VALIDATION OF METHODS TIME MEASUREMENT DATA

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ABSTRACT

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This thesis shows the results of an experiment in order to test the validity of Methods Time Measurement (MTM) data. MTM, developed in 1948, is one of the most commonly used Predetermined Motion Time Systems to calculate standard time for a task. However, there is limited research on the validity of the MTM data in the literature. Today's technology provides new computerized tools to perform time studies. One of such tools is Real Time Method Study (RTMS). RTMS is a computerized method study tool being developed in METU Technopolis, which uses Image Processing and Machine Learning to conduct time studies automatically. RTMS uses MTM data as a benchmark data to compare observed performance results; therefore validity of MTM data is an important issue for it. In order to test the validity of MTM data an experiment conducted in the Ergonomics Laboratory of the METU Industrial Engineering Department. In this experiment 40 undergraduate students performed four different tasks. These tasks were recorded by a video camera and analyzed frame by frame to calculate normal times for basic motions of MTM. Results are compared with the original MTM data and it is shown that MTM times do not fit the observed data. This study in the end suggests updating MTM data or constructing a new standard time database by using a tool like RTMS.

Keywords: Work Study, MTM, Validation

ÖZ

METHODS TIME MEASUREMENT VERİLERİNİN DOĞRULANMASI

Bahçıvancılar, Uğur

M.S., Department of Industrial Engineering

Tez Yöneticisi: Prof. Dr. Canan Çilingir

Eylül 2012, 55 sayfa

Bu tez Methods Time Measurement (MTM) verilerinin doğrulanması üzerine yapılan bir deneyin sonuçlarını açıklamaktadır. 1948 yılında geliştirilen MTM, en yaygın kullanılan ön tanımlı zaman sistemlerinden biridir. Ancak bugüne kadar MTM verilerinin doğrulanması ile ilgili literatürde kısıtlı miktarda çalışma yer almıştır. Bugünün teknolojisi zaman etüdü çalışmaları için bilgisayar destekli yeni imkanlar yaratmaktadır. Bu imkanlardan biri de ODTÜ Teknokent'te geliştirilmekte olan Gerçek Zamanlı Metod Analizi (RTMS) sistemidir. RTMS görüntü işleme ve makine öğrenimi (yapay zeka) konularından faydalanarak zaman etüdü çalışmalarını otomatik olarak yapar. RTMS, MTM verilerini gözlemlenen performansla karşılaştırmak için kullandığından bu verilerin doğrulanması sistem için önemli bir konudur.MTM verilerinin doğrulamasını test etmek için ODTÜ Endüstri Mühendisliği Bölümü'nün ergonomi laboratuvarında bir deney yapılmıştır. Bu deneyde 40 lisans öğrencisi dört farklı iş yapmıştır. Bu işler bir kamera aracılığıyla kaydedilip kare kare incelenmiş ve MTM'in temel hareketlerinin normal süreleri hesaplanmıştır. Sonuçlar MTM tablolarındaki sürelerle karşılaştırılınca arada belirgin farklar gözlemlenmiştir. Sonuç olarak bu çalışma, RTMS gibi bir araçla MTM verilerinin güncellenmesini ya da yeni bir standart zaman sisteminin geliştirilmesini tavsiye etmektedir.

Anahtar Kelimeler: İş Etüdü, MTM, Doğrulama

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CHAPTER I

INTRODUCTION

Calculating standard times is a fundamental part of many studies related to production systems. Standard times form a basis for work measurement, production efficiency, labor performance and similar topics. Efforts to calculate standard times started with Frederick Taylor at the early 20th century. Frank Gilbreth created the idea of dividing manual work to simple basic motions. He called these motions as 17 therbligs. Since then, several advancements have occurred; new methods have been developed and used. Some methods required trained analysts to observe tasks and rate them, while some methods required analysts to use standard time tables which are predetermined called as predetermined motion time systems. In 1948 H.B. Maynard proposed a system called Methods Time Measurement (MTM) as a predetermined motion time system. MTM is now one of the most widely used predetermined motion time system all around the world. MTM provides its user with normal time tables for basic motions with relevant work parameters (Groover, 2007). However there is no literature on the validity of the time values given in these tables, therefore their validity is unclear. There is little research on how these values are calculated and updated to today.

In the recent years, analysis of basic human motions can be done through motion capture systems, which are frequently used in movie and game industry. Conventional motion capture methods require usage of markers on the body of a person to obtain motion data. The person to be observed is required to wear a specialized costume or attach electrodes to his or her joints and other body parts. This method is obviously inadequate to use in time study applications at manufacturing sites, since the material used might interfere with the actions and they can distract the person as well. Today there is a new opportunity to break the chains of markers from the motion capture systems, image processing. It enables marker-less motion capture to make motion analysis easily in a production environment. Data obtained from marker-less motion capture can be used to classify basic human motions within chosen standard time system. A software product named as "Real Time Method

Study" (RTMS) is being developed at a private R&D company in METU Technopolis uses this opportunity. RTMS provides the opportunity to make quick and accurate MTM analysis of many different tasks, therefore enabling the validation of MTM data. RTMS can recognize human motions simultaneously while a person performs different tasks. Through image processing, motion capturing and machine learning stages it can label a person's actions with basic motions and record these actions' durations. Therefore it can do MTM analysis and set a standard time for a task and also observe a person's performance at the same time.

The main purpose of this study is testing the validity of MTM data in order to see whether updating MTM time tables is required or not. Results of this study can suggest using original MTM data for RTMS or updating these data or even constructing a new predetermined motion time system for RTMS. In order to test MTM data a few standard tasks such as pegboard exercise, card dealing, simple reach and move tasks are recorded in METU IE's ergonomics laboratory. Gathered data are tested for the hypothesis of whether they fit the original MTM data or not.

CHAPTER II

KEY CONCEPTS

2.1. Methods Engineering

Methods engineering can be defined as the analysis and design of work methods and systems including the tooling, equipment, technologies, workplace layout, plant layout, and environment used in these methods and systems (Groover, 2007).

2.2. Motion Study

Motion study is the analysis of basic hand, arm, and body movements of workers as they perform work (Groover, 2007).

Frank B. Gilbreth, in his early work in motion study, developed certain subdivisions or events which he thought common to all kinds of manual work. He called 17 elementary subdivisions of a cycle of motions as Therbligs (Barnes, 1980), (Gilbreth, Gilbreth, 1924). 17 Therbligs include the following motions: search, select, grasp, transport empty, transport loaded, hold, release load, position, pre-position, inspect, assemble, disassemble, use, unavoidable delay, avoidable delay, plan and rest for overcoming fatigue.

2.3. Time Study

Time study refers to all of the ways in which time is investigated and analyzed in working environments, whether the work is accomplished by human workers or automated systems (Groover, 2007).

The result of time study is the time that a person suited to the job will require to perform the job if he or she works at a normal standard tempo. This time is called the standard time for the operation (Barnes, 1980).

Analyst in a time study plays a critical role. The time study analyst should ensure that the correct method is being used; accurately record the times taken, honestly evaluate the performance of the operator (rating), and refrain from any operator criticism (Niebel, Freivalds, 2003).

The PFD allowance, for personal, fatigue and delay, as it is often called, is usually expressed as a percentage of the standard time and added to the time allowed to complete a particular task being studied (Lawrence, 2000).

Important time study methods are direct time study (stopwatch), predetermined motion time systems, standard data systems, work sampling and computerized work measurement.

2.4. Predetermined Motion Time Systems

A predetermined motion time system (PMTS) is a database of basic motion elements and their associated normal time values, together with a set of procedures for applying the data to analyze manual tasks and establish standard time for tasks.

Time values given in PMT systems do not include any allowances. Allowance for a task should be added to normal time value obtained from the selected PMTS later with the equation given below:

$$T_{std} = T_n \times (1+A_{pfd}) \quad (1)$$

where T_{std} is standard time, T_n is normal time obtained from the PMTS and A_{pfd} is the allowance factor (Groover, 2007).

Allowance for a task can be easily selected via the guide provided by the International Labour Organization (ILO). The allowance setting table is given in the Appendix A.

PMTS Generations

Predetermined motion time systems are divided to levels based on their measurement accuracy and ease of use. The level of a specific PMT system refers to its generations. Difference between the higher and lower level systems are given in the Table-1 (Groover, 2007):

Table 1 Characteristics of PMT System Levels

Characteristic	First-Level	Higher-Level
Accuracy	Most accurate	Less accurate
Application time	Much time to set standard	Less time to set standard
Suited to specific types of tasks	Highly repetitive	Repetitive or batch
Cycle times	Short cycle	Longer cycle
Motion elements	Basic motions	Aggregates of basic motions
Methods description	Very detailed	Less detailed, easier to apply
Flexibility of application	Highest flexibility	Less flexibility

Common PMT systems used in the literature are Methods Time Measurement (MTM), Maynard Operations Sequence Technique (MOST), Motion Time Analysis (MTA), Work Factor and MODAPT. Since this research is focused on MTM only MTM system will be explained in detail.

2.5. Methods Time Measurement (MTM)

Maynard et al. explained MTM as "A procedure which analyzes any manual operation or method into basic motions required to perform it and assigns to each motion a predetermined time standard which is determined by the nature of the motion and the conditions under which it is made (Maynard, Stegemerten, Schwab, 1948).

Dr. Harold B. Mike Maynard graduated from Cornell University with an Industrial Engineering degree at 1924. Shortly after his graduation he joined to Westinghouse, where he became an authority on time on motion study. With the experience he earned during this time he had founded Methods Engineering Council (MEC) in Pittsburgh, USA as a time study consulting company in 1934. In 1941, he started to a research at Westinghouse together with Gus Stegmerten and Jack Schwab. This research resulted with the Methods and Time Measurement (MTM) work measurement technique and it was published in 1948. Their research included many workers in the Westinghouse Company. In 1950, MEC opened a new office in Sweden and started to observe European working environment as well, which will lead them to the development of MOST. In 1952, Maynard founded MTM Association and MTM became known worldwide. In 1957, MEC merged with an another firm and renamed as H. B. Maynard and Company, Inc. Maynard, retired from his company in 1960 yet his legacy continued on. In the following years new work measurement techniques such as MTM-2 (United Kingdom) and MOST (Sweden) are developed based on MTM in different countries (Smith, 2004).

MTM consists of different generations of predetermined motion time systems. Original MTM sometimes referred as MTM-1 as it is a first generation PMT system. There are other MTM systems like MTM-2, MTM-3, MTM-UAS, MTM-MEK, MTM-C and etc. These systems are whether different generations of PMTS or tools developed for specific purposes.

MTM System Selection

Since there are different MTM systems with different generations choosing the appropriate MTM for a task analysis is important. Based upon the comparison table of different MTM systems from Karger and Hancock Figure 1 represent the standard deviations of MTM-1, MTM-2 and MTM-3 (Karger, Hancock, 1982). This table shows based on time (TMU) task times calculated by higher generations have higher standard deviations.

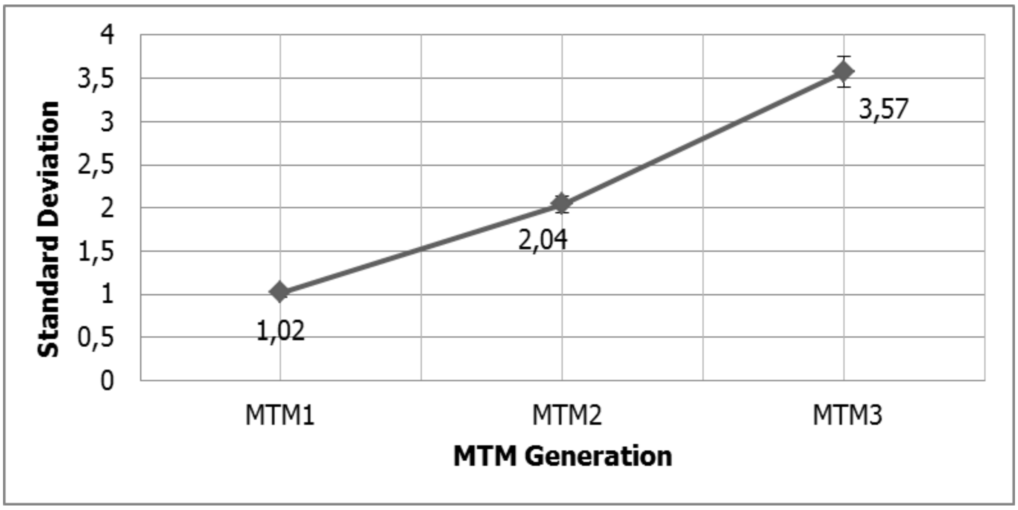

Figure 1 Standard deviations of MTM Generations

According to The MTM Association for Standards and Research the following equation is to be used when deciding which system suits the task at hand.

$$\pm A\% = \frac{K_i \times S_j}{\sqrt{NRT}} \quad (2)$$

A refers to the desired accuracy while applying MTM, K_i represents the Z value for desired confidence interval i, S_j represents the standard deviation of the MTM generation j and NRT represents the time required for the non-repetitive manual task. Non-repetitive manual task refers to a single run of a repetitive task such as turning a screwdriver once etc.

