AN INVESTIGATION OF METHODS-TIME MEASUREMENT SYSTEMS FOR WORK MEASUREMENT APPLICATION

by

Kenneth Knott

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Supervisor: Professor R. J. Sury, Ph.D.
Department of Engineering Production

SYNOPSIS

This research had two objectives. First, to examine the possible superiority of any of the three principal MTM systems for the derivation of time standards, recognizing the natural variability of actual work times arising from unpaced operator performance. Then, to consider whether the use of further simplifications of predetermined motion time systems, which may be derived from MTM, might permit equally acceptable time standards to be obtained.

Factory studies were used to compare the standards predicted by MTM-1, 2 and 3 against actual performance by well trained workers. No significant difference was detected between the times predicted by MTM-1, MTM-2 and MTM-3.

Four simplified systems were developed from the factory data and, except for the system in which motion cases were ignored, no statistically significant differences were found between cycle times predicted by these systems and by the general levels of MTM.

Times for similar operations in the same factory as the original sample were determined using MTM-1, MTM-2, MTM-3 and two simplified systems. The results were equally acceptable by each of these five systems. Further testing based upon maintenance type work data did not show a satisfactory transferability of simplified systems into this entirely different working environment.

The study did not support the widely held view that there are minimum cycle times below which MTM-2 and MTM-3 should not be used to establish a time standard.

In considering the variability of the actual work times, it was not possible to account for the individual effects of factors which create variability of operators performing unpaced tasks. Nevertheless, a representative distribution for this variability was estimated, in which the variability of the operator work-time was related to the average cycle time.

LIST OF CONTENTS

Page

Page

LIST OF FIGURES

Page

Page

Page

Page

1.0.0. INTRODUCTION AND STATEMENT OF OBJECTIVES

1.0.1 Background to the Problem

For almost half a century the validity of predetermined motion-time systems (PMTS) has been challenged and investigated. The success of PMTS in application has given their users confidence in the systems, in spite of the conflicting views of academic researchers. By the early 1960's, the concept of PMTS and their validity was widely accepted and the only concern seemed to be which particular basic system, for example, Methods-Time Measurements (MTM) or Work Factor, should be selected by a company. The actual way in which this choice was made seems to have depended upon the sales skills of the consultant promoting a particular system or the previous experience of the person making the choice, rather than upon any formal evaluation process.

Analysis of the literature appertaining to PMTS showed a surprising disregard by the academics engaged in research in this area for a basic skill in the techniques which they were investigating. This lack of skill led to serious misapplications of the technique and questionable interpretations of the experimental results. For this reason, the present investigation has been restricted to the MTM based systems, where the investigator has had extensive application experience.

Simplified MTM had been available since before the publication of the original text on MTM by Maynard, Stegemerton and Schwab (1948) and specific data systems, such as Universal Maintenance Standards, had been discussed by Maynard and Stegemerton (1955). In the late 1960's and early 1970's there was a reawakening of the interest in higher-level PMTS. This caused a proliferation of these systems, which were both general and specific in character. This can be shown by considering the MTM group of PMTS, where two general levels of data were developed in the space of a few years, namely MTM-2 and MTM-3. The specific systems generated by the MTM Associations include MTM-C for clerical activities, MTM-V for applications in machine shop, and MTM-M for use in tasks requiring visual magnification. This, incidentally, is not a complete listing.

The question of validity of systems now took on a different tone, since the choice was between systems generated from the same base. The numeracy of the users was far greater than that of their predecessors; however, this did not serve to reduce the acrimony of some of the comparisons* used to claim the superiority of one system over another. Evaluation of the superiority of the MTM systems for application was based principally upon a measure of the confidence interval of the times predicted by the system relative to those predicted by the base system (MTM-1). This measure, the so-called "Balance Time" was established, in particular by Hancock (1970), upon an analysis of the data card values using highly questionable assumptions.

A limitation of the use of particular higher level MTM data systems was recommended in the form of a minimum cycle time value. Experience, however, showed this time to be poorly defined and furthermore, many practitioners questioned its validity.

The development of the MTM-2 and MTM-3 data systems was based upon studies indicating the frequency of occurence of Basic Manual Motions; however, the analysis for evaluating and comparing the system was, to a large extent, theoretical. The influence of the natural variability of the operator in performing the tasks was ignored.

1.0.2 Objectives of the Research

The objectives of this research will be:
"To examine the possible superiority of any of the three principal MTM systems for the derivation of time standards, recognizing the variability of actual work times arising from the natural variability of unpaced operator performance.

To consider whether the use of predetermined motion time systems, which may be derived from MTM, might permit equally acceptable time standards to be obtained."

