ≤ 4 inches (10 cm)
6	2 stages > 12 inches (30 cm)	3	2.5	.04	.0007	to two points > 4 inches (10 cm)
10	3 - 4 stages	6	4.5	.07	.0012	
16		11	7.0	.1	.0019	precision

The "get" phase of this example is similar in nature to the get phase of the example in the section on General Move, so it will not be explained in detail. For the "move" or "actuate" phase, an M_1 is used because the move controlled is stitch, which is ≤ 12 inches. A processing time of 3.5 seconds corresponds with an X_{10}. There is no alignment. Since a return action is not specified, the assumption is that there is not one.

2.1.2.3. The tool use sequence. The tool use sequence is for modeling the movement of an object with the use of a tool. Tools include body parts, such as fingers and hands, as well as conventional hand tools. As with the General Move Sequence and the Controlled Move Sequence, there are a fixed sequence of sub-activities that identify the Tool Use Sequence. They are listed below.

"1. Get object or tool.
2. Place object or tool in working position.
3. Use tool.
4. Put aside object or tool.
5. Return to workplace" (Zandin, 1980, p. 50).

These five activities form the basis for the Tool Use Sequence model that describes movement of an object with the use of a tool. The Tool Use Sequence Model is:

A B G A B P ___ A B P A

where:
A = action distance
B = body motion
G = gain control
P = place

The space (___) in this sequence model is used to identify the tool use parameters for the activity. The tool use parameters are:

F = fasten*	M = measure*
L = loosen*	R = record*
C = cut*	T = think*"
S = surface treat*	

In the Tool Use Sequence, there are five phases—"get object or tool," "place object or tool," "use tool," "aside object or tool," and "return." Four of the five phases are similar to the phases of the General Move Sequence Model. The "get object or tool" and the "return" phases are identical to the "get" and "return" phases of the General Sequence Move. The "place object or tool" and the "aside object or tool" are similar to the "put" phase of the General Move Sequence Model. The "place object or tool" phase is used for placing the tool or object before using the tool and the "aside object or tool" phase is used for placing the tool or object after use of the tool.

As with the other sequence models, numerical subscripts complete the Tool Use Sequence Model. The subscripts are catalogued in the data cards found in Tables 2.3, 2.5, 2.6 and 2.7. Since the same parameters found in the General Move Sequence Model are used for four of the phases of the Tool Use Sequence Model, the subscripts for these parameters can be obtained from the data card found in Table 2.3. Tables 2.5, 2.6, and 2.7 are used for the "tool use" phase of the model.

An example of the use of the Tool Use Sequence model is taken from Zandin (1980, p. 68) and is listed below.

Activity Description An operator picks up a knife from a workbench two steps away, makes one cut across the top of a cardboard box, and sets aside the knife on the workbench.

Table 2.5. Tool Use—Fasten/Loosen Data Card (Zandin, 1980)

Index	ABGABP ABPA	Tool Use Sequence									
	Fasten or Loosen										
	Finger Action	Wrist Action				Arm Action				Tool Action	
	Spins	Turns	Strokes	Cranks	Taps	Turns	Strokes	Cranks	Strikes	Screw Diameter	
	Fingers Screw-driver	Hand Screw-driver Ratchet T-wrench	Wrench Allen Key	Wrench Allen Key Ratchet	Hand Hammer	Ratchet	Wrench Allen Key	Wrench Allen Key Ratchet	Hand Hammer	Power Wrench	
1	1	-	-	-	1	-	-	-	-	-	
3	2	1	1	1	3	1	1	-	1	.25" 6 mm	
6	3	3	2	3	6	2	-	1	3	1" 25 mm	
10	8	5	3	5	10	4	2	2	5		
16	16	9	5	8	16	6	3	3	8		
24	25	13	8	11	23	9	4	5	12		
32	35	17	10	15	30	12	6	6	16		
42	47	23	13	20	39	15	8	8	21		
54	61	29	17	25	50	20	10	11	27		

Values in the table represent the upper limit.

Table 2.6. Tool Use—Cut, Suface Treat, and Measure (Zandin, 1980)

	ABGABP ABPA		Tool Use Sequence					
	C				S			M
	grip, etc.	cutoff	cut	slice	air-clean	brush-clean	wipe	measure
	pliers		scis-sors	knife	nozzle	brush	cloth	measuring device
Index		wire	cuts	strokes	sq. ft. 0,1 M^2	sq. ft. 0,1 M^2	sq. ft. 0,1 M^2	in. (cm) ft. (m)
1	grip		1	-	-	-	-	
3		soft	2	1	-	-	.5	
6	twist bend loop	med.	4		1 point or cavity	1 small object	-	
10		hard	7	3	-	-	1	profile-guage
16			11	4	3	2	2	fixed-scale caliper 12 in. (30 cm)
24			15	6	4	3	-	feeler-guage
32			20	9	7	5	5	steel-tape 6 ft. (2m) depth micrometer
42			27	11	10	7	7	od-micrometer 4 in. (10 cm)
54			33					id-micrometer 4 in. (10 cm)

Values in table represent upper limit.

Table 2.7. Tool Use—Record and Think (Zandin, 1980)

	ABGABP ABPA		Tool Use Sequence (continued)			
	R			T		
	write		mark	inspect	read	
	pencil		marker	eyes fingers	eyes	
INDEX	digits	words	digits	points	digits single words	text of words
1	1	-	check mark	1	1	3
3	2	-	1 scribe line	3	3 guage	8 guage
6	4	1	2	5 touch for heat	6 scale value date/time	15 scale value date/time
10	6	-	3	9 feel for defect	12 vernier scale	24 vernier scale
16	9 signature date	2 signature date	5		table value	38 table value
24	13	3	7			54
32	18	4	10			72
42	23	5	13			94
54	29	7	16			119

Values in the table represent the upper limit.

This activity is a tool use move, because the use of a tool is required to complete the movement.

Tool Use Sequence

A_3 B_0 G_1 A_3 B_0 P_1 C_3 A_3 B_0 P_1 A_0

The "get object or tool," the "place object or tool," the "aside object or tool," and the "return" phases are similar to the "get," "put," and "return" phases of the General Move Sequence Model, and thus will not be explained in detail. In the "tool use" phase, a C_3 is used—C representing cut and 3 indicating one slice with a knife. Other tool use examples can be found in Zandin (1980) that further illustrate the use of the other "tool use" parameters.

2.1.2.4. Validation. MOST System is based on the fundamental statistical standard deviation concept. It is through the application of "engineered deviations" that the system gains its speed, easy application, and accuracy, in addition to an outstanding consistency. MOST was *designed* to produce a predetermined level of accuracy. Other systems were created and then their accuracy was determined. The statistically based deviations on which MOST is built provide accurate and consistent results throughout its application. With MOST, the deviation—the index ranges the index numbers represent—are "engineered inaccuracies," they do not occur haphazardly across the work measurement spectrum. Therefore, industrial engineers always know the system accuracy and the confidence level with which they are working (Zandin, 1980).

During the development of MOST, great care was taken to be certain that resulting standards would be well within acceptable limits. The goal of MOST's standards were to be within ± 5 percent of MTM-1 based standards. This goal was achieved in all tests with the standards of many of these tests being ± 3 percent (Zandin and Weiss, 1977). Additionally, studies were conducted by Dr. William D. Brinkloe of the University of Pittsburgh to determine the accuracy of MOST. These studies indicate that the accuracy of the design of MOST is well within the range that was initially desired.

2.1.3. MODular Arrangement of Predetermined Time Standards (MODAPTS)

MODAPTS, an acronym for MODular Arrangement of Predetermined Time Standards, was developed in 1966 by an informal research consortium headed by C. G. Heyde. It is intended for quick, accurate recording with minimal data analyses. The metric of time measurement, the MOD, is equivalent to 0.129 seconds and is defined as the normal time required to complete a simple finger move (Karger and Bayha, 1987; Masud, et al., 1985; Niebel, 1993).

In MODAPTS, each motion is represented by a two-part code. The first part of the code is an alphabetic character that represents the body member used in the motion or the activity performed. The second part of the code is numeric and is used as a multiplier of the MOD to calculate the time required to complete the motion. For example, a finger move is coded M1 and its normal time is 0.129 seconds. Similarly, a hand move, coded M2, has a normal time of 0.258 seconds. Body motions are coded similarly—F3 is a foot move; E2 is an eye use; and B17 represents bend and arise. The values for MODAPTS were derived empirically from field testing a wide range of jobs performed by factory workers.

MODAPTS elements are presented in three groups: movement elements, terminal elements and supporting elements. "The movement class refers to movements through space done by the finger-hand-arm-shoulder system. Normally a movement is the activity that is required to position a part of the arm to perform a terminal activity" (Niebel, 1993, p. 577).

The terminal class consists of activities done at the end of a movement. There are two types of activities included in this class: GET and PUT. GET activities involve obtaining control of things. PUT activities involve putting things to destinations. Terminal activities are further categorized by level of conscious control. A low conscious control activity is an automatic response requiring little muscular control, no visual control, and no mental control. Low conscious control activities are considered to be free of hesitations because the activity is predetermined. In contrast, a high conscious control involves muscular control and either visual or other sensory modality feedback (Niebel, 1993).

Auxiliary values refer to other activities that do not involve use of the finger-hand-arm-shoulder system. Examples include: walking, bending, etc.

Niebel (1993) identifies four advantages of MODAPTS:

1. Simplicity of method generates ease of use.
2. Job activities are easily characterized by MODAPTS base elements.
3. Memorization is easy.
4. Few calculations.

These advantages have caused some organizations to use the system. One example is Ford Motor Company (Shinnick and Erwin, 1989). MODAPTS was instituted as part of a plan to promote a work force of employees who could address work related problems and facilitate positive changes. The expected benefits of implementing these systems were heightened by several findings:

- Non-productive work was identified and in some instances significantly reduced.
- Physically stressful work such as bending into large containers to obtain parts was quantified.
- Inefficient assembly methods have been identified with corrective action taken.

2.1.4. Historical Systems

There are some systems that are noteworthy because of their historical value to the development and existence of predetermined motion time systems. They are Motion-Time Analysis (MTA) and Work Factor (WOFAC). These systems will be briefly discussed.

2.1.4.1. Motion-Time Analysis (MTA). Motion-Time Analysis is the oldest known predetermined motion time system. It was developed in 1919 by Mr. Asa B. Segur, by analyzing micro-motion films taken of expert operators during World War I. The foundation of MTA is the principle of predetermining times (Brisley and Eady, 1982; Karger and Bayha, 1987).

2.1.4.2. Work Factor (WOFAC). Work Factor is a complicated system of work measurement that requires more extensive training before use and application than other PMTS. It was developed under the direction of Joseph Quick in 1938. It has four levels: the Detailed Work Factor System, the Mento Work Factor System, the Ready Work Factor System, and the Brief Work Factor System. The Detailed Work Factor System is used for general analysis. The Mento Work Factor System is used for measuring mental processes.

Ready Work Factor System is used for simple analysis by persons other than industrial engineers and is suitable for measuring medium to long rung operations. Brief Work Factor System is used for measuring repetitive work (Brisley and Eady, 1982; Karger and Bayha, 1987; and Niebel, 1993).

2.1.5. Other Systems

There are other systems that are not widely known or historically notable (Karger and Bayha, 1987; Brisley and Eady, 1982). Among these are Holmes (1945); Olsen (Quick et al., 1962), and Mundel-Lazarus (Mundel, 1955).

2.1.6. Summary

Each of these Predetermined Motion Time Systems were developed to address a need present at the time of their development; each has advantages that makes it a useful system. One of the major drawbacks of these systems, however, is the neglect of the collection of postural data that is a great concern in organizations today. Of these systems, only MOST and MODAPTS indirectly attempt to address the posture assumed by the body. There are special elements unique to each of these systems that address the position of the trunk of the body, i.e. bending and arising. Posture recording is a separate entity and is an important industrial engineering concern. The following sections identify some of the existing posture recording methods.

2.2. Posture Recording Methods

Several posture recording methods have been developed and instituted in organizations. The primary purpose of these methods is to identify postures that are potentially hazardous to the body's well-being. Although accuracy is essential, Karhu, et al. (1977) advocate two criteria to consider when identifying a useful posture recording method. First, the method should be easy to use by ergonomically untrained personnel. And second, the data collected by the method should be unambiguous. There are four characteristics that are necessary for the accuracy and comprehensiveness of posture recording: the relationship between the recording method and the actual human form, the sensitivity and range of the measurement scale used in the method, the relationship between the technique of the method and the analysts cognitive ability, and the ability of the method to recreate the original posture, if used properly (Malone, 1991).

Recording human postures allows one to encode the posture being used for future reference. The range of methods for posture recording extends from simple to complex, depending on the original application. There are three methods of recording posture: visual, verbal, and a combination of the two. The following sections list and describe some of the methods.

2.2.1. Link model

The link model is a visual representation of posture that depicts the body as a set of interacting links and joints. The link model is one of the most widely used models for posture recording because it meets the requirement of realistic pictorial representation (Shiro, et al.., 1987). Since the body is perceived and described as a system of limbs and joints, the most realistic representation of the body is a system that employs these elements. In the link model, limbs are represented by links, and joints are represented by the connection of the links.

The link model is an accurate system of recording because it is used to describe each link in space. The human body may take on an almost infinite array of postures, however, the links are rigid, and the joints may only travel through a prescribed range of motion. Therefore, describing the position of each link in space separately will accurately define the overall posture (Priel, 1974). Figures 2.1, 2.2, and 2.3, and Tables 2.8 and 2.9 outline many of the ranges of motion possible for the various joints.[2]

The link model does, however, have some limitations. First of all, one of the assumptions of this model is that the centers of rotation* of the joints are fixed. In actuality, many joints, such as the shoulder joint, do not display this property (Pheasant, 1987). Additionally, many models erroneously describe the back as one link— the back is actually composed of many links with complex interactions. Since one of the purposes of posture recording is to identify problems associated with poor postures, and many physical injuries are associated with lower back posture, the back should be modeled as a multiple link system for more accurate posture recording. A two-link system made of the pelvic link and the upper torso link is thought to be adequate to analyze postures associated with lower back injuries (Chaffin and Andersson, 1991).

Another characteristic that can be a problem of the link model is its stick-like structure. In order to provide more realism to the link model, one could add a flesh-like appearance (McDaniel, 1976) and could present the links using realistic proportions of one another (Shiro et al., 1987). Pheasant (1986) notes one method of maintaining proper relationships between links is by expressing the link lengths as proportions of stature. Figure 2.4 and Table 2.10 depict this relationship.[3]

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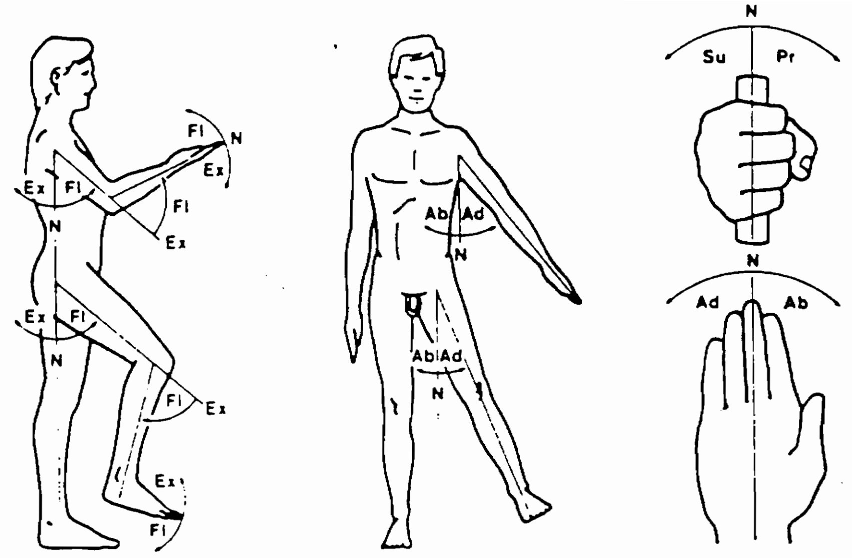
[2] These are not all inclusive. Therefore, other considerations may be needed for various applications.

[3] The relations may not be totally accurate, but the objective of visual realism will be achieved. Describing the position of each link in space accurately describes the posture.



Legend

Fl = flexion
Ex = extension
Ab = abduction
Ad = adduction
Su = supination
Pr = pronation
N = neutral position

Figure 2.1 Visual representation of terms used in Table 2.8 (Pheasant, 1986)

Table 2.8 Link Range of Motion (degrees) (Pheasant, 1986)

JOINT	5th percentile	50th percentile	95th percentile
Shoulder flexion	168	188	208
Shoulder extension	38	61	84
Shoulder abduction	106	134	162
Shoulder adduction	33	48	63
Shoulder medial rotation	61	97	133
Shoulder lateral rotation	13	34	55
Elbow flexion	126	142	159
Pronation	37	77	117
Supination	77	113	149
Wrist flexion	70	90	110
Wrist extension	78	99	120
Wrist abduction (radial deviation)	12	27	42
Wrist adduction (ulnar deviation)	35	47	59
Hip flexion #	92	113	134
Hip abduction	33	53	73
Hip adduction	11	31	51
Knee flexion	109	125	142
Ankle flexion (planar flexion)	18	38	58
Ankle extension (dorsal flexion)	23	35	47

Measured with knee fully flexed.

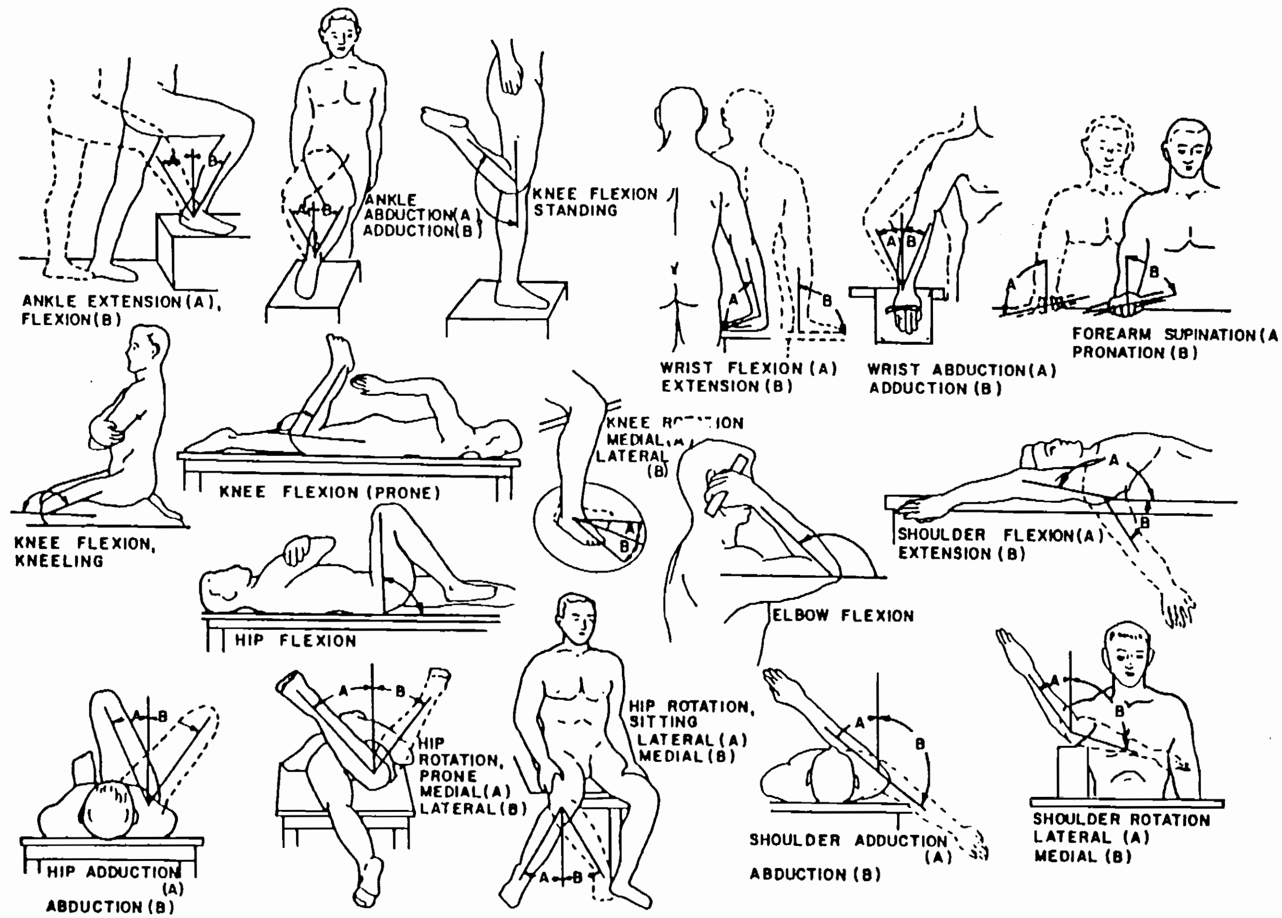


Figure 2.2. Visual respresentation of terms used in Table 2.9 (Van Cott and Kinkade, 1972

Table 2.9. Link Range of Motion (Staff, 1983)

JOINT	MOVEMENT	5th PERCENTILE FEMALE	5th PERCENTILE MALE	50th PERCENTILE FEMALE	50th PERCENTILE MALE	95th PERCENTILE FEMALE	95th PERCENTILE MALE	DIFFERENCE* FEMALE > MALE
Neck	Ventral Flexion	34.0	25.0	51.5	43.0	69.0	60.0	+ 8.5
	Dorsal Flexion	47.5	38.0	70.5	56.5	93.5	74.0	+14.0
	Right Rotation	67.0	56.0	81.0	74.0	95.0	85.0	+ 7.0
	Left Rotation	64.0	67.5	77.0	77.0	90.0	85.0	NS
Shoulder	Flexion	169.5	161.0	184.5	178.0	199.5	193.5	+ 6.5
	Extension	47.0	41.5	66.0	57.5	85.0	76.0	+ 8.5
	Adduction	37.5	36.0	52.5	50.5	67.5	63.0	NS
	Abduction	106.0	106.0	122.5	123.5	139.0	140.0	NS
	Medial Rotation	94.0	68.5	110.5	95.0	127.0	114.0	+15.5
	Lateral Rotation	19.5	16.0	37.0	31.5	54.5	46.0	+ 5.5
Elbow	Flexion	135.5	122.5	148.0	138.0	160.5	150.0	+10.0
Forearm	Supination	87.0	86.0	108.5	107.5	130.0	135.0	NS
	Pronation	63.0	42.5	81.0	65.0	99.0	86.5	+16.0
Wrist	Extension	56.5	47.0	72.0	62.0	87.5	76.0	+10.0
	Flexion	53.5	50.5	71.5	67.5	89.5	85.0	+ 4.0
	Adduction	16.5	14.0	26.5	22.0	36.5	30.0	+ 4.5
	Abduction	19.0	22.0	28.0	30.5	37.0	40.0	- 2.5
Hip	Flexion	103.0	95.0	125.0	109.5	147.0	130.0	+15.5
	Adduction	27.0	15.5	38.5	26.0	50.0	39.0	+12.5
	Abduction	47.0	38.0	66.0	59.0	85.0	81.0	+ 7.0
	Medial Rotation (Prone)	30.5	30.0	44.5	46.0	58.5	62.5	NS
	Lateral Rotation (Prone)	29.0	21.5	45.5	33.0	62.0	46.0	+12.5
	Medial Rotation (Sitting)	20.5	18.0	32.0	28.0	43.5	43.0	+ 4.0
	Lateral Rotation (Sitting)	20.5	18.0	33.0	26.5	45.5	37.0	+ 6.5
Knee	Flexion (Standing)	99.5	87.0	113.5	103.5	127.5	122.0	+10.0
	Flexion (Prone)	116.0	99.5	130.0	117.0	144.0	130.0	+13.0
	Medial Rotation	18.5	14.5	31.5	23.0	44.5	35.0	+ 8.5
	Lateral Rotation	28.5	21.0	43.5	33.5	58.5	48.0	+10.0
Ankle	Flexion	13.0	18.0	23.0	29.0	33.0	34.0	- 6.0
	Extension	30.5	21.0	41.0	35.5	51.5	51.5	+ 5.5
	Adduction	13.0	15.0	23.5	25.0	34.0	38.0	NS
	Abduction	11.5	11.0	24.0	19.0	36.5	30.0	+ 5.0

*Listed are only differences at the 50th percentile, and if significant ($\alpha < 0.5$)

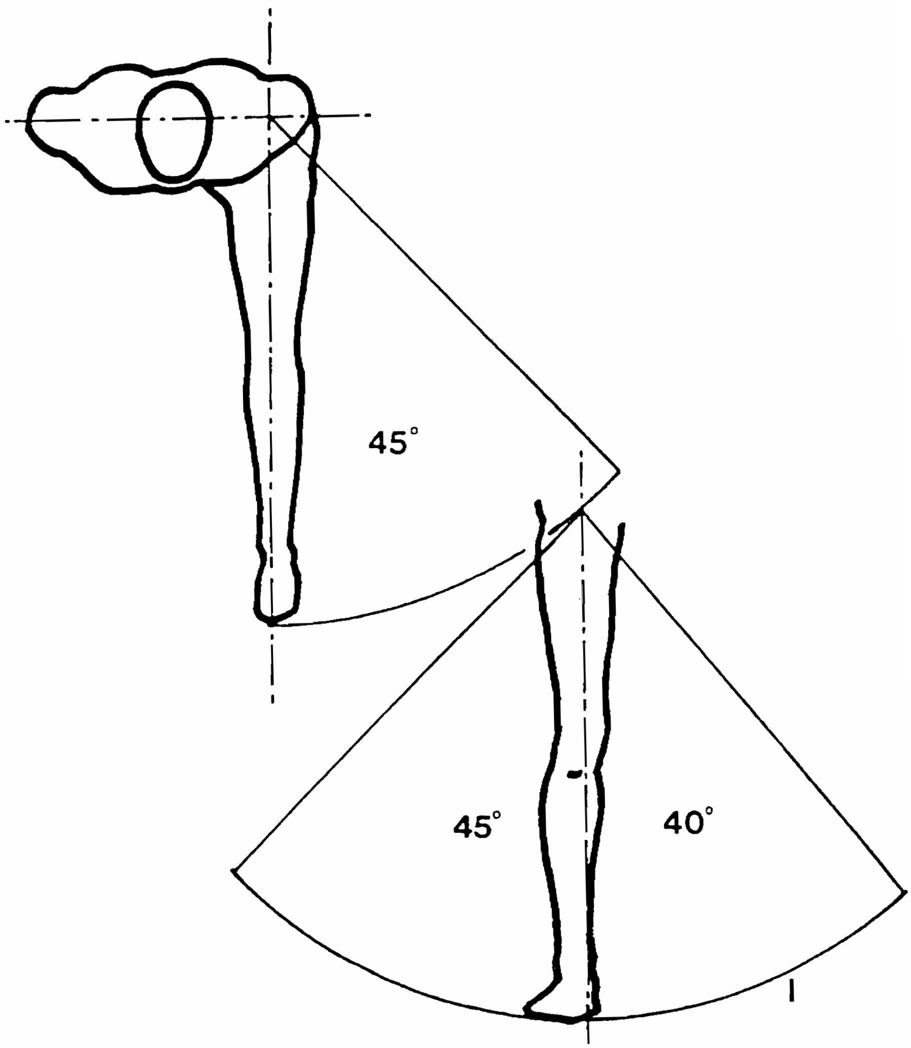


Figure 2.3. Link Range of Motion (Croney, 1971)

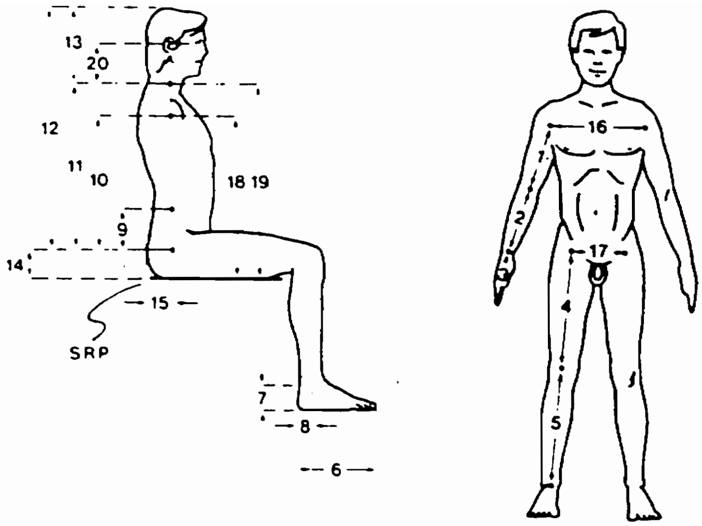


Figure 2.4. Visual representation of terms used in Table 2.10 (Pheasant, 1986)

Table 2.10 Average Link Length as Percentage of Stature (Pheasant, 1986)

SEGMENT NUMBER	SEGMENT NAME	MEN	WOMEN
1.	Upper Arm	17.4	17.2
2.	Forearm	15.6	14.9
3.	Hand	10.9	10.8
4.	Thigh	24.3	24.2
5.	Shank	23.6	23.0
6.	Foot	15.2	14.7
7.	Ankle above sole	4.2	4.1
8.	Ankle in front of heel	3.3	3.2
9.	Hip—lumbosacral joint	5.7	5.7
10.	Hip—shoulder joint	28.8	30.4
11.	Hip—C_7	47.9	48.7
12.	Hip—vertex	47.9	48.7
13	C_7—vertex	14.5	14.7
14.	Hip above the SRP	4.3	4.3
15.	Hip in front of the SRP	7.0	8.2
16.	Transverse shoulders	21.9	21.2
17.	Transverse hips	9.9	10.9

2.2.2. Posturegram (Priel, 1974)

The posturegram method is a numerical method of recording posture that uses a link representation of the body, presented pictorially in the horizontal, frontal, and lateral planes (Figure 2.5). Two numerical scales are used for measurement. Using the first scale, the vertical position of each joint relative to reference points on the body (Figure 2.6) is described. The second scale is used to numerically describe the rotation of each link in comparison to the reference position. The measurements are then encoded and transferred to a recording sheet (Figure 2.7).

Each recording sheet is divided into three sections: top, middle, and bottom. The top section is provided for administrative purposes—to record history and background of the organization, the operator and task being performed, and recording statistics, such as date, analyst, etc. Additionally, a sketch is drawn of the operator's original position, which is used as the reference position. The middle portion of the sheet is provided for the analyst to record the initial position of each joint with reference to the vertical identifiers shown in Figure 2.6. There are three columns in the middle section. The left and right columns are identical in appearance but are used to record the postures of the left and right sides of the body, respectively. The center section identifies the levels of the joints at zero position, i.e. when one is standing straight up, as shown in Figure 2.6. As an added identifier, positive (+) and negative (-) signs are used to indicate the position of a joint slightly above the reference point (+) or slightly below the reference point (-). Using circles, the analyst records the operator's initial position. The bottom section is for

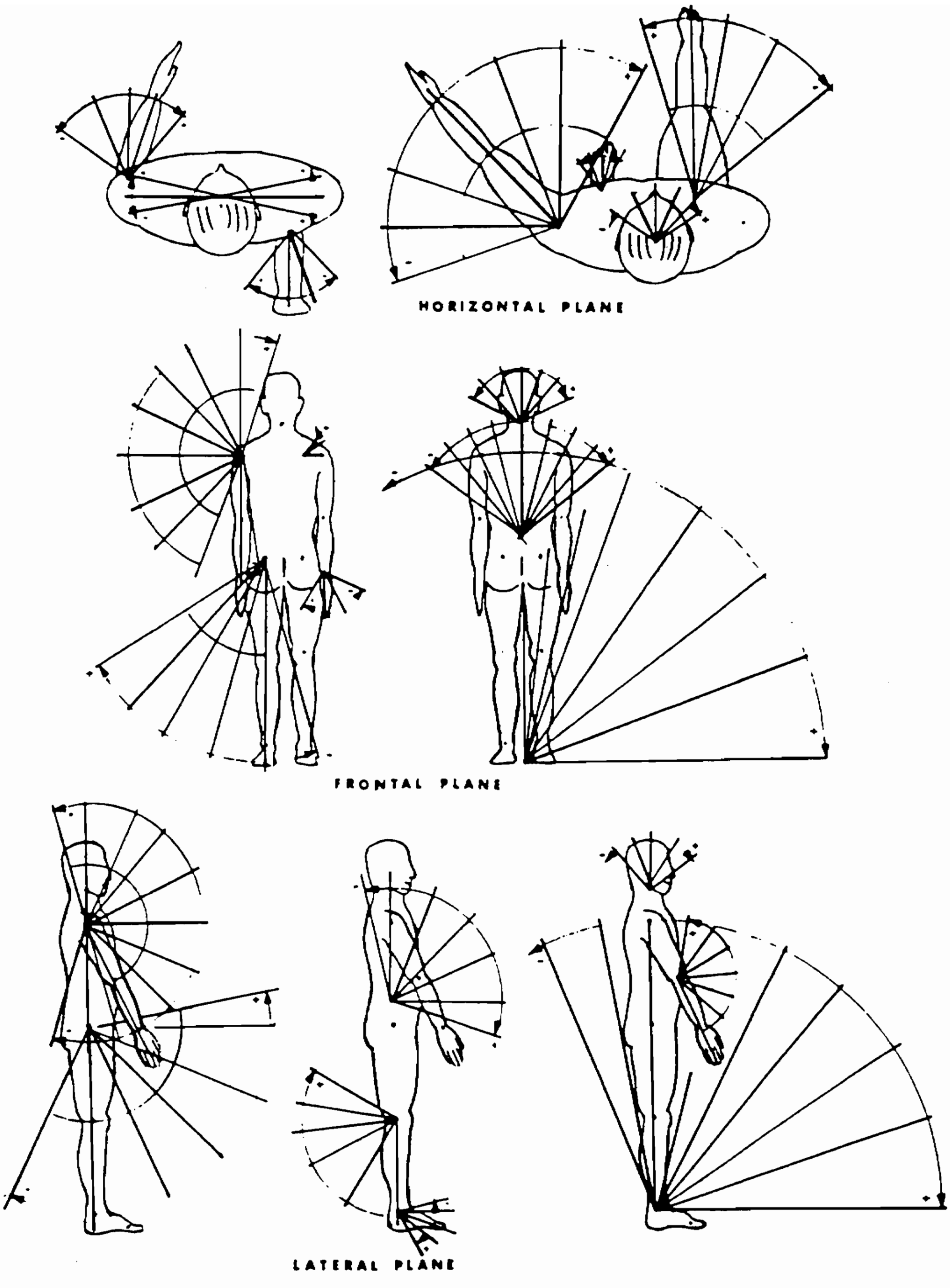


Figure 2.5. Planes used for Posture Recording in Posturegram (Priel, 1974)

recording the angular movement of the body's limbs in each of the reference planes. Positive and negative signs are used to record the direction of movement. Lastly, there is a section for a verbal description of posture.

In the example in Figure 2.7, the operator is kneeling on his left knee performing a machine adjustment. The analyst has recorded the operator's initial position as having the left shoulder slightly below the zero position, the hips slightly below the knee's reference point, the left knee where the toes usually are, and the ankles and the toes are slightly above their reference points. The other joints are at their reference points. The posture of the right side has been recorded similarly. The angles of rotation of the limbs have also been recorded to identify the different postures assumed.