After applying necessary calculations the accuracy obtained by the each system is compared with the desired accuracy. Among those accuracy results, the system which satisfies the accuracy condition with the higher generation is chosen.

This research is mainly focused on MTM-1 since it is the most basic and generally used MTM system and all MTM-1 normal time tables are given in Appendix B.

2.6. Computerized Work Measurement

Work measurement effort can be very demanding and time consuming for the analysts, thus a number of hardware and software products have been developed to improve this process. These products can be grouped as computerized work measurement techniques (Groover, 2007).

Examples of commonly used software based on MTM data are TiCon, MTM-LINK, ADAM, Time Ladders, PC Graphics (MTM Association). Among those TiCon is the most widely used and capable one. According to MTM Association its basic functions are:

- Elemental Time Development
- Operation Standard Time Development
- Part Routing Development
- Where-Used and Mass Updating
- Maintenance of a Comprehensive Standards Database

With all its capabilities even though TiCon is useful tool it can be only used offline, after the work is observed. When TiCon is compared to RTMS, RTMS' ability to perform time study analysis in real time highlights it as the next generation computerized work measurement tool.

2.7. Real Time Method Study

RTMS is to be a modern world application of computerized PMTS which uses MTM data and Image Processing Technology to enhance method study. It is developed by A-Information Systems Ltd. in METU Technopolis. It mainly captures the video of an operator via eight video cameras and builds a 3D model of the operator. After that it captures the motion capture data and via machine learning applications it labels the operator's motions with MTM basic motions. From there it automatically performs the time study of the task. Details of the system are given in the rest of this section, however since the main focus of this research is on the validity of MTM data and also RTMS is commercial product technical details will not be explained here.

2.7.1. Functions of RTMS

- Task standardization: RTMS benefits from several topics for standardizing a task. Firstly, the task is defined by its relevant NACE code, which is the standard definition of economic activities in European Union (European Commission). For instance, one of the tasks conducted in this research is putting thirty pegs into a pegboard which is similar to a simple assembling process in the manufacturing industry and can be fall under the NACE code of "C28 - Manufacture of machinery and equipment". Secondly, general information about the production environment is entered. Then, PFD allowance suited for the task is calculated and based on required accuracy appropriate MTM system is chosen. Finally, task method is defined by chosen MTM system.
- Task monitoring: RTMS enables user to monitor the operator's performance in real time. With the help of image processing and machine learning it calculates the standard time automatically and compares it to the observed time of the task.
- Method improvement: RTMS provides the analyst with the set of motions may require improvement based on their times or whether they fit Principles of Motion Economy.

2.7.2. Image Processing and Motion Capture

RTMS uses Image Processing technology to build a 3D model of the person being observed.

Image processing is described as "a set of computational techniques for analysing, enhancing, compressing, and reconstructing images. Its main components are importing, in which an image is captured through scanning or digital photography; analysis and manipulation of the image, accomplished using various specialized software applications; and output" in Britannica (Britannica). Image processing basically creates silhouettes of the person to make it easier to identify the features of the body.

The output from the image processing part is used in the motion capture process. Different images from all eight cameras get together to build a 3D model of the person being observed. Motion capture data provides the system with body motion data, distance and time travelled by each node of the body.

In order to emphasize the strength of RTMS compared to other techniques a previous study by Ma et al. In their "Framework for Interactive Work Design based on Motion Tracking, Simulation, and Analysis" Liang Ma et.al, developed a motion tracking system to track a worker's operation in real time. The data is transferred to a computer for digital human simulation (a 3D model) and used for work efficiency evaluation and subjective work task evaluation (Liang MA, 2010). In their study for motion tracking purposes they required the worker to wear a specialized suit to capture the coordinates of the worker's key joints. Subject's motions and their transference to the simulation model can be seen in the Figure 2.

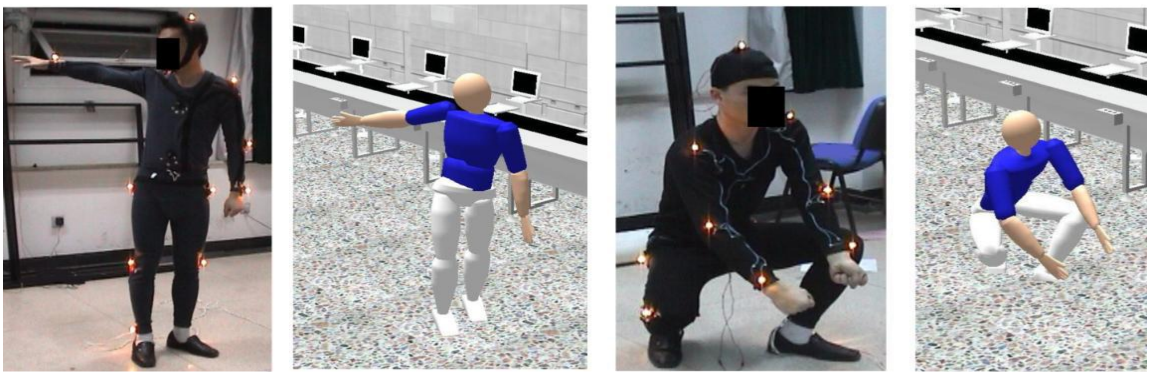

Figure 2 Motion capturing from the study by Liang Ma et. al.

As it can be seen from Figure 2 this kind of motion tracking would be very insufficient in real life situations since the worker will be required to wear a motion capture suit and it may affect his\her routine performance. RTMS differs from such methods since it uses Image Processing to obtain the motion data, it does not require any other equipment to be used by workers.

2.7.3. Machine Learning and Tracking

RTMS uses the motion capture data to conduct time study. In order to do this, motion capture data are transformed to MTM or a newly developed PMTS basic motions. Identification of body motions as basic motions is performed by machine learning algorithms. In order to provide the system with continuous data, tracking algorithms are used.

In the end, RTMS provides the analyst with a time study analysis of the task performed and gives the standard time required to complete the operation as well as the actual time observed. With increasing technology, RTMS can analyze motions of a person far more objective than conventional methods can, since it does not just rely on the still photographs of a person, it can track the slightest motion of even a single joint through tracking. This ability of RTMS can easily decrease the analyst bias and errors and makes it a more accurate tool the conduct time studies compared to techniques when original MTM was established.

CHAPTER III

LITERATURE REVIEW

In the literature review part, previous researches about validation of standard time systems and Methods Time Measurement and Computerized Time study are summarized.

3.1. Validation of Standard Time Systems

Lawrence (2000) in his book "Work Measurement and Methods Improvement" suggested a method for developing standard data systems. His method consists of three stages: developing a database, calculating average base time and preparing a check curve. Check curve shows how well the standard data relationship fits the existing data (Lawrence, 2000). This method is useful for both generating a system and validating an existing system.

Brown (1994), from MTM UK, proposed the validation study of a new MTM system called as MTM Core Data (CD). His study shows how this new system compared to the previous ones (Brown, 1994). MTM CD was developed in 1970s by Peter Evans. This system basically combines MTM-1, MTM-2 and MTM-3. In the study MTM CD was tested on four parameters: speed of application, bias, system error and application error. In order to test these parameters, fifteen non-repetitive and repetitive cycle tasks (i.e, sharpening a pencil, loading slides to a projector etc.) were measured by both MTM-1 and MTM CD. After that, results were compared to see the validity of MTM CD. They have found that MTM CD is twice faster than MTM-1 based on speed of application and its total error is ±5%.However, this study does not provide any information regarding the reliability of MTM-1.

Karger (1976) in his book Engineered Work Measurement, mentioned two independent researches at Cornell and Michigan Universities soon after the publication of MTM. Cornell stated that MTM was only applicable with itself due to classification differences with other Predetermined Motion Time Systems. However details of those researches are not available. Karger also stated in his book all MTM data and original research are made available by Maynard to public through assigning all data and development rights to a non-profit organization called MTM Association for Standards and Research, which later transferred them to International MTM Directorate (Karger, 1976).

Through all communication attempts with International MTM Directorate any detail of the original MTM research was made available in this research unfortunately.

3.2. Methods Time Measurement

Appelgren et al. (1971) participated in the development of MTM-2 system, a second generation MTM system based on MTM-1. They have aggregated basic motions of MTM-1 to new motion aggregates. With this simplification both the number of motions and dimension of work parameters were lowered. For instance they have defined only three cases and for distance intervals for reach motion (Appelgren, Magnusson, Skargard, 1971). Main reason behind this study was to develop a system which is easier to implement than MTM-1. In their study aggregation of motions were based on two aspects: frequency and sequence of motions. For instance, reach motion is mostly followed by grasp motion in MTM-1 analyses. They had decided to combine reach and grasp into one motion called get. While creating normal time tables for get motion, researches looked for the most frequently observed distance and case values for reach and grasp motion. With this approach they have also decreased the number and size of parameters to describe get motion.

3.3. Computerized Time Study

Chaffina et al. (1970) proposed a model to design work tasks with aid of computers. Their model predicts the normal time for a manual task and also it predicts the capability of reach and preferred body position for a task. Their article describes posture requirements in more detail and for time calculations they had used MTM data (Chaffin; Kilpatrick; Hancock, 1970).

Booneya and Schoeielda (1971) had done a research on providing a range of computer techniques to help design and evaluation of tasks. They used AUTOMAT system and MTM 2 for developing a work place layout and job analysis. They evaluated a simple job and discussed the advantages and disadvantages of such an approach. Their study only includes application of MTM-2 manually by using a computer (Bonneya; Schoeielda, 1971).

Eberhardt et al. (2010) proposed a MTM based computerized time measurement system, TiCon, in order to integrate time management into digital factory design. In their study they had designed an interface between two software programs Teamcenter Manufacturing and Ticon. They emphasized the opportunity of integrating unit production time data and production planning. However, Ticon provides the user only an interface which aids the analyst. It does not actively participate in time study, thus using such software can be considered as only semi-automated time study (Eberhardt; Rulhoff; Stjepandic, 2010).

3.4. Motion Picture for Time Study

Using motion pictures for time study is a common method in the practice. Barnes (1980) explained in his book how to use motion picture techniques to conduct time study. Video records enable analysts to observe each element of an operation in detail. Most frequently used time camera speed is 1000 frames per minute, which refers to a rate of 16 fps. When a recording is done, the motion capture is split into its frames. In order to measure time easily frames are numbered starting from 0, therefore for each element it is easier to count the number of frames and calculate actual time. It is also important to set up camera angles in a direct angle to observe the operator so that hand motions can be seen easily (Barnes, 1980). It should be noted here that today's advanced motion picture technology enables easier and more accurate recording of human motions.

To summarize, there is limited research conducted on the development and validation of time measurement methods. Even though these systems are used in practice very often academic interest seems to be lower. MTM systems developed after MTM-1, in practice are generally compared with MTM-1; however there is no study on the validity of MTM-1. Manufacturing technologies and methods changed very radically since MTM's initial launch, therefore testing its validity for today's needs is essential. Another important finding from the literature review, even there are many computerized time study systems, most of them can be classified as decision support systems, since they help the analysts in their observations, time calculations and etc. However, with today's technology it is quite possible to create systems which can do the time study on its own. With the light of these findings this study aims to validate the MTM data, decide whether RTMS should use it or develop a new database and evaluate how RTMS would be beneficial for studying time measurement methods in the future.

CHAPTER IV

BACKGROUND INFORMATION FOR THE MTM VALIDATION STUDY

The normal time values in the MTM-1 tables have not changed much since their development. This situation created a need for enquiring the validity of these data. The time tables for some of the most commonly used MTM motions; reach, move and position are analyzed in further detail for this purpose.

4.1. Review of Reach Motion

Time required to perform a reach motion depends on two work parameters. First one is the distance (in inches) travelled by the hand and the second one is the case of the reach, which basically refers to conditions as whether the reach is toward a single object or an object jumbled with others. Five cases of reach are:

- A: Reaching to an object in a fixed location
- B: Reaching to a single object in a location which can slightly change from cycle to cycle
- C: Reaching to an object which is jumbled in a group
- D: Reaching to a very small object so an accurate grasp is required
- E: Reaching to an indefinite location so body balance is required
- A – Hand in motion: Hand is already in motion before case A
- B – Hand in motion: Hand is already in motion before case B

It should be noted here that, time values for case C and D are given same in MTM tables therefore they act like only one case.