1.0.3 Outline of the Thesis

A review of the literature relevant to the major criticisms of PMTS is carried out in Chapter 2.0.0. The research appropriate

*Some of the comparisons used included number of lines of analysis, time to do analysis and the number of letters required in the analysis.

to these criticisms is discussed in the light of its historical development: the limitations and suspected areas of doubt, together with the practical implications of this research, are considered. From this review, the importance of the compatibility of the data, the speed of its application, accuracy as the basis of evaluation, and the question of additivity of PMTS elements are established.

In Chapter 3.0.0, the need for research, which is based in industry rather than in the laboratory, is emphasized. As part of this, the experimental milieu is described, together with the methods used for the collection of the data. Only selected elements of the field data were used in the study. The basis used to justify the selection of this sample is described.

In Chapter 4.0.0, the concept of the accuracy of a time standard is discussed. Three measures of accuracy of the time standards are then identified, compared and their interpretation examined.

There has been a great deal of controversy on the methods of evaluating the general levels of MTM for work measurement applications. Chapter 5.0.0, the first chapter concerned with analysis of the data, considers this comparison, using both regression and analysis of variance for each of the three criteria described in the previous chapter.

The simplification of the data is carried out in Chapter 6.0.0. Here, alternative data systems are developed using different models and the field data. In this way, the concepts of the development of data development and any synthetic restrictions which are placed on their use are tested. A framework for applying these systems is also established in this chapter.

The characteristics of the natural motion-time distributions of the operator in performing a task are analyzed in Chapter 7.0.0. From this analysis, the matter of the distribution and its parameters is considered.

Chapter 8.0.0, the final chapter, summarizes the conclusions and suggests some broad areas for future research.

2.0.0 SURVEY OF CURRENT LITERATURE

2.0.1 Significant Critiques of PMTS

The three most quoted critiques of PMTS were by Davidson (1952), Gomberg (1955) and Buffa (1956). A research project carried out by White (1950) at Cornell University is also a regularly quoted source in any discussions on PMTS. This latter work has taken on such importance in the eyes of the proponents of PMTS that it is often referred to merely as the "Cornell Report".

The real contributions of both Davidson (1952) and Gomberg (1955) are reduced due to their continual condescension, pointing out that the only basis for validity offered by the proponents of PMTS is that "they work". Both of these authors continually quote, or partially quote, research with restricted objectives or with doubtful structure. In addition, they quote parts of experimental results so as to bring into question the whole validity of PMTS. It is as though they are unprepared to accept any discovery or development as scientifically valid unless it is the result of a step by step logical approach, for which the theory has been unquestionably proved at every stage. Unfortunately, the antagonists of PMTS have not seen fit to subject these writings to the same degree of examination as the original data.

White (1950), on the other hand, merely proved the hypothesis of his research, namely that the MTM data could be reproduced. It was a worthwhile scientific effort, but, unhappily not so attractive in print as the work by Davidson (1952) and Gomberg (1955).

Buffa (1956), on the other hand, does provide a more balanced, if somewhat restricted, critique of PMTS. It must be remembered that at that time the real interest in PMTS was just beginning to accelerate.

2.0.2 Influence of Application Rules

The importance of using the correct application rules for a PMTS is emphasized in the work carried out by Schmidtke and Steier (1961). The work examined the validity of PMTS, with particular reference to MTM, Work Factor and Basic Motion Time Study. The misuse of the application rules brought letters of criticism from several people including Bailey (1961), the author of Basic Motion Time Study (1958).

Davidson (1961) also made comment. While his attitude toward PMTS appeared to have softened somewhat, his target for criticism had merely changed. He now referred to "... the purveyors of predetermined elemental time systems (who) constitute a sort of high court which is uniquely qualified to stand in judgement involving these techniques". It is difficult to reconcile this attitude to what appears to be a perfectly valid and reasoned criticism. In developing any data system, certain assumptions are made which must be reflected when applying the data, so as to promote consistency. These are merely the application rules and unless they are followed, erroneous results must be generated.

Most of the critiques and criticism of PMTS seem to have been made by people having no formal training and/or application experience in the PMTS being used, with the exception of Raphael (1952, 1953, 1954, 1955, 1957, 1957), the group led by Hancock at the University of Michigan in the 1960's and early 1970's, Evans (1972, 1974) and the research group of the Swedish MTM Association.

It is proposed to review the literature pertaining to PMTS on the basis that they do work. Furthermore, comment will be restricted to the MTM systems, unless stated to the contrary, since, as stated in the previous chapter, that is where the author's training and experience lies and where the emphasis of the investigation is directed.