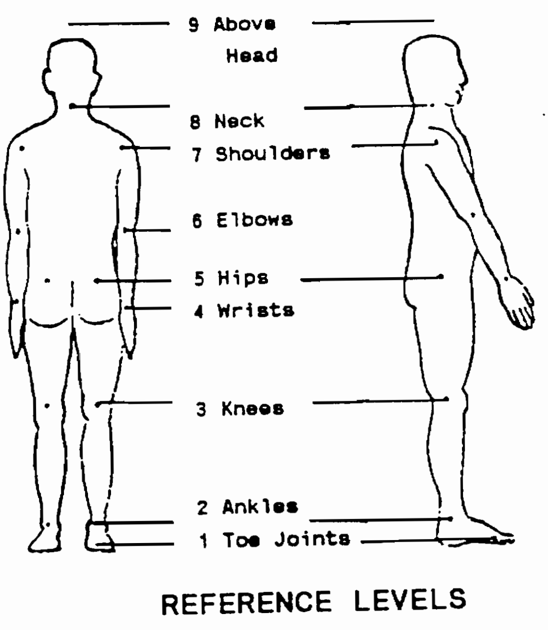
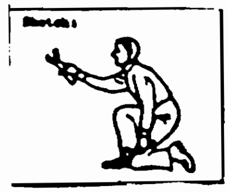


Figure 2.6. Posturegram Reference Levels (Priel, 1974)

POSTUREGRAM

Serial No. 012

Company's Name: Electrocomp Ltd.
Department: Maintenance
Task/Operation: Machine Adjustment
Operator(s): Mechanic (male)
Analyst: V. Z. P. Checked by: A.B.
Date Recorded: 15-5-73 Issued on: 18-5-73
Reviewed on:
Reason:



Circle appropriate inclinations

Reference planes	Inclined towards	Approximate angles
BODY'S FRONTAL PLANE	R.H./L.H.	0 5 10 20 30 45 60 75 90°
BODY'S LATERAL PLANE	Front/Back	0 5 10 20 30 45 60 75 90°

LEFT - HAND SIDE: Located at level number above (+) or below (-)	Levels of joints at zero position			RIGHT - HAND SIDE: Located at level number above (+) or below (-)
+ - 1 2 3 4 5 6 7 8 9 0	9	Above head	9	+ - 1 2 3 4 5 6 7 8 9 0
+ - 1 2 3 4 5 6 7 8 9 0	8	Neck	8	+ - 1 2 3 4 5 6 7 8 9 0
+ - 1 2 3 4 5 6 7 8 9 0	7	Shoulder	7	+ - 1 2 3 4 5 6 7 8 9 0
+ - 1 2 3 4 5 6 7 8 9 0	6	Elbow	6	+ - 1 2 3 4 5 6 7 8 9 0
+ - 1 2 3 4 5 6 7 8 9 0	5	Wrist	5	+ - 1 2 3 4 5 6 7 8 9 0
+ - 1 2 3 4 5 6 7 8 9 0	4	Hips	4	+ - 1 2 3 4 5 6 7 8 9 0
+ - 1 2 3 4 5 6 7 8 9 0	3	Knees	3	+ - 1 2 3 4 5 6 7 8 9 0
+ - 1 2 3 4 5 6 7 8 9 0	2	Ankles	2	+ - 1 2 3 4 5 6 7 8 9 0
+ - 1 2 3 4 5 6 7 8 9 0	1	Toes	1	+ - 1 2 3 4 5 6 7 8 9 0

Record angle and direction + or -

In reference plane: Frontal	Lateral	Horizontal	Direction + or - and angle of inclination of the limbs	In reference plane: Frontal	Lateral	Horizontal
	-10°		Head		-10°	
	XXXXX		Shoulders		XXXXX	
	0		Arms		+100°	
XXXXXX	0		Forearms	XXXXXX	+5°	
	0		Hands		0	
	+45°		Trunk		+45	
	+75°		Thighs		+120°	
XXXXXX	+120°		Legs	XXXXXX	+95°	
	+45°		Feet		0	

Brief verbal definition of the posture: Kneeling on left knee, leaning forward with extended right arm.

Explanatory remarks: Right hand holding spanner; left hand at the side of body

Figure 2.7. Posturegram Recording Sheet (Priel, 1974)

There are several advantages to the use of the posturegram as a recording method for posture. First, use of two numerical scales simultaneously with tri-plane modeling of the links increases the level of accuracy from using either separately. In addition, the complexity of the model is reduced by depicting only the realistic ranges of motions. Lastly, verbal descriptors of the pictorial representations provide added modifiers. There are some drawbacks, however, associated with the use of the posturegram method. For example, the observer is required to make absolute judgments of joint rotation. This could be a source of error, because he/she may not make these judgments accurately. Additionally, the analyst is incapable of recording the numerous postures assumed while performing a task using the specified recording sheet. Throughout the course of a study, many sheets may be needed to record the different postures that an operator can assume while completing one task. This could be both tedious and time consuming.

2.2.3. Ovako working posture analysis system (OWAS)

The Ovako working posture analysis system (OWAS) was developed initially to study working postures of personnel in Finnish Steel mills. Since then, it has been used in research and action projects in many countries (Karhu, Kansi, and Kuorinka, 1977; Louhevaara and Suurnäkki, 1992).

In OWAS, posture is recorded by a six digit, numerical code, with each digit representing a significant postural aspect; limb and torso posture, load action on the body, and task identification. Each of the first three digits represents the posture assumed by one of the following body parts: first digit—the back, second digit—the arms, and third digit—the legs. A link system (shown in figure 2.8) is used to model the body. The four major concerns associated with these digits in the code are: (1) whether the back is twisted or bent; (2) whether one or both arms are over the head; (3) whether one or both legs are loaded; and (4) whether one or both legs are bent. The number in the upper right corner of each cell in figure 2.8 is used to identify the corresponding pictured body posture. These numbers are verbally described in Table 2.11. The fourth digit represents the load action on the body. The three categories for this postural aspect are also identified in Table 2.11. The fifth and sixth digits identify the task being performed (Louhevaara and Suurnäkki, 1992). The numerical code 211107, for example, records the worker's back as bent forward (back = 2); he/she works with both arms below shoulder level (arms = 1); he/she stands with his/her weight on both legs (legs = 1) and handles loads weighing less than 10 kg (load or use of force = 1). The work phase number (07) may show that the work consists of the wiping activity in cleaning work.

Table 2.11. Description of codes used in OWAS (first four digits)

CODE LEGEND				
CODE	**BACK**	**ARMS**	**LEGS**	**LOAD/USE OF FORCE**
1	straight	both below shoulder	standing with both legs straight	weight or force needed is 10 kg or less
2	bent forward, backward	one arm at or above shoulder level	standing with the weight on one straight leg	weight or force needed exceed 10 kg but is less than 20 kg
3	twisted or bent sideways	both arms at or above shoulder level	standing or squatting with both knees bent	weight or force needed exceeds 20 kg
4	bent and twisted or bent forward and sideways		standing or squatting with one knee bent	
5			kneeling on one or both knees	
6			walking or moving	
7			sitting	

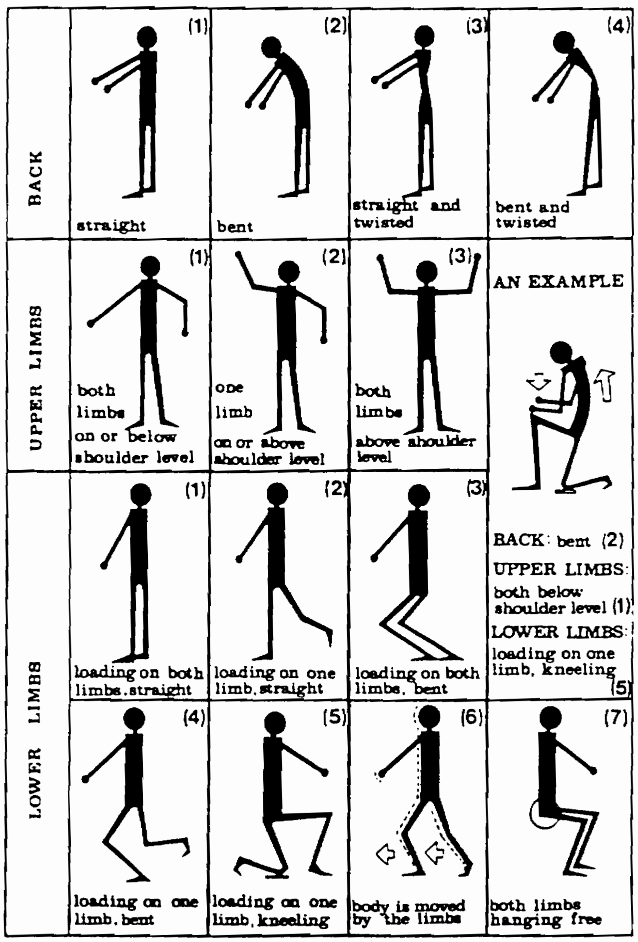


Figure 2.8. Link Model and Coding Used in OWAS (Karhu et al, 1977)

One of the uses of the data collected by OWAS is to identify those work postures and work posture combinations that are potentially harmful to the body. Therefore, work postures and work posture combinations are classified into four action categories (shown in Table 2.12) that identify the consideration needed in rectifying postures. The action categories were determined by experts'[4] assessments of the musculoskeletal load caused by postures based upon the percentage of time a worker assumes a given position.

Table 2.12 Defined action categories of OWAS.

ACTION CATEGORIES	MEANING
1	normal postures that do not need any special attention, except in some special cases.
2	postures must be considered during the next regular check of working methods.
3	postures need consideration in the near future.
4	postures need immediate consideration.

The chart shown in Figure 2.9 illustrates the experts' classification of the action categories for each body position based upon the percentage of time the position is assumed in a work task. The intersection of body posture and the percentage of time the body assumes the position is represented by a numerical value that denotes the action category.

When making observations using the OWAS method, work sampling is used. The observer collects data by observing the worker's posture at random points in time and then recording the numerical code that corresponds to the posture observed. He/she later determines the relative proportions of total working time of the observed posture and compares the findings to the action

[4] The experts included physicians, work analysts, and workers.

categories defined and classified by the experts. Support for the results of the OWAS method is given by video recordings of the workplace (Louhevaara and Suurnäkki, 1992). Additionally, Karhu et al. (1977) report an experiment conducted to determine the reliability of OWAS. The data collected by two work study engineers were compared for fifty-two tasks (36,240 observations). Findings show that the work study engineers produced a median percentage of agreement of 93%, with a range of 74%—99%.

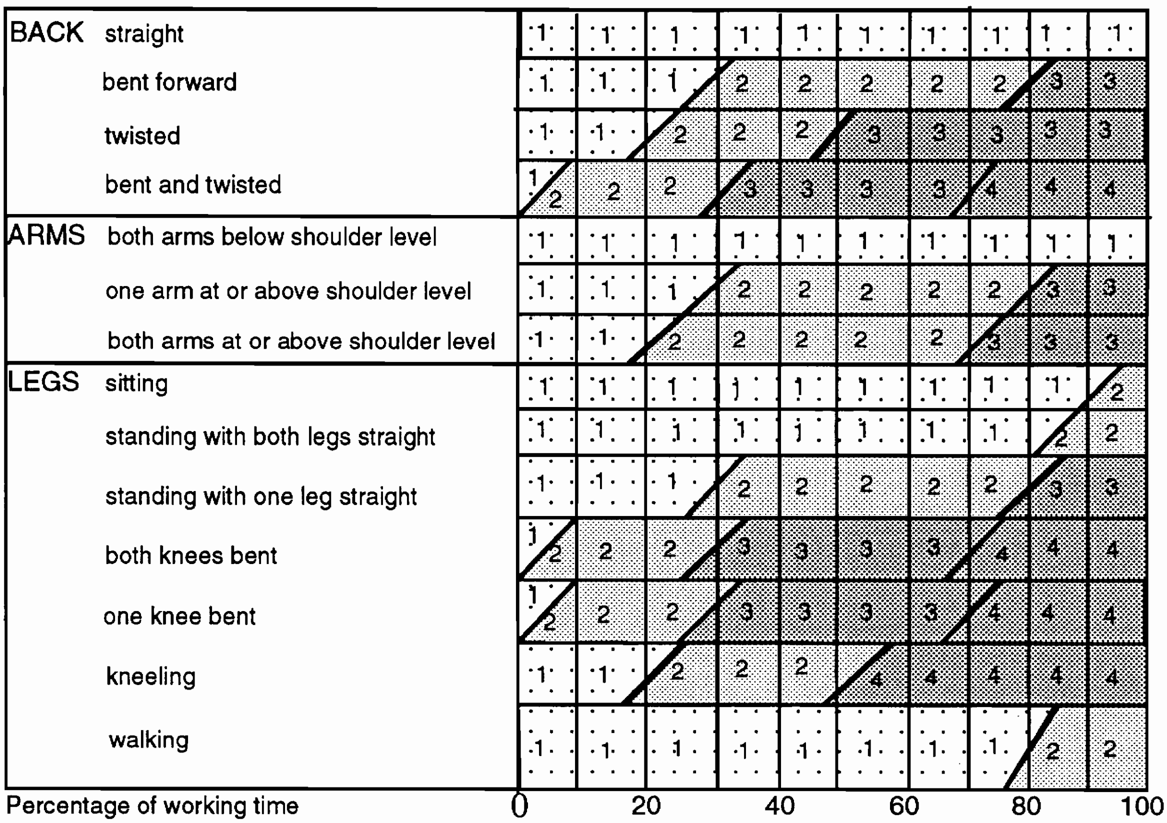


Figure 2.9. Action categories for work postures (Louhevaara and Suurnäkki, 1992)

The OWAS system has proven particularly useful for identifying and rectifying incorrect postures. It was applied at the Ovako steel company and contributed to improved working conditions by identifying tasks where workers were adopting postures that are potentially harmful to the body (Karhu, Harkönen, Sorvali, and Vepsäläinen, 1981).

Some of the positive aspects of OWAS include: the provision of spatial compatibility, the ability to indicate bends and twists of the back, and the simplicity and ease of use. However, the recording method is so simple that it lacks comprehensiveness. The lack of measurement sensitivity reduces the accuracy of the method, because body postures are not recorded exactly.

2.2.3.1. Validation. The frequencies of the work postures incorporated in the OWAS method, and their relative proportions of the total working time, are determined by observation. Data are collected using visual, split-second observations that classify the worker's back, arm, and leg posture, use of force, and the work phase at the moment when the observer glances at the worker. Once the observation has been made, the observer looks away from the worker and chooses the correct numerical code for the observation. Observations are usually made directly in an actual work situation. The results of the OWAS method can be obtained from, are always supported by, video recordings. The videotapes may reveal reasons for poor work postures, and they can be used as background material for discussions with the workplace staff on how to improve the workplace or a particular work method. The observations can be compiled using either a microcomputer or special forms devised for this purpose.

The inter-observer reliability of the OWAS method has been tested in numerous work tasks in the steel, food, wood processing, mining, textile, and metal industries. The reliability was high—an average of 93 of 100 observations were the same between different observers. Work postures of the back were the most difficult to distinguish.

2.2.4. Posture targeting (Corlett et al., 1979)

This method records the position of each link of the body, using a target procedure. A pictorial representation of the frontal plane (figure 2.10) is used as a reference, with the targets placed beside each link. The link position is recorded directly onto the target as a single point so the analyst can record multiple postures over time. The targets consist of a series of segmented concentric circles. The segments indicate angular rotation, and the concentric circles indicate rotation from the vertical axis. The center point for the concentric circles indicates the standard position as shown in figure 2.10. Any deviations from the standard position in the vertical plane are recorded on the target, between or on the concentric circles. Additionally, tables of verbal descriptors are used to identify any motions of the extremities.

This system represents an improvement over the Posturegram method by recording link positions directly onto the reference standards. In addition, the postures of the extremities are recorded verbally—not neglected as in the Posturegram method. In using this method, however, the recorder must make absolute judgments in the vertical plane.

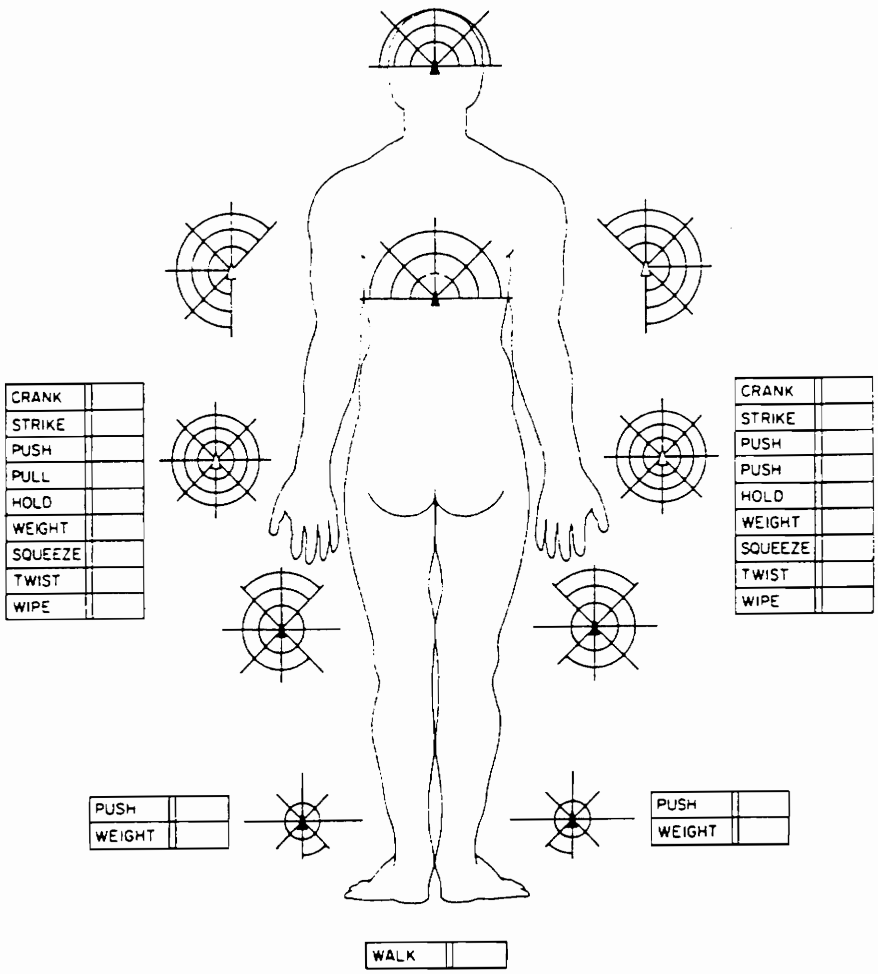


Figure 2.10. Posture Targeting (Corlett et al., 1979)

2.2.5. Classroom seating postures (Gil and Tunes, 1989)

This method was designed to record seating postures in the classroom. A pictorial representation is provided of the seated, sagittal plane. Beside each link is a graded scale of link position, depicting realistic ranges of motion for that link, relative to an adjacent link. Verbal descriptors supplement the pictorial representation, which is one of the few positive points of this method.

It is designed to record only those postures assumed while performing seated tasks, which reduces its applicability. Errors in recording are compounded due to the fact that measurement is related to previous link measurements.

2.2.6. Summary

Until recently, the only means for posture recording were drawings and/or photographs supplemented by narrative (Priel, 1974). This procedure requires an analyst with expert drawing or photography abilities. Even if this person is available, one cannot be certain that all details have been recorded or that accurate interpretations will be made. To address these deficiencies, posture recording has been studied and the various methods have been developed. Of these, only OWAS attempts to portray the method utilized in the work task, and none of them include time considerations.

2.3. Implications For Research

Currently, Predetermined Motion Time Systems and posture recording methods are separate tools for data collection and analysis. PMTS are used to record the time taken and method used for tasks that comprise B-Work. The important considerations of accuracy, comprehensiveness, and ease of application are often traded with one another within the different PMTS. MTM is both accurate and detailed, but this detail and accuracy requires a lot of time to achieve. On the contrary, MOST and MODAPTS are easy and quick to apply, but sacrifice some of the accuracy and detail found in MTM.

In posture recording, ease of application, accuracy, and comprehensiveness are also important considerations. Another important consideration is lack of ambiguity. Lack of ambiguity is necessary for all successful posture recorded data. Ease of application, accuracy, and comprehensiveness, however, are traded with one another in different methods of posture recording. In the link model, accuracy of the posture and ease of reproduction of the posture is often sacrificed for comprehensiveness. Using the posturegram method, comprehensiveness is the least important of these considerations, allowing only one assumed posture to be recorded per sheet. OWAS is best at meeting each of these considerations. It is accurate, comprehensive, and somewhat easy to use after some training. Posture targeting and classroom seating postures are easy to use, but leave something to be desired in accuracy and comprehensiveness.

In this research, accuracy, comprehensiveness and ease of application are all important considerations. The data yielded by the recommended tool should accurately depict the method used to perform the task, as well as the posture assumed. One should be able to describe both the posture and the method from the data collected with this tool. Additionally, the tool should be easy to apply and easy to understand. These considerations are important for wide acceptance and use of the tool.

CHAPTER 3. WORK AND POSTURE ANALYSIS SEQUENCE TECHNIQUE (WAPAST)

3.1. Introduction

Documenting the current status of B-Work is important for measuring change efforts. One major concern of early job analysts was reducing the total cycle time of specified tasks. The Gilbreths' found this to be possible through methods engineering. The motion patterns that are used in B-Work affect the total time of that work. To reduce the total cycle time, motion patterns of various tasks were identified and subsequently changed. Consequently, historical job analysis focused on improving the method used and the cycle time of work tasks.

For many years, job analysts gave primary consideration to work measurement and methods engineering. In recent years, however, another consideration has captured their attention—that of the effect of the posture assumed on the body while performing a task. Medical professionals report an increase in reported cases of repetitive trauma disorders (RTDs). A large percentage of RTDs may result from the posture assumed while performing the repetitive activities that compose some B-Work. Job analysts aim to prevent RTDs by changing the posture used for tasks to reflect the natural body posture. This may involve a change in method, a change in equipment or equipment design, or a change in both method and equipment/equipment design. To assist in deciding which approach is best, the current posture should be identified and documented.

As discussed in the previous chapters, many tools have been developed in an attempt to document these components of B-Work. Predetermined motion time systems meet the objectives of work measurement and methods engineering simultaneously. Posture recording is separate from PMTS and is used to record the posture assumed. Since the posture assumed often affects the method used, both of these components must be considered when attempting to correct the posture. The aim of this research was to simplify the subsequent use of methods data, work measurement data, and postural data by combining these data collection processes. In this research, a tool was developed that addresses this need—the Work and Posture Analysis Sequence Technique (WAPAST). The following sections discuss WAPAST, including its development, its application, and its output.

3.2. The Parent Tools of WAPAST

The Work and Posture Analysis Sequence Technique (WAPAST) is used to record the task description(s), the posture(s) assumed, and the time to complete task(s) in an activity. It combines some characteristics of MOST with some characteristics of OWAS in a computerized application. OWAS was selected because it accurately yields the data needed for this application. One constraint originally defined for the tool was that the postures of the back and the extremities would only be considered. OWAS is one tool that considers these postures and does so in a simple manner that is easy to understand by many individuals. MOST was selected because it was thought to be more compatible with OWAS than other predetermined motion time systems. The activities are defined by alphabetic code and are grouped into phases. A body part is naturally associated with each alphabetic code, thereby making body positions as described by OWAS easy to associate with the codes.

MOST is a system to measure work that concentrates on the movement of objects. It consists of sequence models based upon the concept that efficient, smooth, productive work is performed when the basic motion patterns are tactically arranged and smoothly choreographed. The movement of objects follows certain consistently repeating patterns that were identified and arranged as a sequence of events. Three sequence models are used to describe manual work: the general move sequence, the controlled move sequence, and the tool use sequence. The general move sequence is used for spatial movement of an object freely through the air. The controlled move sequence is used for objects that remain in contact with a surface or are attached to another object during the movement. The tool use sequence is used for common hand tools (Zandin, 1980).

The OWAS system of posture recording uses a five category classification system represented by six digits. Each digit corresponds to postural information. The first three digits represent the position of the back, the position of the upper limbs, and the position of the lower limbs, respectively. The range of possible positions assumed by each of these body parts are defined both pictorially and verbally and are assigned ratings for level of discomfort. (See Figure 2.8 and Table 2.11 for further description). The fourth digit represents the load action on the body and is also defined in Table 2.11. The fifth and sixth digits identify the task being performed.

3.3. *WAPAST Explained*

WAPAST is a computerized tool used to collect methods, work measurement, and postural data for B-Work. For proper use of WAPAST, B-Work activities should be delineated into one or more tasks that can be categorized by one of the two types of moves associated with WAPAST—the general move and the controlled move.[5] As with MOST, the general move is for spatial movement of objects freely through the air, and the controlled move is used for objects that remain in contact with a surface or are attached to another object during movement.[6] Analysis of an activity consists of a process of multiple task analyses.

The process of multiple task analyses is three-fold. First, the analyst describes the task in a short concise manner. Complete sentences are not necessary. The objective is to communicate a description of the task in as few words as possible. Second, the analyst determines if the task is a general move or a controlled move. Finally, the analyst inputs data about the task that is ultimately converted to work measurement and postural information. This process continues for each task until all tasks have been analyzed. Upon completion of the process, the total time for the activity is calculated.

The results of the analysis are stored in a text file created by WAPAST. For each task, the task identification, i.e. verbal description, the total time for the task, and the action category for the arms, legs, and back are recorded.

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[5] For this application an activity is defined as human effort exerted for a specific purpose. Examples include, but are not limited to sharpening pencils, sweeping the floors, etc. Tasks are the individual movements that, when put together, comprise one activity. A position is a collection of all activities performed by one person. Finally, a job is a group of positions highly similar or identical (Turner, et al, 1987).

[6] The tool use move was not used in WAPAST, because of the multiple tools associated with its usage. These multiple tools make the tool use sequence too complex to include in initial development of WAPAST. Future research will include expansion of WAPAST to include tool use.

3.4. Equipment Used in WAPAST's Development

WAPAST was developed using Microsoft Visual Basic on an IBM Personal System/2. In conceptual development of WAPAST, the researcher envisioned a series of related, interactive windows. With a minimal number of key strokes and mouse clicks, the user would be able to input all of the general data pertaining to each task. WAPAST would then record the task description, the part of the body requiring attention from a postural aspect, and the time to complete the task.

Microsoft Visual Basic is specifically designed for this type of application. It is more than a traditional programming language. Using Microsoft Windows, Microsoft Visual Basic helps the programmer build sophisticated, Windows-style programs. The purpose of the multifaceted programming environment is to streamline the development process by providing the visual elements of a Windows user-interface as ready-made controls that can be incorporated into the application (Hergert, 1991).

3.5. The Application of WAPAST

WAPAST is composed of sixteen interactive forms that are classified into four categories: the introduction, tracking data, the activity, and the task. Figure 3.1 details the sequence of interaction of these forms in a flow diagram. The rectangles in the figure represent the name of the form as used and discussed in subsequent sections. The forms will be discussed in their appropriate categories in the following four sections and their use illustrated through an example.

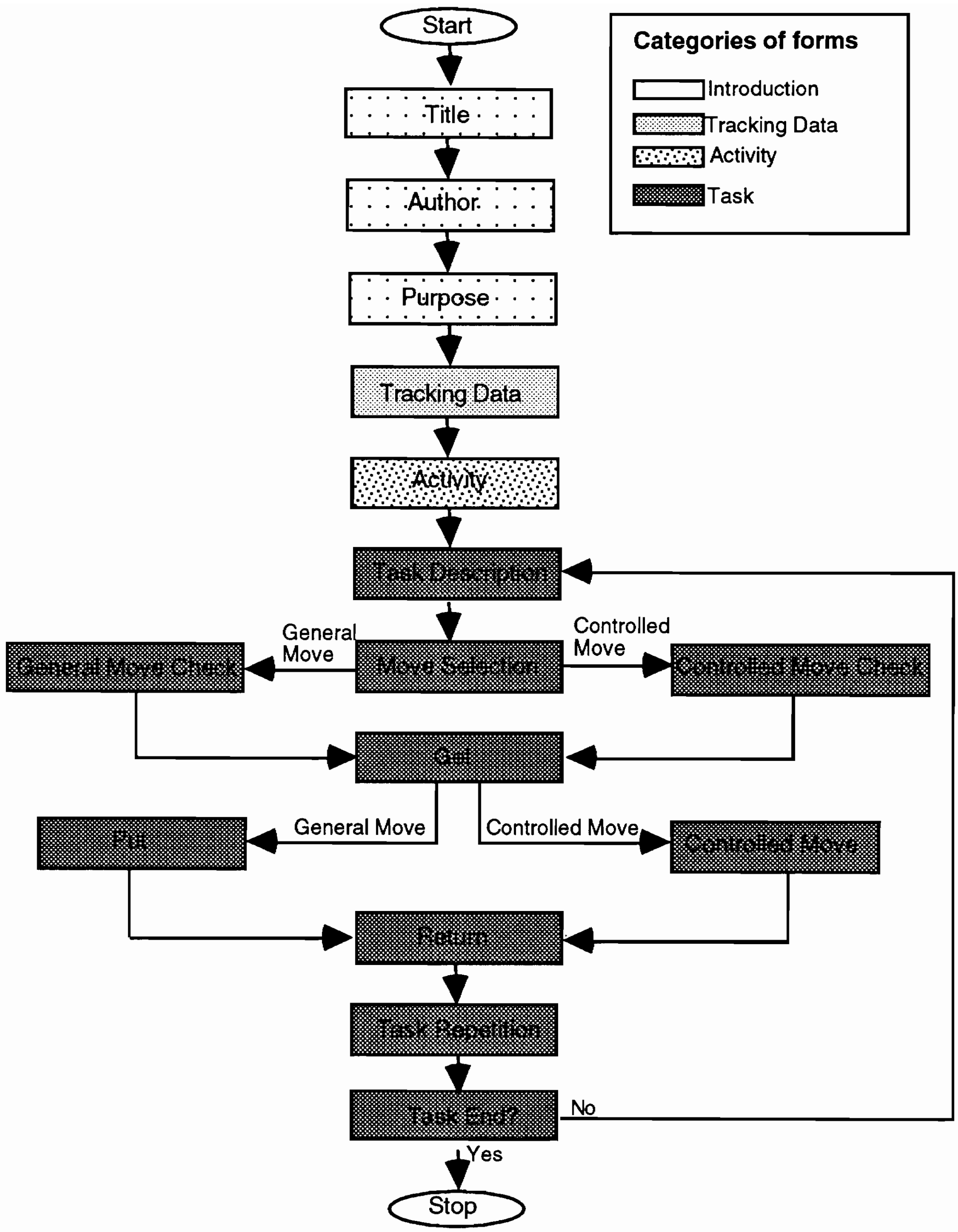

Figure 3.1. WAPAST Flow Diagram

3.5.1. The Introduction

Three forms comprise the introduction of WAPAST. When the application begins, the Title form (Figure 3.2) is shown. It identifies the name of the tool, its acronym, and its logo.[7] In order to move to the next screen, the user should double click on the form.

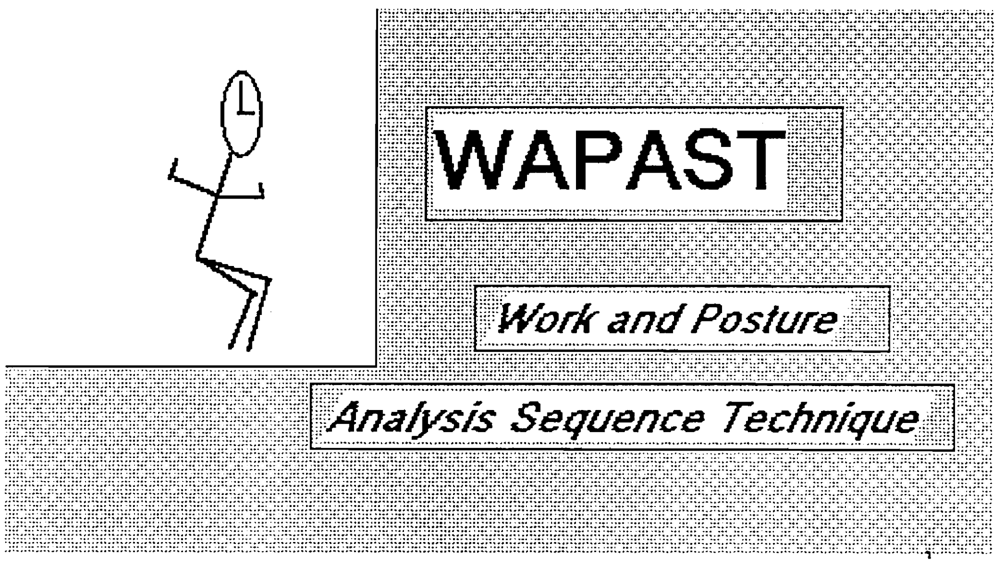

Figure 3.2. The Title form of WAPAST.

This clicking action leads to the Author form shown in Figure 3.3. It identifies the researcher, the department and university in which the research was conducted, and the date of development. To move on to the next form, the user must double click on the form with the mouse.

The final screen of the introduction category briefly defines the purpose of WAPAST and is shown in Figure 3.4. After reading the purpose, the user

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[7] The logo is a stick person figure representing two of the three types of data that WAPAST records.

should continue by double clicking on the form. This action completes the introduction category and commences the tracking data category.

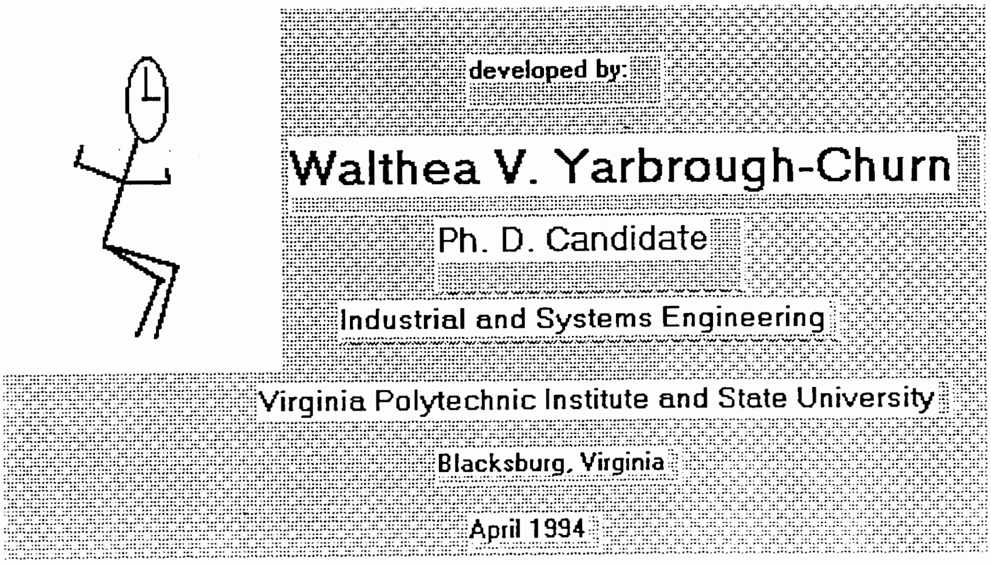

Figure 3.3. The Author form of WAPAST.

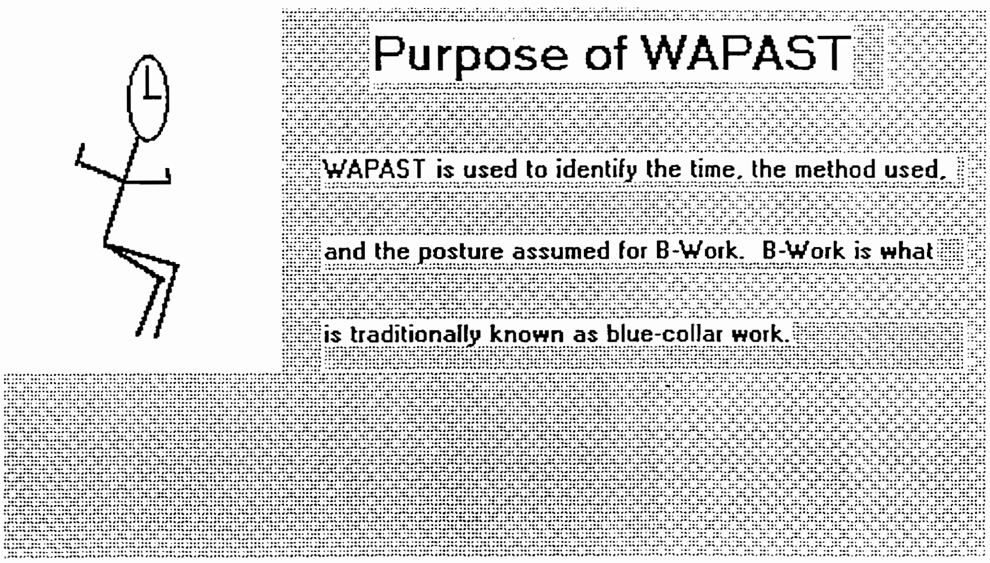

Figure 3.4. The Purpose form of WAPAST.

3.5.2. Tracking Data

The tracking data category is composed of one form (Figure 3.5) that allows the user to input organizational and study related data. In each of the boxes (except the date and time boxes)[8] the user inputs the information requested using the keyboard. After completing all input, clicking "OK" with the mouse button continues the application.

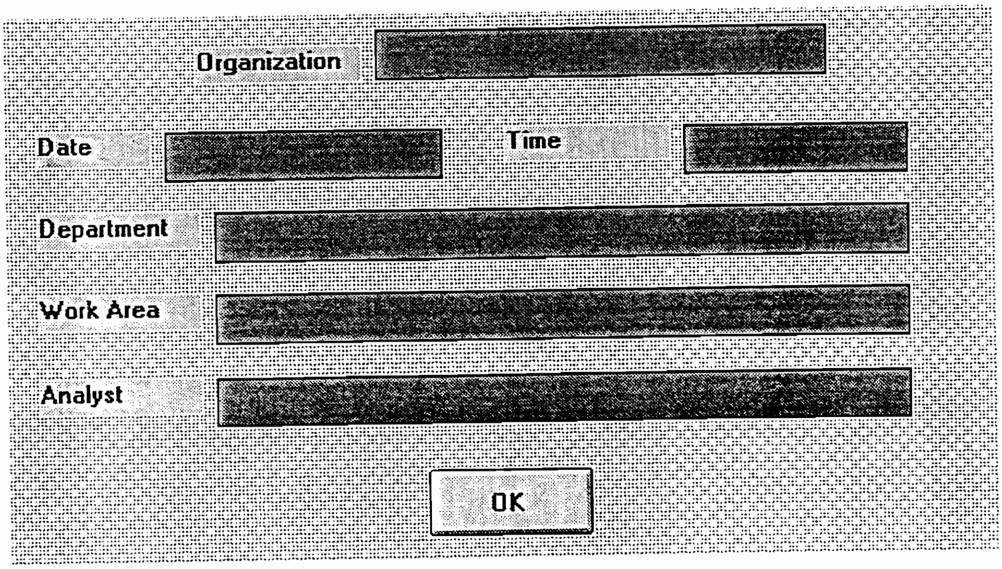

Figure 3.5. The Tracking Data form of WAPAST

Example

Consider the following hypothetical analysis made in a packaging department of a pharmaceutical company called Wally Pharmaceuticals. The cartoner is located on Line #32. These data would be input in the appropriate places in the Tracking Data form.