Individual Value Plot of time values versus distance for each reach case, constructed from MTM tables by Minitab, is given in the following Figure 3.

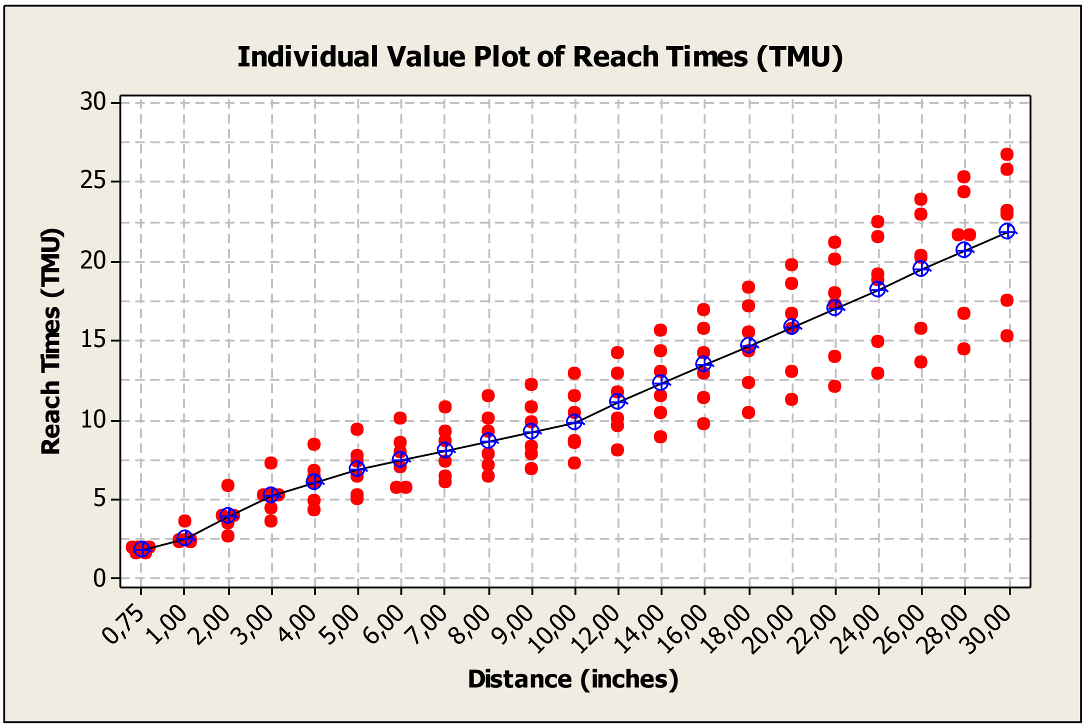

Figure 3 Individual Value Plot of Time for each Reach case

The red dots shows the individual time values for each case referring to a specific distance, while the blue line represents the average of all six cases of reach.

As it can be seen from the table, distances can be divided to three subgroups, since time values show a different slope after distinct distances. These subgroups are:

i. Between 0 and 4 inches

ii. Between 5 and 12 inches

iii. Between 13 and 30 inches

Such observations based on distance segmentation can raise questions on testing specific distance values and compare those observations with MTM values.

4.2. Review of Move Motion

Time required to perform a move motion depends on three work parameters. First one is the distance (in inches) travelled by the hand, second one is the case of the move which basically refers to the difficulty and the last one is the weight of the object carried. Four cases of move are:

A: Moving object to other hand or against a stop

B: Moving object to an approximate location

C: Moving object to exact location

B – Hand in motion: Hand is already in motion before case B

Individual Value Plot of time values versus distance for each move case, with 0 to 1kg of weight, constructed by Minitab, is given in the following Figure 4.

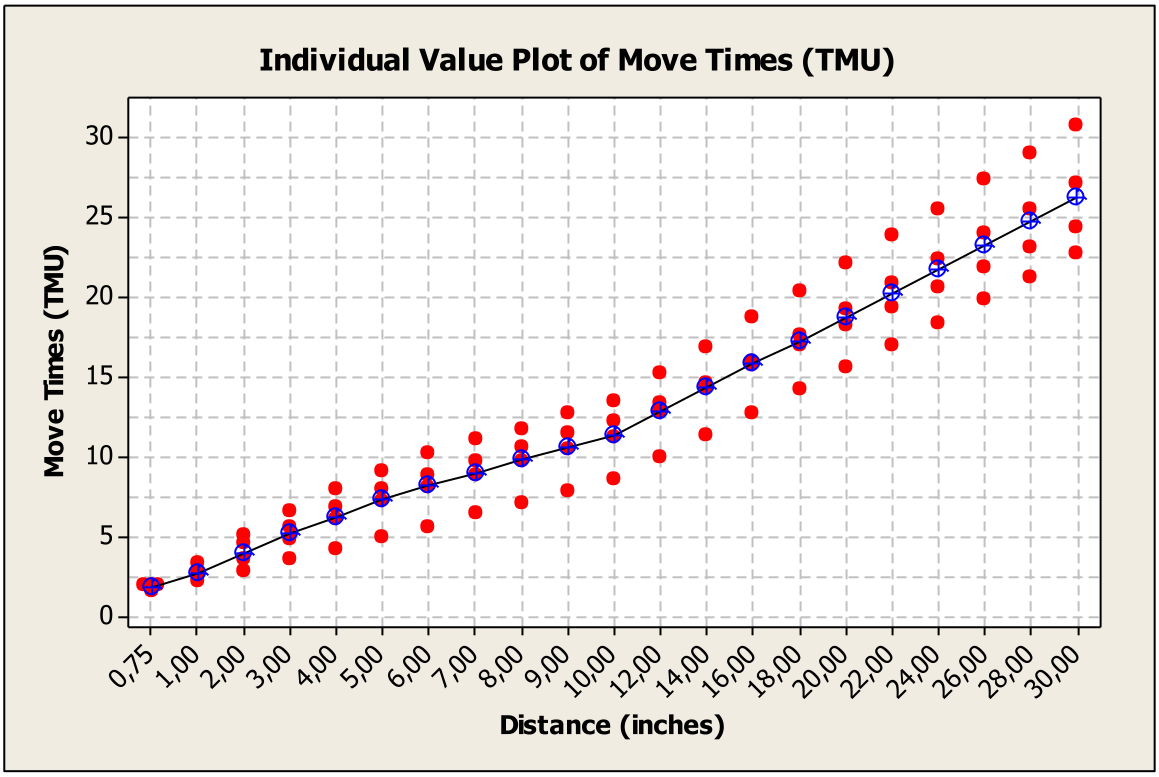

Figure 4 Individual Value Plot of Time for each Move case

The red dots shows the individual time values for each case referring to a specific distance, while the blue line represents the average of all four cases of move.

As it can be seen from the table, distances can be divided to three subgroups, since time values show a different slope after distinct distances. These subgroups are:

i. Between 0 and 4 inches

ii. Between 5 and 12 inches

iii. Between 13 and 30 inches

Such observations based on distance segmentation can raise questions on testing specific distance values and compare those observations with MTM values.

4.3. Review of Position Motion

Basic motion of position is described by the fitness of object to its place, symmetry between the place and the object and difficulty of handling the object. When the time table for position motion (Appendix B) is looked in detail it can be seen that the time difference between the easy to handle case and difficult to handle case is constant (5,6 TMU) independent from all other factors. This fact raised questions about the validity of this table as well.

To sum up, from the observation of these three different MTM motions a need for validation of MTM data is raised, since there is not enough explanation of how the data collected and the characteristics of the sample population. Therefore, an experiment to observe such motions and compare them with MTM values is conducted in this study.

CHAPTER V

METHODS AND APPARATUS

In order to test the validity of MTM's standard time tables, each participant performed four different tasks. These tasks are recorded by a video camera in the Ergonomics Laboratory of METU Industrial Engineering department. After tasks are recorded, in order to perform their MTM analysis they were split into their frames and manually analyzed. Finally, the collected data was statistically analyzed by using Minitab 16.

5.1. Population

40 university students from METU Industrial Engineering department participated in the study voluntarily. Their mean age was 21,78 ± 1,19 years, mean height was 172,46 ± 5,86 centimeters and mean weight was 69,55 ± 14,48 kilograms. 26 of them were male and 14 of them were female students. They were given a briefing which explains the procedure and the purpose of the study.

5.2. Equipment

In order to perform time study with motion picture analysis, a setting was established in the Ergonomics Laboratory. For video recording a Canon Legria HF R106 HD camera was used. To observe and measure distance and case of basic motions easily during tasks, an A1 size grid paper with distinct distances marked on it laid on a table (at a height of 76cm) was used. The camera was set vertically with respect to the table in order to get a view with direct angle. All videos were shot with a 30 frame per second (fps) rate, which gives almost twice accuracy compared to original MTM study which was done with 16fps rate. For pegboard task a peg board, peg box and forty pegs are used. For card dealing task a deck of fifty two cards are used. For reach and move task a small cell phone is used. Equipment and experiment setup are showed in Appendix C.

5.3. Experimental Procedure

There were four different tasks: pegboard exercise, card dealing, reaching to an object and moving an object. Each participant performed the pegboard task first, then the card dealing task, then reach task and finally the move task with the same order. Performing all tasks for a participant took 12 minutes on the average for each participant and the whole experiment took approximately 8 hours of video recording conducted in eight days.

Two weeks prior to actual experiment twelve of the participants participated in the learning curve assessment task on pegboard and card dealing exercises to set the number of trials before starting to the actual experiment.

For the tasks, PFD allowance is taken as 0 since this study calculates normal time values as the same case with MTM time tables.

MTM analysis is performed via the following steps:

i. Divide task into a single non-repetitive cycle if applicable.
ii. Divide the non-repetitive cycle into its basic motions through video records.
iii. For each basic motion, calculate normal times based on the factors given in basic motion time tables.
iv. Sum up the normal times for each basic motion
v. Sum up the normal times for each non-repetitive cycle
vi. In order to calculate standard times add allowance factor to the normal time for the task.

5.4. Tasks

a. Pegboard task:

In pegboard task, participants were asked to place thirty pegs into holes on a pegboard. They must start from inner lower section and go to up and outer section. Illustration of the task is given in Figure 5. When all pegs are placed the task is completed.

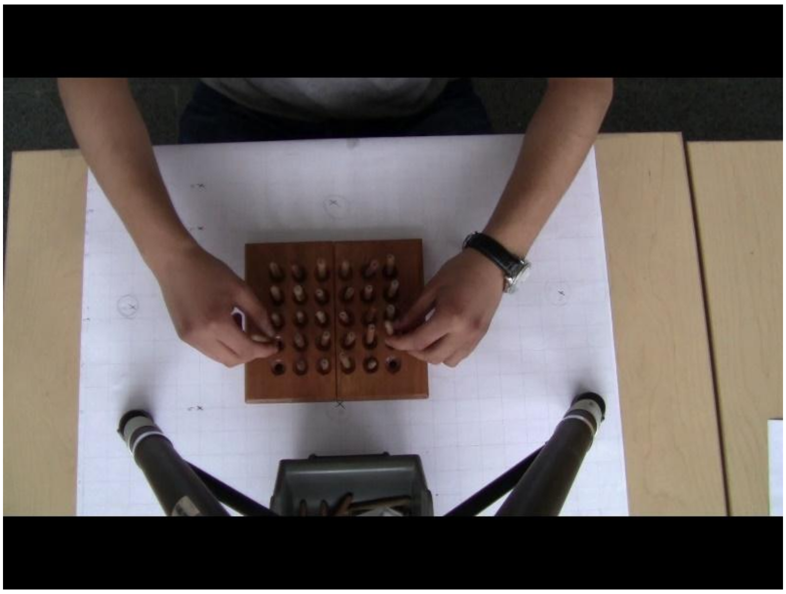

Figure 5 A participant performing pegboard task

MTM motions included in pegboard task are:

1. Reach motion with case C with distances between 9 and 14 inches (R9C, R10C, R11C, R12C, R13C and R14C).
2. Move motion with case C with distances between 9 and 13 inches (M9C1, M10C1, M11C1, M12C1 and M13C1).
3. Grasp motion with case 1A, which refers to picking up a small object easily by itself (with no handle required) (G1A).
4. Position motion with case 2SE, which refers to slightly pushing an easily handled object to a symmetrical place (P2SE).
5. Release motion with case 1, which refers to releasing an object by simply opening fingers (RL1).

b. Card Dealing task:

In card dealing task, participants are asked to deal a deck of fifty two cards on the grid paper. Four distinct positions where the cards will be placed on the paper are indicated by numbers. Participants started to position cards with the first position indicated by number one and then preceded to next position indicated by number two and continued until position with number four. When the deck is depleted the task is also completed. Illustration of task is given in Figure 6.