2.1.0 COMPATIBILITY OF PMTS DATA

2.1.1 Defining Compatibility

Compatibility implies the ability to coexist; however, the basis for compatibility always requires some qualification. In the case of PMTS, it is the qualification that time standards developed by one PMTS can be substituted directly into a scheme based upon another PMTS, without any significant effects on the resulting time standards. Several previous authors have considered this aspect of PMTS, and their views will be presented later. The previous authors used the term "comparability"; however, the term "compatibility" has been chosen here.

Gombert (1948, 1955) identified the problem of compatibility of systems as follows:

> "Too little is known about the origins of the data of most microscopic standard data plans. On the basis of inconsistency among themselves, we can conclude that they are very dangerous to use. All too often correction factors are rationalized after it is demonstrated that the standard set is too tight. If we could be sure of the initial choice of the correction factors, then perhaps the argument that the system has empirical validity might be defensible."

Rather than questioning the validity of PMTS, White (1950) recognized the two principal differences in the systems developed by Segur (1956), Holmes (1938), Quick, et al. (1962) and Maynard et al. (1948) as follows:

1. The nature of the classifications of the motions into which operations are subdivided.
2. The performance levels upon which the elements are based.

White did agree with Gomberg that the fundamental approach to PMTS should be "factually and in the open".

2.1.2 Reproducibility as a Measure of Compatibility

The reproducibility of the MTM data was tested by White (1950) but unfortunately lacked the discipline of analysis exhibited by Raphael (1952 through 1957) in his work carried out for the MTM Association for Standards and Research. This lack of discipline shown by White allowed one of his principal critics, Nadler (1952), to strengthen the position of those who questioned the validity of PMTS, by using White's own data to question the concept of reproducibility. Examination of Nadler's work, however, shows the same lack of thoroughness as White's.

The detailed calculations upon which this discussion is based are given in Appendix A.

White (1950) concluded that the MTM data was reproducible since

> "...for all elements the check studies have ranged within plus or minus one percent of the MTM TMU's."

It is difficult to see from the tables how White could possibly have come to this conclusion. Nadler (1952) points out this discrepancy as follows:

> "... only 20% of the values are within 1%. Actually, there was a difference from the studied system's value of greater than 4.6% to 6.7% one third of the time."

Nadler uses this statement as the basis of an argument to prove that the MTM data is not reproducible. The analyses need to be deeper than this, however.

If time/distance curves are plotted for Reach Case A (R-A) and Move Case C (M-C) of the data card values and the data obtained by White (1950), a remarkable similarity is seen. In spite of this, neither White nor Nadler seemed to have carried out an analysis of variance of the data. The results of such an analysis for R-B and M-C is shown in Figures A-1 through A-4 in Appendix A. It is abundantly clear from the results of these analyses that the MTM data is reproducible.

White (1950) also considered the frequency of occurrence of the percentage difference between the levelled TMU of the check studies and the TMU quoted on the MTM data card. White recognized that the Reach and Move represented a large proportion of the total occurrences in a study - something which was later confirmed by Aberg (1963). Based upon this, White chose to combine the results for Reach and Move, while ignoring the other MTM-1 motions. Again, only the most cursory analysis of the data, shown in Figure A-5 and Figure A-6, seems to have been made by White, who claimed reproducibility of the MTM data from this in the following way:

> "... approximately 75% of the levelled times for individual operations fall between plus and minus 7½% of the times obtained from the curve values."

Not surprisingly, Nadler (1952) takes the opposite point of view, indicating that:

"... there is more than 7½% error 25% of the time."

In spite of the statistical nature of the data, neither of these investigators considers the bias of the difference or the confidence interval of the data. From the calculations made in Appendix A, it will be seen that the confidence interval is ±4.77% with a bias of only +0.77%. All of the results of his study are not reproduced in the report by White (1950); therefore, it may be assumed that this 0.77% is the 1% to which he referred.

The unfortunate features of this interchange were:

1. That both White (1950) and Nadler (1952) failed to carry out the rigorous analysis which could have been reasonably expected.
2. That Nadler's (1952) apparent desire to prove the non-reproducibility of the data resulted in some basic information presented by White (1950) being ignored.
3. That Gomberg (1955) used Nadler's (1952) adverse comments to try to show the invalidity of PMTS, while choosing to ignore the constructive comments by White (1950).

White's (1950) report made no direct contribution to the problem of the compatibility between systems using different source data, for example between Motion Time Analysis (1956), Basic Motion Time Study (1958), Work Factor (1962) and MTM (1948). Nevertheless, confirmation of the reproducibility of the data of a single base system had the short term advantage of confirming that the Basic Manual Motions of the MTM-1 System could be consistently recognized by persons other than the originators of the system. In the long term, (although this was almost certainly not recognized at the time) it produced a confidence that these Basic Manual Motions could be used for developing higher level data systems.