8 These boxes display the system date and the system time at the stroke of any key.

3.5.3. The Activity

The activity category is also composed of one form—the Activity form (shown in Figure 3.6). This form should be used to describe the activity or task that is to be analyzed. The user briefly describes the activity using the keyboard input. When complete, clicking "OK" with the mouse button continues WAPAST.

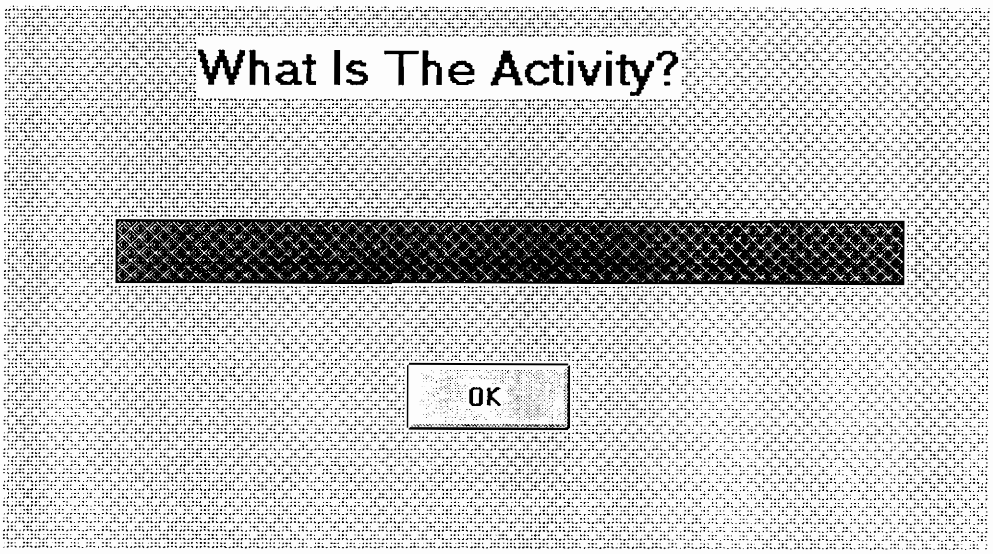

Figure 3.6. The Activity form of WAPAST.

Example Continued

Referring to the example of Wally Pharmaceuticals, the activity has been identified as, "Load the cartoner." This sentence would be typed into the Activity form.

3.5.4. The Task

Each activity is delineated by tasks, i.e. an activity is comprised of one or more tasks. The task category has four sub-categories: the task description, the general move, the controlled move, and task repetition. The forms for each of these sub-categories will be discussed in the next four sections.

3.5.4.1. The task description. Four forms compose the task description sub-category. In the first form, the Task Description form (Figure

3.7.), the user briefly describes the task using the keyboard and should click "OK" when finished.

Example Continued

In the example at Wally Pharmaceuticals, loading the cartoner can be separated into the following seven tasks.

1. Bring box of cartons onto assembly line.
2. Stop cartoner.
3. Open cartoner's door.
4. Place cartons in cartoner.
5. Close cartoner door.
6. Restart cartoner.
7. Move remaining cartons aside.

Using WAPAST each task is analyzed separately. Therefore, the analyst enters the first task, "Bring box of cartons onto assembly line," on the Task Description form.

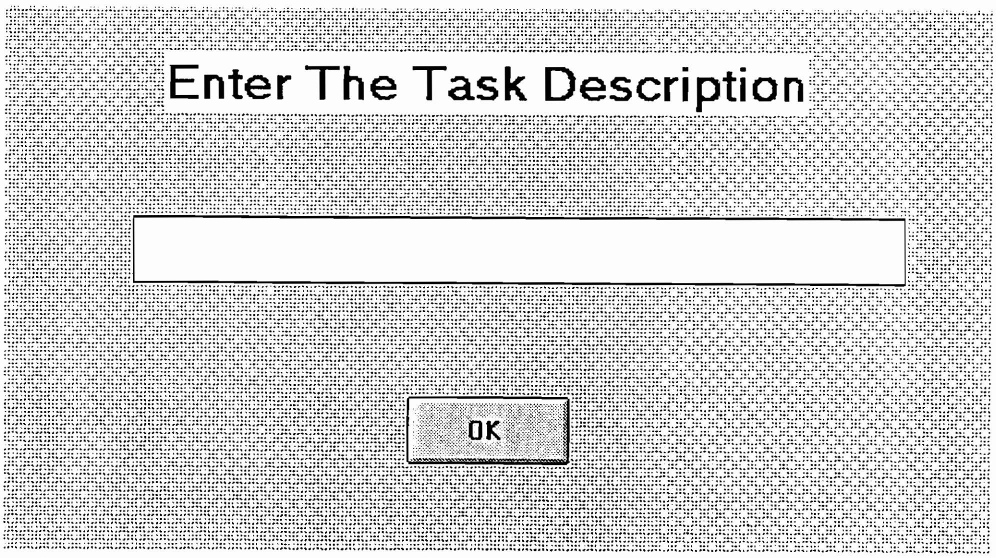

Figure 3.7. The Task Description form of WAPAST.

A task can be identified as a general move or a controlled move. The General Move is used for unrestricted object handling, i.e., moving an object freely through the air. If an object is in contact with, or restrained by, another object during movement, the General Move is not applicable and the Controlled Move must be used. Examples of the Controlled Move include, but are not limited to, a lever, a push button, and a crank. The Move Selection form is shown next (Figure 3.8) and prompts the user to identify the type of move of the task. After making the selection, the user is given the opportunity to check his/her selection using the forms shown in Figures 3.9 and 3.10. If the original selection is the desired one, the task description sub-category ends and the next sub-category begins.[9] If the original selection is not the desired one, then the application returns to the form shown in Figure 3.8.

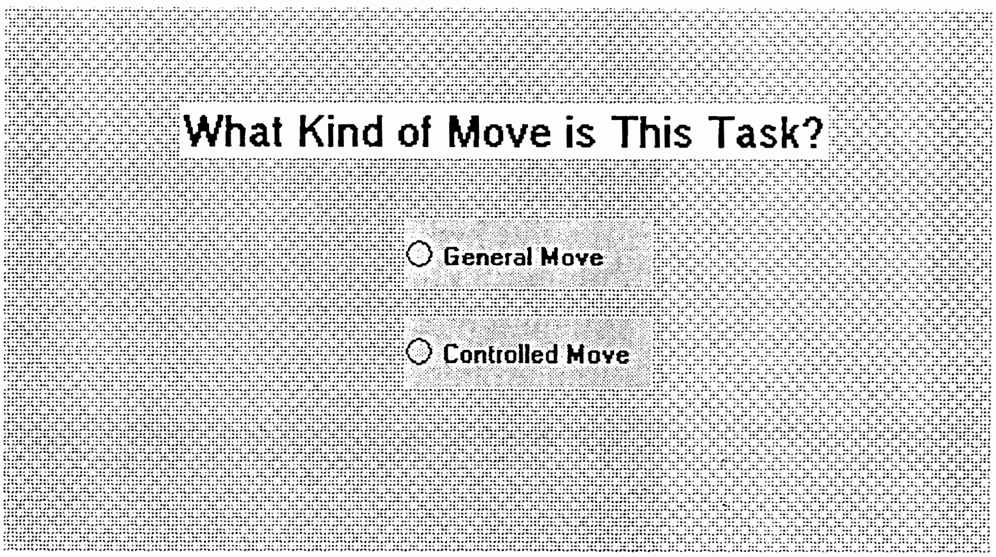

Figure 3.8. The Move Selection form of WAPAST.

[9] The next sub-category depends upon the move selected. If the general move is selected, the general move sub-category begins; if the controlled move is selected, the controlled move sub-category begins.

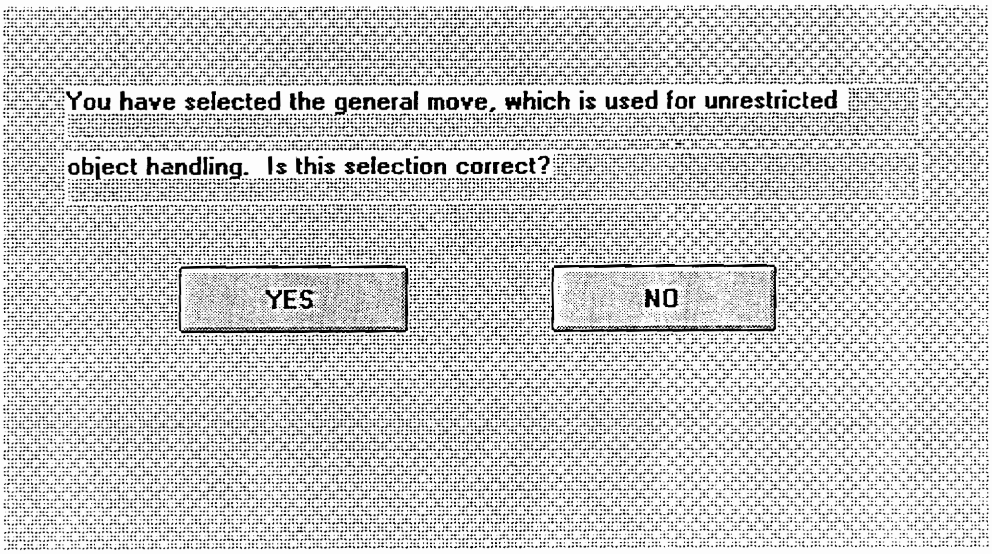

Figure 3.9. The General Move Check form of WAPAST.

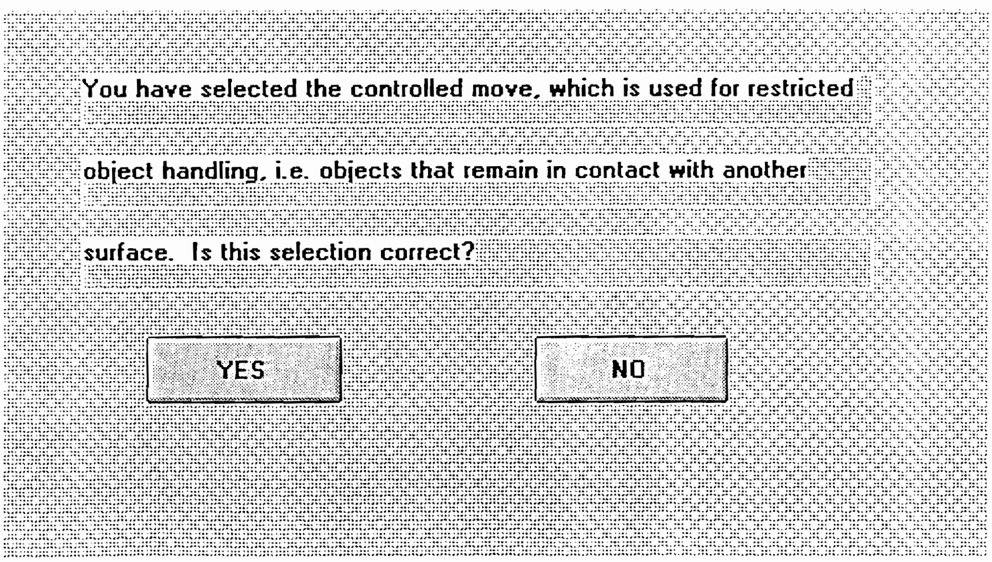

Figure 3.10. The Controlled Move Check form of WAPAST.

Example Continued

Bringing the box of cartons is a general move, because the analyst will carry them from a table setting away from the assembly line onto the assembly line. Therefore, the appropriate circle and box should be selected in the Move Selection form and the General Move Check form.

3.5.4.2. The general move. The general move sub-category is one of the two sub-categories to which WAPAST moves from the Task Description sub-category. It has three forms that represent each of the three phases of the general move. The first form (Figure 3.11) is the Get form and represents the Get phase of WAPAST. This form is used to input data regarding three motions: the action distance the operator moves to gain control of the object, the vertical body motion associated with gaining control of the object, and the type of object to be moved. Additionally, this form requests information regarding the position of the body parts associated with this type of move and the percentage of time during the motion the body retains this position.

To simplify the use of WAPAST, pull down menus are provided for some of the required input for this sub-category. For instance, the data required for action distance represent the distance that an operator must move to gain control of the object. The operator has several choices from which to select for this distance as well as the corresponding arm and leg positions (Figure 3.12). After determining the distance the operator must move to gain control of the object, the analyst selects the appropriate choice. The choice is then displayed

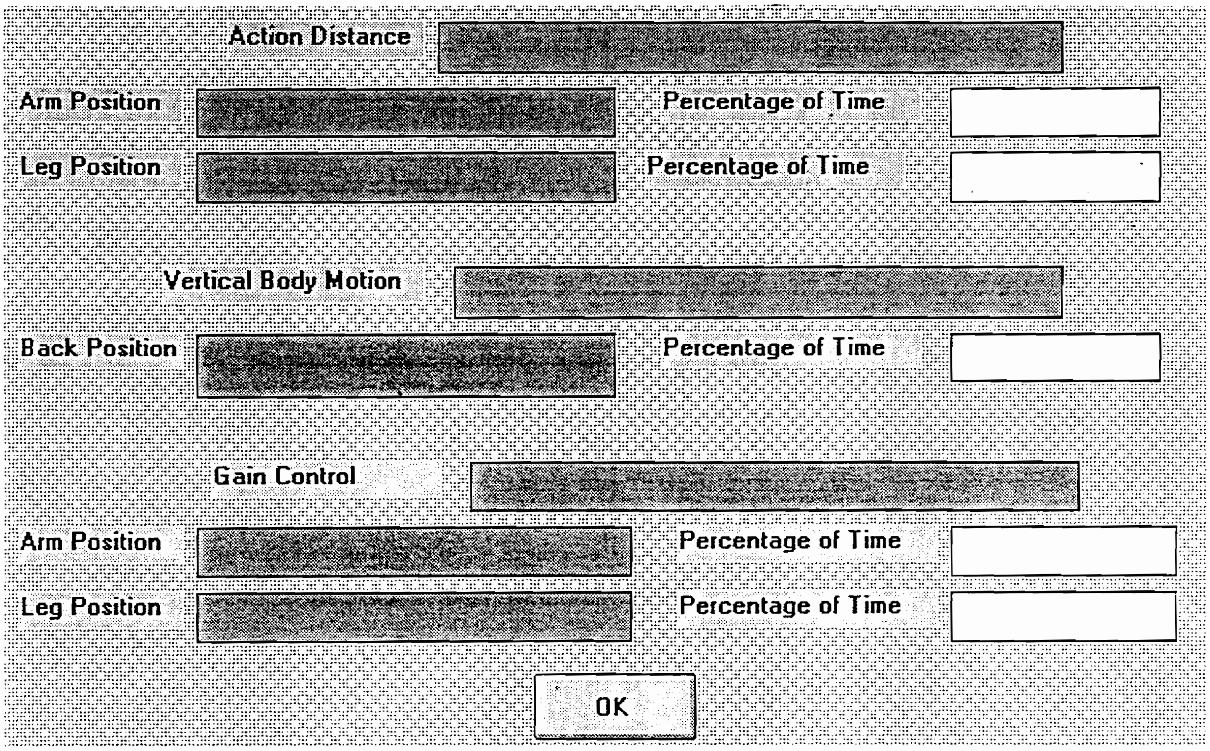

Figure 3.11. The Get form of WAPAST

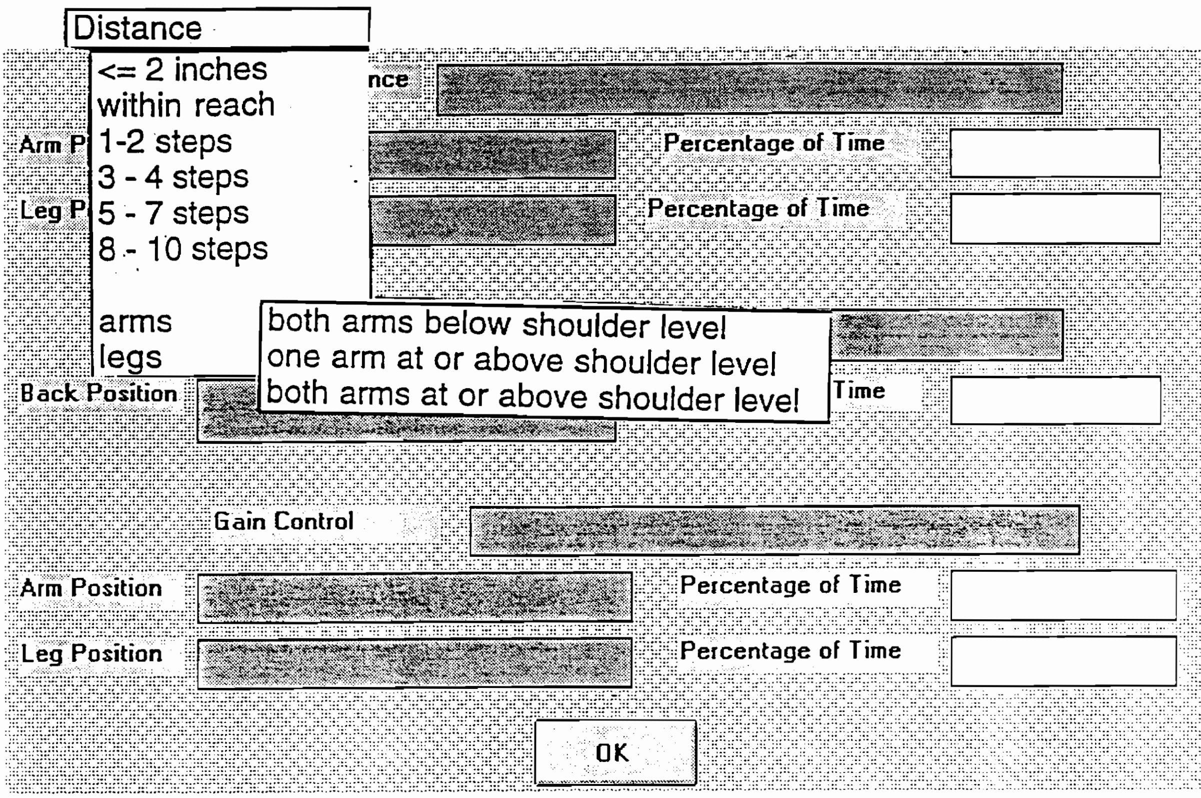

Figure 3.12. The Get form of WAPAST with the action distance pull down menu.

in the box labeled "action distance." Afterwards, the arm and leg positions must be identified from the distance pull down menu.[10]

Example Continued

In the first task, the operator must walk approximately 6 steps, lift the box, and return to his/her original position. Since the operator must walk about 6 steps to get the box, the analyst would select 5-7 steps from the pull down menu. Additionally, the arms are below the shoulder level, which would correspond to the arm position that should be selected. The legs are walking, therefore, the selection for leg position would be walking. Selecting each of these items forces them to be placed in the box with the appropriate label. The percentage of time that the arms assume that position while walking to get the cartons is 100%; the percentage of time that the legs are walking while moving to get the cartons is 100%. These values would be typed in the appropriate boxes by the analyst.

These data are supplied to each of the other boxes in much the same manner, with pull down menus for all of the boxes, except those labeled percentage of time. The pull down menus for vertical body motion and for gain control are shown in Figures 3.13 and 3.14.

VertBodyMtion

none
bend and arise (50% occurrence)
bend and arise
sit or stand
through door
climb on or off

back

Figure 3.13. The pull down menu for Vertical Body Motion

[10] The analyst records the positions he/she deems the operator retains the greatest percentage of time during the activity.

Gain Control
light object
light objects simultaneously
non-simultaneously
heavy or bulky
blind or obstructed
disengaged
interlocked
collect
arms
legs

Figure 3.14. The pull down menu for Gain Control

Example Continued

There is no vertical body motion because the box is located on a table and the back is straight. The data for the gain control box represent the type of object that must be moved. The box is a bulky object. When gaining control of the object, the arms are below the shoulder level and both of the legs are straight.

Clicking the "OK" button at the bottom of the form continues the application. The next form is the Put form (Figure 3.15) representing the put phase. This form is used to record data corresponding to the motion involved in placing the object. The only difference between the Get form and the Put form is the Place motion. The Action Distance and the Vertical Body Motion are defined in the same way for the Put form as for the Get form.[11] The data input into the Place box represent the type of place that one makes. The choices are shown on the pull down menu in Figure 3.16.

[11] All boxes with the same label have the same drop screens, regardless of the form to which they are associated.

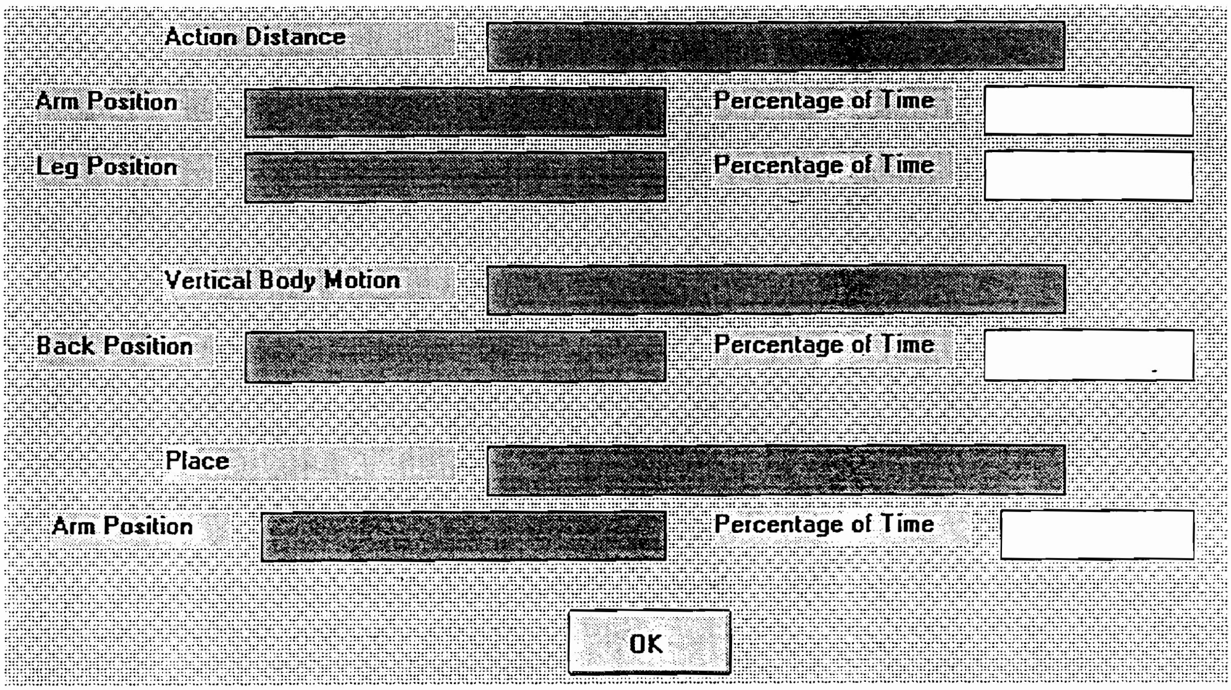

Figure 3.15. The Put form of WAPAST

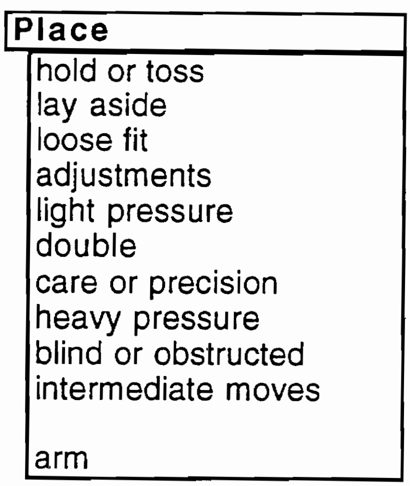

Figure 3.16. The pull down menu for the Place box in the Put form

Example Continued

To place the box of cartons, the operator must move another 6 steps, requiring the analyst to choose the action distance of 5-7 steps. Again both arms are below shoulder level and the operator is walking. He/she must bend to place the box on the floor, making the vertical body motion a bend and arise, and the back bent 100% of the time. The operator places the box with light adjustments and both arms below the shoulder level.

After all of these data have been input, the analyst will click "OK" to go to the last form in the General Move sub-category—the Return form (Figure 3.17). The return form is used to illustrate the action distance the operator must take to get to his/her original position or to begin the next task.

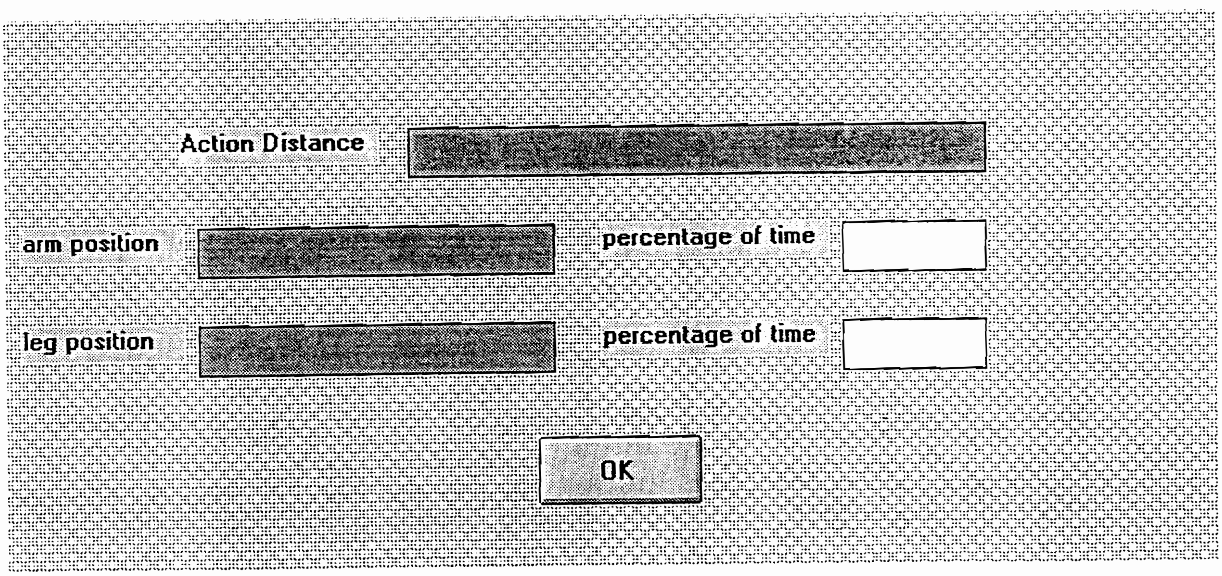

Figure 3.17. The Return form of WAPAST.

Example Continued
In the example at Wally Pharmaceuticals, the next task is "stop cartoner." This action is within reach, which would be noted on the Return form.

3.5.4.3. The task repetition. After clicking "OK" the application moves to the task repetition sub-category. This sub-category has only one form (shown in Figure 3.18) and asks the user to input from the keyboard the number of times the task that has just been analyzed is to be repeated consecutively.

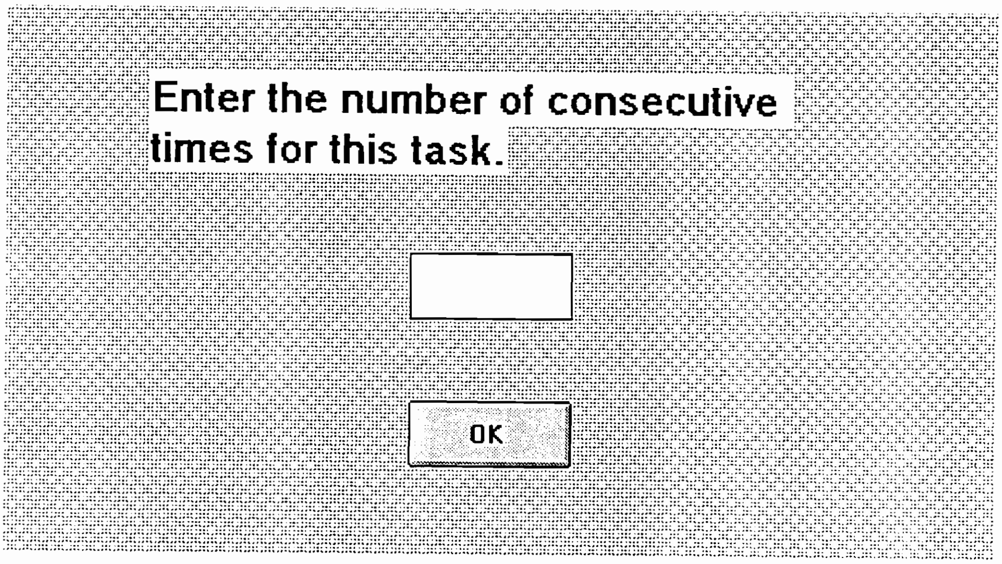

Figure 3.18. The Task Repetition form of WAPAST

Example Continued
In the example, this task is only performed one time, therefore the analyst would enter 1 in the appropriate box.

After completing this action, the analyst is asked if this is the final task for the activity. If it is not, the application returns to the Task Description form and repeats the cycle; otherwise the application ends.

3.5.4.4. The controlled move. For illustration purposes, the second task in the activity, "stopping the cartoner" will be analyzed. This task is a controlled move. The controlled move sub-category also has three forms representing three phases. The first and third forms in this sub-category are identical to the first and third forms in the general move sub-category, i.e. Get form and the Return form. (Please refer to section 3.5.4.2 for information regarding use of these forms.)

The second form is the controlled move form, (Figure 3.19) and it is used to identify the motions made after gaining control of the object when making a controlled move. Data are input into it in the same way as the Get and the Return forms.

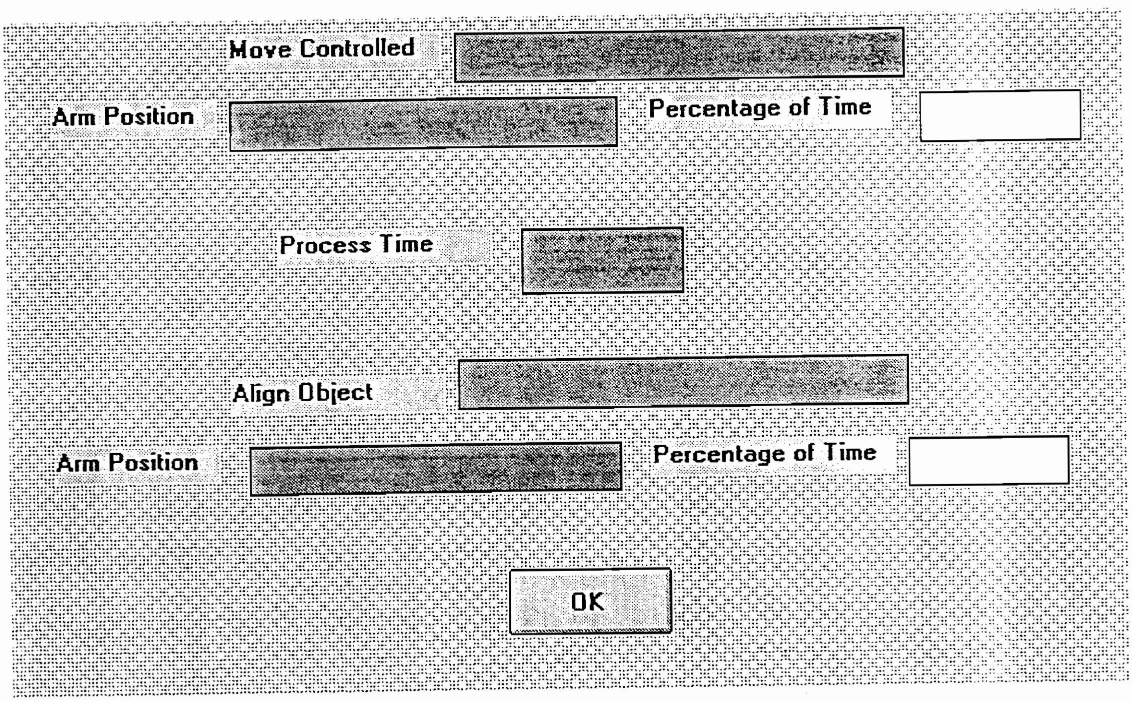

Figure 3.19 Controlled Move form of WAPAST

3.6. Output of WAPAST

WAPAST data are saved in a text file called WAPAST. TXT and can be retrieved after completing the application. The first five lines restate the tracking data input on the tracking data form. The first line identifies the organization; the second line shows the date and beginning time of the analysis; the third line shows the department; the fourth line shows the work area; and the fifth line identifies the analyst. The sixth line of the output is the activity description as it is input on the activity form. The next several lines detail data pertaining to the tasks of the activity with each line representing a different task. For each task, there is a verbal description, followed by four numbers that represent the total time to complete the task, the largest action categories for the arms, the back, and the legs, respectively. The last line of the output represents the total time to complete the activity, i.e. the summation of all of the individual times for the tasks.

Example Continued

The output for the example at Wally Pharmaceuticals is as follows:

```
Wally Pharmaceuticals
2-2-94        3:00 PM
Packaging
Line #32
Walthea V. Yarbrough
Load cartoner.
Bring cartons onto assembly line.         320    1     1     2
Stop cartoner.        40     1     1     2
Open cartoner's door.        40     1     1     2
Place cartons in cartoner. 140     1     4     2
Close cartoner's door.       40     1     1     2
Restart cartoner.     40     1     1     2
Move remaining cartons aside.   250     1     1     2
                             830
```

CHAPTER 4. THE RESEARCH METHODOLOGY

4.1. Introduction

Until this research effort, the objectives of work measurement and posture recording have been met with the use of separate industrial engineering tools for data collection and analysis, as identified and discussed in Chapter 2. Since work measurement data and postural data are interrelated, the simultaneous collection of these data may enhance subsequent use of them. The purpose of this research is to meet the objectives of posture recording and work measurement in one tool. To fulfill this purpose, the principles of MOST, a predetermined motion time system, and OWAS, a posture recording method were combined into one tool—Work and Posture Analysis Sequence Technique. WAPAST was described in detail in Chapter 3 and the explanation reiterated through an example.

Though the objective of this research is met through WAPAST, the research effort is not complete until the tool has been evaluated. Evaluation is necessary for validation and acceptance, i.e. WAPAST's potential for use cannot be accurately determined until it has been evaluated. This chapter details the methodology for evaluating WAPAST. It defines both the research hypothesis and the hypotheses to be tested and details the experimental design for data collection to test the hypotheses.

4.2. Hypotheses

4.2.1. Research Hypothesis

Throughout the development of WAPAST, three concerns persisted. These concerns are of validity of the tool, acceptance of the tool, and the tool's overall value in industry. These concerns are the basis of the research hypothesis stated below.

Research Hypothesis Statement

WAPAST can be effectively used to simultaneously collect postural, work measurement, and methods engineering data.

4.2.2. Hypotheses To Be Tested

From the broad statement of the research hypothesis, several hypotheses to be tested were developed. These hypotheses are based upon three important concepts—application time, accuracy, and reliability. Each of these concepts will be discussed, culminating with a hypothesis to be tested that is based upon the stated concept.

4.2.2.1. Application Time. Application time is an important consideration for selection of and planning use of a tool. When considering a tool for data collection and analysis, the application time should be less than or equal to the time allocated for use. If the application time of a tool is greater than the time allocated to use it, the tool may not be selected. Additionally, an analyst may need to plan multiple activities in his/her work day. In order to do this, he/she should have an approximate length of time required to complete each activity. The first hypothesis addresses this by comparing the application times of WAPAST and MOST. It is expected that the two differ, with WAPAST's application time being greater than MOST's.

First Hypothesis to be Tested

The length of time to apply WAPAST equals the length of time to apply MOST.

4.2.2.2. Accuracy. Since the data yielded by the tool will not be used until a future date and time, they should accurately reflect the activity. MOST and OWAS have proven to accurately reflect manual work activities. Therefore, the data collected using WAPAST should be consistent with the data collected using MOST and OWAS. Two hypotheses result from this.

Second Hypothesis To Be Tested

The work measurement data collected using WAPAST are not significantly different from the data collected using MOST.

Third Hypothesis To Be Tested

The postural data collected using WAPAST are not significantly different from the data collected using OWAS.

4.2.2.3. Reliability. Reliability is probably one of the most important concerns of a new tool. It refers to the consistency of data over time (Sanders and McCormick, 1991). In regards to the use of WAPAST, the data must be reliable in two ways—among different users and for the same user at different time periods. The data obtained using WAPAST should not be significantly different for all users studying the same activity. Significant differences may indicate lack of reliability of WAPAST.

The second reliability issue deals with repeatability. The data obtained using WAPAST should not vary from one time period to the next, given the same activity for study and analysis. These issues of reliability among users and among time periods lead to four hypotheses to be tested for reliability.