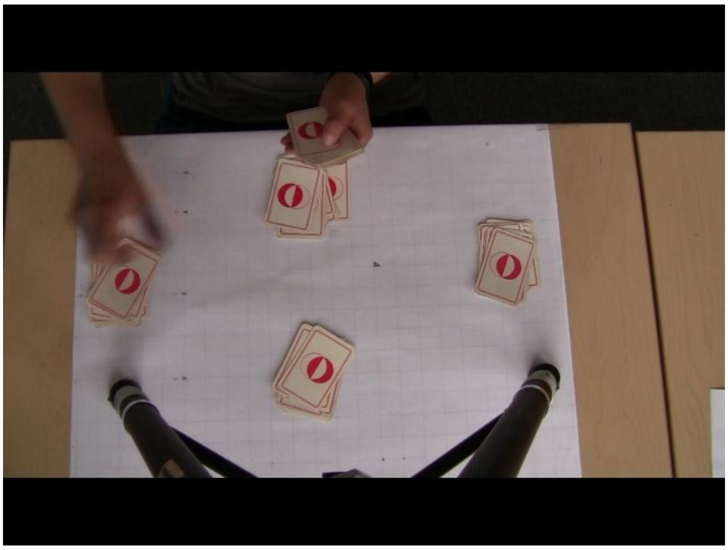

Figure 6 A participant performing card dealing task

MTM motions included in card dealing task are:

1. Reach motion with case A (while hand in motion) with distances 3 (closest distance), 9 (on the sides) and 10 (in front of the participant) inches (R3Ahm, R9Ahm and R10Ahm).
2. Move motion with case B (while hand in motion) with distances 3 (closest distance), 9 (on the sides) and 10 (in front of the participant) inches (M3Bhm1, M9Bhm1 and M10Bhm1).
3. Grasp motion with case 1B, which refers to picking up an object very small or lying close against a flat surface (G1B).
4. Release motion with case 1, which refers to releasing an object by simply opening fingers (RL1).

c. Reach task:

Participants are asked to reach to a single small object. There were twelve different distances to be reached. Distance values are chosen according to the findings from the questioning of MTM data (section 4). They represent the cut points and two other points of each distance segment. An illustration of the task is given in Figure 11.

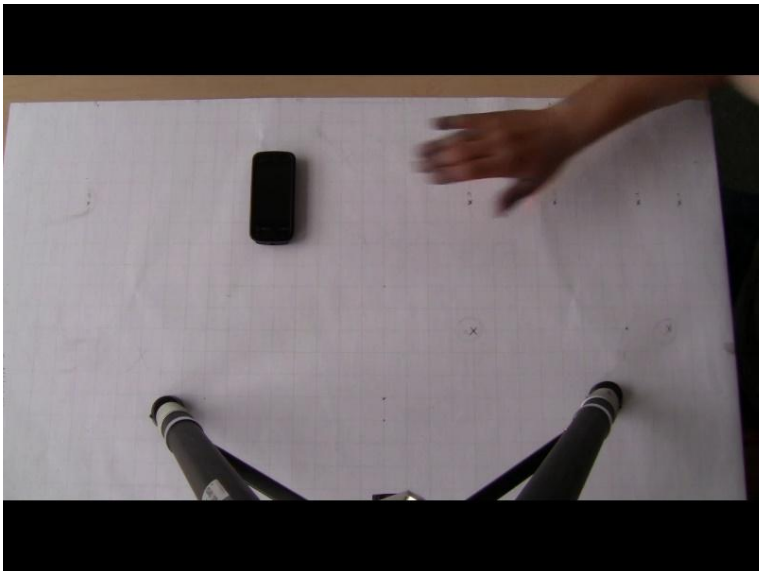

Figure 7 A participant performing reach task

MTM motions included in reach task are: R2A, R3A, R4A, R6A, R8A, R10A, R12A, R16A, R21A, R24A, R28A and R30A.

d. Move task:

Participants are asked to move a single small object which weighs less than one kg. There were twelve different distances to move the object. Distance values are chosen according to the findings from the questioning of MTM data (section 4). They represent the cut points and two other points of each distance segment. An illustration of the task is given in Figure 8.

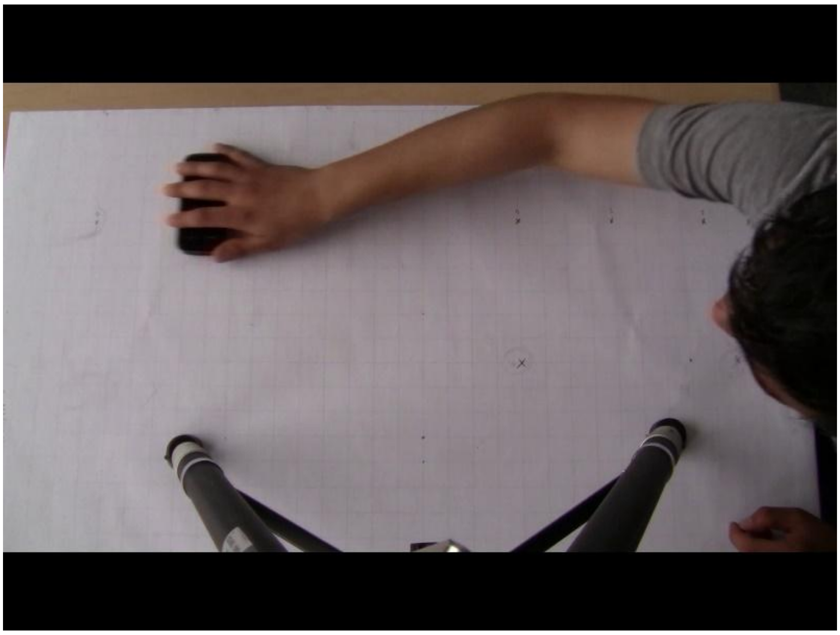

Figure 8 A participant performing move task

MTM motions included in move task are: M2A1, M3A1, M4A1, M6A1, M8A1, M10A1, M12A1, M16A1, M21A1, M24A1, M28A1 and M30A1.

MTM analyses of tasks are given in Appendix D.

5.5. Statistical analysis

Each participant performed each task for ten times. When collecting results data, for each participant the mean score of these ten observations is used. Afterwards for each task the average values of each participant are used. Therefore for standard tasks the sample sizes are 40 (collected from 400 different observations), for the reach and move motion task sample sizes are 20 (collected from 200 different observations). After these scores are calculated, a sign test conducted to evaluate a median score with a 95% confidence interval for each motion in order to set representability of population mean. The main reason using these tests are showing that population means are between these sign test confidence interval results thus it shows similarity to normal distribution and can be used in alternative comparisons. All data collected were put into Minitab and sorted accordingly. All sign test results from Minitab can be found in Appendix E.

Population mean for standard tasks are tested through Hypothesis tests in order to compare with MTM and literature times. Basic motions are tested through Hypothesis tests as well in order to compare with MTM times.

Before entering data into Minitab all experimental data and MTM data were converted to TMU. MTM times are given in Time Measurement Units (TMU) and they were multiplied by 0,036 since 1 TMU is taken equal to 0,00001 hour in order to convert them to seconds (Groover, 2007). The observed data were multiplied by 0,033 since experiment videos were split into their frames.

CHAPTER VI

RESULTS

Results from all tasks are given together in this section. Since the purpose is to validate MTM data, results are given for each basic motion observed through reach and move tasks. Results from the learning curve exercise and results by each standard task are given as well.

6.1. Learning Curve

Two weeks prior to actual experiment, twelve of the participants performed a learning curve exercise for standard tasks.

For pegboard exercise participants performed seven trials. As it can be seen from the Figure 9, after five trials time required to perform the pegboard exercise is leveled. Therefore before the actual experiment numbers of training trials are set to five for every participant. Red line refers to the average time of each trial.

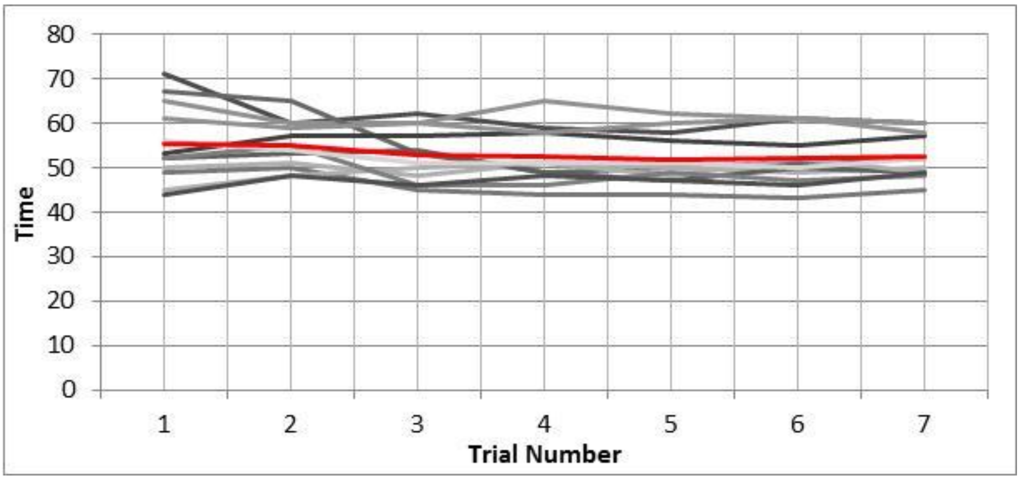

Figure 9 Learning curve for the pegboard task

For card dealing exercise participants performed five trials. As it can be seen from the Figure 10, after three trials time required to perform the card dealing exercise is leveled. Since card dealing is relatively a more simple exercise than pegboard and most of the participants are familiar with card dealing it is expected to have fewer number of repetitions required to learn the exercise. Therefore before the actual experiment numbers of training trials are set to three for every participant. Red line refers to the average time of each trial.

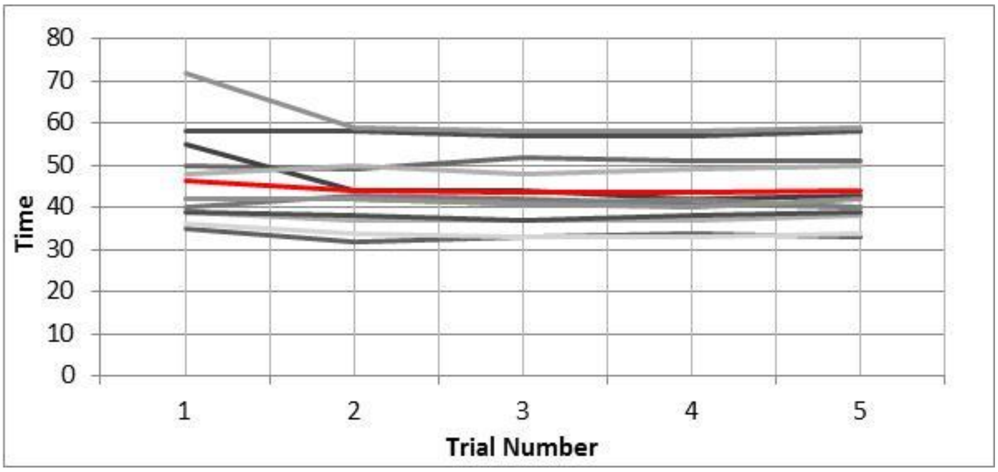

Figure 10 Learning curve for the card dealing task

All learning curve assessment data are given in the Appendix F.

6.2. Standard Tasks

Normal times required for pegboard and card dealing exercises are known from the literature. In order to complete a pegboard exercise 24,60 seconds are required and in order to complete a card dealing task 30,00 seconds are required (Barnes, 1980).

Through MTM analysis, average time required to complete a pegboard task is found 26,09 seconds, and average time required to complete a card dealing task is found as 33,75 seconds.

In the study, average time required to complete a pegboard task is found as 26,55 seconds, and average time required to complete a card dealing task is found as 32,46 seconds.

Results of the sign tests for standard tasks are given in the Table 2.

Table 2 Sign Test Result for Card Dealing and Peg Board (Sample size is 40)

(seconds)	Mean	Median	95% CI	
Card Deal	32,46	32,00	28,37	36,21
Peg Board	26,55	25,75	25,49	27,75

From the sign test results it can be seen that for population median with 95% confidence intervals are close to population mean suggesting a similarity to normal distribution, hence it can be said that these mean values are representative for the population.