2.1.3 Performance Level of the System Data

One of the principal differences between PMTS recognized by White (1950) was the different performance levels at which the data was developed. Schmidtke and Steir (1961) indicated that Barker (1948) and Abruzzi (1956) had reported that large scale European enterprises had

> "... carried through comparative investigations, in the course of which times were developed by means of a predetermined elemental time system as well as by means of the traditional time study methods. In these investigations it was found out that comparative time values are developed only if the synthetic time values are multiplied by a constant value."

One must ask if the assumption here is that time study is right, therefore PMTS must be wrong. In the light of the results of studies which were being carried out into the accuracy of time study rating at that time, it would not be considered a reasonable assumption.

The author's recollection of U. K. industry during the period 1948 to 1960 was that PMTS were rarely used. Furthermore, the level of training and experience in application of practitioners in these techniques was of a low order. Therefore, wide variations in the time standards set by any PMTS could be expected. This effect could easily have been amplified if different PMTS were used and then comparisons made.

The problem of the non-compatibility of PMTS really came to light as the result of a paper presented by Neale (1967) to the 15th MTM conference. The paper was based upon one chapter of his textbook, Primary Standard Data (1967) and was concerned about the reconciliation of the "average" performance level of MTM and the "standard" performance level of the B. S. I. (1969) performance rating scale. The same problem was also considered by Knott and Goodall (1970) who, using a different approach, came to the same conclusion. In his textbook, Neale (1967) made the statement,

> "From this it can be deduced that MTM is 11 percent right in comparison with U. K. daywork rates."

The effect of the implications of this statement on the attitude of Trade Unionists and others is easily predictable. The result was a number of philosophical and emotional communications to the technical press. However, Neale (1967) and Knott and Goodall (1970) considered this important aspect of compatibility in quantitative terms.

There still appears to be no basis to compare the performance levels of different PMTS in the way used by Neale (1967) and Knott and Goodall (1970). To illustrate this, the comments of originators of five accepted PMTS will be considered. These systems are MTM, Work Factor, Basic Motion Time Study, Dimensional Motion Times and Simplified PMTS.

According to Maynard et al., (1948) the original MTM data was based upon only 1350 feet of film of thirty-six different drilling operations, which were subsequently analyzed and levelled, using the Westinghouse levelling procedure. This "average" performance level is described by the originators of the system, Lowry, et al. (1940) as"

> "That rate of working which would be expected from an average qualified operator, following the prescribed method without effects of an incentive. When subjected to an incentive, the operator should be able to increase his performance so as to earn 120% to 125% of his basic pay rate without any ill effects on his well being."

The developers of Work Factor use a performance level which they call the "Work Factor Select Time". This definition is not so concise as that for MTM. Quick, et al. (1962) initially define this performance level as:

> "... that required for an Average Experienced Operator working with good skill and good effort ... and under good working conditions to perform one work cycle, or operation, on one unit, or piece, according to prescribed method and specified quality."

Later in the same source material, the definition is expanded, in the following way:

> "Work Factor Select Time is not comparable with times referred to as normal, daywork performance, sixty minute hour performance, or other terms used to indicate the work pace expected of the average worker who performs without incentive or at a level of productivity commensurate with base rate output."

This is emphasized by means of an example, showing that if an incentive potential of say 20% is required in the company, the select time is multiplied by a factor of 1.20. Finally, it is stated clearly (24):

> "... the Average Experienced Operator normally motivated will work at the Work Factor Select Time."

Clearly, this performance level is that which Fien (1972) designated as the "Motivated Performance Level" and the BSI designated as "Standard Performance".

In discussing the development of BMT, Bailey and Presgrave (1958) mention both levelling and pace rating but neglect to indicate the way in which the BMT performance level can be related to other systems. Their description of the BMT performance level is as follows:

> "... the BMT are net standard times. They are based upon the work pace of walking at 3 miles per hour or of dealing a deck of 52 playing cards into 4 hands in .50 minutes."

Fien (1972) described an "Acceptable Performance Level" (APL) which can fluctuate, depending upon many prevailing levels. Since the benchmark given above has been used to define several different APL, it must be regarded with suspicion. At best, it can only be regarded as indicating that the BMT data may be at the Average Performance Level on the Westinghouse Performance rating scale.