Fourth Hypothesis To Be Tested

The work measurement data collected using WAPAST are the same for all users.

Fifth Hypothesis To Be Tested

The postural data collected using WAPAST are the same for all users.

Sixth Hypothesis To Be Tested

The work measurement data collected using WAPAST are the same for each user for each application.

Seventh Hypothesis To Be Tested

The postural data collected using WAPAST are the same for each user for each application.

4.3. Experimental Design

In order to test the proposed hypotheses, a three phase experiment was conducted. The subject selection, apparatus, setting, procedure, and number of applications were identical for each phase of the experiment; the only variation among phases was the tool used for data collection. MOST was used for data collection in the first phase, OWAS in the second phase, and WAPAST in the third phase. Application of the tool was repeated, making a total of two applications of each tool.

The experimental design was 2X4 repeated measures. Activity and application were within subjects variables, tools was a between subjects variable. After training, each subject analyzed each of 4 activities using one of the three tools, i.e. each subject analyzed all four activities using the one tool he/she was trained to use. Each subject was recalled to perform the experiment one additional time. In the repeated application, the subjects analyzed the same activities using the tool that was initially assigned to them. Figure 4.1 illustrates the experimental design. S_{ij} represents the ith tool used by the jth subject. The tools, OWAS, MOST, and WAPAST, correspond to i=1,2, and 3, respectively. Subjects are identified as j=1,2,3,4, and 5.

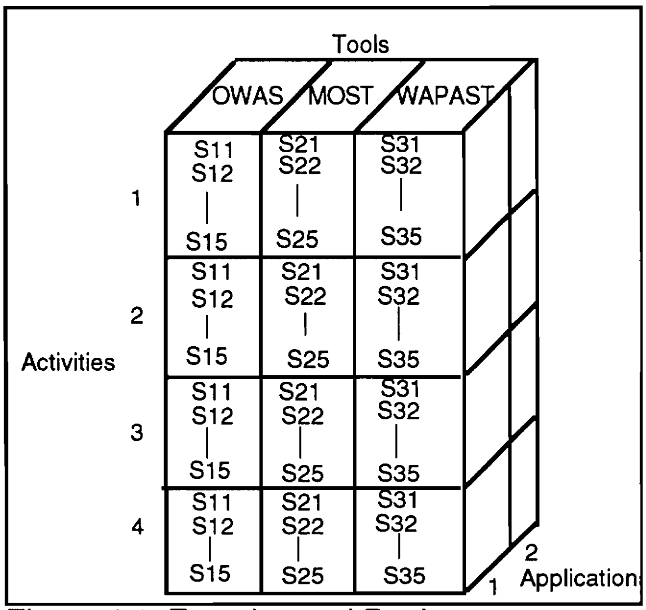

Figure 4.1 Experimental Design

4.4. Experimental Protocol

4.4.1. Subject Selection

Students from Virginia Polytechnic Institute and State University were solicited as volunteer subjects for these experiments. A total of fifteen subjects were needed—five subjects to use each tool. Each subject was paid $5 per hour for each hour they participated in the experiment. Each subject only participated in one phase of the experiment, i.e. they were trained for and used only one tool for data collection. However, each subject was asked to perform the experiment two times. As an added incentive, the subjects were given a $5 bonus for attending each session of the experiment.

4.4.2. Apparatus

Video taped activities were shown on a 25 inch color television. Data were collected according to the specifications of the tool. In Phase 1 and Phase 2 of the experiment, i.e., when MOST and OWAS were used, data were collected using data collection sheets included in experimental kits given to each subject at the beginning of the experiment and collected at the end of the experiment. In Phase 3 of the experiment (when WAPAST was used) data were collected in a text file made by WAPAST.

4.4.3. Setting

A room was located and furnished with a 25 inch color television connected to a video cassette recorder. The room had a table and chair for the subject to use while working. The lighting was sufficient for subjects to view the activities on the television screen, free from glare. Furthermore, the experimental room was quiet and free from distractions.

4.4.4. Procedure

The subjects were separated into three groups—each group used one tool when performing the experiment, however the subjects performed the experiment individually. The procedure for this experiment was divided into four parts—explanation of purpose, subject training, data collection, and subject payment. After the purpose of the experiment was explained, each subject was trained to use the appropriate tool. Next, each subject in the group collected data by applying the tool to each of the four activities shown in the video. Finally, each subject was paid and excused.

4.4.4.1. Explanation of purpose. Upon arrival to the experimental room, each subject was given a copy of one of the explanatory documents found in Appendix C, depending upon which tool the subject used. The first few minutes were set aside for the subject to read the entire document. Afterwards, a verbal summary of the purpose was given, and the subject was given the opportunity to seek clarification about what he/she had read or heard. After all questions were answered, the subject was asked to sign the consent form attached as the last page of the explanatory document. After obtaining the consent form from the subject, the next part of the experiment began. (Average time: 10 minutes).

4.4.4.2. Training. Each subject was given the experimental kit that corresponded to the tool that he/she used. (The experimental kits for Phases 1, 2, and 3 are found in Appendices D, E, and F, respectively.) Each experimental kit contained instructions for using the tool and the necessary supporting documents. Each portion of the kit was explained in detail. Next, the responsibilities of the subject as analyst were explained, including two examples of proper tool usage, using two video taped activities. Though the subject was encouraged to ask questions at anytime during the training, they were prompted for more clarification after each video taped activity. After questions were answered, the subjects were then shown two activities to analyze. There results were evaluated for accuracy. Satisfactory results showed that the subjects were sufficiently trained to use the tool for this experiment. The third part of the experiment began. (Average time: 2 hours).

Since each of the tools are very different, it is important that the use of each of them be explained in detail. The use of each of the tools are explained here.

OWAS. OWAS is based on work sampling, therefore subjects using OWAS used work sampling in their analyses. The videotaped activities were shown repeatedly to each of the subjects with random pauses in the tape during which the subject recorded the position of the arms, legs, and back at the time of the pause. Each subject made 300 recordings of each position during each session. After all of the recordings were made, the subject calculated the percentage of time each position was used and identified the corresponding action category from Figure 2.9.

MOST. Subjects using MOST did their analyses by completing the data collection sheet found in the experimental kit for Phase 2 (Appendix E). First, the subjects delineated the tasks of the activity by separating the activity into a series of "get, put, and return" phases and/or "get, move/actuate, and return" phases. Next, each task was identified as either a general move or a controlled move. Then the subscripts for the alphabetic code were identified and placed on the recording sheet. The total time for each task was calculated by adding the subscripts for each task and multiplying the sum by 10. The total time for the entire activity was the sum of the times for all tasks.

WAPAST. Since WAPAST is computerized, analysis using WAPAST is also computerized. Subjects using WAPAST identified the tasks for each activity. They selected the appropriate characteristics for each of the tasks using the drop menus provided The posture selected reflected the posture that the subject viewed as being used "most of the time."

4.4.4.3. Data collection. Each subject viewed the four video taped activities and analyzed each activity using the tool on which he/she was trained in the training phase. Subjects were allowed to watch the activity as many times as necessary to analyze it. Each activity was analyzed separately. (Average time: 1.5 hours).

4.4.4.4. Payment. Upon completion of data collection for the second application, each subject was asked to sign his/her name beside the pre-printed name on the sign in sheet and compensated for his/her participation (average compensation per participant: $35.00). Additionally, he/she was thanked for his/her time and cooperation and excused.

4.5. Experimental Preparation

Four B-Work activities from different work environments were selected for analysis. Each of these activities were recorded by video camera prior to the beginning of the experiment. In addition, two other activities were identified to be used during the training part of the experiment.

The activities to be analyzed using WAPAST were both long activities and short repetitive tasks. Activities used for the experiment were: putting a blanket on a bed, administrative assistant copying papers, shelving books, and unpacking a computer. These activities represent many work environments and many activities.

For this experiment, there were both independent and dependent variables. The independent variables are: activities and tools. The dependent variables are application time, action category for each position, and the total time for each category.

CHAPTER 5. DATA ANALYSES AND DISCUSSION OF RESULTS

Several analyses were performed in an attempt to validate WAPAST. The results include evaluations of application time, accuracy, inter-observer reliability, and intra-observer reliability. The times to apply the tool were compared to determine the complexity of the tool. Accuracy was tested by comparing the data collected by subjects using WAPAST to the data collected by subjects using MOST and OWAS—two validated tools. The results of each of the WAPAST subjects were compared with one another to determine the inter-observer reliability. The results of data collected by subjects were compared with the data collected in a subsequent application to determine the intra-observer reliability of the tool over time.

5.1. Application Time

When developing WAPAST, an attempt was made to make it user friendly, by simplifying the procedures and by reducing the level of knowledge required for proper use. In order to determine the success of this attempt the application time of WAPAST was determined and compared with that of MOST.

First Hypothesis to be Tested

> The length of time to apply WAPAST equals the length of time to apply MOST.

Application time is an important consideration for selection and subsequent use of the tool. The application time is needed to aid the analyst in applying his/her work schedule or work day. A potential user may be presented with tools for data collection and analysis and may weigh the benefits of the choices with one another. Two choices for tools could be MOST and WAPAST. It was desired that the application times between the two tools would not be significantly different, however a difference was expected. If this were achieved, potential analysts would not be able to use application time as a reason for abandoning the use of WAPAST. The application time for WAPAST would be the same as for MOST, but the information content would be greater. The average length of time to apply WAPAST for each of the activities was compared with the average length of time to apply MOST to the same activities.[12] Subjects were timed from the first time they viewed each activity until they completed the analysis.[13] The input data are shown in Tables 5.1a and b.

Table 5.1a. Application times using MOST.

	Time of Application (minutes)							
	Application 1				Application 2			
Subject	**Act 1**	**Act 2**	**Act 3**	**Act 4**	**Act 1**	**Act 2**	**Act 3**	**Act 4**
S_{21}	10	15	15	50	10	16	17	47
S_{22}	8	14	20	48	10	11	14	40
S_{23}	12	15	18	45	10	10	10	30
S_{24}	11	14	15	50	10	10	10	35
S_{25}	10	16	17	47	8	14	20	40
Σ	51	74	85	199	48	61	71	200
Avg.	10.2	14.8	17	39.8	9.6	12.2	14.2	40

[12] The times for application of OWAS were not considered, because they were controlled by the experimenter.

[13] Analysis includes both observing and recording actions.

Table 5.1b. Application times using WAPAST.

Subject	Time of Application (minutes)							
	Application 1				Application 2			
	Act 1	Act 2	Act 3	Act 4	Act 1	Act 2	Act 3	Act 4
S_{31}	45	35	40	60	20	25	30	45
S_{32}	50	35	38	57	22	25	28	45
S_{33}	50	32	38	60	22	24	25	49
S_{34}	40	30	30	50	35	32	30	53
S_{35}	47	33	42	58	21	20	32	47
$\sum$	232	165	188	285	120	126	145	239
Avg.	46.4	33	37.6	57	24	25.2	29	47.8

5.1.1. Test Procedure

To test the differences between the application times of MOST and the application times of WAPAST, a repeated measures Analysis of Variance was conducted. The null hypothesis for this test is there is no difference between the means of application times for each activity using the two tools. In statistical terms: H_o: $\mu_2 - \mu_1 = 0$. The source table is shown as Table 5.2.

5.1.2. Results

The F-ratios shown in the ANOVA table (Table 5.2) suggest that the null hypothesis should be rejected. There are significant differences in the mean application times for the two tools. Since there are significant differences, the adjusted probability levels (the Greenhouse-Geisser epsilon and the Hunyh-Feldt epsilon) were studied. These values support the original decision to reject the null hypothesis. To further illustrate the differences, the means are graphed and shown in Figures 5.1, 5.2, and 5.3. Figure 5.1 charts the activity x tool effect. For Activity 1, the mean application time for WAPAST is more than triple that of MOST. The ratio of application time for WAPAST to application time for

Table 5.2. ANOVA Source Table for Application Time Data

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	G-G	H-F
Tool	1	5882.450	5882.450	602.942	.0001		
Subject(Group)	8	78.050	9.756				
App	1	1201.250	1201.250	25.023	.0010	.0010	.0010
App * Tool	1	296.450	296.450	6.175	.0378	.0378	.0378
App * Subject(Group)	8	384.050	48.006				
Act	3	9379.450	3126.483	283.849	.0001	.0001	.0001
Act * Tool	3	652.450	217.483	19.745	.0001	.0001	.0001
Act * Subject(Group)	24	264.350	11.015				
App * Act	3	161.050	53.683	11.189	.0001	.0004	.0001
App * Act * Tool	3	356.050	118.683	24.736	.0001	.0001	.0001
App * Act * Subject(Group)	24	115.150	4.798				

Dependent: Application Times

Legend: App = Application Act = Activity Tool = Tool Used

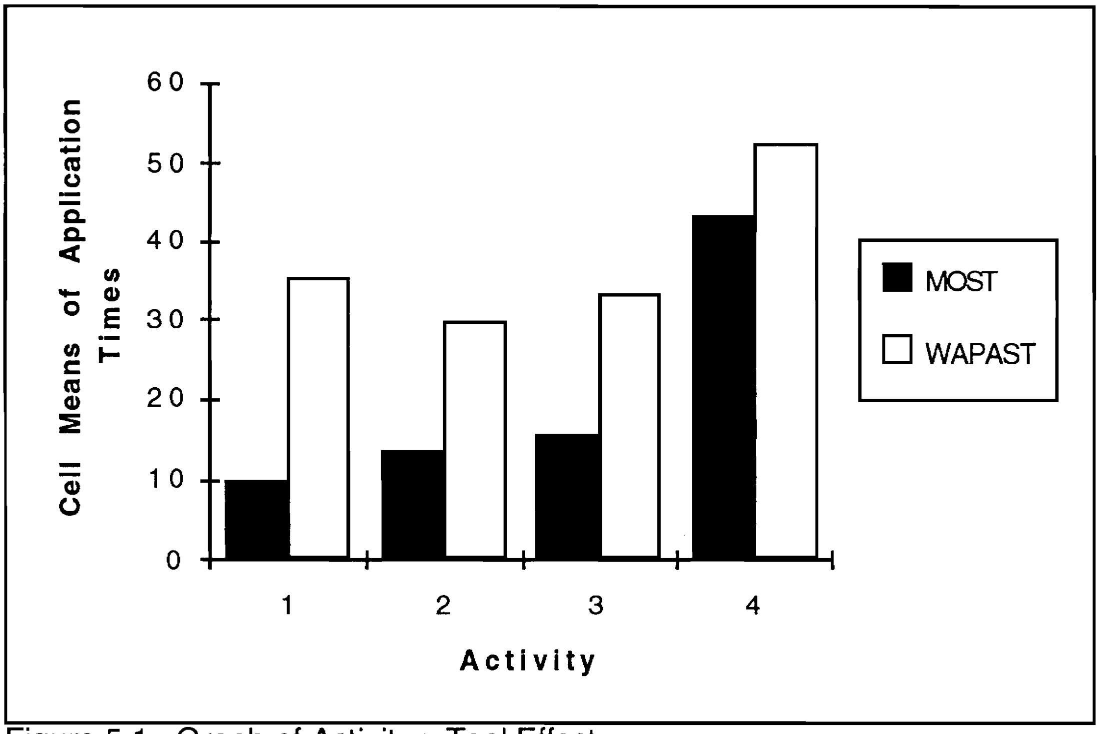

Figure 5.1. Graph of Activity x Tool Effect

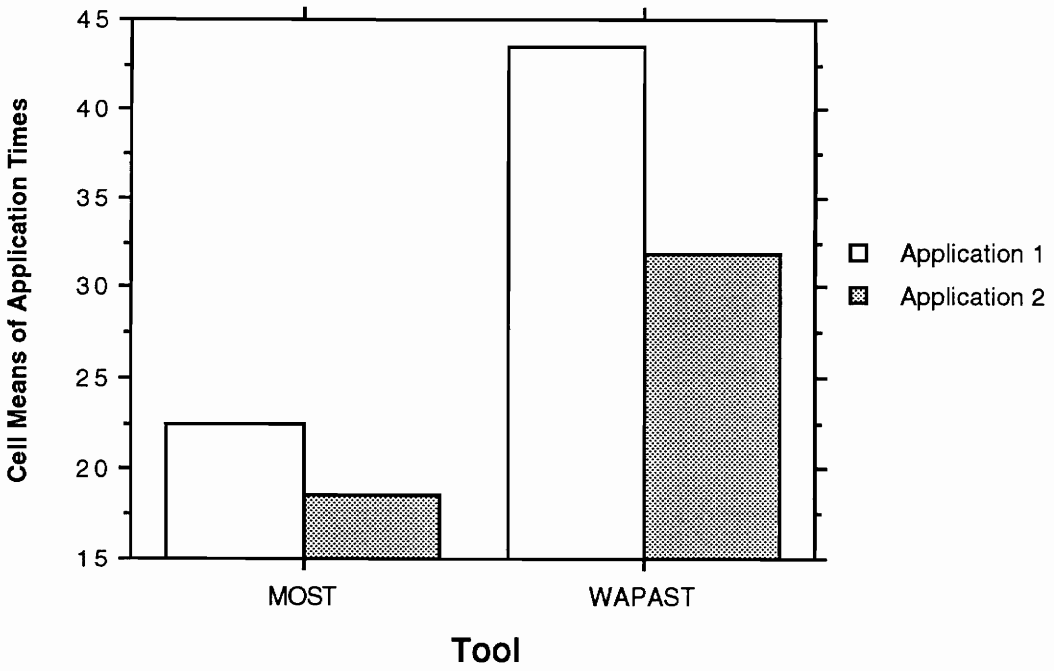

Figure 5.2. Graph of Application x Tool Effect

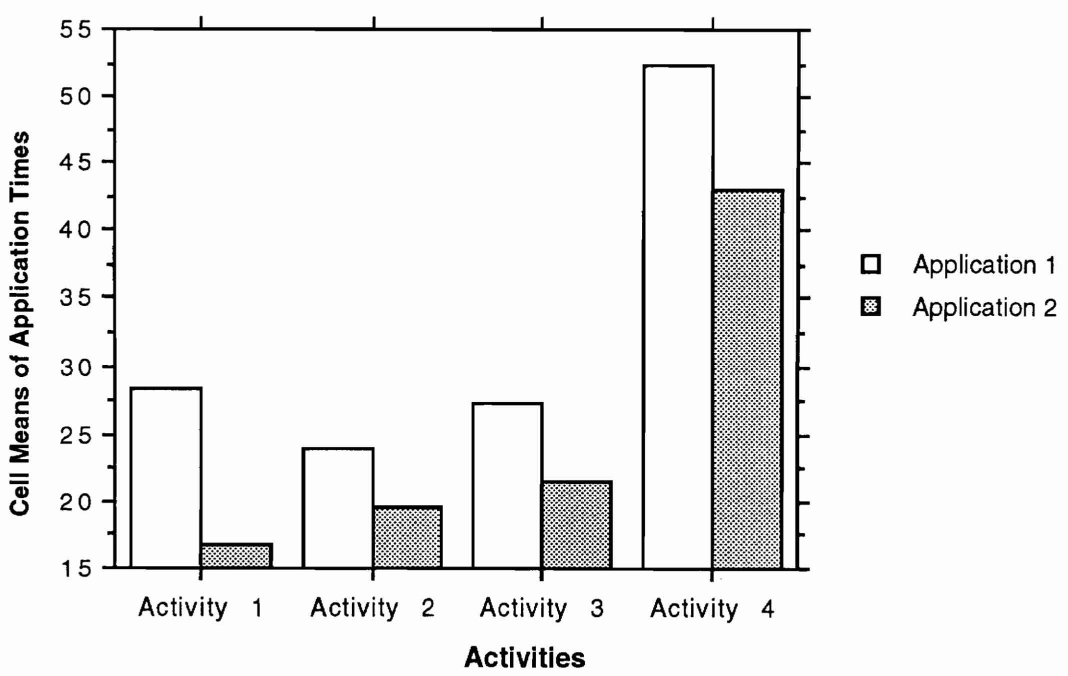

Figure 5.3. Graph of Application x Activity Effect

MOST is approximately 2 to 1 for Activities 2 and 3. The application times for the fourth activity are closer, however, the application time for WAPAST is still greater than for MOST. Figure 5.2 charts the application x tool effect. For both tools, the second application takes approximately one-third less time than the first application. The application x activity effect is shown in Figure 5.3. For each activity, the average application time is greater for the first application than for the second application.

5.1.3. Discussion

Average application times using WAPAST are considerably longer than the two application times for MOST. Although this was expected, it was not the desired outcome. It was hoped that any differences in application times would be insignificant, thereby negating any time related discussion when choosing between the two tools. When selecting a tool, consideration must be given to the trade-off between application time and data collected. Selection depends in part on the importance of these two factors. While the application time is significantly greater for WAPAST, the information content is also. This may be one reason for the difference in application times.

Another reason could be the difference in tool design. MOST is a pen and paper method, whereas WAPAST is computerized. Application of these tools require different skills, which could take different amounts of time.

The analysis of variance conducted on the application time data show that the application times are greater for WAPAST than for MOST. The attempt to make WAPAST take as little time to use as MOST was not successful. From Table 5.1b and Figures 5.2 and 5.3, however, it can be noted that the average application times for the second application are shorter than the first one. This may indicate a reduction in application time due to practice.

5.2. *Accuracy*

One concern is the accuracy of the data collected using WAPAST. The data will not be used until a future point in time, and therefore should reflect the actual activity. In order to address this concern, two hypotheses were tested to determine the accuracy of data.

Second Hypothesis To Be Tested

The work measurement data collected using WAPAST are not significantly different from the data collected using MOST.

Third Hypothesis To Be Tested

The postural data collected using WAPAST are not significantly different from the data collected using OWAS.

5.2.1. Work Measurement Analysis

The work measurement analysis for accuracy is based on the premise that the data collected using MOST accurately represent the activities. The experimental data were analyzed to determine if they accurately reflect the activity. The input data are shown in Table 5.3.

5.2.1.1. Test Procedure. To test the differences between the work measurement data collected using WAPAST and the work measurement data collected using MOST, a repeated measures ANOVA was conducted with total time as the dependent variable. The null hypothesis for this test is that there is no significant difference between the means of the total times for activities as reported by subjects using WAPAST and the means of the total times for activities as reported by MOST. In statistical terms: H_o: $\mu_1 - \mu_2 = 0$. The source table is shown as Table 5.4.

5.2.1.2. Results. The F-ratios shown in Table 5.4 were considered and reveal significant differences for the activity main effect. Other differences are not significant. Differences in the activity main effect are expected, because the activities are different in content. From these data, the null hypothesis is accepted. There is no difference between the work measurement data collected using WAPAST and that collected using MOST.

5.2.1.3. Discussion. This analysis shows that the work measurement data collected using WAPAST do accurately represent the activity. The only significant difference between the data reported using WAPAST and that reported using MOST is with the activity main effect. This is expected, because the activities used in the experiment were very different—with variation in the length of time for each activity and variation in the number of tasks that comprise the activity. The average total time increases from Activity 1 through Activity 4, which indicates difference in the length of time to complete the activities.

Table 5.3. Total Times for Activities as reported by subjects.

	Total Time (TMUs)								
		Application 1				Application 2			
Subject	**Tool**	***Act 1***	***Act 2***	***Act 3***	***Act 4***	***Act 1***	***Act 2***	***Act 3***	***Act 4***
S_{21}	MOST	1200	710	800	4620	900	620	730	2500
S_{22}	MOST	1600	330	750	4010	1300	320	830	1950
S_{23}	MOST	1500	590	650	1210	1260	490	790	1590
S_{24}	MOST	900	410	820	8940	1000	530	790	6850
S_{25}	MOST	1600	310	800	3430	2200	300	790	3280
S_{31}	WAPAST	1170	810	890	3220	630	720	1280	4000
S_{32}	WAPAST	1150	360	1060	5090	2010	550	960	2900
S_{33}	WAPAST	1160	710	910	3840	1810	600	1080	3000
S_{34}	WAPAST	1140	790	990	4000	1900	680	1000	2650
S_{35}	WAPAST	1100	780	1100	4880	1670	580	1200	3400

Table 5.4. ANOVA Source Table for Total Time Data

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	G-G	H-F
Tool Used	1	1336445.000	1336445.000	.748	.4124		
Subject(Group)	8	14297680.000	1787210.000				
App.	1	459045.000	459045.000	.139	.7193	.7193	.7193
App. * Tool Used	1	1512500.000	1512500.000	.457	.5182	.5182	.5182
App. * Subject(Group)	8	26491530.000	3311441.250				
Act.	3	192557050	6.419E7	31.266	.0001	.0004	.0001
Act. * Tool Used	3	11045145.000	3681715.000	1.793	.1753	.2166	.2140
Act. * Subject(Group)	24	49268880.000	2052870.000				
App. * Act.	3	456145.000	152048.333	.044	.9876	.8440	.8741
App. * Act. * Tool Used	3	8238870.000	2746290.000	.788	.5126	.4027	.4173
App. * Act. * Subject(Group)	24	83683710.000	3486821.250				

Dependent: Total Time

Legend: App. = Application   Act. = Activity

5.2.2. Postural Analysis

The third hypothesis to be tested concerns the accuracy of the postural data collected using WAPAST. The premise for testing this hypothesis is that the data collected using OWAS accurately represent the posture assumed in the activities. The experimental data were analyzed to determine if they accurately reflect the activity. The input data are shown in Table 5.5.

5.2.2.1. Test Procedure. To determine the accuracy of the postural data, the PI coefficient was used. This statistical technique is designed to provide a coefficient of agreement between two observers (Light, 1971). In this case, one observer's responses were those made by a subject using WAPAST and the other observer's responses were the mode of the responses reported by subjects using OWAS. PI coefficients were calculated to determine the similarity between the categories reported by the subjects using WAPAST and the categories reported by the subjects using OWAS.

Several 4X4 data matrices were formed for each subject, with each cell in the matrix, n_{ij}, referring to the number of responses where category j was chosen when the correct category was i. These responses were collapsed across subjects, while maintaining separate matrices for each body part and for each application. The matrices are similar to the one shown as Table 5.6 and are presented as Tables 5.7 through 5.12.

Table 5.5. Action Categories as reported by the subjects

		Application 1											
		Activity 1			*Activity 2*			*Activity 3*			*Activity 4*		
Subj.	**Tool**	***arms***	***legs***	***back***	***arms***	***legs***	***back***	***arms***	***legs***	***back***	***arms***	***legs***	***back***
S_{31}	WAPAST	1	2	4	1	2	1	1	4	3	1	4	4
S_{32}	WAPAST	1	2	4	1	2	1	1	2	2	1	2	2
S_{33}	WAPAST	1	2	4	1	2	1	1	4	2	2	4	3
S_{34}	WAPAST	1	2	3	1	2	1	1	2	4	1	2	2
S_{35}	WAPAST	1	2	4	1	2	1	1	2	2	2	4	2
S_{11}	OWAS	1	2	2	1	2	1	1	2	2	1	3	3
S_{12}	OWAS	2	1	2	2	1	1	1	2	2	1	3	2
S_{13}	OWAS	1	2	2	1	2	1	1	2	2	1	3	2
S_{14}	OWAS	1	2	2	1	2	2	2	2	3	1	3	2
S_{15}	OWAS	1	2	3	1	2	1	1	2	2	1	2	2
MODE		1	2	2	1	2	1	1	2	2	1	3	2
		Application 2											
S_{31}	WAPAST	1	2	3	1	2	1	1	4	3	2	4	3
S_{32}	WAPAST	1	2	3	1	2	1	1	2	2	1	2	2
S_{33}	WAPAST	1	2	4	1	2	1	1	2	4	2	2	2
S_{34}	WAPAST	1	2	3	1	2	1	1	2	2	1	4	2
S_{35}	WAPAST	1	2	3	1	2	1	1	2	3	2	2	3
S_{11}	OWAS	2	3	3	2	2	1	1	3	3	1	2	3
S_{12}	OWAS	1	2	2	1	1	1	1	2	2	1	1	2
S_{13}	OWAS	1	2	2	1	2	1	1	2	2	1	2	2
S_{14}	OWAS	1	2	2	1	2	1	1	2	2	1	2	2
S_{15}	OWAS	1	2	2	1	2	1	2	2	2	1	2	2
MODE		1	2	2	1	2	1	1	2	2	1	2	2

Table 5.6. PI Coefficient—Sample Data Matrix

Action Category determined using WAPAST	Action Category determined using OWAS (i)			
	1	2	3	4
1	n_{11}	n_{12}	n_{13}	n_{14}
2	n_{21}	n_{22}	n_{23}	n_{24}
3	n_{31}	n_{32}	n_{33}	n_{34}
4	n_{41}	n_{42}	n_{43}	n_{44}

Each cell of the matrix represents the number of action category responses where the action category reported by subjects using WAPAST was j when the correct action category was i.

Table 5.7. PI Coefficient Data Matrix for Arms—First Application

Action Category determined using WAPAST	Action Category determined using OWAS (i)			
	1	2	3	4
1	18	—	—	—
2	2	—	—	—
3	—	—	—	—
4	—	—	—	—

Table 5.8. PI Coefficient Data Matrix for Legs—First Application

Action Category determined using WAPAST	Action Category determined using OWAS (i)			
	1	2	3	4
1	—	—	—	—
2	—	15	—	—
3	—	—	—	—
4	—	5	—	—

Table 5.9. PI Coefficient Data Matrix for Back—First Application

Action Category determined using WAPAST	Action Category determined using OWAS (i)			
	1	2	3	4
1	5	—	—	—
2	—	6	—	—
3	—	3	—	—
4	—	6	—	—

Table 5.10. PI Coefficient Data Matrix for Arms—Second Application

Action Category determined using WAPAST	Action Category determined using OWAS (i)			
	1	2	3	4
1	17	—	—	—
2	3	—	—	—
3	—	—	—	—
4	—	—	—	—

Table 5.11. PI Coefficient Data Matrix for Legs—Second Application

Action Category determined using WAPAST	Action Category determined using OWAS (i)			
	1	2	3	4
1	—	—	—	—
2	—	17	—	—
3	—	—	—	—
4	—	3	—	—

Table 5.12. PI Coefficient Data Matrix for Back—Second Application

Action Category determined using WAPAST	Action Category determined using OWAS (i)			
	1	2	3	4
1	5	—	—	—
2	—	5	—	—
3	—	8	—	—
4	—	2	—	—

The data points contained in the diagonal cells of the matrix, occurring where i=j, indicate the number of correct responses for each postural category.

A PI coefficient of 1 indicates perfect agreement between a subject's responses and the correct responses. A PI coefficient of 0 indicates that the agreement only occurred by chance. Values between 0 and 1 indicate less than perfect agreement, but the actual level of agreement is hard to define. Consequently, it is useful to place a significance on the calculated PI coefficients to determine whether a PI coefficient is greater than would be expected to have occurred by chance. The Gamma statistic was used to determine the significance of the PI coefficients. It is also used to compare the joint agreement between several subjects with that of a standard. As previously indicated, the standard correct action categories were the mode of results reported by subjects using OWAS. The Gamma statistic examines all individual subject data matrices for a given posture and determines if a significant number of data points lie in these diagonal cells (Light, 1971) From these values the significance levels of the Gamma statistic are determined from the tables of the cumulative normal distribution.

5.2.2.2. Results. Using the data in Tables 5.6 through 5.12, the PI coefficients and the Gamma statistic were calculated for each body part for both applications. Results for these calculations are shown in Table 5.13.

Table 5.13. Calculated PI Coefficients, Gamma Statistic and Significance

Body	Application 1			Application 2		
Part	PI	Gamma	p	PI	Gamma	p
arms	0.4736	1.5625	0.0594	0.4594	1.9188	0.0281
legs	0.4286	1.5923	0.0559	0.4594	1.8025	0.0359
back	0.4690	0.9084	0.1841	0.4286	0.5508	0.2912

5.2.2.3. Discussion. The results shown in Table 5.13 indicate only moderate accuracy in the data collected using WAPAST. In Application 1, the accuracy of the results reported for the arms and the legs are at or beyond the $p<0.05$ level. The accuracy is greater for Application 2. For the back, however, agreement is poor. Tables 5.6 through 5.12 support these findings. For each table, perfect agreement would have occurred if all the data fell into the diagonal cells. The actual data, however, are not always in the diagonal cells. Most of the data for the arms and legs do lie in the diagonal cell.

Much of the disagreement may be due to the posture that was recorded. Activities were delineated into several tasks. The completion of each task may require the operator to assume more than one posture. WAPAST, however, is designed so that only one position per body part can be selected for each phase of a task. Those tasks that are completed using multiple positions cannot be properly represented with WAPAST.

Additionally, there may have been some variation in the subject's input. Subjects identified the position that used the largest percentage of time within a phase. Since this position was not specifically identified for them, they may have selected different positions.

5.2.3. Summary

The work measurement data reported by subjects using WAPAST are accurate. The postural data, however, are only moderately accurate. The accuracy of the postural data could be improved if the tool were modified to include multiple body positions that are required to complete some tasks. This is a major necessity for future use of the data.

5.3. Inter-Observer Reliability

One form of reliability refers to the consistency of measures of a variable across representative samples (Sanders and McCormick, 1993). The effectiveness of WAPAST depends, in part, upon this form of reliability, called inter-observer reliability. It is important that there is no significant difference among data collected by different analysts to support the reliability issue of the tool. There were two hypotheses tested to determine inter-observer reliability.

Fourth Hypothesis To Be Tested

The work measurement data collected using WAPAST is the same for all users.

Fifth Hypothesis To Be Tested

The postural data collected using WAPAST is the same for all users.

5.3.1. Work Measurement Analysis

The fourth hypothesis to be tested concerns the inter-observer reliability of the work measurement data collected using WAPAST. The experimental data were analyzed to determine if several different people may use WAPAST to analyze the same activity and achieve identical results. WAPAST requires the analyst to input data that will subsequently be used to calculate the total time to complete an activity. The input data are shown as Table 5.14.

Table 5.14. Work Measurement Data collected using WAPAST.

Subject	Application	Activities			
		Activity 1	Activity 2	Activity 3	Activity 4
S_{31}	1	1170	810	890	3220
S_{32}	1	1150	360	1060	5090
S_{33}	1	1160	710	910	3840
S_{34}	1	1140	790	990	4000
S_{35}	1	1100	780	1100	4880
S_{31}	2	630	720	1280	4000
S_{32}	2	2070	550	960	2900
S_{33}	2	1810	600	1080	3000
S_{34}	2	1900	680	1000	2650
S_{35}	2	1670	580	1200	3400

5.3.1.1. Test Procedure. To test the differences in the work measurement data collected by subjects using WAPAST, a repeated measures ANOVA was conducted. The null hypothesis for this test is there is no difference among the means of the work measurement data for each subject, i.e. H_o: $\mu_1=\mu_2=\mu_3=\mu_4=\mu_5$. The source table is shown as Table 5.15.

5.3.1.2. Results. The F-ratios shown in Table 5.15 were considered and reveal significant differences for the activity main effect. However, this was expected due to the variety in activities used in the experiment. Other differences are not significant. From these data, the null hypothesis is accepted. The G-G and H-F values are considered for the activity main effect and support the original decision to accept the original hypothesis. There is no difference among the subjects work measurement data collected using WAPAST.

The differences subjects data are plotted in Figure 5.4. The subjects data fall within 1000 TMUs of each other.

Table 5.15. Repeated Measures ANOVA Source Table for Total Time Data

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	G-G	H-F
Subject	4	341865.000	85466.250	1.069	.4590		
Subject(Group)	5	399637.500	79927.500				
Activities	3	56065047.500	18688349.167	46.349	.0001	.0008	.0001
Activities * Subject	12	1457315.000	121442.917	.301	.9788	.8742	.9569
Activities * Subject(Group)	15	6048112.500	403207.500				

Dependent: Total Time

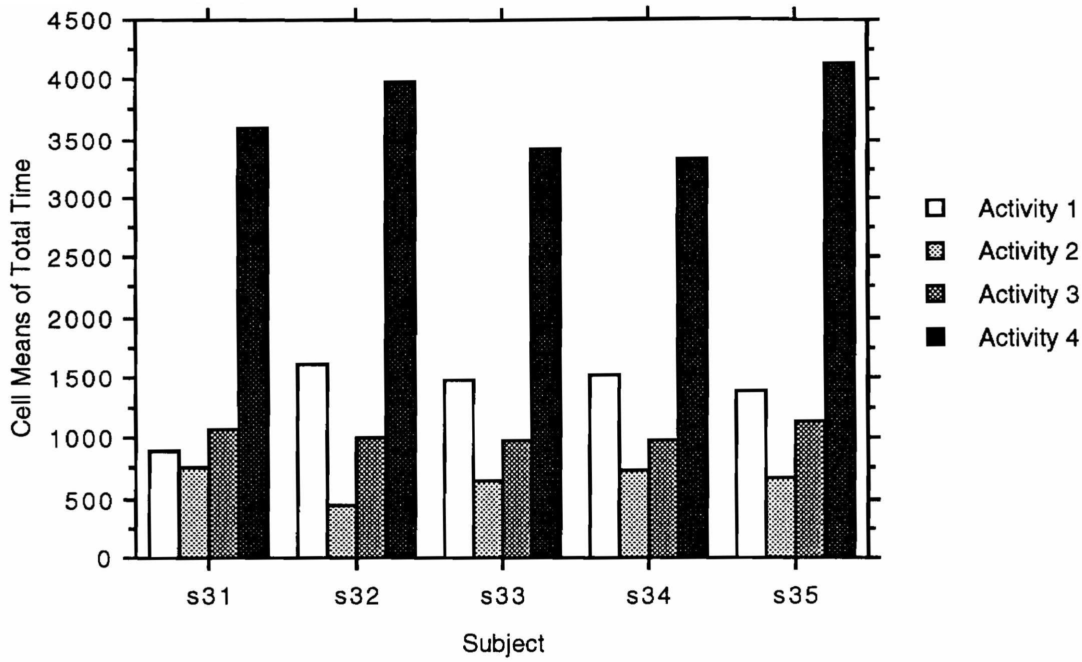

Figure 5.4. Graphical Representation of Subject Responses for Each Activity

<u>5.3.1.3. Discussion</u>. This analysis shows that the work measurement data collected using WAPAST are reliable among users. The only significant difference in the reported data is with the activity main effect. As mentioned earlier this is expected, because the activities used in the experiment were very different—with variation in the length of time for each activity and variation in the number of tasks that comprise the activity. The chart in Figure 5.3 supports this expectation. It graphically shows the differences in average time for the four different activities. The average total time increases from Activity 1 through Activity 4, which indicates difference in the length of time to complete the activities.