Population means are tested through Hypothesis tests via Minitab. Null hypothesis for each case is equality to MTM or Literature times.

- For Peg Board task;
  - First Hypothesis is that Population Mean is equal to MTM time (26,09 seconds) or not for a confidence interval of 95%:

    H_0=26,09 sec; p=0,04 where 95% CI: (26,10; 26,99), null hypothesis is rejected.

  - Second Hypothesis is that Population Mean is equal to Literature time (24,60 seconds) or not for a confidence interval of 95%:

    H_0=24,60 sec; p=0,00 where 95% CI: (26,10; 26,99), null hypothesis is rejected.

- For Card Dealing task;
  - First Hypothesis is that Population Mean is equal to MTM Time (33,75) seconds or not for a confidence interval of 95%:

    H_0=33,75 sec; p=0,00 where 95% CI: (31,85; 33,07), null hypothesis is rejected.

  - Second Hypothesis is that Population Mean is equal to Literature Time (30,00) seconds or not for a confidence interval of 95%:

    H_0=30,00 sec; p=0,00 where 95% CI: (31,85; 33,07), null hypothesis is rejected.

It can be seen that p values are lower than for 0,05 for both tests and all hypothesizes are rejected for equality to MTM and Literature times. It shows that MTM and Literature times did not fit into these observations.

6.3. Basic Motions

6.3.1. Reach Motion:

Reach motions tested in this research are: R2A, R3A, R4A, R6A, R8A, R10A, R12A, R16A, R21A, R24A, R28A and R30A.

Results of the sign tests for reach motions are given in the Table 3.

Table 3 Sign Test Result for Reach Motions (Sample size is 20)

(seconds)	Mean	Median	95% CI	
R2	0,36	0,35	0,34	0,37
R3	0,35	0,33	0,29	0,38
R4	0,36	0,36	0,35	0,38
R6	0,38	0,36	0,33	0,41
R8	0,41	0,41	0,40	0,42
R10	0,42	0,41	0,38	0,46
R12	0,46	0,46	0,45	0,47
R16	0,48	0,46	0,41	0,53
R21	0,54	0,54	0,54	0,55
R24	0,57	0,56	0,48	0,63
R28	0,72	0,72	0,66	0,75
R30	0,76	0,77	0,75	0,78

From the sign test results it can be seen that for sample median with 95% confidence intervals are close to sample mean suggesting a similarity to normal distribution.

In Table 3 it is seen that average time required for reaching a distance of 2 inches requires the same time of reaching to 4 inches while it took longer than reaching to distance of 3 inches. These results require a closer approach to these observations.

Therefore, in order to test whether these three series shows significant difference One-Way ANOVA tests are done between each other. Figure 11 shows the results of these tests.

One-way ANOVA: R2 versus R3

```
Source   DF      SS    MS     F      P
R3        7    6,64  0,95  0,82  0,575
Error   192  223,16  1,16
Total   199  229,80

S = 1,078   R-Sq = 2,89%   R-Sq(adj) = 0,00%
```

One-way ANOVA: R2 versus R4

```
Source   DF      SS    MS     F      P
R4        5    5,19  1,04  0,90  0,485
Error   194  224,61  1,16
Total   199  229,79

S = 1,076   R-Sq = 2,26%   R-Sq(adj) = 0,00%
```

One-way ANOVA: R3 versus R4

```
Source   DF      SS    MS     F      P
R4        5    3,99  0,80  0,56  0,734
Error   194  278,61  1,44
Total   199  282,60

S = 1,198   R-Sq = 1,41%   R-Sq(adj) = 0,00%
```

Figure 11 One-Way ANOVA test results between Reach 2,3 and 4

As it seen in Figure 11 all p values are larger than 0,05 indicating that there is no significant difference between these series observations which explains why their mean values are very close and shows their oscillating behavior.

Additionally all distance observations samples are tested against MTM times through Hypothesis tests as well. All population means are tested for equality to MTM times:

- **2 inches:** H_0=0,14 sec; p=0,00 where 95% CI: (0,35; 0,37), null hypothesis is rejected.
- **3 inches:** H_0=0,19 sec; p=0,00 where 95% CI: (0,32; 0,38), null hypothesis is rejected.
- **4 inches:** H_0=0,22 sec; p=0,00 where 95% CI: (0,35; 0,38), null hypothesis is rejected.
- **6inches:** H_0=0,25 sec; p=0,00 where 95% CI: (0,35; 0,41), null hypothesis is rejected.
- **8 inches:** H_0=0,28 sec; p=0,00 where 95% CI: (0,40; 0,42), null hypothesis is rejected.
- **10 inches:** H_0=0,31 sec; p=0,00 where 95% CI: (0,39; 0,46), null hypothesis is rejected.
- **12 inches:** H_0=0,35 sec; p=0,00 where 95% CI: (0,45; 0,47), null hypothesis is rejected.
- **16 inches:** H_0=0,41 sec; p=0,00 where 95% CI: (0,43; 0,53), null hypothesis is rejected.
- **21 inches:** H_0=0,49 sec; p=0,00 where 95% CI: (0,53; 0,55), null hypothesis is rejected.
- **24 inches:** H_0=0,54 sec; p=0,19 where 95% CI: (0,53; 0,61), null hypothesis is not rejected.
- **28 inches:** H_0=0,60 sec; p=0,00 where 95% CI: (0,67; 0,76), null hypothesis is rejected.

- **30 inches:** H_0=0,63 sec; p=0,00 where 95% CI: (0,75; 0,77), null hypothesis is rejected.

As can be seen from the results, except 24 inches equality to MTM times are rejected for the observations.

6.3.2. Move Motion:

Move motions tested in this research are: M2A1, M3A1, M4A1, M6A1, M8A1, M10A1, M12A1, M16A1, M21A1, M24A1, M28A1 and M30A1.

Results of the sign tests for move motions are given in the Table 4.

Table 4 Sign Test Result for Move Motions (Sample size is 20)

(seconds)	Mean	Median	95% CI	
M2	0,43	0,42	0,39	0,44
M3	0,43	0,42	0,39	0,45
M4	0,46	0,47	0,43	0,49
M6	0,46	0,46	0,41	0,49
M8	0,52	0,52	0,48	0,55
M10	0,53	0,51	0,47	0,55
M12	0,58	0,56	0,53	0,61
M16	0,57	0,57	0,53	0,60
M21	0,67	0,65	0,61	0,70
M24	0,67	0,65	0,63	0,69
M28	0,77	0,76	0,73	0,80
M30	0,78	0,76	0,73	0,79

Observation results are given in detail in Appendix G.

From the sign test results it can be seen that for sample median with 95% confidence intervals are close to sample mean suggesting a similarity to normal distribution.

Additionally all distance observations samples are tested against MTM times through Hypothesis tests as well. All population means are tested for equality to MTM times:

- **2 inches:** H_0=0,13 sec; p=0,00 where 95% CI: (0,40; 0,45), null hypothesis is rejected.

- **3 inches:** H_0=0,18 sec; p=0,00 where 95% CI: (0,40; 0,45), null hypothesis is rejected.

- **4 inches:** H_0=0,22 sec; p=0,00 where 95% CI: (0,43; 0,49), null hypothesis is rejected.

- **6inches:** H_0=0,29 sec; p=0,00 where 95% CI: (0,43; 0,50), null hypothesis is rejected.
- **8 inches:** H_0=0,35 sec; p=0,00 where 95% CI: (0,49; 0,56), null hypothesis is rejected.
- **10 inches:** H_0=0,41 sec; p=0,00 where 95% CI: (0,49; 0,56), null hypothesis is rejected.
- **12 inches:** H_0=0,46 sec; p=0,00 where 95% CI: (0,54; 0,61), null hypothesis is rejected.
- **16 inches:** H_0=0,58 sec; p=0,81 where 95% CI: (0,54; 0,61), null hypothesis is not rejected.
- **21 inches:** H_0=0,72 sec; p=0,00 where 95% CI: (0,63; 0,70), null hypothesis is rejected.
- **24 inches:** H_0=0,81 sec; p=0,00 where 95% CI: (0,64; 0,70), null hypothesis is rejected.
- **28 inches:** H_0=0,92 sec; p=0,00 where 95% CI: (0,73; 0,81), null hypothesis is rejected.
- **30 inches:** H_0=0,98 sec; p=0,00 where 95% CI: (0,73; 0,82), null hypothesis is rejected.

As can be seen from the results, except 16 inches equality to MTM times are rejected for the observations.

CHAPTER VII

FINDINGS

7.1. Pegboard Task

In the literature the average time required to perform pegboard task is 24,60 seconds. From the MTM analysis of the task, relevant MTM time is found as 26,09 seconds. However in this study it is observed as 26,55. This result suggests that achieving literature and MTM times was harder for the participants in the study.

7.2. Card Dealing Task

In the literature the average time required to perform card dealing task is 30,00 seconds. From the MTM analysis of the task, relevant MTM time is found as 33,75 seconds. However in this study it is observed as 32,46. This result suggests that achieving literature time was harder for the participants in the study even though they were faster than the MTM time.

7.3. Reach Task

Figure 12 shows a comparison of reach times observed in the study and the reach times from the MTM data. Blue line represents the plot of the observed values together with their 95% confidence interval. As it can be seen distance of 24 inches' confidence interval contains the MTM data as well.

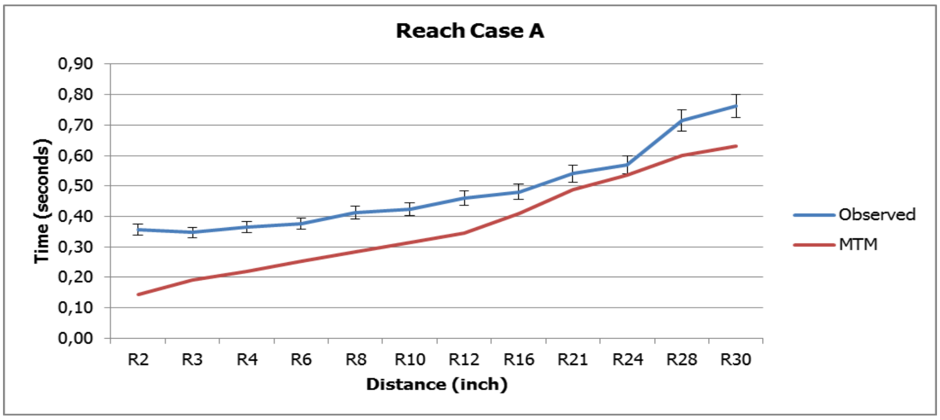

Figure 12 Comparison of MTM Reach Data with observed Data

As it can be seen from the Figure 12 observed reach times are higher than MTM times. Similar to MTM times observed times shows an increasing trend with the distance, which is expected. However for shorter reach distances (1 to 3 inches) observed times exceptionally higher than MTM times. This may be due to two different alternatives:

1) In the original MTM research time values for such shorter times might be calculated via interpolation.
2) For the population in this study reaching to shorter distances might be somewhat harder than the population in the original MTM research.

7.4. Move Task

Figure 13 shows a comparison of reach times observed in the study and the move times from the MTM data. Blue line represents the plot of the observed values together with their 95% confidence interval. As it can be seen distance of 16 inches' confidence interval contains the MTM data as well.

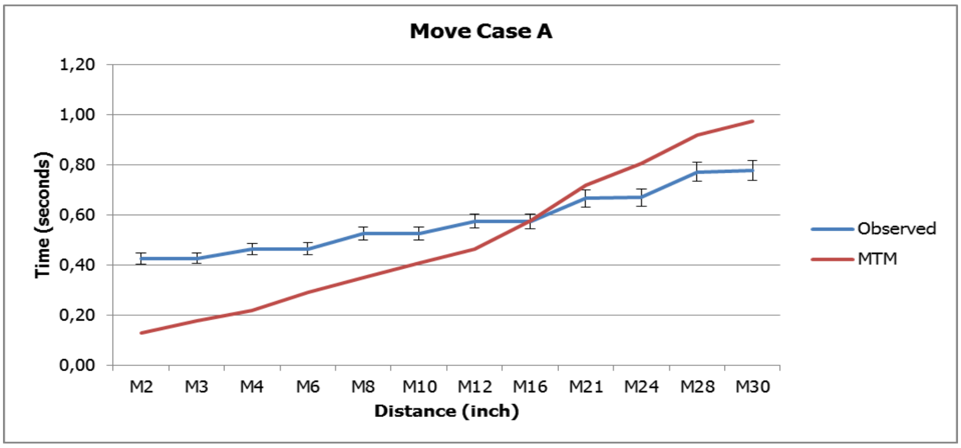

Figure 13 Comparison of MTM Move Data with observed Data

As it can be seen from the Figure 13 observed move times are higher than MTM times until 16 inches, afterwards MTM times are higher. Similar to MTM times observed times shows an increasing trend with the distance, which is expected. However for shorter reach distances (1 to 3 inches) observed times exceptionally higher than MTM times similar to the reach case mentioned in the previous section. The reason behind why MTM times are higher than the observed times for longer distances might be the differences between the populations of the each study.