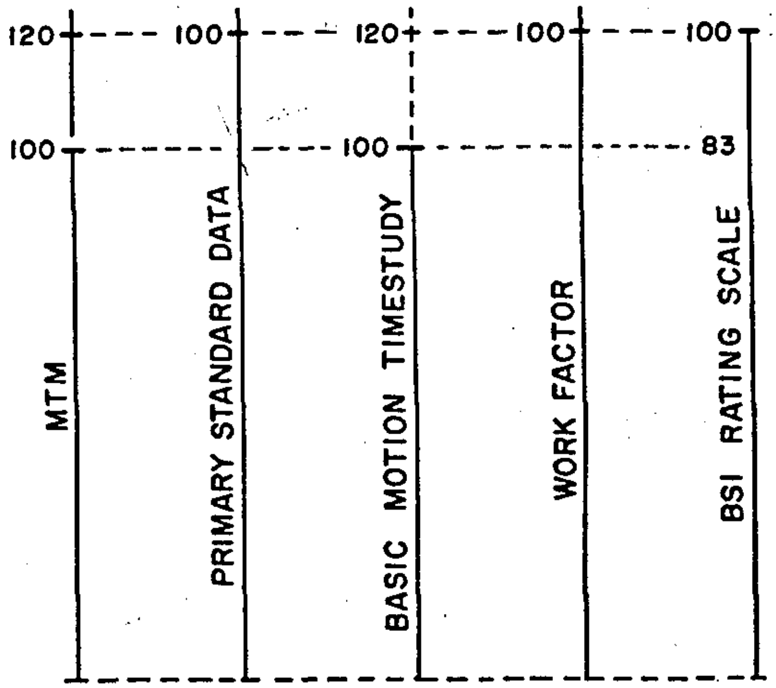
In the case of Geppinger's (1955) system of Dimensional Motion Times, it becomes impossible to even guess at what the performance level might be since on page 9 of the source text, optional incentive allowance of the type used in Work Factor is suggested. But this is optional, not mandatory, promoting a flexible performance level!

The problem of lack of definition does not exist with Neale (1963) in his discussion of the simplified PMTS, where it is clearly stated that:

"The only point that needs to be kept in mind at the outset is that data ... is expressed in Basic Time, that is, time at the Standard Rate of Working ...."

Comparison of performance level is, therefore, only possible between four of these five PMTS, a comparison which is shown in diagram form in Figure 2-1. The comparison is based on the premise that "irrespective of the performance rating system, it is the MPL which will be common and is discussed in detail by Knott and Goodall (1970).

Figure 2-1: A Diagrammatic Comparison of the Performance Levels of Four Different PMTS



Buffa (1956, 1957) quotes a study into the differences between MTM, Work Factor and Basic Motion Time Study, appearing in an unpublished Master of Science Thesis by Piispanen at the University of California. In this study, adjustments were made to reflect the differences in performance levels of the systems, but it was concluded that there was still a significant difference in the results produced by the three systems.

While the influence of the difference in performance levels of PMTS has been demonstrated, the work by Piispanen shows the need to consider the problem with respect to the other factors.

2.1.4 Other Effects on System Compatibility

White's (1950) comment that a factor influencing the compatibility of alternative PMTS was:

> "the nature of the classification of the fundamental motions into which the operations are sub-divided"

is far more complex than would appear at first sight. It involves at least the following sub-factors:

1. The statistical characteristics of the base data.
2. The differences in the work elements with respect to breakpoints and their significant variables.
3. The application rules of the system.
4. The analysts' skills in using the system.

Since the development of the data used in all of the systems is based upon the observation of samples, error in the values used to represent data elements is inevitable, yet the distributions and statistical parameters of the data for any of the systems is unknown - a characteristic which will be discussed later.

Let the Work Factor and MTM-1 systems be used as the example of element motion breakdown. Both systems recognize the Therbligs Transport Empty and Transport Loaded as the basis of the motion elements Reach and Move, respectively. In the case of the MTM system, they are separated out as "Reach" and "Move". On the other hand, the Work Factor System combines them under the heading "Transport". Superficially, there is a similarity in the variables affecting these elements, however, the way in which the levels of these elements are classified is significantly different. In the case of Work Factor, the classification is done by comparison with commonplace actions which have been described and illustrated, as shown in the text, by Quick, et al. (1962). The classification in MTM-1, however, is on the basis of algorithms which recognize the level of visual attention which is required during the time the motion is being performed.

The motion element grasp emphasizes this difference in concept between the systems to an even greater extent. In introducing the "standard element grasp" used in Work Factor, Quick, et al. (1962) state:

> "Work Factor establishes four grasp classifications involving about 350 time values."

During a discussion on the element "Transport" in the same text, it is stated that:

> "The Work Factor elements Transport, Grasp, Pre-position, Assemble, Disassemble and Release consist of one or more Transport Motions."