5.3.2. Postural Analysis

As previously discussed, WAPAST requires the analyst to input postural data. From these inputs, action categories for each of the body parts in question are determined. Therefore, any postural data taken from WAPAST output are categorical and nonparametric tests are appropriate for data analysis.

5.3.2.1. Test Procedure. The Kappa coefficient is a nonparametric measure of agreement among raters who must assign several items to different categories and may be used to determine agreement among subjects analyzing activities using WAPAST (Siegal and Castellan, 1988). For the purposes of this study, the Kappa coefficient will serve as a good indicator of inter-observer reliability for the postural data.

For each of the four activities used in each session, the data input by each subject resulted in action categories for the arms, the legs, and the back. Considering all four activities, twelve action categories were determined by each of the five subjects for each of the two applications. For each body part, a data matrix similar to the one in Table 5.16 was formed. These matrices are presented as Tables 5.17 through 5.22.

Table 5.16. Kappa Statistic—Sample Data Matrix

	Action Categories (w)				
Activity (x)	**1**	**2**	**3**	**4**	**S_x**
Activity 1	n_{11}	n_{12}	n_{13}	n_{14}	S_1
Activity 2	n_{21}	n_{22}	n_{23}	n_{24}	S_2
Activity 3	n_{31}	n_{32}	n_{33}	n_{34}	S_3
Activity 4	n_{41}	n_{42}	n_{43}	n_{44}	S_4
C_w	C_1	C_2	C_3	C_4	

Each cell of the matrix represents the number of subjects whose data yields action category w for activity x.

Table 5.17. Kappa Statistic Data Matrix for Arms—First Application

Activity (x)	Action Categories (w)				S_x
	1	2	3	4	
Activity 1	5	—	—	—	1
Activity 2	5	—	—	—	1
Activity 3	5	—	—	—	1
Activity 4	3	2	—	—	0.4
C_w	18	2	—	—	
p_j	0.9	0.1	—	—	

Table 5.18. Kappa Statistic Data Matrix for Legs—First Application

Activity (x)	Action Categories (w)				S_x
	1	2	3	4	
Activity 1	—	5	—	—	1
Activity 2	—	5	—	—	1
Activity 3	—	3	—	2	0.4
Activity 4	—	2	—	3	0.4
C_w	—	15	—	5	
p_j	—	0.75	—	0.25	

Table 5.19 Kappa Statistic Data Matrix for Back—First Application

Activity (x)	Action Categories (w)				S_x
	1	2	3	4	
Activity 1	—	—	1	4	0.6
Activity 2	5	—	—	—	1
Activity 3	—	3	1	1	0.3
Activity 4	—	3	1	1	0.3
C_w	5	6	3	6	
p_j	0.25	0.30	0.15	0.30	

Table 5.20. Kappa Statistic Data Matrix for Arms—Second Application

Activity (x)	Action Categories (w)				S_x
	1	2	3	4	
Activity 1	5	—	—	—	1
Activity 2	5	—	—	—	1
Activity 3	5	—	—	—	1
Activity 4	2	3	—	—	0.4
C_w	17	3	—	—	
p_j	0.85	0.15	—	—	

Table 5.21. Kappa Statistic Data Matrix for Legs—Second Application

Activity (x)	Action Categories (w)				S_x
	1	2	3	4	
Activity 1	—	5	—	—	1
Activity 2	—	5	—	—	1
Activity 3	—	4	—	1	0.6
Activity 4	—	3	—	2	0.4
C_w	—	17	—	3	
p_j	—	0.85	—	0.15	

Table 5.22. Kappa Statistic Data Matrix for Back—Second Application

Activity (x)	Action Categories (w)				S_x
	1	2	3	4	
Activity 1	—	—	4	1	0.6
Activity 2	5	—	—	—	1
Activity 3	—	2	2	1	0.2
Activity 4	—	3	2	—	0.4
C_w	5	5	8	2	
p_j	0.25	0.25	0.4	0.1	

For this study, the calculation of the Kappa coefficient is based on the cell values of Table 5.16. The Kappa coefficient is the ratio of the proportion of times the subjects' postural data agree to the total proportion of times the subjects could have agreed, corrected for agreements expected to have occurred by chance (Siegal and Castellan, 1988).

5.3.2.2. Results. Using the data in Tables 5.17 through 5.22, Kappa coefficients and associated significance were calculated for each body part for both applications. Results for these calculations are shown in Table 5.23.

Table 5.23. Calculated Kappa Coefficients and Significance

Body Part	Application 1			Application 2		
	Kappa	Z	p	Kappa	Z	p
arms	0.166	0.2689	0.3936	0.411	0.8819	0.1894
legs	0.2	0.6605	0.2546	0.009	0.0193	0.4920
back	0.388	3.93	<0.001	0.362	2.8441	0.0023

5.3.2.3. Discussion. The results of Table 5.23 show little agreement among subjects for most body parts in both recording sessions. The only agreement is for the back in application 1. An inspection of Tables 5.17 through 5.22 show only moderate agreement among subjects. For each row in these tables, perfect agreement would have occurred if all the data in the row fell within a single cell. The actual data, however, are usually not in a single cell. However, they are often in one cell for activities 1 and 2.

This disagreement is due largely to the omission of multiple body postures in the analysis and to the variation in subject's responses. WAPAST is designed to allow one position per body part to be selected for each phase of the task. This sometimes does not accurately reflect the task. Secondly the subject used his/her discretion in selecting the position to record when many were considered.

5.3.3. Summary

The inter-observer reliability for the work measurement data is good. The postural inter-observer reliability leaves something to be desired. The postural inter-observer reliability could be improved if WAPAST were upgraded to record multiple positions for one task.

5.4. Intra-Observer Reliability

Another form of reliability refers to the consistency of measures of a variable over time, also known as repeatability (Sanders and McCormick, 1993). The effectiveness of WAPAST depends, in part, upon this form of reliability, called intra-observer reliability. It is important that there is no significant difference among data collected in different time periods to support the reliability issue of the tool. There were two hypotheses tested to determine intra-observer reliability.

Sixth Hypothesis To Be Tested

The work measurement data collected using WAPAST are the same for each user for each application.

Seventh Hypothesis To Be Tested

The postural data collected using WAPAST are the same for each user for each application.

5.4.1. Work Measurement Analysis

The sixth hypothesis to be tested concerns the intra-observer reliability of the work measurement data collected using WAPAST. The experimental data were analyzed to determine if several different people may use WAPAST to analyze the same activity and achieve identical results. WAPAST requires the analyst to input data that will subsequently be used to calculate the total time to complete an activity. The input data are shown as Table 5.24.

Table 5.24. Work Measurement Data collected using WAPAST.

Subject	Application	Activities			
		Activity 1	Activity 2	Activity 3	Activity 4
S_{31}	1	1170	810	890	3220
S_{32}	1	1150	360	1060	5090
S_{33}	1	1160	710	910	3840
S_{34}	1	1140	790	990	4000
S_{35}	1	1100	780	1100	4880
S_{31}	2	630	720	1280	4000
S_{32}	2	2070	550	960	2900
S_{33}	2	1810	600	1080	3000
S_{34}	2	1900	680	1000	2650
S_{35}	2	1670	580	1200	3400

5.4.1.1. Test Procedure. To test the differences in the work measurement data collected in different time periods with WAPAST, a repeated measures ANOVA was conducted. The null hypothesis for this test is there is no difference among the means of the work measurement data for different time periods. In statistical terms, H_o: μ_1-μ_2=0. The source table is shown as Table 5.25.

Table 5.25 Repeated Measures ANOVA Source Table for Intra-Observer Reliability Analysis

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	G-G	H-F
Subject	4	341865.000	85466.250				
Applications	1	152522.500	152522.500	2.469	.1912	.1912	.'912
Applications * Subject	4	247115.000	61778.750				
activities	3	56065047.500	1.869E7	153.886	.0001	.0001	.0001
activities * Subject	12	1457315.000	121442.917				
Applications * activities	3	3027807.500	1009269.167	4.010	.0343	.1123	.1089
Applications * activities * Subject	12	3020305.000	251692.083				

Dependent: Total Time

5.4.1.2. Results. The F-ratios shown in Table 5.25 were considered and reveal no differences among the mean data collected for different time periods. From this analysis, the null hypothesis is accepted. The differences in time period data for WAPAST are plotted in Figure 5.5.

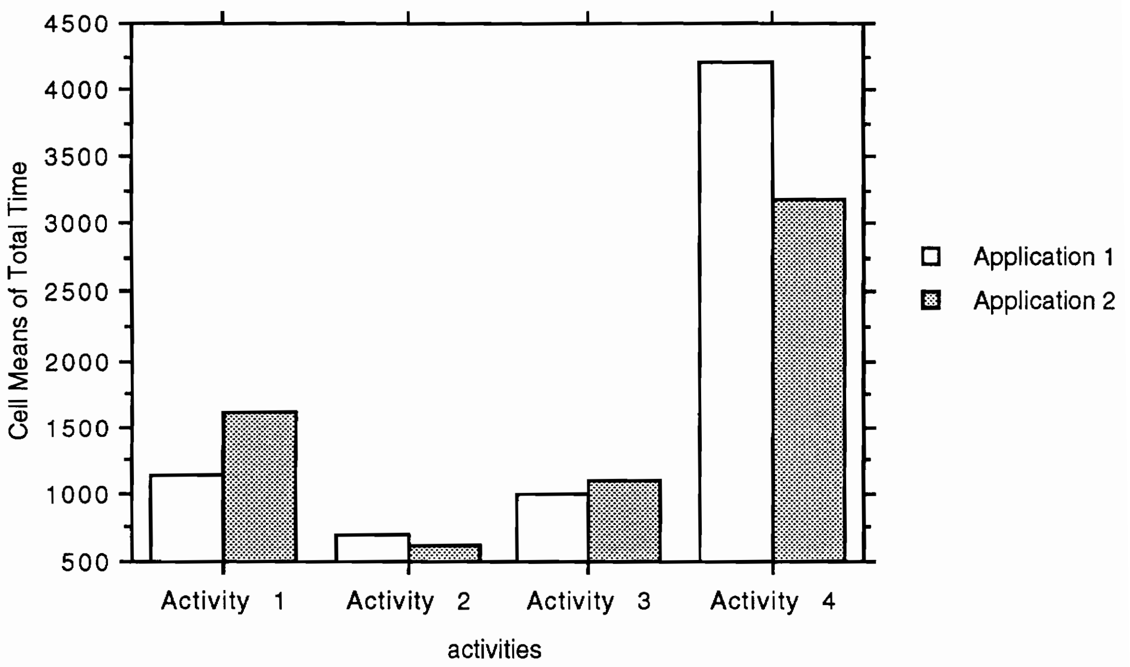

Figure 5.5. Graphical Representation of Mean Time for Activities per Application

5.4.1.3. Discussion. This analysis shows that the work measurement data collected using WAPAST are different between applications. The chart in Figure 5.5 shows that the mean times for activities 2 and 3 are approximately the same for both applications. For Activity 1, the time is are less for Application 1 than for Application 2. The reverse is true for Activity 4.

5.4.2. Postural Analysis

The seventh hypothesis to be tested concerns the intra-observer reliability of the postural data collected using WAPAST. The experimental data were analyzed to determine if several people may use WAPAST to analyze the same activity and achieve identical results. WAPAST requires the analyst to input data that will subsequently be used to identify action categories for different postures. The input data are shown as Table 5.26.

5.4.2.1. Test Procedure. Intra-observer reliability for postural data can be determined by comparing the Kappa and PI coefficients of one recording session with those of another. Each of the Kappa coefficients calculated for a given action category for the Application 1 can be compared with its counterpart in Application 2. Based on these comparisons, differences between Kappa coefficients may be determined. Similarly, the differences between PI coefficients may be determined. After the differences in these coefficients were calculated, Student t values were calculated to show the level of significance.

5.4.2.2. Results. Using the results in Tables 5.13 and 5.23, the differences in PI coefficients and Kappa coefficients were determined. Student t values were calculated for these differences and the significance determined. Results are presented in Tables 5.27 and 5.28.

Table 5.26. Action Categories as reported by the subjects

		Application 1											
		Activity 1			***Activity 2***			***Activity 3***			***Activity 4***		
Subj.	**Tool**	***arms***	***legs***	***back***	***arms***	***legs***	***back***	***arms***	***legs***	***back***	***arms***	***legs***	***back***
S_{31}	WAPAST	1	2	4	1	2	1	1	4	3	1	4	4
S_{32}	WAPAST	1	2	4	1	2	1	1	2	2	1	2	2
S_{33}	WAPAST	1	2	4	1	2	1	1	4	2	2	4	3
S_{34}	WAPAST	1	2	3	1	2	1	1	2	4	1	2	2
S_{35}	WAPAST	1	2	4	1	2	1	1	2	2	2	4	2
S_{11}	OWAS	1	2	2	1	2	1	1	2	2	1	3	3
S_{12}	OWAS	2	1	2	2	1	1	1	2	2	1	3	2
S_{13}	OWAS	1	2	2	1	2	1	1	2	2	1	3	2
S_{14}	OWAS	1	2	2	1	2	2	2	2	3	1	3	2
S_{15}	OWAS	1	2	3	1	2	1	1	2	2	1	2	2
MODE		1	2	2	1	2	1	1	2	2	1	3	2
		Application 2											
S_{31}	WAPAST	1	2	3	1	2	1	1	4	3	2	4	3
S_{32}	WAPAST	1	2	3	1	2	1	1	2	2	1	2	2
S_{33}	WAPAST	1	2	4	1	2	1	1	2	4	2	2	2
S_{34}	WAPAST	1	2	3	1	2	1	1	2	2	1	4	2
S_{35}	WAPAST	1	2	3	1	2	1	1	2	3	2	2	3
S_{11}	OWAS	2	3	3	2	2	1	1	3	3	1	2	3
S_{12}	OWAS	1	2	2	1	1	1	1	2	2	1	1	2
S_{13}	OWAS	1	2	2	1	2	1	1	2	2	1	2	2
S_{14}	OWAS	1	2	2	1	2	1	1	2	2	1	2	2
S_{15}	OWAS	1	2	2	1	2	1	2	2	2	1	2	2
MODE		1	2	2	1	2	1	1	2	2	1	2	2

Table 5.27 . Comparison of PI Coefficients Between Recording Sessions

Body Part	Difference
arms	0.0142
legs	-0.0308
back	0.0404
average	0.0238
t_s	0.018
p	> 0.20

Table 5.28 . Comparison of Kappa Coefficients Between Recording Sessions

Body Part	Difference
arms	-0.245
legs	0.191
back	0.026
average	-0.009
t_s	-0.346
p	>0.2

5.4.2.3. Discussion. The results of Tables 5.27 and 5.28 reveal no statistical significant change in agreement from the first recording session to the second. Therefore, the proficiency of WAPAST is maintained over a 14 day period.

CHAPTER 6. IMPLICATIONS OF THIS RESEARCH

Within industrial engineering are several areas, each of which focus on a portion of the entire system. With the growing need for a systems approach to management and operations, the different areas of industrial engineering must become more interrelated for the benefit of the organization being served. Though efforts have been made to develop a stronger relationship among areas of industrial engineering, some areas are still somewhat alien to one another. One example is the relationship between work measurement and biomechanics. Both of these areas have an aim of improving work activities—work measurement with the hope of increasing productivity; biomechanics (through posture recording and other techniques) with the hope of reducing RTDs. WAPAST, the tool developed in this research, is an attempt to bridge the gap between these two areas of industrial engineering. It is intended to be used in the same capacities as traditional work measurement tools; however, the addition of postural data should increase the value of the resulting information.

6.1. Output of Research

The output of this research is WAPAST, a computerized analysis and data collection tool to simultaneously determine the time taken, the method used, and the action categories for body positions used in B-Work. After data are input, subsequent calculations are performed and data are stored in a text file created by WAPAST. The time of the activity is calculated by summing the time of the individual tasks that comprise the activity. Therefore, there is a time estimate for each task, as well as the entire activity. Additionally, the analyst records the method by describing each task in sequence of occurrence. Posture is recorded by identifying the position of the back, the arms, and the legs, based on the percentage of time that the particular posture is assumed. Categories that determine the level of action required for these postures, based on the potential harm to the body, are identified and the highest one reported for each task.

The data collected by WAPAST will be used as a basis for decision making. These data can help formulate decisions regarding necessary changes in an activity based upon two of the three types of data collected using WAPAST—time and posture. If the total cycle time is greater than desired, one can identify the task(s) with the greatest time and take steps to reduce the times of these tasks. The postural data identify those tasks in which the body assumes postures that are potentially harmful to it. The higher action categories of 3 or 4 require more immediate attention than the lower ones, 1 or 2. Those tasks with action categories of 3 or 4 should be considered for possible change. Either of these scenarios may cause a change in the method of the task. Since the method is recorded using WAPAST, one can also utilize these data when instituting change.

6.2. Conclusions

The major expectation of this research was that this tool will help bridge the gap between two important aspects of industrial engineering—work measurement and biomechanics. Prior to this effort, there is no documented attempt to combine the data resulting from work measurement, methods engineering, and posture recording activities. This is a novel application, and provides valuable lessons for future extensions or attempts at posture recording in conjunction with work measurement and methods engineering.

WAPAST was developed to simultaneously collect work measurement, methods engineering, and postural data. However, this objective was not met. The work measurement data are accurate and reliable. To the contrary, the postural data are not.

6.3. Recommendations for Future Research

Because WAPAST does not meet its original objective, there are several recommendations for future research. First, the cause of the overrated postural data should be investigated. The first consideration should be the addition of a feature that would enable the analyst to record multiple body postures for each phase of the task. This should reduce some of the error of body postures.

Second, WAPAST can only be used to analyze a portion of B-Work activities, those that can be considered as a combination of general and controlled moves. This was an initial constraint of the tool that reduces its usefulness. As a future research endeavor, WAPAST should be extended to include work tasks that require the use of a tool.

Next, there are design changes to WAPAST that should be considered. Specifically, the code of WAPAST should be revised to enable the analyst to manipulate data after leaving a particular screen. This will allow the analyst to make any changes to the data that may be realized later in the analysis process. Besides, changes should be made to the WAPAST code that will provide a reminder to the analyst of the task he/she is analyzing. This will be beneficial, especially if the activity has many tasks.

Finally, the experiment should be replicated multiple times to re-test the accuracy, complexity, and reliability of WAPAST. With each replication, activities that are similar in composition should be tested as a group. For example, repetitive, short-cycled tasks, long-cycled tasks, and tasks that are not repetitive in nature. Analysis of these data may determine which type of activities are best suited for analysis by WAPAST.

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APPENDICES

APPENDIX A. GLOSSARY OF TERMS

abduction—an anatomical term related to movement that means movement away from the mid-line; rotate out (upward).

action distance [A] (Zandin, 1980, p. 16)—A parameter for the sequence models of MOST that "covers all spatial movement or actions of the fingers, hands, and/or feet, either loaded or unloaded."

adduction—an anatomical term related to movement that means movement toward the mid-line; rotate in (down).

align [I] (Zandin, 1980, p. 37)—A parameter for the controlled move sequence model that "refers to manual actions following the controlled move or at the conclusion of process time to achieve the alignment of objects.

body motion [B] (Zandin, 1980, p. 16)—A parameter for the sequence models of MOST that "refers to either vertical (up and down) motions of the body or the actions necessary to overcome an obstruction or impairment to body movement."

cartoner—a machine that opens flattened cartons into a usable shape, places pre-filled bottles of medicine into them, and seals the cartons.

extension—an anatomical term related to movement that means an increase in the angle formed by two bones.

flexion—an anatomical term related to movement that means a decrease in the angle formed by two bones.

gain control [G] (Zandin, 1980, p. 16)—A parameter for the sequence models of MOST that "covers all manual motions (mainly finger, hand, and foot) employed to obtain complete manual control of an object(s) and to subsequently relinquish that control. The G parameter can include one or several short-move motions whose objective is to gain full control f the object(s) before it is to be moved to another location."

job analysis (Niebel, 1993, p. 319)—"a procedure for making a careful appraisal of each job and then recording the details of the work so that it can be evaluated fairly by a trained analyst."

methods engineering (Niebel, 1993, p. 7)—"the systematic, close scrutiny of all direct and indirect operations to find improvements, making work easier to perform and allowing work to be done in less time with less investment per unit."

move controlled [M] (Zandin, 1980, p. 37)—A parameter for the Controlled Move Sequence model that "covers all manually guided movements or actions of an object over a controlled path.

performance rating (Niebel, 1993; Zandin, 1980)—the measure of performance determined by comparing the pace of the worker observed to an ideal, imaginary, average worker at a level of 100% of effort and skill .

place [P] (Zandin, 1980, p. 19)—"A parameter of the general move that refers to actions at the final sage of an object's displacement to align, orient, and/or engage the object with another object(s) before control of the object is relinquished."

predetermined motion time systems (PMTS) (Karger and Bayha, 1987)—"...an organized body of information, procedures, and techniques employed in the study and evaluation of work elements performed by human power in terms of the method or motions used, their general and specific nature, the conditions under which they occur, and the application of prestandard or predetermined times which their performance requires."

predetermined times (Turner, Mize, and Case, 1987)—time values assigned to the basic elements of tasks that can be summed to determine the total time required.

process time [X] (Zandin, 1980, p. 37)—A parameter of the controlled move that "occurs as that portion of work controlled by processes or machines and not by manual actions."

pronation—an anatomical term related to movement that means rotation of the forearm away from anatomical position, i.e. palm is down.

supination—an anatomical term related to movement that means rotation of the forearm toward anatomical position, i.e. palm is up.

system (Blanchard and Fabrycky, 1990, pp. 1-2)—"...an assemblage or combination of elements or parts forming a complex or unitary whole such as a river system or a transportation system; any assemblage or set of correlated members such as a system or currency; an ordered and comprehensive assemblage of facts, principles, or doctrines in a particular field of knowledge or thought, such as a system of philosophy; a coordinated body of methods or a complex scheme or plan of procedure, such as a system of organization and management; any regular or special method of plan or procedure, such as a system of marking, numbering, or measuring."

work (Beruvides and Koelling, 1993, p. 230)—"a classification of possible states that can be included in a worker's day. It consists of three forms:

"B-Work is all work of a manual or physical nature whose output is clearly definable or tangible, and whose inputs are clearly definable and directly influential in the output produced with no discretion (or little) permitted in the job task. Job task pursuits and tool use needs can best be described as process and project levels on the uncertainty scale; endeavors are functional and operational; decisions are structured; and stages of maturity can be described in the visibility to control level.

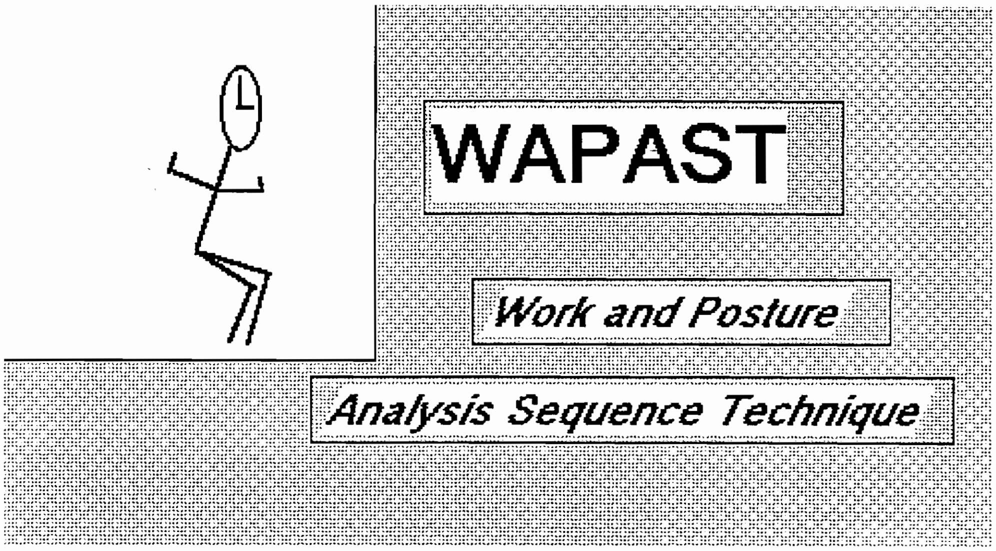
"W-Work is all work of any nature whose output is composed mainly of tangible factors, and whose inputs are definable and directly influential in the output produced, with little or no discretion in the job task. Job task pursuits and tool use needs can best be described as process, project, and program levels on the uncertainty scale; endeavors are operational to tactical; decisions are structured as well as semi-structured; and stages of maturity can be described in the visibility to control level.

"K-Work is all work of any nature whose output is composed of some tangible factors but is mainly of an intangible nature, and whose inputs are not as clearly definable and may be influential in the output produced, with substantially high discretion permitted in the job task. Job task pursuits and tool use needs can best be described as program, problem, and perplexity levels on the uncertainty scale; endeavors are tactical and strategic; decisions are mainly semi-structured to unstructured; and stages of maturity is all work of any nature whose output is composed of some tangible factors but is mainly of an intangible nature, and whose inputs are not as clearly definable and may be influential in the output produced, with substantially high discretion permitted in the job task. Job task pursuits and tool use needs can best be described as program, problem, and perplexity levels on the uncertainty scale; endeavors are tactical and strategic; decisions are mainly semi-structured to unstructured; and stages of maturity can be described in the control to optimization level."

work measurement (Turner, Mize, and Case, 1987)—the timing of individual operations to measure organizational efficiency.

Appendix B. Code for WAPAST

```
Global TskTMU As Integer         'TMU for the task
Global TMU As Integer            'Total number of time motion units
Global A1 As Integer             'A subscript - get phase
Global B1 As Integer             'B subscript - get phase
Global G1 As Integer             'G subscript - get phase
Global A2 As Integer             'A subscript - put phase
Global B2 As Integer             'B subscript - put phase
Global P1 As Integer             'P subscript - put phase
Global A3 As Integer             'A subscript - return phase
Global M1 As Integer             'M subscript - put phase
Global X1 As Integer             'X subscript - put phase
Global I1 As Integer             'I subscript - put phase
Global Rms1 As Integer           'Arms posture for action distance - get phase
Global Rms2 As Integer           'Arms posture for gain control - get phase
Global Rms3 As Integer           'Arms posture for action distance - put phase
Global Rms4 As Integer           'Arms posture for place - put phase
Global Rms5 As Integer           'Arms posture for action distance - return phase
Global Rms6 As Integer           'Arms posture for move controlled
Global Rms7 As Integer           'Arms posture for align object
Global Bck1 As Integer           'Back posture for vertical body motion - get phase
Global Bck2 As Integer           'Back posture for vertical body motion - put phase
Global Lgs1 As Integer           'Legs posture for action distance - get phase
Global Lgs2 As Integer           'Legs posture for gain control - get phase
Global Lgs3 As Integer           'Legs posture for action distance - return phase
Global Org As String             'Name of organization.
Global DateID As String           'Date of study.
Global TimeID As String           'Time of study.
Global Dept As String            'Department that activity takes place.
Global WArea As String           'Work area in which activity occurs.
Global Analyst As String         'Analyst's identification.
Global Act As String             'Activity description.
Global T As String               'Number of Tasks
Global N As Integer              'Number of Tasks (numerical)
Global Tsk(100) As String        'Task identification
Global ActCat(100) As Integer    'Action category for posture.
Global TaskID As String          'Task ID
Global Mve As Integer            'Move identification.
Global Const file$ = "WAPAST.TXT"   'Data file storage
Global AMax As Integer           'Max arm action category
Global BMax As Integer           'Max back action category
Global LMax As Integer           'Max leg action category
Global Rep As Integer            'Number of consecutive repetitions for a task.
```




```
'Remove the title form and replace with the author form
Sub Form_dblClick ()
   Unload Title
   Author.Show
End Sub
```

developed by:

Walthea V. Yarbrough-Churn

Ph. D. Candidate

Industrial and Systems Engineering

Virginia Polytechnic Institute and State University

Blacksburg, Virginia

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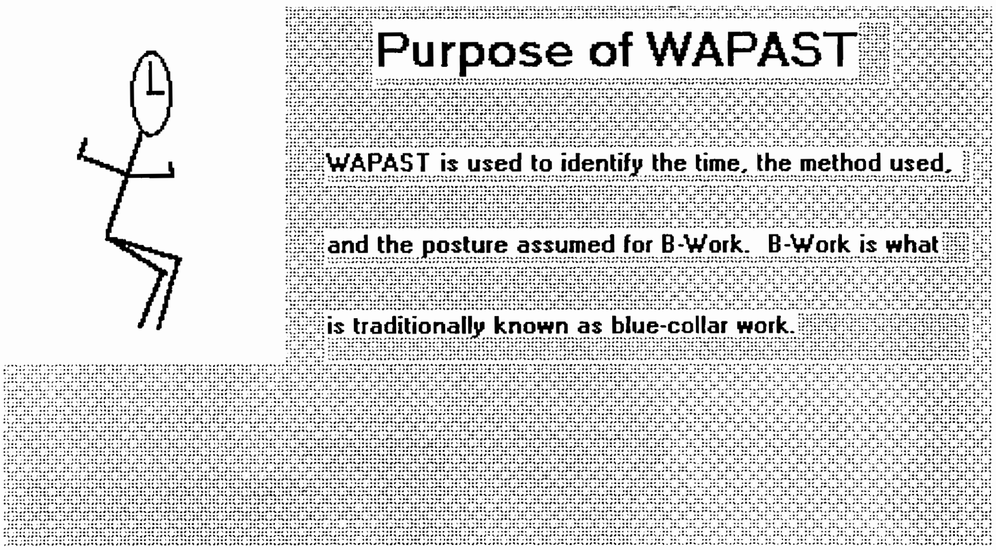
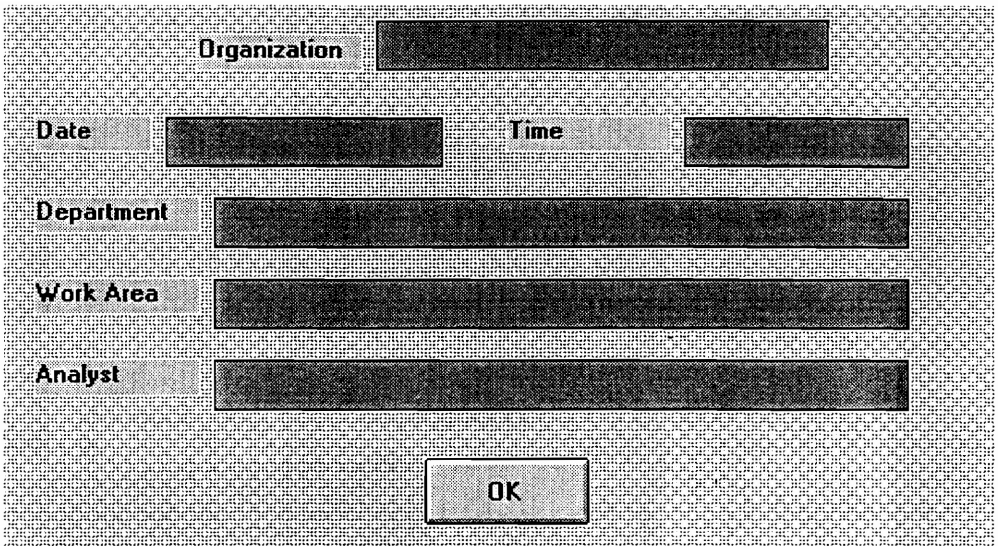
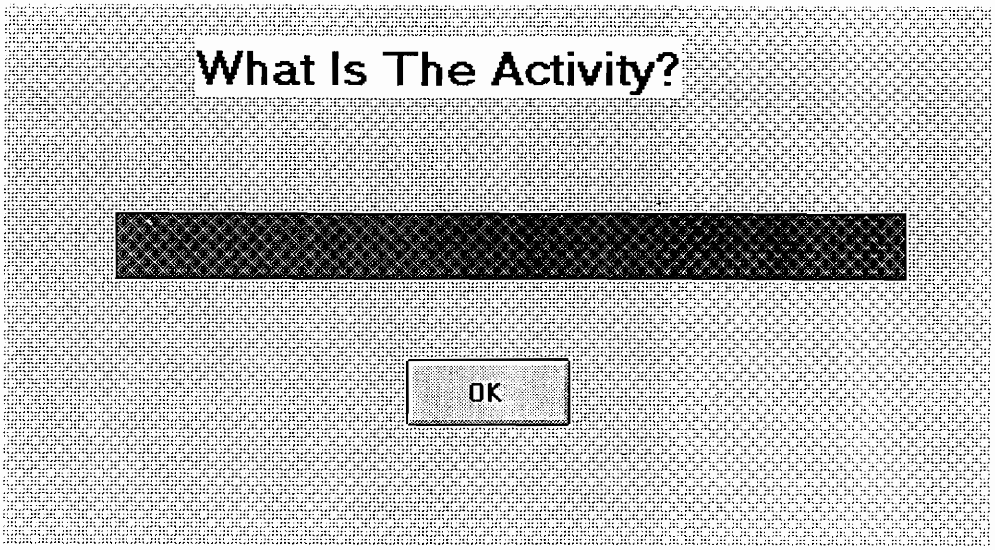
```
'Remove the author form and replace with the purpose form.
Sub Form_DblClick ()
    Unload Author
    Purpose.Show
End Sub
```



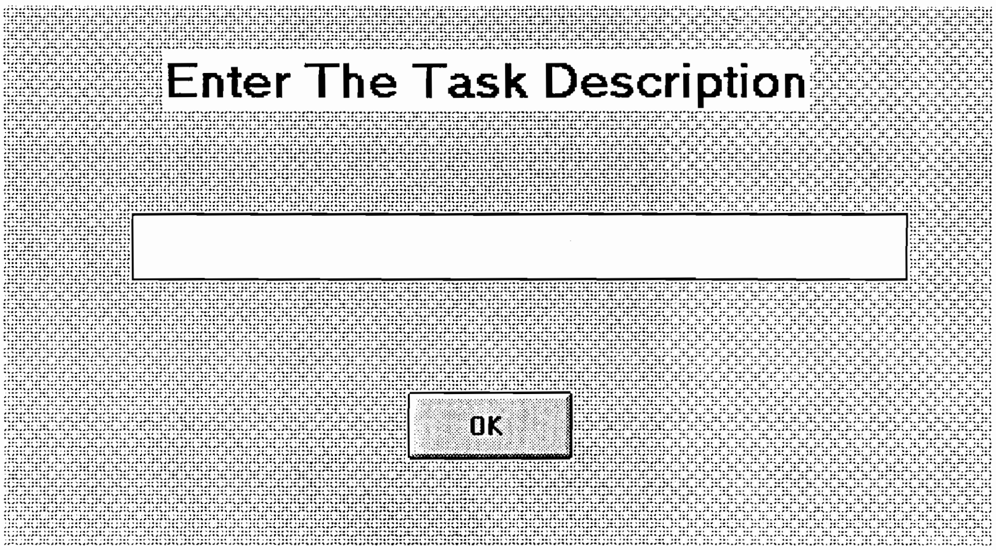

```
Sub Form_dblClick ()
    Unload Purpose
    Tracking.Show
End Sub
```