CHAPTER VIII

CONCLUSION

Results from this research showed that original MTM time data does not fit into real life observations.

In most cases MTM times are lower than observed values. For the most commonly used basic motions of reach and move, for shorter distances the gap between observed times and MTM times are higher. The reason behind this issue might be the fact that people tend give more attention to object which are very close to them, which might be neglected in the original MTM research. Another conclusion about reach and move motions that, for longer distances the gap between observed times and MTM times starts to decrease, even in some cases it is seen that MTM times are higher. The reason behind this issue might be the difference between the anthropometric measures of the samples used in this research and the original MTM research. The average horizontal arm reach (as illustrated in Figure 14) for US army men is 88,0 cm according to Bradtmiller et al. and the average vertical arm reach for Turkish army men is 81,3 cm according to the research conducted by Kayis and Özok (Bradtmiller, Hodge, Kristensen, Mucher, 2008) (Kayis, Özok, 1991).

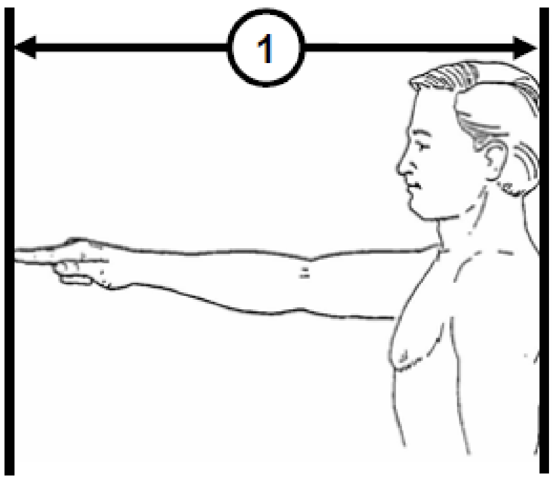

Figure 14 Horizontal Arm Reach

This might suggest original MTM times may not be suitable for Turkish population. It should be noted that in the original MTM research Maynard's Methods-time measurement book did not contain any information on the population statistics used in the research. Therefore, for further applications and precise representation of population characteristics usage of local data is more appropriate for building such a time study database.

This research showed that there are significant differences between the real life time values and MTM values for reach and move motions. Even though these individual differences can be considered very small in the sense of time when these motions are grouped together to perform tasks, these differences are shown to be effective. In the case of standard tasks used in this research (pegboard and card dealing) cycle time differences was around 10 percentages as observed cycle times were longer than normal times. Observed times were different than MTM times by around 5 percentages, shorter for card dealing, longer for peg board. This might be caused by the industrial factors of the time when the original MTM constructed, which required a higher work rate for the workers. Whatever the reason is, it can be concluded based on this research that there is a need for updating time values of MTM tables.

With the advanced technology of today compared to the 1948, when MTM was constructed, there are more accurate and reliable ways to conduct such analysis now. Real Time Method Study tool is an appropriate candidate for such a task. With the help of today's more powerful video camera options, image processing technologies, machine learning algorithms a tool like RTMS can easily and accurately observe and process motion study techniques automatically. In order to use RTMS in Turkish Industry, instead of setting standard times based on MTM a new time database can be constructed easily in the long run. Since, data collection would be faster in RTMS, with larger samples more precise time values can be obtained. Another benefit of developing new time tables for Turkey is that it would be more representative for Turkish Industry, since the working conditions of Turkey and other countries may differ. RTMS can also provide other basic motion time data from different countries if it is used there as well.

In the end, it is seen that MTM time tables are not representative for Turkish operators and with the opportunities brought through RTMS developing new time standards is required.

CHAPTER IX

FUTURE STUDIES

For further research, with the aid of such high-end systems like RTMS more flexible time study systems can be developed. Since RTMS can bring time study and method analysis such new systems can bring the concepts of time and ergonomic efficiencies together. During such studies, other basic motions of MTM could be compared with real observation values as well. Another important point for such new replications, it should be noted that this study has been done with only university students. In order to reflect real life working conditions further studies can be done in with actual operators, in addition difference between female and male participants can be analyzed in more detail as well.

During such real life working conditions, experience of workers may result in different learning curve effects their performance might give different results. During this study, participants have performed all tasks in the same order with minor rest periods. Learning effect between those tasks might have increased their performance on the later task.

Application of MTM study by a time study analyst is also a difficult job. Original MTM research includes rating work and operator skill as well (Karger, 1976). Therefore, it is difficult to compare it with stop watch time study which usually uses performance rating. In addition, accepted operator performance in this research might be different than the acceptable performance expected in our industry today.

With the aid of RTMS, a research based on the correlation of ergonomic and time analysis of a task can be helpful the create guidelines of how ergonomic improvements of tasks would affect the time efficiency.

Since this study suggests that developing more demographically representative time measurement systems is required together with the data collected through RTMS, new time measurement systems can include alternative suggestions for motions as well for specific individuals. Both physical and psychological differences between regions can affect worker performance in real life. In order to develop region and sector specific time study databases such differences should be taken into account in more detail.

It should be noted that, in the conclusion part this research highlights the potential effects of anthropometric measures. A research which classifies participants based on their main anthropometric measures and investigates the correlation between time performance and such measures could be done.

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APPENDICES

Appendix A: ILO Recommended Allowances

A.	Constant allowances:			
	1.	Personal allowance		5
	2.	Basic fatigue allowance		4
B.	Variable allowances:			
	1.	Standing allowance		2
	2.	Abnormal position allowance:		
		a.	Slightly awkward	0
		b.	Awkward (bending)	2
		c.	Very awkward (lying, stretching)	7
	3.	Use of force, or muscular energy:		
		Weight lifted, pounds:		
			5	0
			10	1
			15	2
			20	3
			25	4
			30	5
			35	7
			40	9
			45	11
			50	13
			60	17
			70	22
	4.	Bad light:		
		a.	Slightly below recommended	0
		b.	Well below	2
		c.	Quite inadequate	5
	5.	Atmospheric conditions		0-100
	6.	Close attention:		

	a.	Fairly fine work	0
	b.	Fine or exacting	2
	c.	Very fine or very exacting	5
7.	Noise level:		
	a.	Continuous	0
	b.	Intermittent - loud	2
	c.	Intermittent - very loud	5
	d.	High-pitched - loud	5
8.	Mental strain:		
	a.	Fairly complex process	1
	b.	Complex or wide span of attention	4
	c.	Very complex	8
9.	Monotony:		
	a.	Low	0
	b.	Medium	1
	c.	High	4
10.	Tediousness:		
	a.	Rather tedious	0
	b.	Tedious	2
	c.	Very tedious	5

Appendix B: MTM Time Tables

TABLE II - MOVE - M

Distance Moved	Time TMU A	Time TMU B	Time TMU C	Time TMU Hand in Motion B	Wt. Allowance Wt. (lb) Up to	Wt. Allowance Dynamic Factor	Wt. Allowance Static Constant TMU	CASE AND DESCRIPTION
3/4 or less	2.0	2.0	2.0	1.7	2.50	1.00	0.00	A Move object to other hand or against stop.
1	2.5	2.9	3.4	2.3				
2	3.6	4.6	5.2	2.9	7.50	1.06	2.20	
3	4.9	5.7	6.7	3.6				
4	6.1	6.9	8.0	4.3	12.50	1.11	3.90	
5	7.3	8.0	9.2	5.0				
6	8.1	8.9	10.3	5.7	17.50	1.17	5.60	
7	8.9	9.7	11.1	6.5				
8	9.7	10.6	11.8	7.2	22.50	1.22	7.40	B Move object to approximate or indefinite location.
9	10.5	11.5	12.7	7.9				
10	11.3	12.2	13.5	8.6	27.50	1.28	9.10	
12	12.9	13.4	15.2	10.0				
14	14.4	14.6	16.9	11.4	32.50	1.33	10.80	
16	16.0	15.8	18.7	12.8				
18	17.6	17.0	20.4	14.2	37.50	1.39	12.50	
20	19.2	18.2	22.1	15.6				C Move object to exact location.
22	20.8	19.4	23.8	17.0	42.50	1.44	14.30	
24	22.4	20.6	25.5	18.4				
26	24.0	21.8	27.3	19.8	47.50	1.50	16.00	
28	25.5	23.1	29.0	21.2				
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	Time TMU for Degrees Turned 30°	45°	60°	75°	90°	105°	120°	135°	150°	165°	180°
Small - 0 to 2 lbs	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 lbs	4.4	55	6.5	7.5	8.5	9.6	10.6	11.6	12.7	13.7	14.8
Large - 10.1 to 35 lbs	8.4	10.5	12.3	14.4	16.2	18.3	20.4	22.2	24.3	26.1	28.2

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 itsef, 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.	

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 VIII - EYE TRAVEL AND EYE FOCUS - ET AND EF

Eye Travel Time = 15.2 x T/D TMU, with a maximum value of 20 TMU.

Where: T = the distance between points from and to which the eye travels.

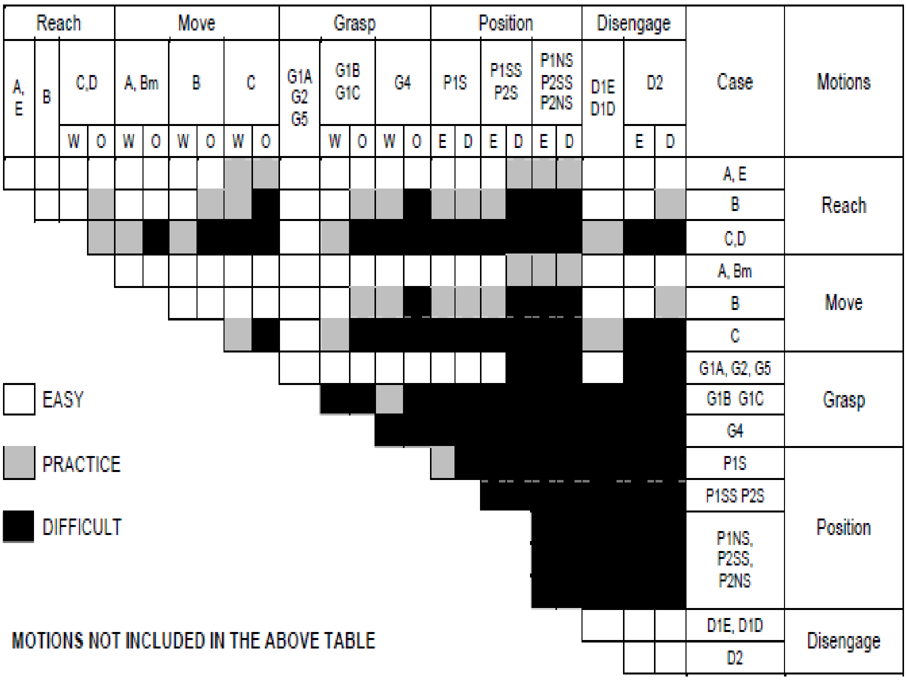
D = the perpendicular distance from the eye to the line of travel T.

Eye Focus Time = 7.3 TMU.

SUPPLEMENTARY INFORMATION

- Area of Normal Vision = Circle 4" in Diameter 16" from Eyes
- Reading Formula = 5.05 N Where N = The Number of Words.

TABLE X - SIMULTANEOUS MOTIONS



MOTIONS NOT INCLUDED IN THE ABOVE TABLE

TURN - Normally EASY with all motions, except when TURN is controlled or with DISENGAGE

APPLY PRESSURE - May be EASY, PRACTICE or DIFFICULT. Each case must be analyzed.

POSITION - Class 3 - Always DIFFICULT.

DISENGAGE - Class 3 - Usually DIFFICULT.