Later, Quick (1962), shows the method used to develop times for Complex Grasps in Work Factor in detail. It involves using other elemental times, a principle which in MTM is referred to as the Theory of Grasp. In Work Factor, the value developed by the theoretical value is used for data development, while in MTM its use is normally restricted to be a check on some data card value.

The purpose here is not to argue a correct approach, but rather to show, beyond any doubt, a difference in the structure of the systems which precludes any direct compatibility.

2.1.5 The Need for System Compatibility

Davidson (1952) quotes tests carried out by one R. W. McGuire, a Research Fellow at Ohio State University. The tests were reported to have been based upon a carefully constructed experimental design which showed that there were significant differences in the movement times given in the data tables for MTM, Work Factor and BMT.

This result was hardly surprising; however, Gombert (1955) seized upon this and justified his criticism further by the implication that:

> "It therefore could not be justified that inexperienced people were using the system."

While both Davidson and McGuire may have been experienced in the field of Industrial Engineering, there is no evidence that either or both had experience in actually applying PMTS at that time.

Buffa's (1956) comment on this work was far more searching and appears to be more relevant than either Davidson's (1952) or Gomberg's (1955). Buffa's observation on this research and the ensuring discussion was:

> "There is no question being raised about this result, but there does seem to be a logical question to be raised about the implied conclusion,... This approach to determining if they are different overlooks the fact that the data compared are not necessarily meant to be comparable."

In view of the previous discussions, the answer to Buffa's implied question is that the data from individual systems, particularly at the motion level, were not meant to be compatible. Furthermore, due to the variance of the data given in the tables for individual motions, it is highly unlikely that there would be compatibility, particularly on short cycles. Finally, since all of these systems were developed for commercial purposes, it is reasonable to assume that compatibility with other systems was the last thing desired or claimed.

This is not to suggest that the compatibility of data systems is unimportant. On the contrary, in the following situations, compatibility is essential.

1. Where a PMTS is being integrated into a time data system which is currently based upon stopwatch time study.
2. Where a higher level data system is being integrated into a time data system based upon its root PMTS (for example, MTM-2 and MTM-1).

In the former case, the accuracy of the time study data would be cause for concern. This would be the result of errors in reading the stopwatch, recording data and the expected errors in performance rating. By adjusting the level at which the data generated by a PMTS is expressed, at least one of these sources of non-compatibility can be reduced.

Intuitively, one could reason that compatibility would exist where a higher level data system was developed from some root PMTS. Details of the development of MTM-2 from MTM-1 are given by Appelgren (1968) and the development of MTM-3 from MTM-1 are given by Magnusson (1970). Each of these systems used a different MTM-1 based model in their construction, however, both Appelgren (1968) and Magnusson (1970) specified one of the basic system demands as:

> "Combinable (Compatible) with other MTM data."

There appears to have been no controlled experimentation on the level of this compatibility of data. It does seem that it would be more profitable to consider the long term compatibility of data systems of the same root (for example, MTM) than single motion compatibility of competing systems.

2.2.0 CONSTRUCTION AND DATA COLLECTION OF BASE SYSTEMS

As introduction to their paper, "An Experimental Evaluation of Validity of Predetermined Elemental Time Standards", Schmidtke and Stier (1961) made a highly critical evaluation of all of the existing PMTS. They established the point of view of the psychologist and physiologist in the following terms:

> "Even when one looks superficially at the methodical basis of predetermined elemental time systems, it becomes obvious that the idea underlying these concepts is almost identical with that of elementary physiology and elementary psychology. However, physiology and psychology have long ago advanced beyond the area of elemental thinking... this concept has been gradually replaced by a dynamic and functional concept of living organisms. The mechanistic approach of elemental time systems has thus to be considered a relapse into the discredited beliefs of elemental physiology and psychology."

To justify this position, they then quote well-known facts such as:

> "There is a functional relationship between the duration and the form of a motion in such a way that the form is changed with different speeds and visa versa."

Perhaps this is related to Dudley's (1968) questioning of the practice of levelling and rating by "is this (rating) significant over the range of performance levels encountered in an industrial task?"

Schmidtke and Stier (1961) attempted to confirm their point of view by means of laboratory tests. While the tests may have been suitable to investigate physiological and psychological principles, they were totally inadequate to represent industrial tasks. Several authorities and users of PMTS commented upon these tests; one of them, Honeycutt (1962) as follows:

> "It must be remembered that MTM is not synthesized to explain physiological and psychological phenomena which occur in a motion pattern."

He then continued to show just how inappropriate the comparison was, due to the fact that the subjects of the experiments had their hands supported by cables so as to prevent fatigue (thereby introducing interference of involvement), pacing being introduced by a metronome and finally that the MTM data was misapplied in the experiments.