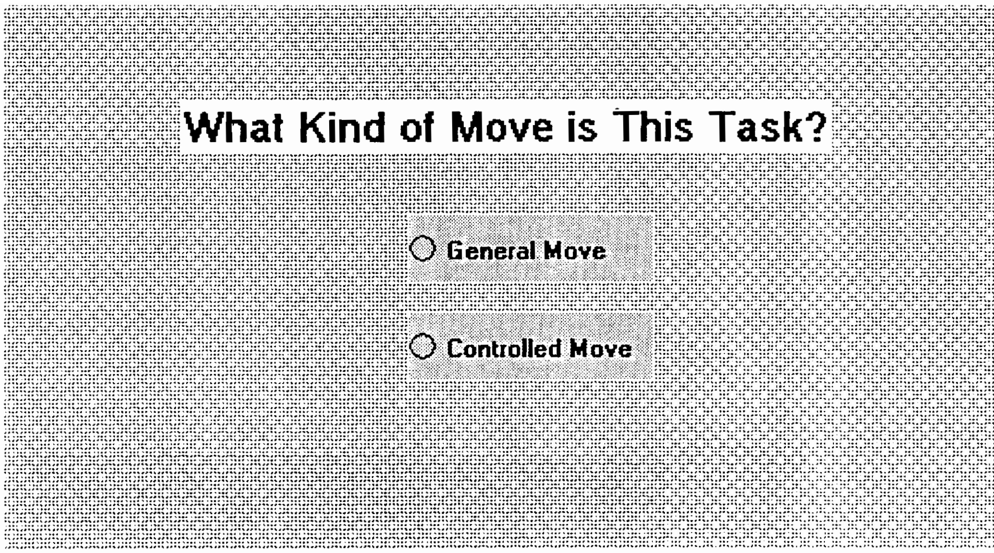

```
Sub OrgName_Change ()
    Org = OrgName.Text
End Sub

Sub SDate_Change ()
    SDate.Text = Date$
    DateID = SDate.Text
End Sub

Sub STime_Change ()
    STime.Text = Time$
    TimeID = STime.Text
End Sub

Sub DeptName_Change ()
    Dept = DeptName.Text
End Sub

Sub WAreaName_Change ()
    WArea = WAreaName.Text
End Sub

Sub AnalID_Change ()
    Analyst = AnalID.Text
End Sub

Sub OK_Click ()
    Open file$ For Append As #1
        Print #1, Org
        Print #1, DateID, TimeID
        Print #1, Dept
        Print #1, WArea
        Print #1, Analyst
    Close #1
    Unload Tracking
    Activity.Show
End Sub
```



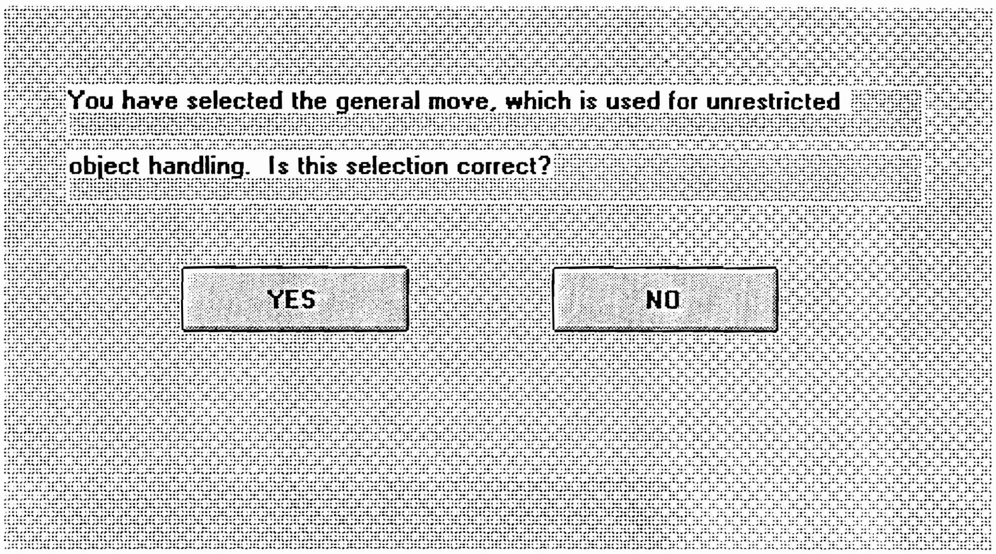

```
Sub Desc_Change ()
    Act = Desc.Text
End Sub

Sub OK_Click ()
    Open file$ For Append As #1
        Print #1, Act
    Close #1
    Unload Activity
    TskList.Show
End Sub
```



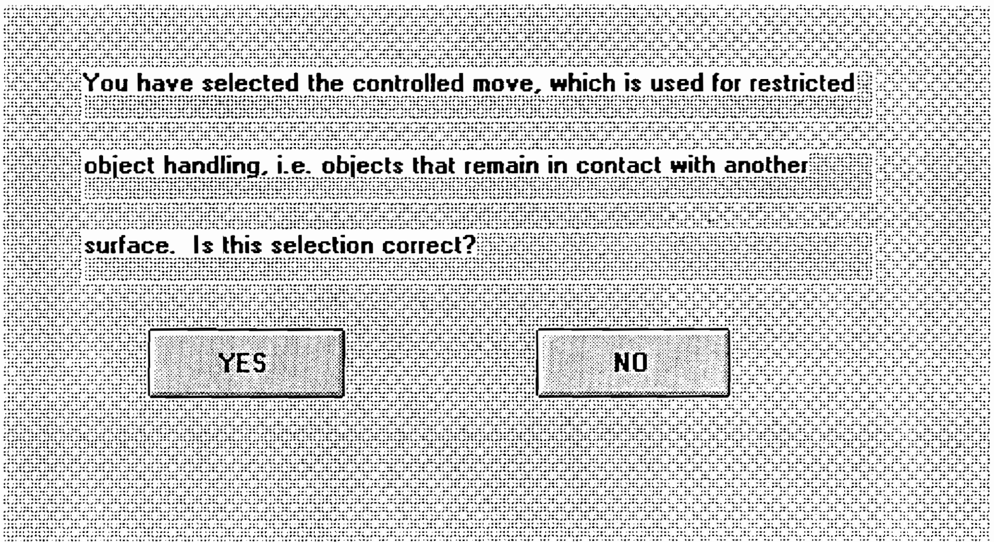

```
Sub Tsk_Change ()
    TaskID = Tsk.Text
End Sub

Sub OK_Click ()
    Unload TskList
    Task.Show
End Sub
```



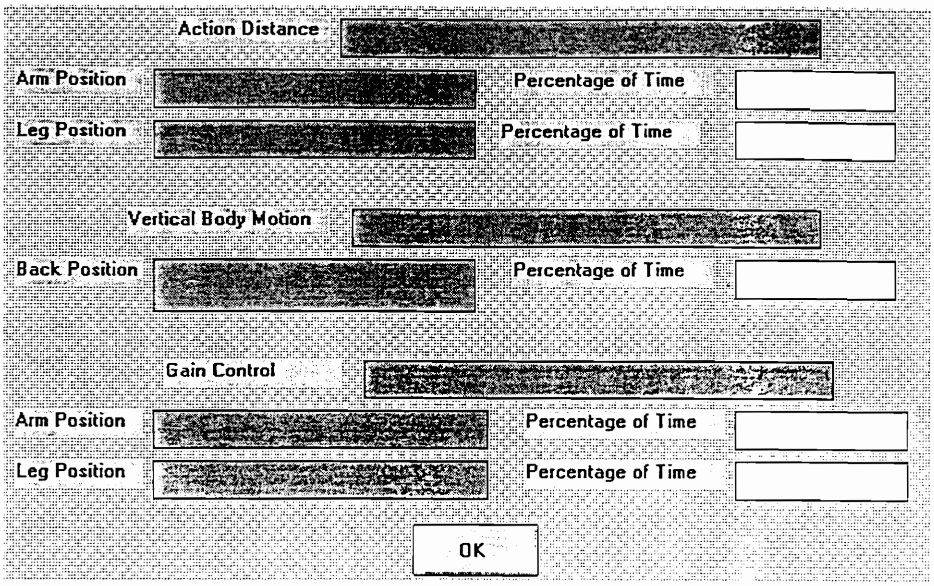

```
Sub MoveType_DblClick (Index As Integer)
    Select Case Index
        Case 0
            Unload Task
            GMove.Show
        Case 1
            Unload Task
            CMove.Show
    End Select

End Sub
```




```
Sub Yes_Click ()
    'Go to the Get Phase form
    Unload GMove
    Mve = 1            'General Move
    GetPhase.Cls
    GetPhase.Show
End Sub

Sub No_Click ()
    'Go to the move selection form
    Unload GMove
    Task.Show
End Sub
```




```
Sub Yes_Click ()
    'Go to Get Phase form.
    Unload CMove
    Mve = 2      'Controlled Move
    GetPhase.Cls
    GetPhase.Show
End Sub

Sub No_Click ()
    'Go to move selection form.
    Unload CMove
    Task.Show
End Sub
```




```
Dim A As Integer, L As Integer, B As Integer, X As Integer, Y As Integer
Dim Decision(100) As Integer             'Decision Number for action categories
Dim Trans(100) As String

'Identify the action distance and the A subscript in the get phase.
Sub Dist_Click (Index As Integer)
    Select Case Index
        Case 0
            ADis.Text = "<= 2 inches"
            A1 = 0
        Case 1
            ADis.Text = "within reach"
            A1 = 1
        Case 2
            ADis.Text = "1 to 2 steps"
            A1 = 3
        Case 3
            ADis.Text = "3 to 4 steps"
            A1 = 6
            TMU = A1
        Case 4
            ADis.Text = "5 to 7 steps"
            A1 = 10
        Case 5
            ADis.Text = "8 to 10 steps"
            A1 = 16
    End Select
End Sub
```

```
'Identify the vertical body motion and the B subscript in the get phase
Sub VBM_Click (Index As Integer)
    Select Case Index
        Case 0
            VBMtion.Text = "None"
            B1 = 0
        Case 1
            VBMtion.Text = "bend & arise (50% occurrence)"
            B1 = 3
        Case 2
            VBMtion.Text = "bend and arise"
            B1 = 6
        Case 3
            VBMtion.Text = "sit or stand"
            B1 = 10
        Case 4
            VBMtion.Text = "through door"
            B1 = 16
        Case 5
            VBMtion.Text = "through door"
            B1 = 16
    End Select
End Sub

'Identify the type of object and the G subscript in the get phase.
Sub GnCntrl_Click (Index As Integer)
    Select Case Index
        Case 0
            GainCon.Text = "light object"
            G1 = 1
        Case 1
            GainCon.Text = "light objects simultaneously"
            G1 = 1
        Case 2
            GainCon.Text = "non-simultaneously"
            G1 = 3
        Case 3
            GainCon.Text = "heavy or bulky"
            G1 = 3
        Case 4
            GainCon.Text = "blind or obstructed"
            G1 = 3
        Case 5
            GainCon.Text = "disengaged"
            G1 = 3
        Case 6
            GainCon.Text = "interlocked"
            G1 = 3
        Case 7
            GainCon.Text = "collect"
            G1 = 3
    End Select
End Sub
```

```
'Calculate the time and indentify the body posture.
'
Sub OK_Click ()
    TMU = 0
    AMax = 0
    BMax = 0
    LMax = 0
    Rms1 = ActCat(1)
    If Rms1 > AMax Then AMax = Rms1 Else AMax = AMax
    Rms2 = ActCat(4)
    If Rms2 > AMax Then AMax = Rms2 Else AMax = AMax
    Bck1 = ActCat(3)
    If Bck1 > BMax Then BMax = Bck1 Else BMax = BMax
    Lgs1 = ActCat(2)
    If Lgs1 > LMax Then LMax = Lgs1 Else LMax = LMax
    Lgs2 = ActCat(5)
    If Lgs2 > LMax Then LMax = Lgs1 Else LMax = LMax
    Unload GetPhase
    If Mve = 1 Then
        PutPhase.Cls
        PutPhase.Show
    Else
        MvActPhase.Cls
        MvActPhase.Show
    End If
End Sub

'Identify the position of the arms with the action distance
Sub APos_Click (Index As Integer)
    Select Case Index
        Case 0
            A = 0
            ArmPos(0).Text = "both arms below shoulder level"
        Case 1
            A = 1
            ArmPos(0).Text = "one arm at or above shoulder level"
        Case 2
            A = 2
            ArmPos(0).Text = "both arms at or above shoulder level"
    End Select
End Sub
```

```
'Input the percentage of time that one is in a given position and
identify the action category associated with it
'
Sub PercTime_Change (Index As Integer)
    Select Case Index
        Case 0                      'Percentage for arm with action distance
            Trans(1) = PercTime(0).Text
            Decision(1) = Val(Trans(1))
            If A = 0 Then
                ActCat(1) = 1
            ElseIf A = 1 Then
                If Decision(1) <= 25 Then
                    ActCat(1) = 1
                ElseIf 25 < Decision(1) And Decision(1) <= 75 Then
                    ActCat(1) = 2
                ElseIf 75 < Decision(1) And Decision(1) <= 100 Then
                    ActCat(1) = 3
                End If
            ElseIf A = 2 Then
                If Decision(1) <= 18 Then
                    ActCat(1) = 1
                ElseIf 18 < Decision(1) And Decision(1) <= 68 Then
                    ActCat(1) = 2
                ElseIf 68 < Decision(1) And Decision(1) <= 100 Then
                    ActCat(1) = 3
                End If
            End If
```

```
Case 1                        'Percentage for leg with action distance
     Trans(2) = PercTime(1).Text
     Decision(2) = Val(Trans(2))
     If L = 0 Then
         If Decision(2) <= 81 Then
             ActCat(2) = 1
         Else ActCat(2) = 2
         End If
     ElseIf L = 1 Then
         If Decision(2) <= 25 Then
             ActCat(2) = 1
         ElseIf 25 < Decision(2) And Decision(2) <= 75 Then
             ActCat(2) = 2
         ElseIf 75 < Decision(2) And Decision(2) <= 100 Then
             ActCat(2) = 3
         End If
     ElseIf L = 2 Then
         If Decision(2) <= 5 Then
             ActCat(2) = 1
         ElseIf 5 < Decision(2) And Decision(2) <= 25 Then
             ActCat(2) = 2
         ElseIf 25 < Decision(2) And Decision(2) <= 65 Then
             ActCat(2) = 3
         ElseIf 65 < Decision(2) And Decision(2) <= 100 Then
             ActCat(2) = 4
         End If
     ElseIf L = 3 Then
         If Decision(2) <= 5 Then
             ActCat(2) = 1
         ElseIf 5 < Decision(2) And Decision(2) <= 25 Then
             ActCat(2) = 2
         ElseIf 25 < Decision(2) And Decision(2) <= 65 Then
             ActCat(2) = 3
         ElseIf 65 < Decision(2) And Decision(2) <= 100 Then
             ActCat(2) = 4
         End If
     ElseIf L = 4 Then
         If Decision(2) <= 15 Then
             ActCat(2) = 1
         ElseIf 15 < Decision(2) And Decision(2) <= 44 Then
             ActCat(2) = 2
         ElseIf 44 < Decision(2) And Decision(2) <= 100 Then
             ActCat(2) = 4
         End If
     ElseIf L = 5 Then
         If Decision(2) <= 78 Then
             ActCat(2) = 1
         Else ActCat(2) = 2
         End If
     End If
```

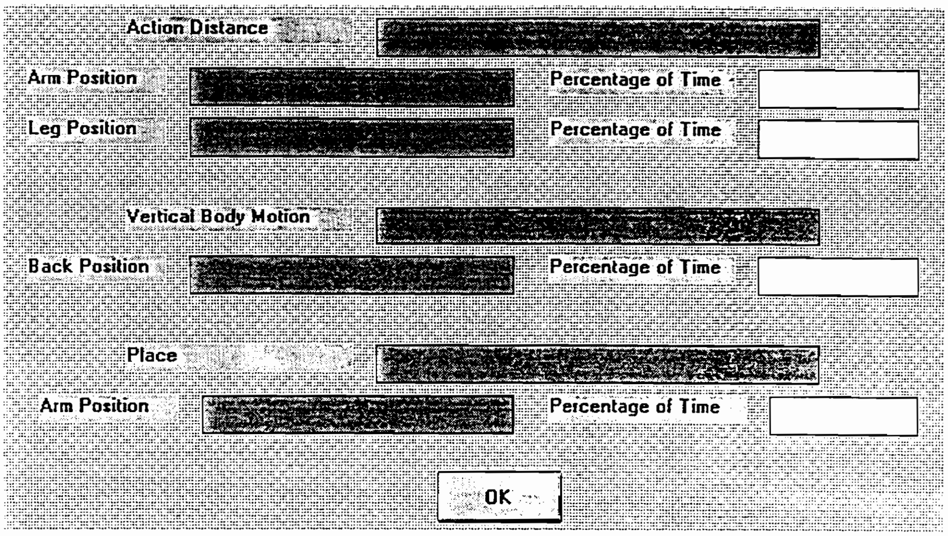
```
Case 2                          'Percentage for back with vertical body motion.
     Trans(3) = PercTime(2).Text
     Decision(3) = Val(Trans(3))
     If B = 0 Then
         ActCat(3) = 1
     ElseIf B = 1 Then
         If Decision(3) <= 25 Then
             ActCat(3) = 1
         ElseIf 25 < Decision(3) And Decision(3) >= 75 Then
             ActCat(3) = 2
         ElseIf 75 < Decision(3) And Decision(3) <= 100 Then
             ActCat(3) = 3
         End If
     ElseIf B = 2 Then
         If Decision(3) <= 18 Then
             ActCat(3) = 1
         ElseIf 18 < Decision(3) And Decision(3) <= 38 Then
             ActCat(3) = 2
         ElseIf 38 < Decision(3) And Decision(3) <= 100 Then
             ActCat(3) = 3
         End If
     ElseIf B = 3 Then
         If Decision(3) <= 5 Then
             ActCat(3) = 1
         ElseIf 5 < Decision(3) And Decision(3) <= 25 Then
             ActCat(3) = 2
         ElseIf 25 < Decision(3) And Decision(3) <= 65 Then
             ActCat(3) = 3
         ElseIf 65 < Decision(3) And Decision(3) <= 100 Then
             ActCat(3) = 4
         End If
     End If
```

```
Case 3                              'Percentage for arms with gain control
     Trans(4) = PercTime(3).Text
     Decision(4) = Val(Trans(4))
     If X = 0 Then
          ActCat(4) = 1
     ElseIf X = 1 Then
          If Decision(4) <= 25 Then
               ActCat(4) = 1
          ElseIf 25 < Decision(4) And Decision(4) <= 75 Then
               ActCat(4) = 2
          ElseIf 75 < Decision(4) And Decision(4) <= 100 Then
               ActCat(4) = 3
          End If
     ElseIf X = 2 Then
          If Decision(4) <= 18 Then
               ActCat(4) = 1
          ElseIf 18 < Decision(4) And Decision(4) <= 68 Then
               ActCat(4) = 2
          ElseIf 68 < Decision(4) And Decision(4) <= 100 Then
               ActCat(4) = 3
          End If
    End If
```

```
    Case 4                        'Percentage of leg position with gain control.
        Trans(5) = PercTime(4).Text
        Decision(5) = Val(Trans(5))
        If Y = 0 Then
            If Decision(5) <= 81 Then
                ActCat(5) = 1
            Else ActCat(5) = 2
            End If
        ElseIf Y = 1 Then
            If Decision(5) <= 25 Then
                ActCat(5) = 1
            ElseIf 25 < Decision(5) And Decision(5) <= 75 Then
                ActCat(5) = 2
            ElseIf 75 < Decision(5) And Decision(5) <= 100 Then
                ActCat(5) = 3
            End If
        ElseIf Y = 2 Then
            If Decision(5) <= 5 Then
                ActCat(5) = 1
            ElseIf 5 < Decision(5) And Decision(5) <= 25 Then
                ActCat(5) = 2
            ElseIf 25 < Decision(5) And Decision(5) <= 65 Then
                ActCat(5) = 3
            ElseIf 65 < Decision(5) And Decision(5) <= 100 Then
                ActCat(5) = 4
            End If
        ElseIf Y = 3 Then
            If Decision(5) <= 5 Then
                ActCat(5) = 1
            ElseIf 5 < Decision(5) And Decision(5) <= 25 Then
                ActCat(5) = 2
            ElseIf 25 < Decision(5) And Decision(5) <= 65 Then
                ActCat(5) = 3
            ElseIf 65 < Decision(5) And Decision(5) <= 100 Then
                ActCat(5) = 4
            End If
        ElseIf Y = 4 Then
            If Decision(5) <= 15 Then
                ActCat(5) = 1
            ElseIf 15 < Decision(5) And Decision(5) <= 44 Then
                ActCat(5) = 2
            ElseIf 44 < Decision(5) And Decision(5) <= 100 Then
                ActCat(5) = 4
            End If
        ElseIf Y = 5 Then
            If Decision(5) <= 78 Then
                ActCat(5) = 1
            Else ActCat(5) = 2

            End If
        End If
    End Select
End Sub
```

```
'Identify the position of legs with action distance.
Sub LPos_Click (Index As Integer)
    Select Case Index
        Case 0
            L = 0
            LegPos(0).Text = "standing with both legs straight"
        Case 1
            L = 1
            LegPos(0).Text = "Standing with one leg straight"
        Case 2
            L = 2
            LegPos(0).Text = "both knees bent"
        Case 3
            L = 3
            LegPos(0).Text = "one knee bent"
        Case 4
            L = 4
            LegPos(0).Text = "kneeling"
        Case 5
            L = 5
            LegPos(0).Text = "walking"
    End Select
End Sub

'Identify position of arms with gain control.
Sub GAPos_Click (Index As Integer)
    Select Case Index
        Case 0
            X = 0
            ArmPos(1).Text = "both arms below shoulder level"
        Case 1
            X = 1
            ArmPos(1).Text = "one arm at or above shoulder level"
        Case 2
            X = 2
            ArmPos(1).Text = "both arms at or above shoulder level"
    End Select
End Sub
```

```
'Identify position of legs with gain control
Sub GLPos_Click (Index As Integer)
    Select Case Index
        Case 0
            Y = 0
            LegPos(1).Text = "standing with both legs straight"
        Case 1
            Y = 1
            LegPos(1).Text = "Standing with one leg straight"
        Case 2
            Y = 2
            LegPos(1).Text = "both knees bent"
        Case 3
            Y = 3
            LegPos(1).Text = "one knee bent"
        Case 4
            Y = 4
            LegPos(1).Text = "kneeling"
        Case 5
            Y = 5
            LegPos(1).Text = "walking"
    End Select
End Sub

'Identify position of back with vertical body motion.
Sub BPos_Click (Index As Integer)
    Select Case Index
        Case 0
            B = 0
            BackPos.Text = "straight"
        Case 1
            B = 1
            BackPos.Text = "bent forward"
        Case 2
            B = 2
            BackPos.Text = "twisted"
        Case 3
            B = 3
            BackPos.Text = "bent and twisted"
    End Select
End Sub
```




```
Dim A As Integer, L As Integer, B As Integer, X As Integer, Y As Integer
Dim Decision(100) As Integer            'Decision Number for action categories
Dim Trans(100) As String


'Input the percentage of time that one is in a given position and
'identify the action category associated with it.
'
Sub TimePerc_Change (Index As Integer)
    Select Case Index
        Case 0                          'Percentage for arm with action distance
            Trans(1) = TimePerc(0).Text
            Decision(1) = Val(Trans(1))
            If A = 0 Then
                ActCat(6) = 1
            ElseIf A = 1 Then
                If Decision(1) <= 25 Then
                    ActCat(6) = 1
                ElseIf 25 < Decision(1) And Decision(1) <= 75 Then
                    ActCat(6) = 2
                ElseIf 75 < Decision(1) And Decision(1) <= 100 Then
                    ActCat(6) = 3
                End If
            ElseIf A = 2 Then
                If Decision(1) <= 18 Then
                    ActCat(6) = 1
                ElseIf 18 < Decision(1) And Decision(1) <= 68 Then
                    ActCat(6) = 2
                ElseIf 68 < Decision(1) And Decision(1) <= 100 Then
                    ActCat(6) = 3
                End If
           End If
```

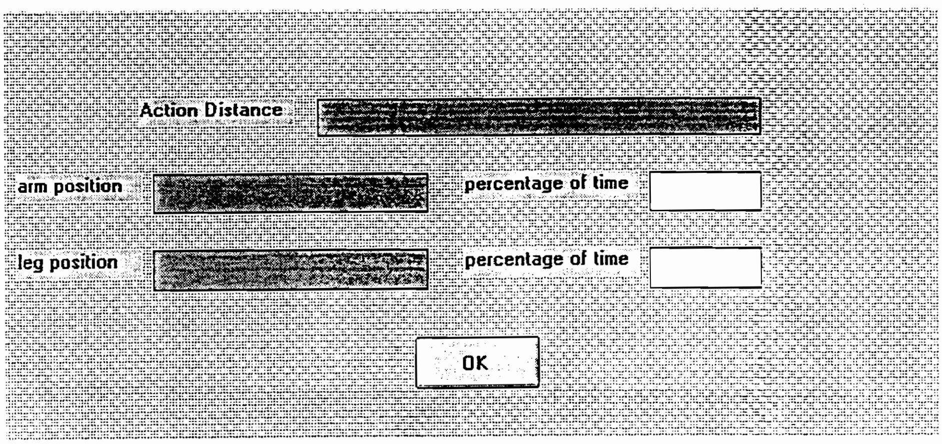
```
Case 1                         'Percentage for leg with action distance
     Trans(2) = TimePerc(1).Text
     Decision(2) = Val(Trans(2))
     If L = 0 Then
         If Decision(2) <= 81 Then
             ActCat(7) = 1
         Else ActCat(7) = 2
         End If
     ElseIf L = 1 Then
         If Decision(2) <= 25 Then
             ActCat(7) = 1
         ElseIf 25 < Decision(2) And Decision(2) <= 75 Then
             ActCat(7) = 2
         ElseIf 75 < Decision(2) And Decision(2) <= 100 Then
             ActCat(7) = 3
         End If
     ElseIf L = 2 Then
         If Decision(2) <= 5 Then
             ActCat(7) = 1
         ElseIf 5 < Decision(2) And Decision(2) <= 25 Then
             ActCat(7) = 2
         ElseIf 25 < Decision(2) And Decision(2) <= 65 Then
             ActCat(7) = 3
         ElseIf 65 < Decision(2) And Decision(2) <= 100 Then
             ActCat(7) = 4
         End If
     ElseIf L = 3 Then
         If Decision(2) <= 5 Then
             ActCat(7) = 1
         ElseIf 5 < Decision(2) And Decision(2) <= 25 Then
             ActCat(7) = 2
         ElseIf 25 < Decision(2) And Decision(2) <= 65 Then
             ActCat(7) = 3
         ElseIf 65 < Decision(2) And Decision(2) <= 100 Then
             ActCat(7) = 4
         End If
     ElseIf L = 4 Then
         If Decision(2) <= 15 Then
             ActCat(7) = 1
         ElseIf 15 < Decision(2) And Decision(2) <= 44 Then
             ActCat(7) = 2
         ElseIf 44 < Decision(2) And Decision(2) <= 100 Then
             ActCat(7) = 4
         End If

     ElseIf L = 5 Then
         If Decision(2) <= 78 Then
             ActCat(7) = 1
         Else ActCat(7) = 2
         End If
     End If
```

```
        Case 2                          'Percentage for back with vertical body motion.
             Trans(3) = TimePerc(2).Text
             Decision(3) = Val(Trans(3))
             If B = 0 Then
                 ActCat(8) = 1
             ElseIf B = 1 Then
                 If Decision(3) <= 25 Then
                     ActCat(8) = 1
                 ElseIf 25 < Decision(3) And Decision(3) >= 75 Then
                     ActCat(8) = 2
                 ElseIf 75 < Decision(3) And Decision(3) <= 100 Then
                     ActCat(8) = 3
                 End If
             ElseIf B = 2 Then
                 If Decision(3) <= 18 Then
                     ActCat(8) = 1
                 ElseIf 18 < Decision(3) And Decision(3) <= 38 Then
                     ActCat(8) = 2
                 ElseIf 38 < Decision(3) And Decision(3) <= 100 Then
                     ActCat(8) = 3
                 End If
             ElseIf B = 3 Then
                 If Decision(3) <= 5 Then
                     ActCat(8) = 1
                 ElseIf 5 < Decision(3) And Decision(3) <= 25 Then
                     ActCat(8) = 2
                 ElseIf 25 < Decision(3) And Decision(3) <= 65 Then
                     ActCat(8) = 3
                 ElseIf 65 < Decision(3) And Decision(3) <= 100 Then
                     ActCat(8) = 4
                 End If
             End If
        Case 3                          'Percentage for arms with place
             Trans(4) = TimePerc(3).Text
             Decision(4) = Val(Trans(4))
             If X = 0 Then
                 ActCat(9) = 1
             ElseIf X = 1 Then
                 If Decision(4) <= 25 Then
                     ActCat(9) = 1
                 ElseIf 25 < Decision(4) And Decision(4) <= 75 Then
                     ActCat(9) = 2
                 ElseIf 75 < Decision(4) And Decision(4) <= 100 Then
                     ActCat(9) = 3
                 End If
             ElseIf X = 2 Then
                 If Decision(4) <= 18 Then
                     ActCat(9) = 1
                 ElseIf 18 < Decision(4) And Decision(4) <= 68 Then
                     ActCat(9) = 2
                 ElseIf 68 < Decision(4) And Decision(4) <= 100 Then
                     ActCat(9) = 3
                 End If
            End If
    End Select
End Sub
```

```
'Identify the action distnce and the A subscript in the get phase.
'
Sub AAPos_Click (Index As Integer)
    Select Case Index
        Case 0
            PActDis.Text = "<= 2 inches"
            A2 = 0
        Case 1
            PActDis.Text = "within reach"
            A2 = 1
        Case 2
            PActDis.Text = "1 to 2 steps"
            A2 = 3

        Case 3
            PActDis.Text = "3 to 4 steps"
            A2 = 6
            TMU = A2
        Case 4
            PActDis.Text = "5 to 7 steps"
            A2 = 10
        Case 5
            PActDis.Text = "8 to 10 steps"
            A2 = 16
    End Select
End Sub

'Indentify te position of the arms with the action distance.
'
Sub PAArmPos_Click (Index As Integer)
    Select Case Index
        Case 0
            A = 0
            PAAPos.Text = "both arms below shoulder level"
        Case 1
            A = 1
            PAAPos.Text = "one arm at or above shoulder level"
        Case 2
            A = 2
            PAAPos.Text = "both arms at or above shoulder level"
    End Select
End Sub

'Identify the position of the legs with action distance.
'
Sub PALegPos_Click (Index As Integer)
    Select Case Index
        Case 0
            L = 0
            PALPos.Text = "standing with both legs straight"
        Case 1
            L = 1
            PALPos.Text = "Standing with one leg straight"
        Case 2
            L = 2
            PALPos.Text = "both knees bent"
        Case 3
            L = 3
            PALPos.Text = "one knee bent"
        Case 4
            L = 4
            PALPos.Text = "kneeling"
        Case 5
            L = 5
            PALPos.Text = "walking"
    End Select

End Sub
```

```
'Identify the vertical body mtion and the B subscript in
'the get phase.
'
Sub PVBM_Click (Index As Integer)
    Select Case Index
        Case 0
            PVerBMtion.Text = "None"
            B2 = 0
        Case 1
            PVerBMtion.Text = "bend & arise (50% occurrence)"
            B2 = 3
        Case 2
            PVerBMtion.Text = "bend and arise"
            B2 = 6
        Case 3
            PVerBMtion.Text = "sit or stand"
            B2 = 10
        Case 4
            PVerBMtion.Text = "through door"
            B2 = 16
        Case 5

            PVerBMtion.Text = "through door"
            B2 = 16
    End Select

End Sub

'Identify position of the back with vertical body motion.
'
Sub PBack_Click (Index As Integer)
    Select Case Index
        Case 0
            B = 0
            PVBMBPos.Text = "straight"
        Case 1
            B = 1
            PVBMBPos.Text = "bent forward"
        Case 2
            B = 2
            PVBMBPos.Text = "twisted"
        Case 3
            B = 3
            PVBMBPos.Text = "bent and twisted"
    End Select

End Sub

'Identify position of arms in the place element.
'
Sub PPlArmPos_Click (Index As Integer)
    Select Case Index
        Case 0
            X = 0
            PPAPos.Text = "both arms below shoulder level"
        Case 1
            X = 1
            PPAPos.Text = "one arm at or above shoulder level"
        Case 2
            X = 2
            PPAPos.Text = "both arms at or above shoulder level"
    End Select

End Sub
```

```
'Identify the way the object is placed and the P subscript
'in the put phase.
'
Sub P1Place_Click (Index As Integer)
    Select Case Index
        Case 0
            PPlace.Text = "hold or toss"
            P1 = 0
        Case 1
            PPlace.Text = "lay aside"
            P1 = 1
        Case 2
            PPlace.Text = "loose fit"
            P1 = 1
        Case 3
            PPlace.Text = "adjustments"
            P1 = 3
        Case 4
            PPlace.Text = "light pressure"
            P1 = 3
        Case 5
            PPlace.Text = "double"
            P1 = 3
        Case 6
            PPlace.Text = "care or prescision"
            P1 = 6
        Case 7
            PPlace.Text = "heavy pressure"
            P1 = 6
        Case 8
            PPlace.Text = "blind or obstructed"
            P1 = 6
        Case 9

            PPlace.Text = "intermediate moves"
            P1 = 6
    End Select
End Sub

Sub OK_Click ()
    Rms3 = ActCat(6)
    If Rms3 > AMax Then AMax = Rms3 Else AMax = AMax
    Rms4 = ActCat(9)
    If Rms4 > AMax Then AMax = Rms4 Else AMax = AMax
    Bck2 = ActCat(8)
    If Bck2 > BMax Then BMax = Bck2 Else BMax = BMax
    Lgs2 = ActCat(7)
    If Lgs2 > LMax Then LMax = Lgs2 Else BMax = BMax
    Unload PutPhase
    ReturnPhase.Cls
    ReturnPhase.Show
End Sub
```

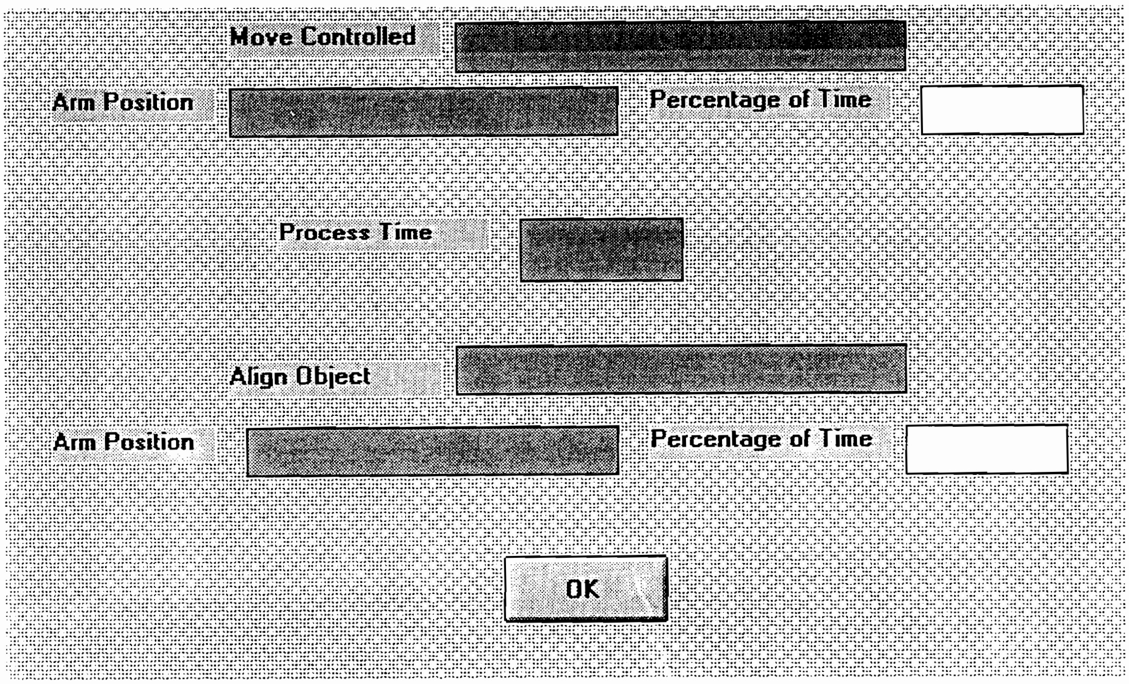



```
Dim A As Integer, L As Integer, B As Integer
Dim X As Integer, Y As Integer
Dim Decision(100) As Integer
Dim Trans(100) As String


'Identify the action distance and the A subscript in the return phase.
'
Sub RADis_Click (Index As Integer)
    Select Case Index
        Case 0
            RActDis.Text = "<= 2 inches"
            A3 = 0
        Case 1
            RActDis.Text = "within reach"
            A3 = 1
        Case 2
            RActDis.Text = "1 to 2 steps"
            A3 = 3
        Case 3
            RActDis.Text = "3 to 4 steps"
            A3 = 6
            TMU = A3
        Case 4
            RActDis.Text = "5 to 7 steps"
            A3 = 10
        Case 5
            RActDis.Text = "8 to 10 steps"
            A3 = 16
    End Select

End Sub
```

```
'Identify the arm position of in the return phase.
'
Sub POA_Click (Index As Integer)
    Select Case Index
        Case 0
            A = 0
            RArmPos.Text = "both arms below shoulder level"
        Case 1
            A = 1
            RArmPos.Text = "one arm at or above shoulder level"
        Case 2
            A = 2
            RArmPos.Text = "both arms at or above shoulder level"
    End Select

End Sub

'Identify the leg position in the return phase.
'
Sub POL_Click (Index As Integer)
    Select Case Index
        Case 0
            L = 0
            RLegPos.Text = "standing with both legs straight"
        Case 1
            L = 1
            RLegPos.Text = "Standing with one leg straight"
        Case 2
            L = 2
            RLegPos.Text = "both knees bent"
        Case 3
            L = 3
            RLegPos.Text = "one knee bent"
        Case 4
            L = 4
            RLegPos.Text = "kneeling"
        Case 5
            L = 5
            RLegPos.Text = "walking"
    End Select

End Sub
```

```
Sub OK_Click ()
    Rms5 = ActCat(11)
    If Rms5 > AMax Then AMax = Rms5 Else AMax = AMax
    Lgs3 = ActCat(12)
    If Lgs3 > LMax Then LMax = Lgs3 Else LMax = LMax
    Unload ReturnPhase
    TaskRepChk.Cls
    TaskRepChk.Show
End Sub

'Input the percentage of time that one is in a given position and
'identify the action category associated with it.
'
Sub POT_Change (Index As Integer)
    Select Case Index
        Case 0                       'Percentage for arm with action distance
            Trans(1) = POT(0).Text
            Decision(1) = Val(Trans(1))
            If A = 0 Then
                ActCat(11) = 1
            ElseIf A = 1 Then
                If Decision(1) <= 25 Then
                    ActCat(11) = 1
                ElseIf 25 < Decision(1) And Decision(1) <= 75 Then
                    ActCat(11) = 2
                ElseIf 75 < Decision(1) And Decision(1) <= 100 Then
                    ActCat(11) = 3
                End If
            ElseIf A = 2 Then
                If Decision(1) <= 18 Then
                    ActCat(11) = 1
                ElseIf 18 < Decision(1) And Decision(1) <= 68 Then
                    ActCat(11) = 2
                ElseIf 68 < Decision(1) And Decision(1) <= 100 Then
                    ActCat(11) = 3
                End If
           End If
```

```
      Case 1                       'Percentage for leg with action distance
           Trans(2) = POT(1).Text
           Decision(2) = Val(Trans(2))
           If L = 0 Then
               If Decision(2) <= 81 Then
                   ActCat(12) = 1
               Else ActCat(12) = 2
               End If
           ElseIf L = 1 Then
               If Decision(2) <= 25 Then
                   ActCat(12) = 1
               ElseIf 25 < Decision(2) And Decision(2) <= 75 Then
                   ActCat(12) = 2
               ElseIf 75 < Decision(2) And Decision(2) <= 100 Then
                   ActCat(12) = 3
               End If
           ElseIf L = 2 Then
               If Decision(2) <= 5 Then
                   ActCat(12) = 1
               ElseIf 5 < Decision(2) And Decision(2) <= 25 Then
                   ActCat(12) = 2
               ElseIf 25 < Decision(2) And Decision(2) <= 65 Then
                   ActCat(12) = 3
               ElseIf 65 < Decision(2) And Decision(2) <= 100 Then
                   ActCat(12) = 4
               End If
           ElseIf L = 3 Then
               If Decision(2) <= 5 Then
                   ActCat(12) = 1
               ElseIf 5 < Decision(2) And Decision(2) <= 25 Then
                   ActCat(12) = 2
               ElseIf 25 < Decision(2) And Decision(2) <= 65 Then
                   ActCat(12) = 3
               ElseIf 65 < Decision(2) And Decision(2) <= 100 Then
                   ActCat(12) = 4
               End If
           ElseIf L = 4 Then
               If Decision(2) <= 15 Then
                   ActCat(12) = 1
               ElseIf 15 < Decision(2) And Decision(2) <= 44 Then
                   ActCat(12) = 2
               ElseIf 44 < Decision(2) And Decision(2) <= 100 Then
                   ActCat(12) = 4
               End If
           ElseIf L = 5 Then
               If Decision(2) <= 78 Then
                   ActCat(12) = 1
               Else ActCat(12) = 2
               End If

           End If
   End Select
End Sub
```