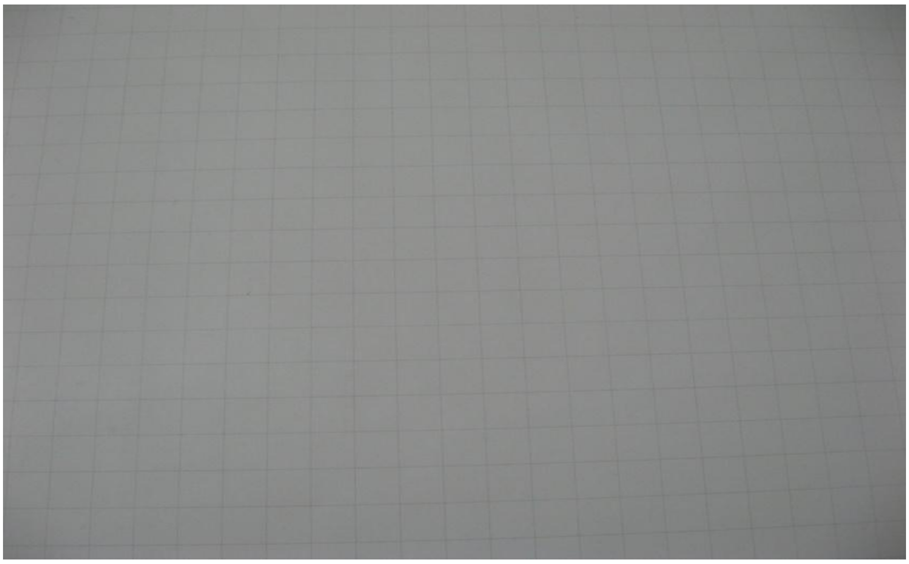
RELEASE - Always EASY.

DISENGAGE - Any class may be DIFFICULT if care must be exercised to avoid injury or damage to the object

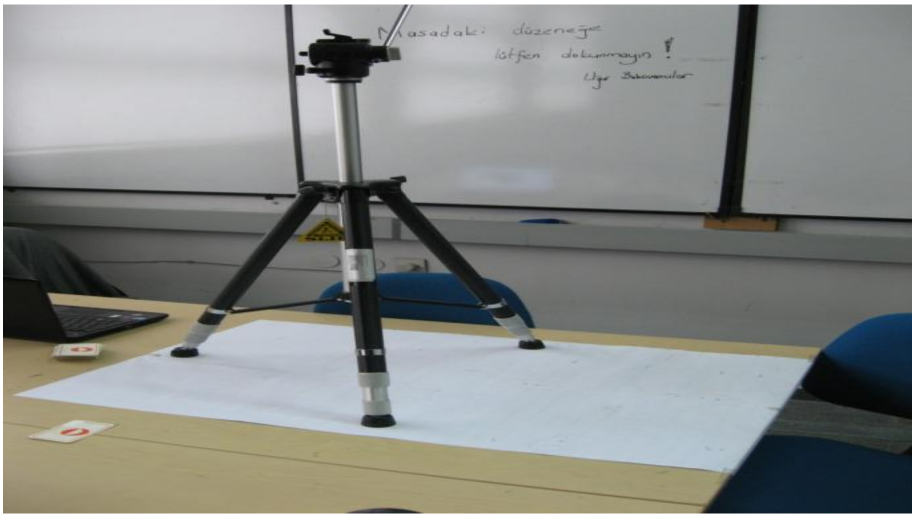
W = Within the area of normal vision
O = Outside the area of normal vision
E = EASY to handle
D = DIFFICULT to handle

Appendix C: Equipment and Setup

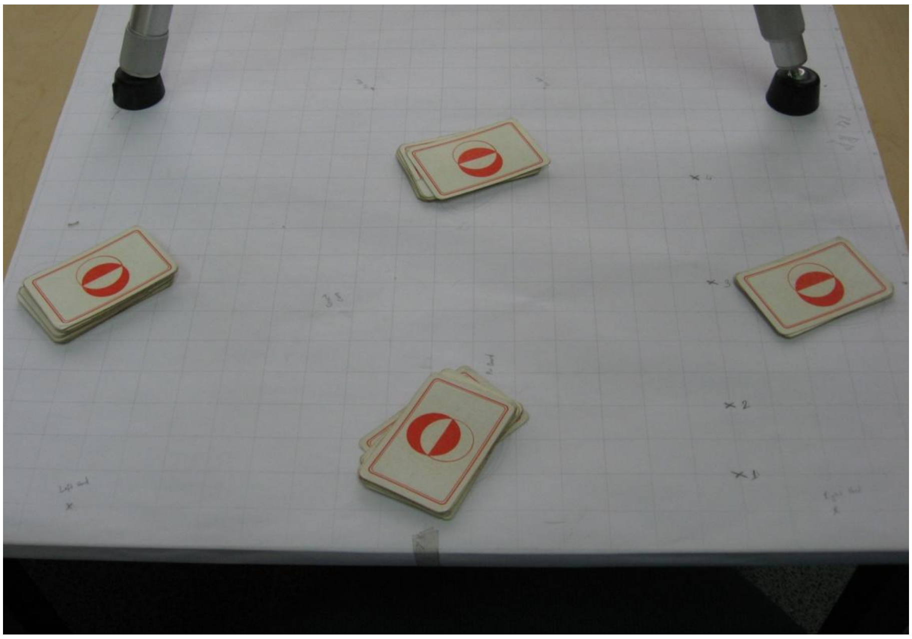
Grid Paper



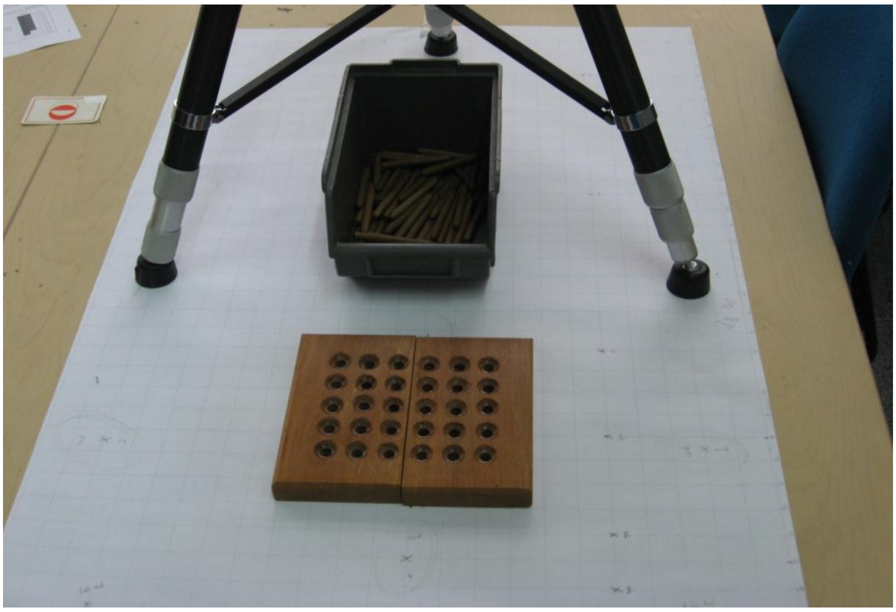
Camera Setup



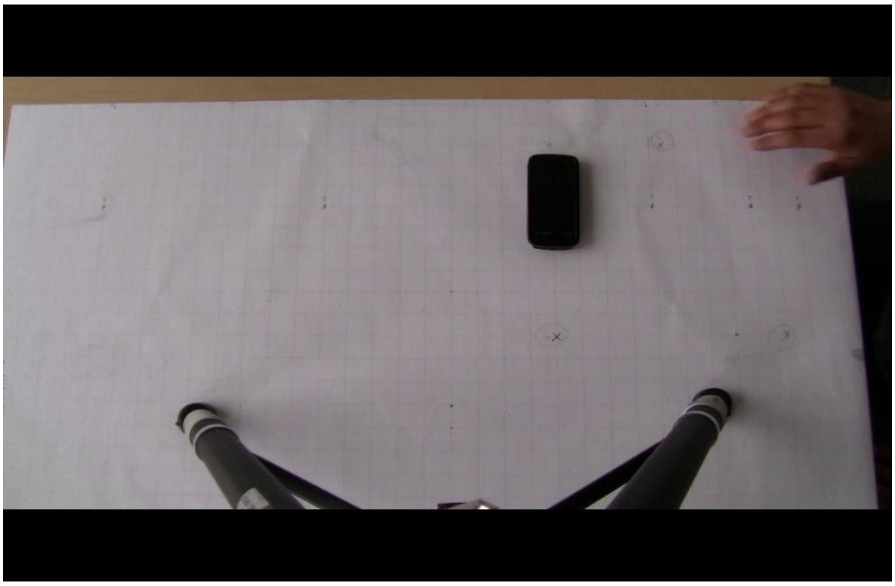
Card Deal Task Setup



Pegboard Task Setup



Reach and Move Tasks Setup



Appendix D: MTM Analysis of Standard Tasks

Card Deal

Seq.	Motion	TMU	Seq.	Motion	TMU	Seq.	Motion	TMU	Seq.	Motion	TMU	Seq.	Motion	TMU	Seq.	Motion	TMU	Seq.	Motion	TMU
1	R3B	5,3	31	M3B	3,6	61	R9B	7,9	91	M9B	7,9	121	R10B	8,6	151	M10B	8,6	181	R9B	7,9
2	G1B	2	32	RL2	2	62	G1B	2	92	RL2	2	122	G1B	2	152	RL2	2	182	G1B	2
3	M9B	7,9	33	R3B	3,6	63	M3B	3,6	93	R9B	7,9	123	M9B	7,9	153	R10B	8,6	183	M10B	8,6
4	RL2	2	34	G1B	2	64	RL2	2	94	G1B	2	124	RL2	2	154	G1B	2	184	RL2	2
5	R9B	7,9	35	M9B	7,9	65	R3B	3,6	95	M3B	3,6	125	R9B	7,9	155	M9B	7,9	185	R10B	8,6
6	G1B	2	36	RL2	2	66	G1B	2	96	RL2	2	126	G1B	2	156	RL2	2	186	G1B	2
7	M10B	8,6	37	R9B	7,9	67	M9B	7,9	97	R3B	3,6	127	M3B	3,6	157	R9B	7,9	187	M9B	7,9
8	RL2	2	38	G1B	2	68	RL2	2	98	G1B	2	128	RL2	2	158	G1B	2	188	RL2	2
9	R10B	8,6	39	M10B	8,6	69	R9B	7,9	99	M9B	7,9	129	R3B	3,6	159	M3B	3,6	189	R9B	7,9
10	G1B	2	40	RL2	2	70	G1B	2	100	RL2	2	130	G1B	2	160	RL2	2	190	G1B	2
11	M9B	7,9	41	R10B	8,6	71	M10B	8,6	101	R9B	7,9	131	M9B	7,9	161	R3B	3,6	191	M3B	3,6
12	RL2	2	42	G1B	2	72	RL2	2	102	G1B	2	132	RL2	2	162	G1B	2	192	RL2	2
13	R9B	7,9	43	M9B	7,9	73	R10B	8,6	103	M10B	8,6	133	R9B	7,9	163	M9B	7,9	193	R3B	3,6
14	G1B	2	44	RL2	2	74	G1B	2	104	RL2	2	134	G1B	2	164	RL2	2	194	G1B	2
15	M3B	3,6	45	R9B	7,9	75	M9B	7,9	105	R10B	8,6	135	M10B	8,6	165	R9B	7,9	195	M9B	7,9
16	RL2	2	46	G1B	2	76	RL2	2	106	G1B	2	136	RL2	2	166	G1B	2	196	RL2	2
17	R3B	3,6	47	M3B	3,6	77	R9B	7,9	107	M9B	7,9	137	R10B	8,6	167	M10B	8,6	197	R9B	7,9
18	G1B	2	48	RL2	2	78	G1B	2	108	RL2	2	138	G1B	2	168	RL2	2	198	G1B	2
19	M9B	7,9	49	R3B	3,6	79	M3B	3,6	109	R9B	7,9	139	M9B	7,9	169	R10B	8,6	199	M10B	8,6
20	RL2	2	50	G1B	2	80	RL2	2	110	G1B	2	140	RL2	2	170	G1B	2	200	RL2	2
21	R9B	7,9	51	M9B	7,9	81	R3B	3,6	111	M3B	3,6	141	R9B	7,9	171	M9B	7,9	201	R10B	8,6
22	G1B	2	52	RL2	2	82	G1B	2	112	RL2	2	142	G1B	2	172	RL2	2	202	G1B	2
23	M10B	8,6	53	R9B	7,9	83	M9B	7,9	113	R3B	3,6	143	M3B	3,6	173	R9B	7,9	203	M9B	7,9
24	RL2	2	54	G1B	2	84	RL2	2	114	G1B	2	144	RL2	2	174	G1B	2	204	RL2	2
25	R10B	8,6	55	M10B	8,6	85	R9B	7,9	115	M9B	7,9	145	R3B	3,6	175	M3B	3,6	205	R9B	7,9
26	G1B	2	56	RL2	2	86	G1B	2	116	RL2	2	146	G1B	2	176	RL2	2	206	G1B	2
27	M9B	7,9	57	R10B	8,6	87	M10B	8,6	117	R9B	7,9	147	M9B	7,9	177	R3B	3,6	207	M3B	3,6
28	RL2	2	58	G1B	2	88	RL2	2	118	G1B	2	148	RL2	2	178	G1B	2	208	RL2	2
29	R9B	7,9	59	M9B	7,9	89	R10B	8,6	119	M10B	8,6	149	R9B	7,9	179	M9B	7,9			
30	G1B	2	60	RL2	2	90	G1B	2	120	RL2	2	150	G1B	2	180	RL2	2			