Clearly, the validity of the much quoted research by Schmidtke and Stier (1961) must be most suspect.

2.3.0 ADDITIVITY OF PMTS

2.3.1 Defining Additivity

One of the fundamental assumptions of PMTS, as with all work measurement, is that of additivity of the elements. This implies that the mean value of the elemental times can be treated as mathematical quantities. Thus,

$$T = \sum_i t_i \qquad \text{(Eq. 2-1)}$$

where:

T = cycle time

t_i = mean time for element i

From this it can be deduced that if, for cycles A, B and C

$$T_A = t_1 + t_2 + t_3 + t_4 \quad \text{(Eq. 2-2)}$$

$$T_B = t_1 + t_2 \quad \text{(Eq. 2-3)}$$

$$T_C = t_3 + t_4 \quad \text{(Eq. 2-4)}$$

then

$$T_A = T_B + T_C \quad \text{(Eq. 2-5)}$$

Critics of PMTS have made extensive efforts to discredit the whole of the PMTS concept on the questionable basis of lack of additivity of the motion elements.

2.3.2 Correlation of Motion Elements

During the time period 1936 - 1940, Dr. Ralph Barnes and his associates (1936, 1938, 1939, 1940, 1940), at the University of Iowa, attempted to isolate the variables affecting motion times and to investigate the effect of these variables. The important property which was detected in each of these investigations was that of interaction, or correlation, between elemental motions, thus confirming that the time to perform a motion is dependent upon the motion preceding or following it. The presence of this interaction or correlation has been confirmed separately by Abruzzi (1952), Nadler and Denholm (1955), Simon and Smader (1955), Smith, et al. (1951), Smith and Wehrkamp (1952), Smith, et al. (1952), Smith and Smader (1953) and Smith and Harris (1954). Supplemental conclusions were also reached by these researchers, however, since they are not germane to the present discussion they will be ignored.

This correlation between motions is recognized by all of the leading PMTS. This correlation is recognized in the MTM-1 system, for example, by the application rule that the only Case of Move which can precede a Position is a Case C.

One of Gomberg's (1955) criticisms of macroscopic standard data systems was based on a paper by Abruzzi (1952) who stated:

> "The tests disclosed that not only were the elements in these operations not independent, they were actually held together by a complicated network of relationships. These relationships varied with the number and the magnitude of the elements involved. They were different from one operator to another. They were different within the distributions of the same operator."

One must assume that this criticism can be transferred to the microscopic systems. While Gomberg quotes Abruzzi correctly, he fails to note that Abruzzi provided none of the data from which these conclusions were drawn. The description in Abruzzi's paper (1952) was such, however, that it is not surprising that there was lack of independence. It is necessary to ask with respect to these experiments, whether what was significant at that time would be significant under other conditions.

2.3.3 Studies on Additivity

An early study of PMTS was made by Ghisselli and Brown (1948) wherein non-additivity was concluded. The experimental procedure consisted of a series of key tapping tests, with cycle times in the range 0.0103 to 0.0301 minutes. Anyone who has been responsible for training practitioners in a PMTS, particularly Trade Union personnel, will have met this problem as the basis of discussion and criticism. The PMTS is a measurement tool of limited sensitivity and practitioners must expect to encounter relatively large errors on individual analyses of such small elements. Therefore, while the results of the work by Ghisselli and Brown (1948) are not in doubt, the universality of their conclusions must be questioned. The validity of the experimental value of this work was questioned by Stilling (1953) who indicated that only one subject was used in the research. This doubt must be strengthened by the fact that Ghisselli and Brown (1948) did not indicate the number of subjects used or the statistical significance achieved in the experiments.

Using similar experiments, Stilling (1953) arrived at exactly the opposite conclusions to Ghisselli and Brown (1948), namely that the PMTS elements are additive. Although the experimental tasks used were the same in both cases there must be greater confidence in Stilling's (1953) work since twenty-four subjects were used and experimental significance was quoted.

Another point of view on the additivity of PMTS elements was expressed by Rowe (1955) who said:

> "... the expected values of the elements may be added up to yield the expected values of the cycle time ... so long as the elements themselves may be considered to be random variables."

Thus if there are three random variables X, Y and Z with a joint density function f(X,Y,Z) then,

$$E(X + Y + Z) = E(X) + E(V) + E(Z) \qquad \text{(Eq. 2-6)}$$

This is a relationship which holds true irrespective of any correlation which may exist between the elements. Thus correlation between elements may exist without affecting the property of additivity of the means of the elements. Rowe (1955) then points out that:

> "Statistical independence is important primarily where one desires an estimate of the variability of the expected values."