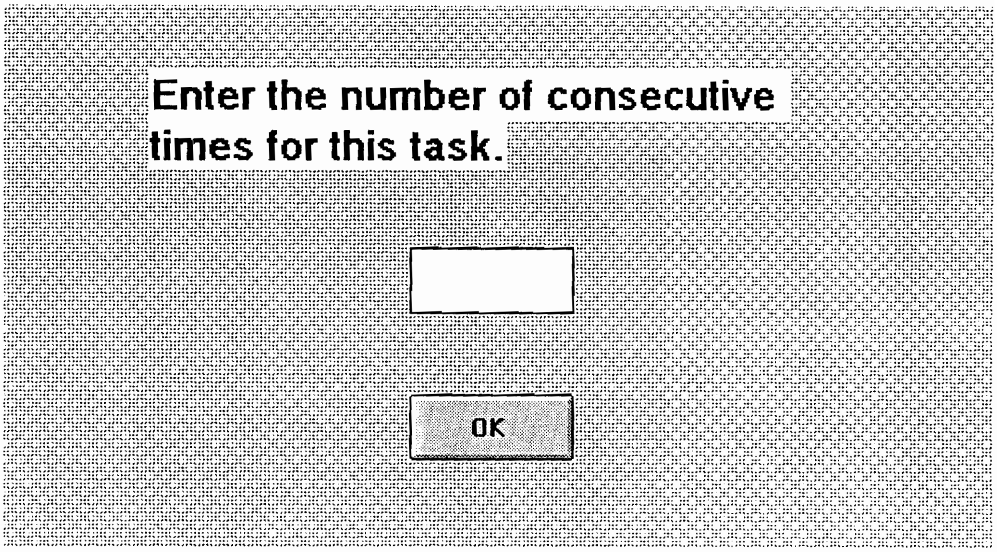

```
Dim A As Integer, W As Integer
Dim Decision(100) As Integer
Dim Trans(100) As String


'Identify position of arms for the move controlled.
'
Sub MvAPos_Click (Index As Integer)
    Select Case Index
        Case 0
            A = 0
            MArmPos.Text = "both arms below shoulder level"
        Case 1
            A = 1
            MArmPos.Text = "one arm at or above shoulder level"
        Case 2
            A = 2
            MArmPos.Text = "both arms at or above shoulder level"
    End Select
End Sub
```

```
'Identify arm position in when there is an alignment
'
Sub AlArmPos_Click (Index As Integer)
    Select Case Index
        Case 0
            W = 0
            AObjArmPos.Text = "both arms below shoulder level"
        Case 1
            W = 1
            AObjArmPos.Text = "one arm at or above shoulder level"
        Case 2
            W = 2
            AObjArmPos.Text = "both arms at or above shoulder level"
    End Select

End Sub

'Identify the Move Controlled and the M subscript
'in the move/actuate phase
'
Sub PPP_Click (Index As Integer)
    Select Case Index
        Case 0
            ContMv.Text = "<= 12 inches"
            M1 = 1
        Case 1
            ContMv.Text = "button/switch/knob"
            M1 = 1
        Case 2
            ContMv.Text = "> 12 inches"
            M1 = 3
        Case 3
            ContMv.Text = "resistance, seat or unseat"
            M1 = 3
        Case 4
            ContMv.Text = "high control"
            M1 = 3
        Case 5
            ContMv.Text = "2 stages <= 12 inches"
            M1 = 3
        Case 6
            ContMv.Text = "2 stages <= 12 inches"
            M1 = 6
        Case 7
            ContMv.Text = "3 - 4 stages"
            M1 = 10
    End Select
End Sub
```

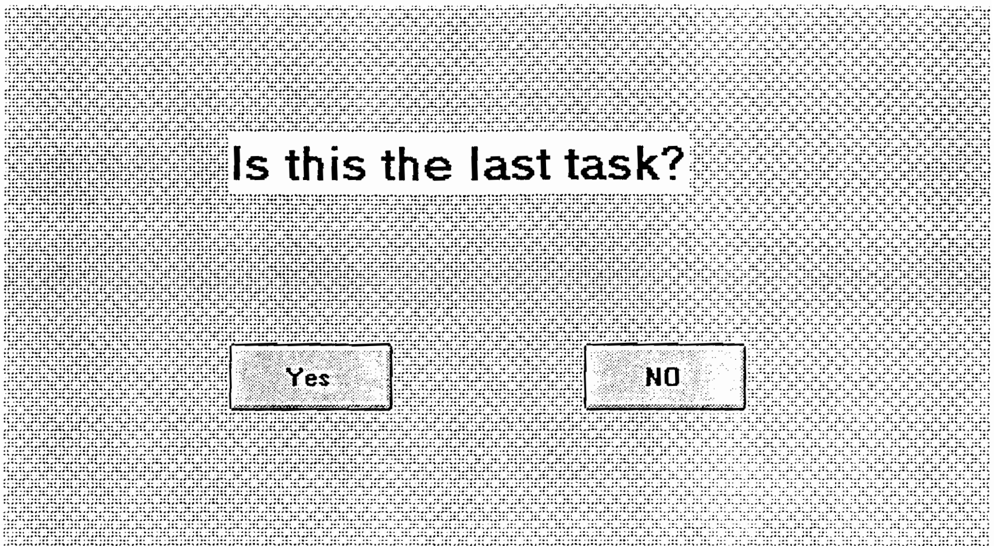
```
Sub ArmPerc_Change (Index As Integer)
    Select Case Index
        Case 0                      'Percentage for arm with controlled move
            Trans(1) = ArmPerc(0).Text
            Decision(1) = Val(Trans(1))
            If A = 0 Then
                ActCat(13) = 1
            ElseIf A = 1 Then
                If Decision(1) <= 25 Then
                    ActCat(13) = 1
                ElseIf 25 < Decision(1) And Decision(1) <= 75 Then
                    ActCat(13) = 2
                ElseIf 75 < Decision(1) And Decision(1) <= 100 Then
                    ActCat(13) = 3
                End If
            ElseIf A = 2 Then
                If Decision(1) <= 18 Then
                    ActCat(13) = 1
                ElseIf 18 < Decision(1) And Decision(1) <= 68 Then
                    ActCat(13) = 2
                ElseIf 68 < Decision(1) And Decision(1) <= 100 Then
                    ActCat(13) = 3
                End If
            End If
        Case 1                  'Percentage for arm with alignment
            Trans(1) = ArmPerc(0).Text
            Decision(1) = Val(Trans(1))
            If W = 0 Then
                ActCat(14) = 1
            ElseIf W = 1 Then
                If Decision(1) <= 25 Then
                    ActCat(14) = 1
                ElseIf 25 < Decision(1) And Decision(1) <= 75 Then
                    ActCat(14) = 2
                ElseIf 75 < Decision(1) And Decision(1) <= 100 Then
                    ActCat(14) = 3
                End If
            ElseIf W = 2 Then
                If Decision(1) <= 18 Then
                    ActCat(14) = 1
                ElseIf 18 < Decision(1) And Decision(1) <= 68 Then
                    ActCat(14) = 2
                ElseIf 68 < Decision(1) And Decision(1) <= 100 Then
                    ActCat(14) = 3
                End If
            End If
    End Select
End Sub
```

```
Sub rev_Click (Index As Integer)
    Select Case Index
        Case 0
            ContMv.Text = "<= 1 revolution"
            M1 = 3
        Case 1
            ContMv.Text = "1 < rev <= 3"
            M1 = 6
        Case 2
            ContMv.Text = "3 < rev <= 6"
            M1 = 10
        Case 3
            ContMv.Text = "6 < rev <= 11"
            M1 = 16
    End Select
End Sub

Sub AlPt_Click (Index As Integer)
    Select Case Index
        Case 0
            AlObj.Text = "To one point"
            I1 = 1
        Case 1
            AlObj.Text = "To two points <= 4 inches"
            I1 = 3
        Case 2
            AlObj.Text = "To two poins > 4 inches"
            I1 = 6
        Case 3
            AlObj.Text = "precision"
            I1 = 16
    End Select
End Sub

Sub OK_Click ()
    Rms6 = ActCat(13)
    If Rms6 > AMax Then AMax = Rms6 Else AMax = AMax
    Rms7 = ActCat(14)
    If Rms7 > AMax Then AMax = Rms7 Else AMax = AMax
    Unload MvActPhase
    ReturnPhase.Cls
    ReturnPhase.Show
End Sub
```

```
Sub Tm_Click (Index As Integer)
    Select Case Index
        Case 0
            ProcTime.Text = "0.5 sec"
            X1 = 1
        Case 1
            ProcTime.Text = "1.5 sec"
            X1 = 3
        Case 2
            ProcTime.Text = "2.5 sec"
            X1 = 6
        Case 3
            ProcTime.Text = "4.5 sec"
            X1 = 10
        Case 4
            ProcTime.Text = "7.0 sec"
            X1 = 16
        Case 5
            ProcTime.Text = "0.01 min"
            X1 = 1
        Case 6
            ProcTime.Text = "0.2 min"
            X1 = 3
        Case 7
            ProcTime.Text = "0.04 min."
            X1 = 6
        Case 8
            ProcTime.Text = "0.7 min"
            X1 = 10
        Case 9
            ProcTime.Text = "0.1 min"
            X1 = 16
        Case 10
            ProcTime.Text = "0.0001 hrs."
            X1 = 1
        Case 11
            ProcTime.Text = "0.0004 hrs."
            X1 = 3
        Case 12
            ProcTime.Text = "0.0007 hrs."
            X1 = 6
        Case 13
            ProcTime.Text = "0.0012 hrs."
            X1 = 10
        Case 14
            ProcTime.Text = "0.0019 hrs."
            X1 = 16
    End Select
End Sub
```




```
Dim TRep As String


Sub OK_Click ()
    If Mve = 1 Then
        TskTMU = Rep * (A1 + B1 + G1 + A2 + B2 + P1 + A3)
        Unload TaskRepChk
        EndChk.Show
    Else
        TskTMU = Rep * (A1 + B1 + G1 + M1 + X1 + I1 + A3)
        Unload TaskRepChk
        EndChk.Show
    End If
End Sub

Sub TaskRep_Change ()
    TRep$ = (TaskRep.Text)
    Rep = Val(TRep$)
End Sub
```




```
Sub Yes_Click ()
    Open file$ For Append As #1
        Print #1, TaskID,
        Print #1, TskTMU, AMax, BMax, LMax
        Print #1,
    Close #1

    TMU = TMU + TskTMU
    Open file$ For Append As #1
        Print #1,
        Print #1, , , TMU
        Print #1,
        Print #1,

    Close #1

    Unload EndChk
    End
End Sub

Sub No_Click ()
    Open file$ For Append As #1
        Print #1, TaskID, ,
        Print #1, TskTMU, AMax, BMax, LMax
        Print #1,
    Close #1

    TMU = TMU + TskTMU
    Unload EndChk
    TskList.Cls
    TskList.Show

End Sub
```

APPENDIX C. Explanatory Documents

Postural Data Incorporated Into Traditional Work Measurement
Instructions for Experiment—Phase 1
Tool Used: MOST

Thank you for participating in this research experiment. The experiment is being run by Walthea V. Yarbrough as part of her doctoral dissertation work and is being supervised by Dr. C. Patrick Koelling, a professor in Industrial and Systems Engineering.

Currently, work measurement data, methods engineering data, and posture recording data are collected using separate tools for data collection and analysis. These data are interrelated and may be better utilized if collected simultaneously. The purpose of this phase of the study is to collect data for validation of a newly developed tool for simultaneously collecting work measurement data, methods engineering data, and posture recording data in the work place. Tests will be performed on the data to determine if they can be effectively and simultaneously collected using the new tool.

In this phase of the experiment data will be collected using MOST. MOST is a predetermined motion time system used to simultaneously collect work measurement and methods engineering data. An experimental kit will be used that contains an explanation of MOST, reference tables, and data collection sheets. When using MOST, data are collected using the data collection sheets provided in the kit.

There will be two sessions for this phase of the experiment. The first session will be a training session and the first application of the tool and will last approximately 3 hours. . The second session will be a tool application session and will last approximately one and a half hours. Training will consist of a brief lecture on the proper use of MOST and a practice session applying the tool in the application portion of this phase, you will apply the tool by analyzing four video-taped activities shown on a television screen. You will receive $5.00 per hour for the entire experiment (both sessions) upon completion of the second session of the experiment.

The data you collect, as well as those of other subjects in the study, will be analyzed to determine if the new tool is adequate for simultaneously collecting work measurement and posture recording data. Your results will be anonymous.

It is important that you attend both sessions. If for some reason you will not be able to attend one of the sessions, please inform me at this time. Once the data have been analyzed, results will be made available to you should you desire to see them. The research team members for this experiment are:

Walthea V. Yarbrough, Graduate Student
Dr. C. Patrick Koelling, Associate Professor, ISE

If you have any concerns about the way in which you have been treated or the manner in which the experiment is being conducted, and you do not wish to express these concerns to the experimental team, you may contact the University's Institutional Review Board. The contact person is:

Dr. E. R. Stout 231-9359

Thank you once again for your participation. We hope you will enjoy your experience in this experiment.

Postural Data Incorporated Into Traditional Work Measurement: Informed Consent Form

This form constitutes informed consent by you to participate in this study. Please read it carefully and sign below.

Your rights as a subject are:

1. It is your right as a subject to withdraw from the study at any time for any reason.
2. Any of the research team members will answer any questions that you may have, and you should not sign this consent form until you understand fully all of the terms involved.
3. You have the right to see your data and withdraw them from the study if you so desire. Please inform the experimenter immediately of this decision, as the data will be handled anonymously and not be possible to track once an experimental session is over.
4. You have the right to be informed of any risks or discomforts in this research. No risk or discomfort is anticipated, however.

If you wish to receive a synopsis of the study, please include your address under the signature line below and a copy will be sent to you. If after reading the synopsis you would like a more detailed report, please contact one of the team members and a full report will be made available to you.

Should any further questions arise, please contact one of the team members. If you have any concerns about the way the experiment is being conducted or the way you are being treated, please contact the Institutional Review Board.

Your participation in this study is greatly appreciated and we hope that you will find the study a pleasant and interesting experience. Your signature below indicates that you have read this document in its entirety, that your questions have been answered, and that you consent to participate in the study described.

I understand that in case of physical injury, no medical treatment or compensation are offered by the research program, or by Virginia Polytechnic Institute and State University.

I understand that for my participation, I will receive payment of $5.00 per hour, and I will receive this payment upon completion of my second session.

I understand that the results of my efforts will be recorded. I consent to the use of this information for scientific or training purposes and understand that any

records of my participation in this study may be disclosed only according to federal law, including the Federal Privacy Act, and its implement regulations. This means that personal information will not be released to any unauthorized third party without my consent.

I, ______________________________________, am participating in this research on a completely voluntary basis. No one has coerced or intimidated me to participate.

Walthea V. Yarbrough has adequately answered any and all questions I have asked about this study, my participation, and the procedures involved, which are described in the instruction forms, which I have signed.

I FULLY UNDERSTAND THAT I AM MAKING A DECISION WHETHER TO PARTICIPATE. MY SIGNATURE INDICATES THAT I HAVE DECIDED TO PARTICIPATE UNDER THE CONDITIONS DESCRIBED ABOVE.

Signature ________________________________ Date __________

Printed Name ______________________________

Address ____

____

Signature of Witness __________________________ Date _________

Postural Data Incorporated Into Traditional Work Measurement
Instructions for Experiment—Phase 2
Tool Used: OWAS

Thank you for participating in this research experiment. The experiment is being run by Walthea V. Yarbrough as part of her doctoral dissertation work and is being supervised by Dr. C. Patrick Koelling, a professor in Industrial and Systems Engineering.

Currently, work measurement data, methods engineering data, and posture recording data are collected using separate tools for data collection and analysis. These data are interrelated and may be better utilized if collected simultaneously. The purpose of this phase of the study is to collect data for validation of a newly developed tool for simultaneously collecting work measurement data, methods engineering data, and posture recording data in the work place. Tests will be performed on the data to determine if they can be effectively and simultaneously collected using the new tool.

In this phase of the experiment data will be collected using OWAS. OWAS is a posture recording method used to collect postural data. An experimental kit will be used that contains an explanation of OWAS, reference tables and figures, and data collection sheets. When using OWAS, data are collected using the data collection sheets provided in the kit.

There will be two sessions for this phase of the experiment. The first session will be the training session and the first application of the tool and will last approximately 3 hours. The first session will consist of a lecture on the proper use of OWAS, a practice session applying the tool and the first application of the tool. The second session will be a tool application session and will last approximately 1 and a half hours each. In the tool application portion you will apply the tool by analyzing four video-taped activities shown on a television screen. You will receive $5.00 per hour for the entire experiment (both sessions) upon completion of the second session of the experiment.

The data you collect, as well as those of other subjects in the study, will be analyzed to determine if the new tool is adequate for simultaneously collecting work measurement and posture recording data. Your results will be anonymous.

It is important that you attend both sessions. If for some reason you will not be able to attend one of the sessions, please inform me at this time. Once the data have been analyzed, results will be made available to you should you desire to see them. The research team members for this experiment are:

Walthea V. Yarbrough, Graduate Student
Dr. C. Patrick Koelling, Associate Professor, ISE

If you have any concerns about the way in which you have been treated or the manner in which the experiment is being conducted, and you do not wish to express these concerns to the experimental team, you may contact the University's Institutional Review Board.

Dr. E. R. Stout 231-9359

Thank you once again for your participation. We hope you will enjoy your experience in this experiment.

Postural Data Incorporated Into Traditional Work Measurement: Informed Consent Form

This form constitutes informed consent by you to participate in this study. Please read it carefully and sign below.

Your rights as a subject are:

1. It is your right as a subject to withdraw from the study at any time for any reason.
2. Any of the research team members will answer any questions that you may have, and you should not sign this consent form until you understand fully all of the terms involved.
3. You have the right to see your data and withdraw them from the study if you so desire. Please inform the experimenter immediately of this decision, as the data will be handled anonymously and not be possible to track once an experimental session is over.
4. You have the right to be informed of any risks or discomforts in this research. No risk or discomfort is anticipated, however.

If you wish to receive a synopsis of the study, please include your address under the signature line below and a copy will be sent to you. If after reading the synopsis you would like a more detailed report, please contact one of the team members and a full report will be made available to you.

Should any further questions arise, please contact one of the team members. If you have any concerns about the way the experiment is being conducted or the way you are being treated, please contact the Institutional Review Board.

Your participation in this study is greatly appreciated and we hope that you will find the study a pleasant and interesting experience. Your signature below indicates that you have read this document in its entirety, that your questions have been answered, and that you consent to participate in the study described.

I understand that in case of physical injury, no medical treatment or compensation are offered by the research program, or by Virginia Polytechnic Institute and State University.

I understand that for my participation, I will receive payment of $5.00 per hour, and I will receive this payment upon completion of my second session.

I understand that the results of my efforts will be recorded. I consent to the use of this information for scientific or training purposes and understand that any

records of my participation in this study may be disclosed only according to federal law, including the Federal Privacy Act, and its implement regulations. This means that personal information will not be released to any unauthorized third party without my consent.

I, ____, am participating in this research on a completely voluntary basis. No one has coerced or intimidated me to participate.

Walthea V. Yarbrough has adequately answered any and all questions I have asked about this study, my participation, and the procedures involved, which are described in the instruction forms, which I have signed.

I FULLY UNDERSTAND THAT I AM MAKING A DECISION WHETHER TO PARTICIPATE. MY SIGNATURE INDICATES THAT I HAVE DECIDED TO PARTICIPATE UNDER THE CONDITIONS DESCRIBED ABOVE.

Signature ____ Date ____________

Printed Name ____

Address ____

____

Signature of Witness _________________________________ Date ___________

Postural Data Incorporated Into Traditional Work Measurement
Instructions for Experiment—Phase 3
Tool Used: WAPAST

Thank you for participating in this research experiment. This study is the independent work of an Industrial Engineering doctoral candidate. The experiment is being run by Walthea V. Yarbrough as part of her doctoral dissertation work and is being supervised by Dr. C. Patrick Koelling, a professor in Industrial and Systems Engineering.

Currently, work measurement data, methods engineering data, and posture recording data are collected using separate tools for data collection and analysis. These data are interrelated and may be better utilized if collected simultaneously. The purpose of this phase of the study is to test a newly developed tool, WAPAST, for collecting work measurement data, methods engineering data, and posture recording data in the work place. Tests will be performed on the data to determine if work measurement data and posture recording data can be effectively and simultaneously collected using WAPAST.

WAPAST is a computerized tool that is accompanied by a training kit. The training kit contains a brief explanation of the tool and reference tables and figures. The data is collected by interacting with a computer interface that prompts the user to input required information.

There will be two sessions of this phase of the experiment. The first session will be training and the first application of the tool and will last approximately 3 hours. The second session will be a tool application session and will last approximately on and a half hours. Training will be a lecture on the proper use of WAPAST and a practice session applying the tool. In the application portion of this phase, you will apply the tool by analyzing four video-taped activities shown on a television screen. You will receive your pay of $5.00 per hour for the entire experiment (both sessions) upon completion of the second session of the experiment.

The data you collect, as well as those of other subjects in the study, will be analyzed to determine if WAPAST is adequate for simultaneously collecting work measurement and posture recording data. Your results will be anonymous.

It is important that you attend both sessions. If for some reason you will not be able to attend one of the sessions, please inform me at this time. Once the data have been analyzed, results will be made available to you should you desire to see them. The research team members for this experiment are:

Walthea V. Yarbrough, Graduate Student
Dr. C. Patrick Koelling, Associate Professor, ISE

If you have any concerns about the way in which you have been treated or the manner in which the experiment is being conducted, and you do not wish to express these concerns to the experimental team, you may contact the University's Institutional Review Board.

Dr. E. R. Stout 231-9359

Thank you once again for your participation. We hope you will enjoy your experience in this experiment.

Postural Data Incorporated Into Traditional Work Measurement: Informed Consent Form

This form constitutes informed consent by you to participate in this study. Please read it carefully and sign below.

Your rights as a subject are:

1. It is your right as a subject to withdraw from the study at any time for any reason.
2. Any of the research team members will answer any questions that you may have, and you should not sign this consent form until you understand fully all of the terms involved.
3. You have the right to see your data and withdraw them from the study if you so desire. Please inform the experimenter immediately of this decision, as the data will be handled anonymously and not be possible to track once an experimental session is over.
4. You have the right to be informed of any risks or discomforts in this research. No risk or discomfort is anticipated, however.

If you wish to receive a synopsis of the study, please include your address under the signature line below and a copy will be sent to you. If after reading the synopsis you would like a more detailed report, please contact one of the team members and a full report will be made available to you.

Should any further questions arise, please contact one of the team members. If you have any concerns about the way the experiment is being conducted or the way you are being treated, please contact the Institutional Review Board.

Your participation in this study is greatly appreciated and we hope that you will find the study a pleasant and interesting experience. Your signature below indicates that you have read this document in its entirety, that your questions have been answered, and that you consent to participate in the study described.

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I understand that for my participation, I will receive payment of $5.00 per hour, and I will receive this payment upon completion of my second session.

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I FULLY UNDERSTAND THAT I AM MAKING A DECISION WHETHER TO PARTICIPATE. MY SIGNATURE INDICATES THAT I HAVE DECIDED TO PARTICIPATE UNDER THE CONDITIONS DESCRIBED ABOVE.

Signature ____ Date ____________
Printed Name ______________________________________

Address ____
____

Signature of Witness ________________________________ Date __________

APPENDIX D. Experimental Kit—Phase 1

Postural Data Incorporated Into Traditional Work Measurement

Experimental Kit—Phase 1

Tool: Maynard Operation Sequence Technique (MOST)

EXPLANATION OF TOOL

Throughout this experiment, you will be using the Maynard Operation Sequence Technique (MOST) to analyze work activities. This experimental kit provides a brief history and description of MOST, a sample of the data collection sheet you will use to analyze the activities, and a glossary of terms for your reference.

The General Move

The General Move is used for unrestricted object handling, i.e., moving an object freely through the air. If an object is in contact with, or restrained by, another object during movement, the General Move Sequence is not applicable. The General Move follows a set of sub activities that are identified by the following steps.

"1. Reach with one or two hands a distance to the object(s), either directly or in conjunction with body motions.
2. Gain manual control of the object.
3. Move the object a distance to the point of placement, either directly or in conjunction with body motions.
4. Place the object in a temporary or final position.
5. Return to the workplace." (Zandin 1980, p. 15)

These five sub activities are the basis of the activity sequence model that describes the manual displacement of an object freely through space—the General Move Sequence model. The General Move Sequence model, used to guide the analyst through the operation, is a series of letters that represent the various sub activities of the General Move. It follows the same steps identified above, with the exception of an additional parameter for body motions. The General Move Sequence model is:

A B G A B P A

where:	A	=	action distance*
	B	=	body motion*
	G	=	gain control*
	P	=	place*

The model is often divided into three phases: get, put, and return. The first three letters of the model above comprise the "get" phase, the second three letters of the model comprise the "put" phase, and the final A represents the "return" phase.

Numerical subscripts are used to indicate the time required for each of the parameters of the sequence model. These numerical subscripts have been developed through extensive research and are catalogued in a data card (Table 1). The analysts use the data card in conjunction with preprinted calculation sheets to determine the time of an activity. Each subscript, multiplied by 10, yields the total time of that parameter in TMUs.

Table 1 General Move Data Card (Zandin, 1980, p. 19)

GENERAL MOVE ABGABPA				
INDEX	**A Action Distance**	**B Body Motion**	**G Gain Control**	**P Place**
0	≤ 2 in ≤ 5 cm			hold toss
1	within reach		light object light objects simo	lay aside loose fit
3	1 - 2 steps	bend and arise (50% occurrence)	non simo heavy or bulky blind or obstructed disengaged interlocked collect	adjustments light pressure double
6	3 - 4 steps	bend and arise		care or precision heavy pressure blind or obstructed intermediate moves
10	5 - 7 steps	sit or stand		
16	8 - 10 steps	through door climb on or off		

An example of the use of the General Move Sequence model follows.

Activity Description A man walks four steps to a small suitcase, picks it up from the floor, and without moving further places it on a table located within reach.

This activity is a general move, because the suitcase is being moved freely through the air.

General Move Sequence A_6 B_6 G_1 A_1 B_0 P_1 A_0

In the "get" phase of the sequence model, the subscript for action distance (A) is 6, because the man walks 4 steps. He must bend and arise to get the suitcase, thus the subscript of B is 6. The G parameter for gaining control of the suitcase, a light object, has a subscript of 1.

The "put" phase can be analyzed similarly. The subscript for A in the "put" phase is 1, since the table on which the suitcase is placed is within reach. There is no vertical body motion, corresponding to a 0 subscript of B. The subscript of P is 1, because the suitcase is laid aside.

Finally, an A_0 is used because there is no return motion. The total time to perform this activity is 150 TMUs, which is equivalent to 5.3571 seconds.

The Controlled Move

The Controlled Move Sequence model is used when an object retains contact with another object during movement. Examples include, but are not limited to, a lever, a push button, and a crank. As with the General Move Sequence, there are a fixed sequence of sub activities that identify the Controlled Move. They are listed below.

"1. Reach with one or two hands a distance to the object, either directly or in conjunction with body motions.
2. Gain manual control of the object.

3. Move the object over a controlled path.
4. Allow time for a process to occur.
5. Align the object following the controlled move or at the conclusion of the process time.
6. Return to workplace" (Zandin, 1980, p. 36).

These six activities form the basis for the Controlled Move Sequence model that describes manual displacement of an object over a controlled path. The Controlled Move Sequence model is:

A B G M X I A

where:			
	A	=	action distance
	B	=	body motion
	G	=	gain control
	M	=	move controlled*
	X	=	process time*
	I	=	align*

There are also three phases for the Controlled Move Sequence—get, move or actuate, and return. The "get" and "return" phases of the Controlled Move phases are identical to the "get" and "return" phases of the General Move. The "move or actuate" phase is the only different phase. The "move or actuate" phase describes actions to either move an object over a controlled path or actuate a control device. Usually, move requires use of the M and I parameters, while actuate requires the M and the X parameters. This is not always the case; thus all parameters should be considered.

Numerical subscripts also complete the Controlled Move Sequence model. The subscripts are catalogued in the data cards found in Tables 1 and 2. Since the "get" and "return" phases of the Controlled Move are identical to those of the General Move, the data card in Table 1 is used to obtain subscripts for these two phases of the Controlled Move Sequence model. Table 2 is used for the "move or actuate" phase.

An example of the use of the Controlled Move Sequence model is taken from Zandin (1980, p. 48) and is listed below.

Activity Description Using the foot pedal to activate the machine, a sewing machine operator makes a stitch requiring 3.5 seconds process time. (The operator must reach the pedal with the foot.)

This activity is a controlled move, because the pedal is a control device to be activated.

Controlled Move Sequence

$$A_1 \quad B_0 \quad G_1 \quad M_1 \quad X_{10} \quad I_0 \quad A_0$$

The "get" phase of this example is similar in nature to the get phase of the example in the section on General Move, so it will not be explained in detail. For the "move" or "actuate" phase, an M_1 is used because the move controlled is stitch, which is ≤ 12 inches. A processing time of 3.5 seconds corresponds with an X_{10}. There is no alignment. Since the author does not specify a return action, the assumption is that there is not one.

Table 2 The Controlled Move Sequence Data Card (Zandin, 1980, p. 38)

CONTROLLED MOVE ABGMXIA						
INDEX	**M**		**X**			**I**
	Move Controlled		**Process Time**			**ALIGN**
	push/pull/ pivot	**Crank (revs)**	**sec.**	**min.**	**hr.**	**OBJECT**
1	≤ 12 inches (30 cm) button /switch/ knob		.5	.01	.0001	To one point
3	> 12 inches (30 cm) resistance, seat or unseat high control 2 stages ≤ 12 inches (30 cm)	1	1.5	.02	.0004	to two points ≤ 4 inches (10 cm)
6	2 stages > 12 inches (30 cm)	3	2.5	.04	.0007	to two points > 4 inches (10 cm)
10	3 - 4 stages	6	4.5	.07	.0012	
16		11	7.0	.1	.0019	precision

The following is a sample of the MOST data collection sheet that will be used to analyze the four activities.

MOST—calculation

Organization ____________________
____
Date ____________ Time ________
Department ____________________
Work Area ____________________
Analyst ____________________
Page ___ of ____

Activity Description
____
____
____

No.	Method	Sequence Model	Freq	TMU
		A B G A B P A		
		A B G M X I A		
		A B G A B P A B P A B G		
		A B G A B P A		
		A B G M X I A		
		A B G A B P A B P A B G		
		A B G A B P A		
		A B G M X I A		
		A B G A B P A B P A B G		
		A B G A B P A		
		A B G M X I A		
		A B G A B P A B P A B G		
		A B G A B P A		
		A B G M X I A		
		A B G A B P A B P A B G		
		A B G A B P A		
		A B G M X I A		
		A B G A B P A B P A B G		
		A B G A B P A		
		A B G M X I A		
		A B G A B P A B P A B G		
		A B G A B P A		
		A B G M X I A		
		A B G A B P A B P A B G		
		A B G A B P A		
		A B G M X I A		
		A B G A B P A B P A B G		
		A B G A B P A		
		A B G M X I A		
		A B G A B P A B P A B G		

Total

TMUs

Glossary of Terms

action distance [A] (Zandin, 1980, p. 16)—A parameter for the sequence models of MOST that "covers all spatial movement or actions of the fingers, hands, and/or feet, either loaded or unloaded."

align [I] (Zandin, 1980, p. 37)—A parameter for the Controlled Move Sequence model that "refers to manual actions following the controlled move or at the conclusion of process time to achieve the alignment of objects.

body motion [B] (Zandin, 1980, p. 16)—A parameter for the sequence models of MOST that "refers to either vertical (up and down) motions of the body or the actions necessary to overcome an obstruction or impairment to body movement."

cut [C] (Zandin, 1980, p. 51)—A parameter for the tool use sequence model of MOST that "describes the manual actions employed to separate, divide, or remove part of an object using a sharp-edged hand tool."

fasten [F] (Zandin, 1980, p. 51)—A parameter for the tool use sequence model of MOST that "refers to mechanically assembling one object to another, using the fingers, a hand, or a hand tool."

gain control [G] (Zandin, 1980, p. 16)—A parameter for the sequence models of MOST that "covers all manual motions (mainly finger, hand, and foot) employed to obtain complete manual control of an object(s) and to subsequently relinquish that control. The G parameter can include one or several short-move motions whose objective is to gain full control f the object(s) before it is to be moved to another location."

loosen [L] (Zandin, 1980, p. 51)—A parameter for the tool use sequence model of MOST that "refers to mechanically disassembling one object from another using the fingers, a hand, or hand tool."

measure [M] (Zandin, 1980, p. 51)—A parameter for the tool use sequence model of MOST that "refers to the actions employed in determining a certain physical characteristic of an object by comparison with a standard measuring device.

move controlled [M] (Zandin, 1980, p. 37)—A parameter for the Controlled Move Sequence model that "covers all manually guided movements or actions of an object over a controlled path.

place [P] (Zandin, 1980, p. 19)—"A parameter of the general move that refers to actions at the final sage of an object's displacement to align, orient, and/or engage the object with another object(s) before control of the object is relinquished."

process time [X] (Zandin, 1980, p. 37)—A parameter of the controlled move that "occurs as that portion of work controlled by processes or machines and not by manual actions."

record [R] (Zandin, 1980, p. 51)—A parameter of the tool use sequence model of MOST that "covers the manual actions performed with a pencil, pen, chalk, or other marking tool for the purpose of recording information.

surface treat [S] (Zandin, 1980, p. 51)—A parameter of the tool use sequence model of MOST that "covers the activities aimed at removing unwanted material or particles from, or applying a substance, coating, or finish to, the surface of an object."

think [T] (Zandin, 1980, p. 51)—A parameter of the tool use sequence model of MOST that "refers to the eye actions and mental activity employed to obtain information (read) or to inspect an object."