Peg Board

Seq.	Motion	TMU	Seq.	Motion	TMU	Seq.	Motion	TMU	Seq.	Motion	TMU
1	R14C	15,6	21	R10C	12,9	41	R11C	13,5	61	R12C	14,2
2	G1B	3,5	22	G1B	3,5	42	G1B	3,5	62	G1B	3,5
3	M13C	16	23	M9C	12,7	43	M10C	13,5	63	M11C	14,3
4	P2SE	16,2	24	P2SE	16,2	44	P2SE	16,2	64	P2SE	16,2
5	RL	2	25	RL	2	45	RL	2	65	RL	2
6	R13C	14,9	26	R9C	12,2	46	R10C	12,9	66	R11C	13,5
7	G1B	3,5	27	G1B	3,5	47	G1B	3,5	67	G1B	3,5
8	M12C	15,2	28	M13C	16	48	M9C	12,7	68	M10C	13,5
9	P2SE	16,2	29	P2SE	16,2	49	P2SE	16,2	69	P2SE	16,2
10	RL	2	30	RL	2	50	RL	2	70	RL	2
11	R12C	14,2	31	R13C	14,9	51	R9C	12,2	71	R10C	12,9
12	G1B	3,5	32	G1B	3,5	52	G1B	3,5	72	G1B	3,5
13	M11C	14,3	33	M12C	15,2	53	M13C	16	73	M9C	12,7
14	P2SE	16,2	34	P2SE	16,2	54	P2SE	16,2	74	P2SE	16,2
15	RL	2	35	RL	2	55	RL	2	75	RL	2
16	R11C	13,5	36	R12C	14,2	56	R13C	14,9			
17	G1B	3,5	37	G1B	3,5	57	G1B	3,5			
18	M10C	13,5	38	M11C	14,3	58	M12C	15,2			
19	P2SE	16,2	39	P2SE	16,2	59	P2SE	16,2			
20	RL	2	40	RL	2	60	RL	2			

Appendix E: Sign Test

	N	Median	Achieved Confidence	Confidence Interval Lower	Confidence Interval Upper	Position
Card	40	480,0	0,9193	425,6	542,6	15
			0,9500	425,6	543,2	NLI
			0,9615	425,6	543,6	14
Peg	40	386,2	0,9193	382,3	413,4	15
			0,9500	382,3	416,3	NLI
			0,9615	382,3	418,4	14
R2	20	5,300	0,8847	5,200	5,500	7
			0,9500	5,124	5,500	NLI
			0,9586	5,100	5,500	6
R3	20	4,900	0,8847	4,500	5,600	7
			0,9500	4,424	5,676	NLI
			0,9586	4,400	5,700	6
R4	20	5,450	0,8847	5,200	5,600	7
			0,9500	5,200	5,676	NLI
			0,9586	5,200	5,700	6
R6	20	5,450	0,8847	5,100	6,000	7
			0,9500	4,947	6,076	NLI
			0,9586	4,900	6,100	6
R8	20	6,200	0,8847	6,000	6,200	7
			0,9500	6,000	6,276	NLI
			0,9586	6,000	6,300	6
R10	20	6,100	0,8847	5,900	6,600	7
			0,9500	5,671	6,829	NLI
			0,9586	5,600	6,900	6
R12	20	6,900	0,8847	6,800	7,000	7
			0,9500	6,800	7,000	NLI
			0,9586	6,800	7,000	6
R16	20	6,950	0,8847	6,500	7,800	7
			0,9500	6,194	7,953	NLI
			0,9586	6,100	8,000	6
R21	20	8,150	0,8847	8,100	8,200	7
			0,9500	8,100	8,200	NLI
			0,9586	8,100	8,200	6
R24	20	8,400	0,8847	7,400	9,200	7
			0,9500	7,247	9,429	NLI
			0,9586	7,200	9,500	6
R28	20	10,75	0,8847	10,00	11,20	7
			0,9500	9,92	11,28	NLI
			0,9586	9,90	11,30	6
R30	20	11,50	0,8847	11,30	11,60	7
			0,9500	11,22	11,68	NLI
			0,9586	11,20	11,70	6
M2	20	6,300	0,8847	5,900	6,600	7
			0,9500	5,900	6,600	NLI
			0,9586	5,900	6,600	6
M3	20	6,350	0,8847	5,800	6,700	7
			0,9500	5,800	6,776	NLI
			0,9586	5,800	6,800	6
M4	20	7,000	0,8847	6,500	7,200	7
			0,9500	6,424	7,353	NLI
			0,9586	6,400	7,400	6
M6	20	6,950	0,8847	6,200	7,300	7
			0,9500	6,200	7,300	NLI
			0,9586	6,200	7,300	6
M8	20	7,750	0,8847	7,200	8,200	7
			0,9500	7,200	8,276	NLI
			0,9586	7,200	8,300	6
M10	20	7,650	0,8847	7,200	8,200	7
			0,9500	7,047	8,276	NLI
			0,9586	7,000	8,300	6
M16	20	8,500	0,8847	8,000	8,900	7
			0,9500	7,924	9,053	NLI
			0,9586	7,900	9,100	6
M12	20	8,450	0,8847	7,900	9,000	7
			0,9500	7,900	9,076	NLI
			0,9586	7,900	9,100	6
M21	20	9,70	0,8847	9,30	10,40	7
			0,9500	9,22	10,48	NLI
			0,9586	9,20	10,50	6
M24	20	9,75	0,8847	9,40	10,30	7
			0,9500	9,40	10,38	NLI
			0,9586	9,40	10,40	6
M28	20	11,45	0,8847	11,00	11,70	7
			0,9500	10,92	11,93	NLI
			0,9586	10,90	12,00	6
M30	20	11,45	0,8847	11,00	11,60	7
			0,9500	10,92	11,91	NLI
			0,9586	10,90	12,00	6

Appendix F: Learning curve for tasks

Card Dealing Task Times (seconds)

Trial	Participant no											
#	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1	58	72	50	55	40	48	35	39	42	39	42	36
2	58	59	49	44	43	50	32	37	42	38	42	34
3	57	58	52	44	42	48	33	37	41	37	41	33
4	57	58	51	42	41	49	34	37	42	38	40	33
5	58	59	51	43	40	50	33	38	40	39	42	34

Pegboard Task Times (seconds)

Trial	Participant no											
#	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1	71	65	67	53	49	50	52	45	52	44	61	56
2	60	60	65	57	50	51	53	48	55	48	59	54
3	62	60	53	57	45	48	54	50	46	46	60	51
4	59	65	49	58	44	51	49	51	46	48	58	51
5	58	62	50	56	44	50	47	48	49	47	60	51
6	61	61	51	55	43	49	50	52	47	46	61	50
7	60	60	52	57	45	50	49	49	48	49	58	52

Appendix G: Frame Counts from the Experiment Card Frame Counts

Card Frames															
469	469	641	680	469	469	490	490	469	469	485	495	469	469	493	485
461	461	686	671	461	461	485	485	461	461	516	499	461	461	485	489
399	399	520	485	399	399	645	625	399	399	628	579	399	399	599	592
405	405	445	510	405	405	437	529	405	405	546	541	405	405	673	676
385	385	515	490	385	385	519	500	385	385	485	680	385	385	569	529
471	471	485	495	471	471	497	485	471	471	510	510	471	471	637	645
450	450	516	499	450	450	473	489	450	450	519	519	450	450	671	673
401	401	628	579	401	401	621	592	401	401	641	678	401	401	495	496
388	388	546	541	388	388	676	677	388	388	445	510	388	388	495	437
383	383	533	637	383	383	556	529	383	383	516	499	383	383	493	515
465	465	641	495	465	465	637	625	465	465	497	490	465	465	485	473
451	451	599	495	451	451	673	676	451	451	485	495	451	451	522	519
409	409	641	680	409	409	495	466	409	409	628	579	409	409	599	621
403	403	445	510	403	403	495	529	403	403	686	677	403	403	520	549
387	387	516	499	387	387	493	485	387	387	570	570	387	387	680	533
474	474	515	490	474	474	485	489	470	470	645	570	470	470	641	495
456	456	485	495	456	456	522	500	457	457	676	677	457	457	599	495
401	401	628	579	401	401	599	592	406	406	496	466	406	406	637	645
415	415	686	671	415	415	520	532	418	418	437	529	418	418	495	437
382	382	570	570	382	382	637	485	386	386	497	485	386	386	522	519
470	470	641	678	470	470	489	489	474	474	473	489	474	474	493	515
457	457	686	677	457	457	522	522	456	456	519	500	456	456	485	473
406	406	520	485	406	406	637	625	401	401	621	592	401	401	599	621
418	418	445	510	418	418	495	529	415	415	549	532	415	415	671	673
386	386	497	490	386	386	522	500	382	382	485	495	382	382	569	553

Peg Board Frame Counts

Peg Frames															
390	410	412	474	387	445	352	374	362	362	404	503	388	388	359	488
415	425	517	426	362	362	371	431	339	339	411	493	410	410	375	405
365	365	460	474	339	339	349	388	359	359	402	503	425	425	508	382
378	378	398	426	359	359	370	384	384	384	406	493	393	393	381	415
368	368	518	408	384	384	349	399	383	383	422	460	404	404	511	426
388	388	460	408	393	393	397	516	368	368	418	460	359	359	386	432
393	393	452	378	404	404	379	510	359	359	446	376	334	334	499	452
404	404	435	381	381	381	399	514	334	334	421	379	365	365	398	435
381	381	452	378	398	445	379	511	410	410	445	363	378	378	501	417
423	445	433	381	362	362	387	476	374	425	422	450	368	368	471	456
365	365	411	401	339	339	384	427	359	359	398	356	388	388	469	420
378	378	387	382	359	359	354	446	384	384	477	380	410	410	459	439
368	368	386	401	384	384	337	467	383	383	367	371	425	425	439	394
388	388	359	382	383	383	353	444	368	368	479	448	393	393	457	384
393	393	385	341	368	368	339	469	410	410	481	400	404	404	442	394
404	404	398	341	381	381	451	401	425	425	479	382	410	410	431	378
381	381	400	393	445	445	474	393	365	365	465	381	425	425	441	376
400	445	384	388	362	362	416	401	378	378	497	449	359	359	431	395
362	362	386	393	339	339	451	393	368	368	465	371	334	334	441	387
339	339	398	388	359	359	473	392	388	388	500	387	365	365	412	383
368	368	355	402	384	384	417	392	383	383	399	483	378	378	412	412
388	388	350	384	383	383	383	361	368	368	526	403	383	383	381	445
393	393	355	383	368	368	376	374	365	365	412	477	368	368	400	401
404	404	350	374	359	359	383	361	378	378	521	403	368	368	381	412
381	381	353	375	334	334	376	374	368	368	364	488	388	388	400	426

Reach Frame Counts

R2		R3		R4		R6		R8		R10		R12		R16		R21		R24		R28		R30	
4	6	5	7	6	5	5	8	6	5	8	8	6	5	6	9	8	8	9	9	10	13	12	11
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6	5	5	7	8	3	5	7	7	7	5	8	8	6	7	8	7	10	9	9	12	11	11	14
7	7	5	7	6	5	5	7	4	5	6	8	6	8	8	8	6	7	9	9	12	10	11	11
7	3	6	7	5	6	6	7	6	5	6	8	6	7	7	8	8	9	10	9	11	10	13	10
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6	5	5	8	6	6	6	7	7	6	6	7	5	8	7	8	8	10	9	9	13	11	11	10
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7	6	5	6	3	7	5	6	8	6	7	5	7	9	5	6	7	8	7	9	10	8	10	12
5	6	4	5	6	6	4	5	5	7	5	6	7	8	4	6	9	7	7	8	7	9	10	12
3	4	5	5	5	6	5	5	7	7	5	5	8	7	5	6	9	9	6	7	8	8	11	12
7	4	5	5	6	6	4	5	6	6	4	6	8	7	6	6	8	7	8	7	9	8	12	11
7	5	4	4	5	5	4	5	7	6	5	5	8	6	5	6	8	9	7	7	9	9	10	13
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Move Frame Counts

M2		M3		M4		M6		M8		M10		M12		M16		M21		M24		M28		M30	
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