Appendix E. Experimental Kit—Phase 2

Postural Data Incorporated Into Traditional Work Measurement

Experimental Kit—Phase 1

Tool: Ovako Working Analysis System (OWAS)

EXPLANATION OF TOOL

Throughout this experiment, you will be using the Ovako Working Posture Analysis System (OWAS) to analyze the postural aspect of work activities. This experimental kit provides a brief history and description of OWAS and a sample of the data collection sheet you will use to analyze the activities.

OWAS was developed initially to study working postures of personnel in Finnish Steel mills. Since then, it has been used in research and action projects in many countries (Karhu, Kansi, and Kuorinka, 1977; Louhevaara and Suurnäkki, 1992). Using work sampling, the observer collects data by making split second observations and then recording the numerical code (shown in the upper right corner of each cell of Figure 1 and verbally identified in Table 1) that corresponds to the posture observed. He/she later determines the relative proportions of total working time of the observed posture and compares the findings to the expert's action categories (Louhevaara and Suurnäkki, 1992).

Each digit of the six digit, numerical code used in OWAS represents a significant postural aspect—limb and torso posture, load action on the body, and task identification. Each of the first three digits represents the posture assumed by one of the following body parts: first digit—the back, second digit—the arms, and third digit—the legs. The fourth digit represents the load action on the body. The three categories for this postural aspect are also identified in Table 1. The fifth and sixth digits identify the task being performed (Louhevaara and Suurnäkki, 1992). The numerical code 212107, for example, records the worker's back as bent forward (back = 2); he/she works with both arms below shoulder level (arms = 1); he/she stands with his/her weight on both legs (legs = 2) and handles loads weighing less than 10 kg (load or use of force = 1).

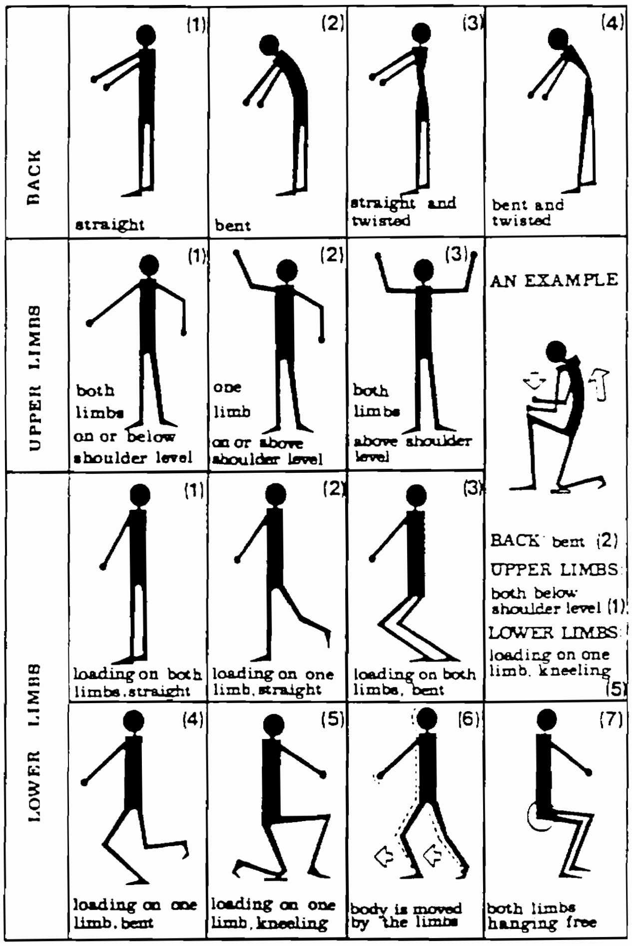

Figure 1. Link Model and Coding Used in OWAS (Karhu et al., 1977)

The work phase number (07) may show that the work consists of the wiping activity in cleaning work.

Table 1. Description of codes used in OWAS (first four digits)

CODE LEGEND				
CODE	**BACK**	**ARMS**	**LEGS**	**LOAD/USE OF FORCE**
1	straight	both below shoulder	standing with both legs straight	weight or force needed is 10 kg or less
2	bent forward, backward	one arm at or above shoulder level	standing with the weight on one straight leg	weight or force needed exceed 10 kg but is less than 20 kg
3	twisted or bent sideways	both arms at or above shoulder level	standing or squatting with both knees bent	weight or force needed exceeds 20 kg
4	bent and twisted or bent forward and sideways		standing or squatting with one knee bent	
5			kneeling on one or both knees	
6			walking or moving	
7			sitting	

In OWAS, work postures and work posture combinations are classified into four action categories on the basis of experts' assessments of the musculoskeletal load caused by postures. The experts included physicians, work analysts, and workers, and their evaluation was based upon the percentage of time a worker spends in a given position. The four action categories for classifying the postures assumed are listed in Table 2. These action categories are assigned based upon the body's posture and the percentage of working time the posture is assumed. Figure 2 is used to identify the action categories for the activities.

Table 2. Defined action categories of OWAS.

ACTION CATEGORIES	MEANING
1	normal postures that do not need any special attention, except in some special cases.
2	postures must be considered during the next regular check of working methods.
3	postures need consideration in the near future.
4	postures need immediate consideration.

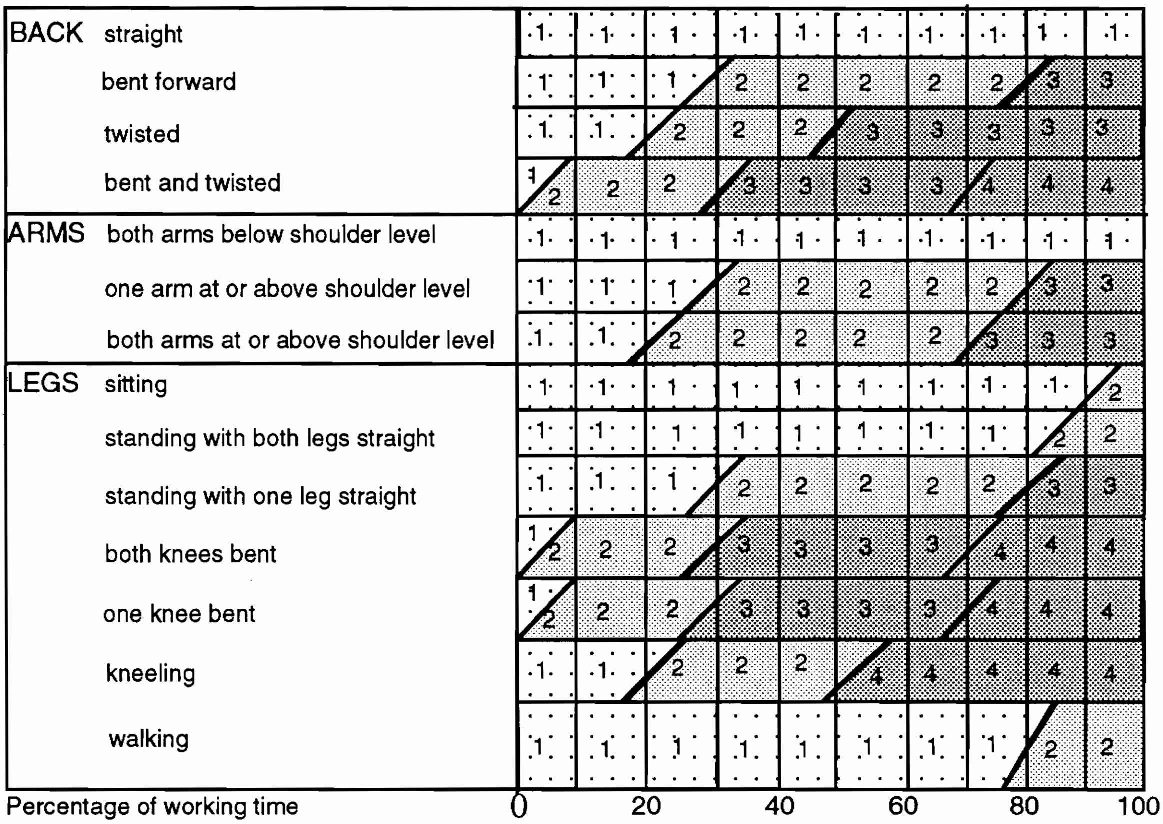

Figure 2. Action categories for work postures (Louhevaara and Suurnäkki, 1992)

OWAS CALCULATION

Activity ____

Obs.	Back				Upper Limbs			Lower Limbs					
#	1	2	3	4	1	2	3	1	2	3	4	5	6
1													
2													
3													
4													
5													
6													
7													
8													
9													
10													
11													
12													
13													
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44													
45													
46													
47													
48													
49													
50													

Obs.	Back				Upper Limbs			Lower Limbs					
#	1	2	3	4	1	2	3	1	2	3	4	5	6
51													
52													
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56													
57													
58													
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101													
102													
103													
104													
105													

Obs.	Back				Upper Limbs			Lower Limbs					
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106													
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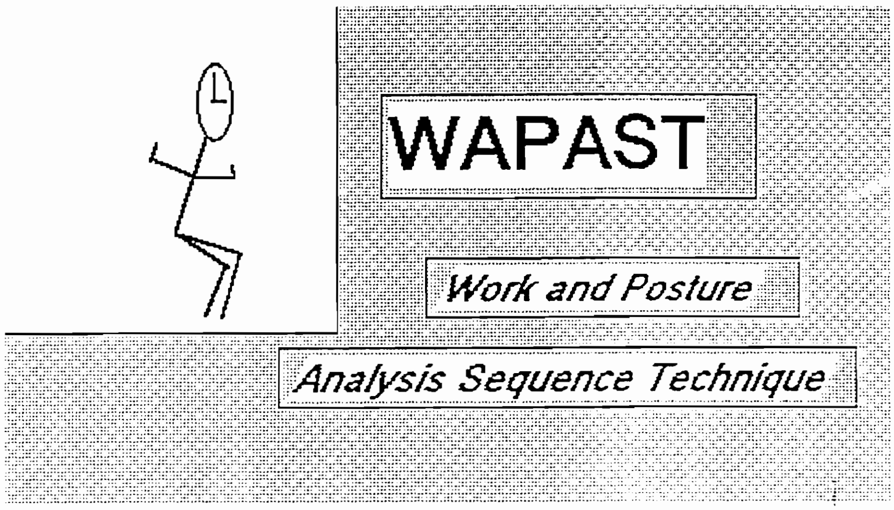
Appendix F. Experimental Kit—Phase 3

Postural Data Incorporated Into Traditional Work Measurement

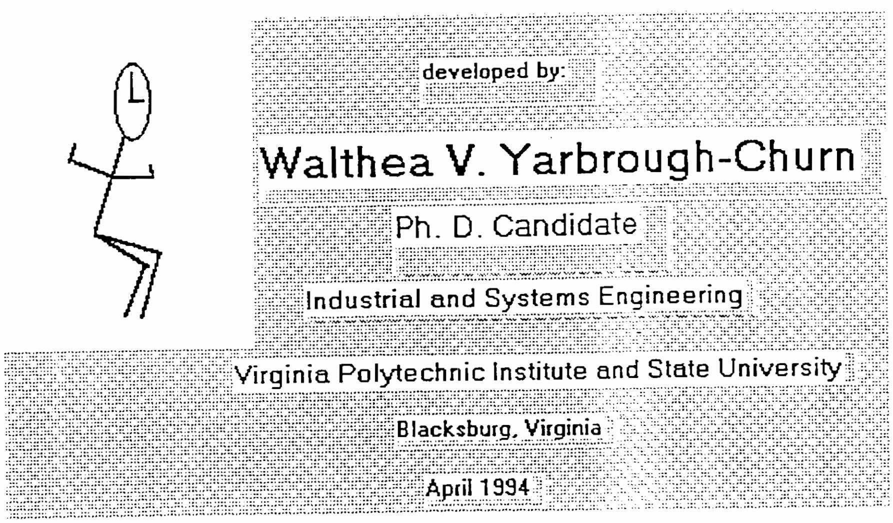
Experimental Kit—Phase 3

Tool: Work and Posture Analysis Sequence Technique (WAPAST)

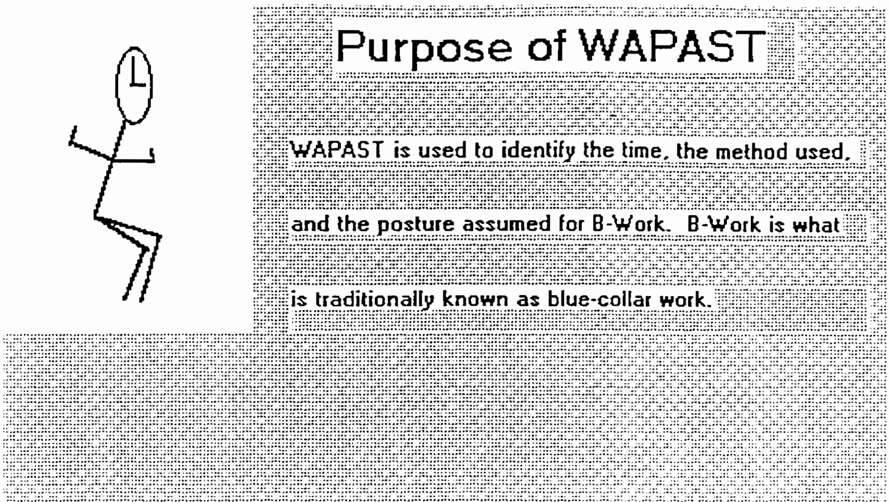
Throughout this experiment, you will be using the Work and Posture Analysis Sequence Technique (WAPAST) to analyze work activities. This experimental kit provides a brief description of WAPAST and a sample of the user interface you will use to analyze the activities.



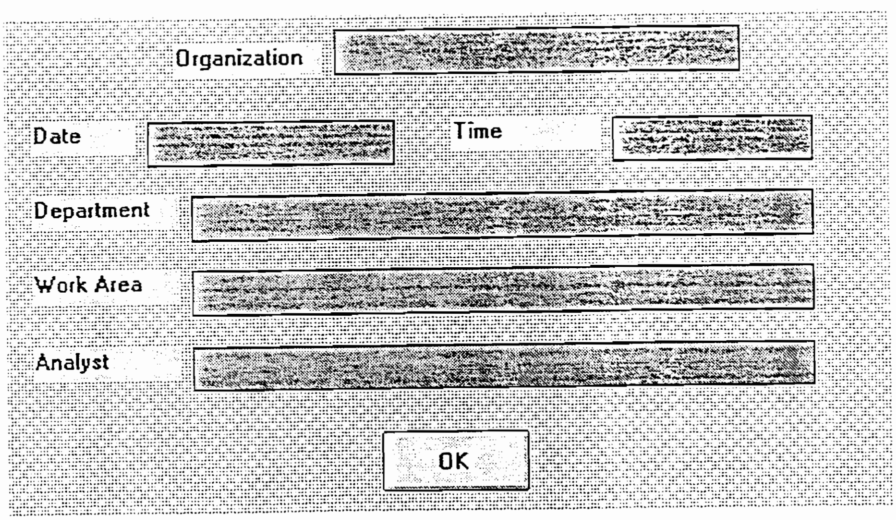
The diagram above depicts the initial screen that you will see. It identifies the name of the tool, its acronym, and its logo. Double click on the purple or white area to go to the next form.



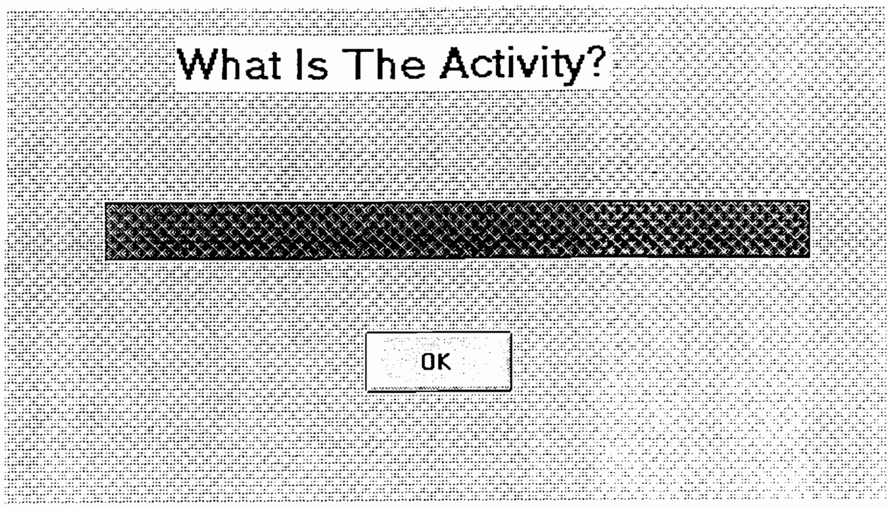
The next screen you will see is shown above and identifies who developed WAPAST, where it was developed, and when it was developed. Double click on the purple or white area to go to the next form.



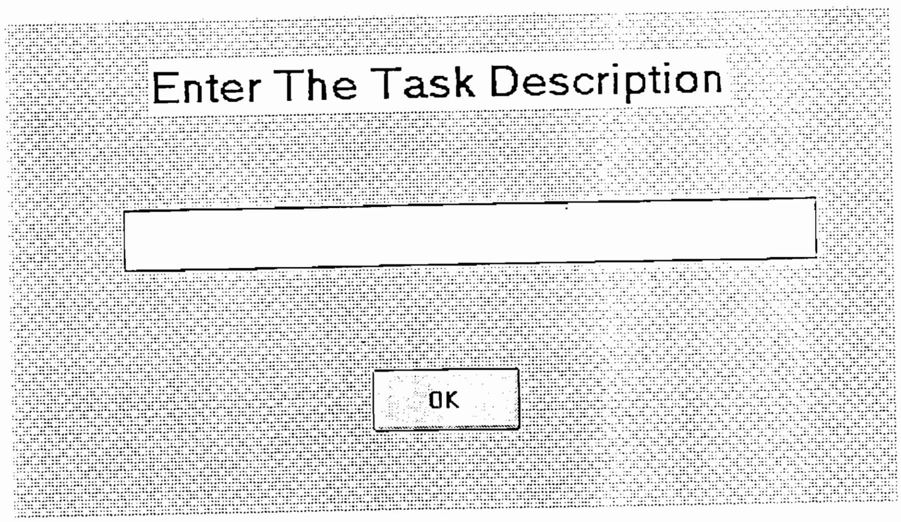
The purpose of WAPAST is displayed on the next screen. Double click to go on.



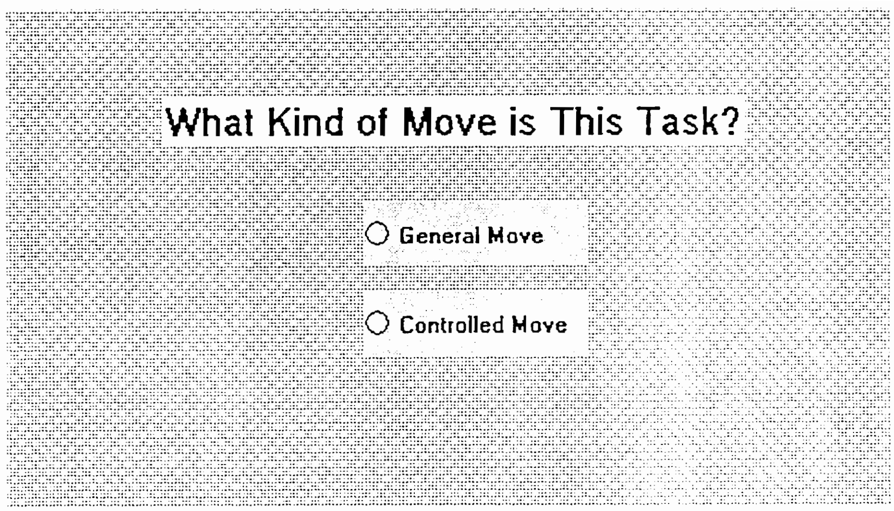
The next screen is used for tracking data. Input the information requested using the keyboard. When you are done, click "OK" with the mouse button.



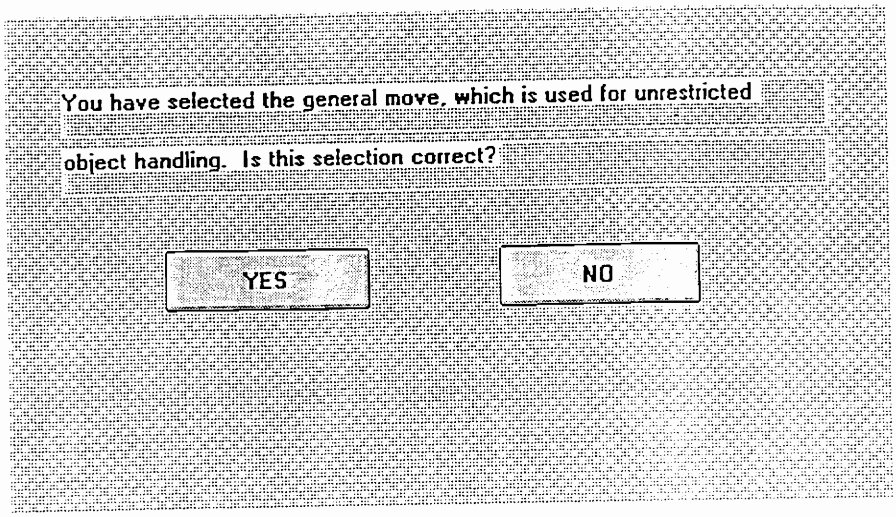
Give a brief description of the activity you will be analyzing using the keyboard. When you are done, click "OK" with the mouse button.

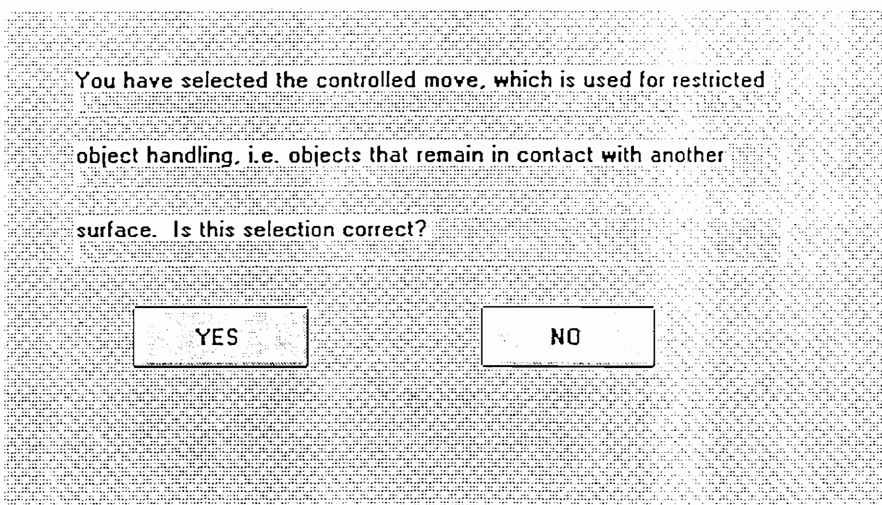


Each activity is delineated by tasks, i.e. an activity is comprised of one or more tasks. A task can be identified as a general move or a controlled move. The General Move is used for unrestricted object handling, i.e., moving an object freely through the air. If an object is in contact wit, or restrained by, another object during movement, the General Move Sequence is not applicable. The Controlled Move is used when an object retains contact with another object during movement. Examples include, but are not limited to, a lever, a push button, and a crank. Describe the task briefly, and press "OK" when finished.

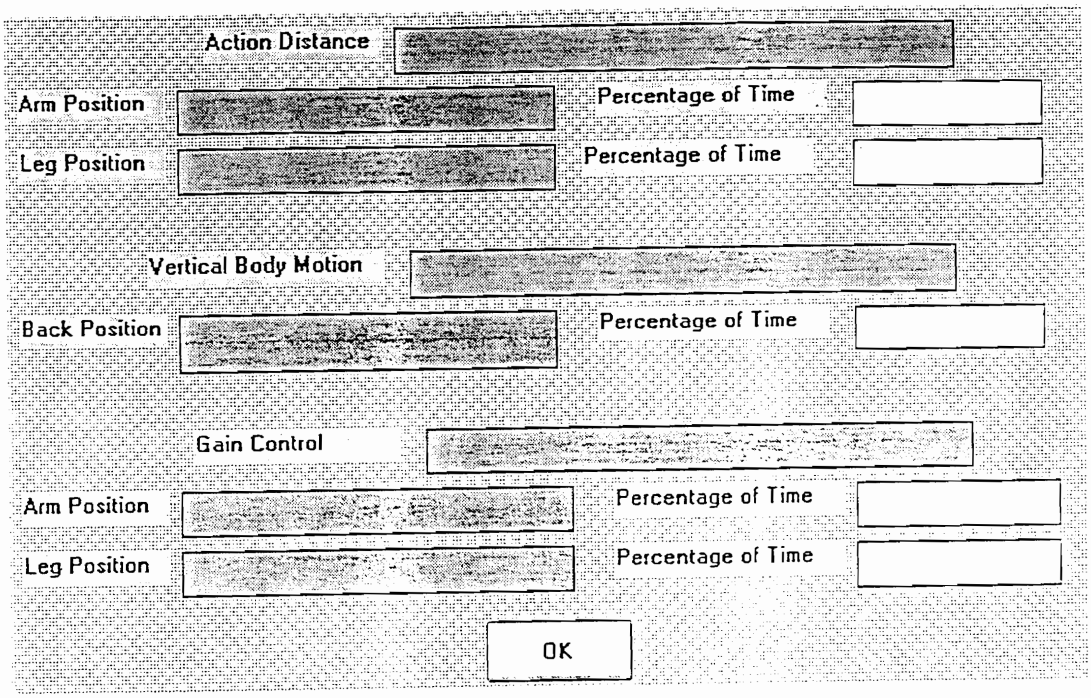


Based on your knowledge of the general move and the controlled move, please identify the type of move for this task. Double click in the circle preceding your choice.

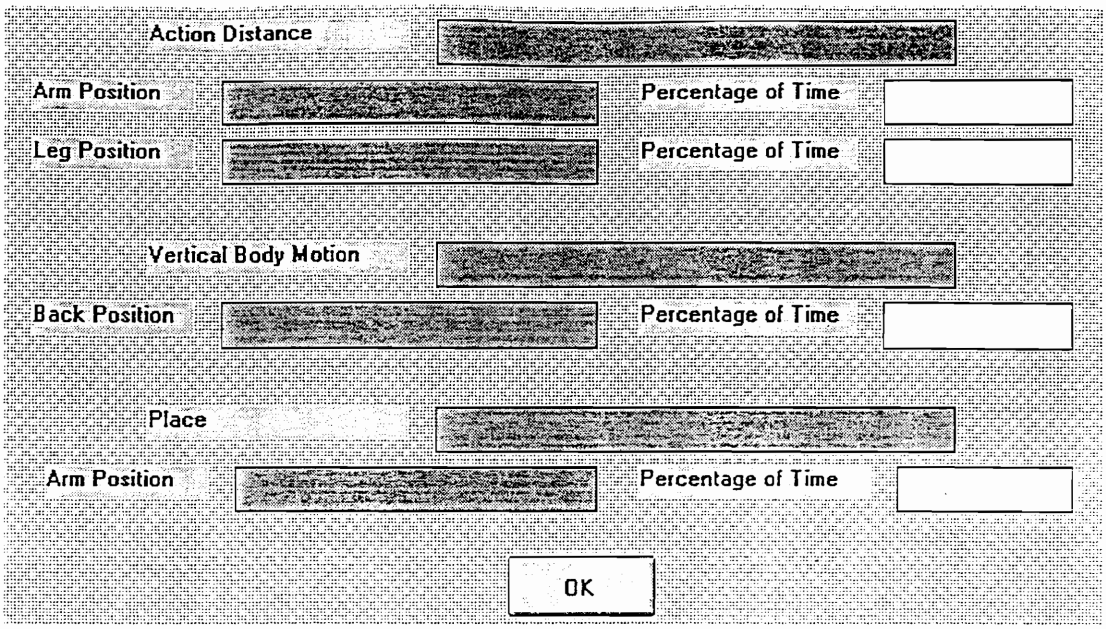




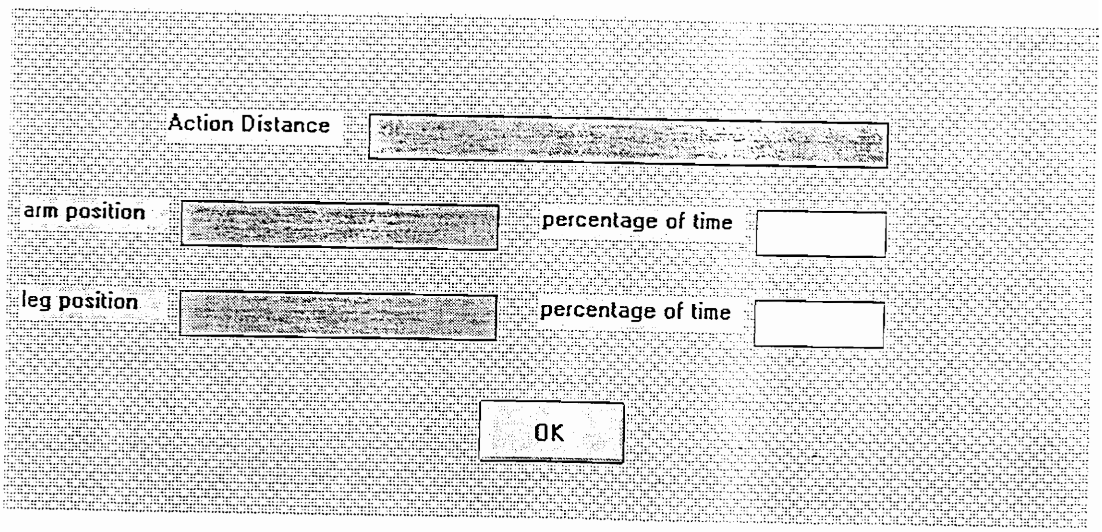
WAPAST forwards you the opportunity to check your choice. If your selection was what you intended click "YES"; if not, click "NO."



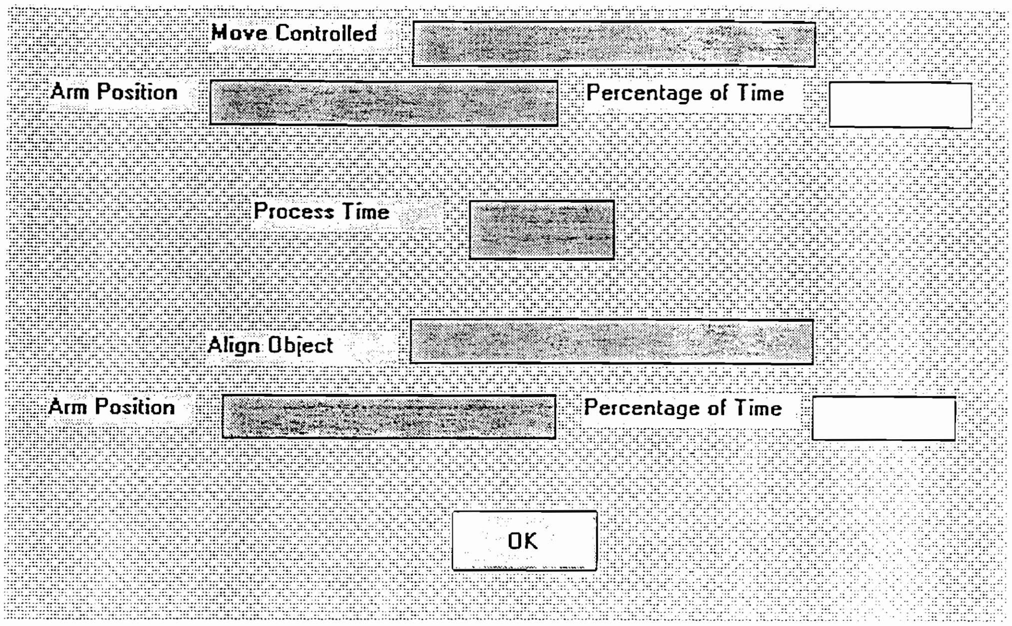
The general move has three phase: get, put, and return. The get phase—worker gains control of the object; the put phase—the worker places the object, and the return—return to the original position. In this screen input the information related to the get phase of the general move. The yell input boxes utilize the information in the drop down menus. You must manually key the information into the white boxes. After you have made sure that all of the information is correct, press OK.



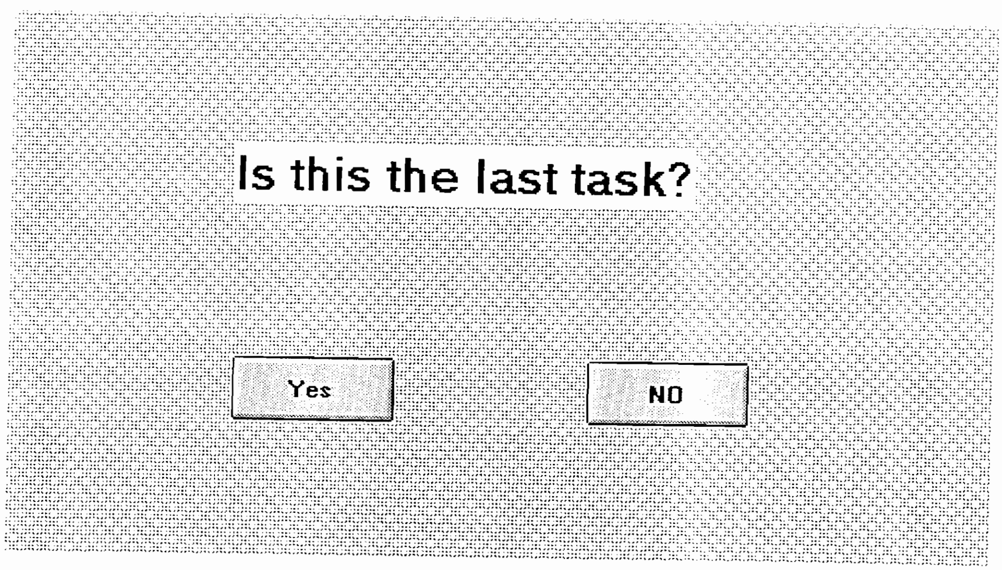
This screen provides user interface for the put phase. As with the get phase, input is retrieved from drop down menus for the yellow boxes and input from the keyboard for the white boxes.



The final phase of the general move is the return phase. The user interface is shown here.



The second move is the controlled move. It also has three phases: get, move or actuate, return. The get and return phases of the controlled move require the same information as the get and return phases of the general move. Please refer to the previous information regarding these phases. the user interface for the move or actuate phase is shown above.



After this task has been analyzed. Determine if this is the last task and make the appropriate response.

VITA

Walthea V. Yarbrough is a native of Franklinton, North Carolina. She graduated valedictorian from Franklinton High School in 1985.

Upon graduation from high school, Walthea enrolled in North Carolina Agricultural and Technical State University, Greensboro, North Carolina, and pursued a Bachelor of Science degree in Industrial Engineering. While completing her undergraduate studies, she was initiated into the Alpha Lambda Delta Freshman Honor Society, the Alpha Pi Mu Industrial Engineering Honor Society, and the Tau Beta Pi Engineering Honor Society. She was also active in the student chapter of the Institute of Industrial Engineers and the North Carolina A&T State University Fellowship Gospel Choir. She is the recipient of the 1986 "Outstanding Freshman Industrial Engineering Student" Award and the 1989 recipient of the "Outstanding Industrial Engineering Student" Award. Walthea graduated with high honors in May of 1989.

Walthea continued her education by pursuing a Master of Science degree in Industrial Engineering at North Carolina Agricultural and Technical State University. For her graduate studies she was awarded a fellowship from the National Consortium for Graduate Degrees for Minorities in Engineering (GEM). With the completion of her thesis, advised by Dr. Sanjiv Sarin, Walthea earned her Master of Science degree in May of 1991. Her thesis topic was "Computational Procedures for n-Job, m-Machine Job Shop Scheduling."

Walthea anticipates earning her Doctorate of Philosophy Degree in Industrial and Systems Engineering at Virginia Polytechnic Institute and State University in August 1994. She was awarded a GEM Fellowship to help her financially with her studies, which she used for the first year of her doctoral studies. After receiving the Charles E. Minor Fellowship in the fall of 1992, she forfeited the fellowship offered by GEM. Walthea's research effort and dissertation topic was "Postural Data Incorporated Into Traditional Work Measurement" and was advised by Dr. C. Patrick Koelling. Her expected graduation date is September, 1994.

Walthea's research interests include work measurement, biomechanics, job sequencing and scheduling, and information systems. Walthea plans to utilize the knowledge she has gained by teaching potential industrial engineers in a college setting.

Walthea V. Yarbrough