Buffa (1956, 1956) carried out the most thorough investigation into the additivity of PMTS elements. The experimental tasks used were varied. Sixteen subjects were studied, levels of significance were stated and there was a full documentation. Buffa's results confirmed additivity of elements over the range of experimental conditions used. One becomes more confident in Buffa's conclusions when it is realized that he was the first researcher to introduce a note of caution that his conclusions might not be universal.

Another interesting outcome of Buffa's work (1956, 1956) was the statement of his opinion that:

> "... if universal standard data is ever to gain a place of respect in the engineering professions, certain basic requirements must be established for it ... they are:

1. Basic additivity of elements or an acceptable error by ignoring non-additivity.
2. A classification or grouping of motion types in such a way that errors could be considered negligible.
3. Data based upon carefully planned experimental designs with full disclosure of methods and results.
4. Data expressed as expected values and variances. This imposes the requirement of obtaining population values for the standard data elements, similar anthropometric data on body size, weight, etc."

Nanda (1968), in considering the subject of additivity of elemental times, concluded that:

"... it appears that the assumptions of unique, independent and additive mean elemental times are valid. This opens up a new avenue to develop variability measures for these time systems. This additional measure would make a significant contribution to solving problems of production planning and control and development of more realistic models for systems analysis."

Nanda's findings must be subject to some question, since the experimental design which was used allowed learning to occur during the tests, which was ignored during the analysis.

2.3.4 Additivity of Higher Level Data Systems

Whereas the protagonists of the PMTS had long accepted the principle of additivity, the question arose within the user groups in the 1960's as a result of the introduction of higher level data systems of MTM.

"Simplified MTM" had existed for many years; however, there was no real evidence as to the extent it was being applied or the manner of these applications. Neither was there any documentation of the basis of its construction. Its main attraction seemed to be its simplicity. In 1962 the MTM Association for Standards and Research in the U.S.A. published "MTM General Purpose Data" (MTM-GPD), a higher level data system whose objectives were stated to be:

"... to simplify the application of the MTM procedure by providing single element values for commonly used motion patterns, thereby eliminating motion to motion description."

In the description of the MTM-GPD system published by the MTM Association (1962) the purpose of the system was stated to be

"... a first level 'building block' in the development of more comprehensive standard data. Individual elements of MTM-General Purpose Data may be added in various combinations to produce standard data for more comprehensive elements of work. This data can also be easily expanded to achieve a greater accuracy. Any group of commonly used elements can also be combined and issued as an abbreviated card."

The additivity property of this new level of data was not questioned by the users. The simplified card resulted in 213 values as compared with 312 values on the original MTM-1 data card.

The MTM-GPD values are based upon modal patterns and their value rounded off. The basic GET in MTM-GPD, for example, is defined as follows in the 1962 publication:

"A combination of Reach and Grasp motions to gain control of one or more object(s) using the hand(s) or finger(s)."

Each basic GET appearing on the data card is then described further and the model MTM-1 pattern which has been used to describe it is given. One such Basic GET is shown in Figure 2-2.

Crossan and Nance (1962) published details of a higher level MTM-1 based data system which had been developed by the Sirge Birn consulting company. This proprietary system, known as Master Standard Data (MSD) had a data card with only 56 values and this alone encouraged a wide application. Two criticisms which can be made of MSD are that, first the theoretical construction of the data does not appear to have been published and, second, there was no control with respect to its usage.

The system known as MTM-2 was released by the MTM-International Management Directorate in 1965. While the system was developed by the Svenska MTM Foreningen, the Sirge Birn company made a major and unselfish contribution to this development, a contribution which, unfortunately, does not appear to have been fully recognized.

Figure 2-2: Construction of the MTM General Purpose Data Element BGT-JO-12

DESCRIPTION - LEFT HAND	No.	LH	TMU	RH	No.	DESCRIPTION - RIGHT HAND
			14.2	R12C		Reach to object
			9.1	G4B		Grasp object
			2.0	RL1		Release object
		Total	25.3	TMU		

(Distance Variable in inch units)

Title: Get, jumbled object - one hand.

Starts: With movement of the hand towards the object.

Includes: All motions required to reach, gain control and release an object jumbled with other objects so search and select occur.

Ends: When object is released.

The new MTM-2 data system consisted of only 32 values. These values are supplemented by some very specific application rules to encourage consistent results. The definitions and applications are given by Evans and Magnusson (1966) and are described in detail by Knott and Goodall (1970). This further reduction in the number of the data card values was achieved through the application of probability concepts, the mathematics of which are fully described by Appelgren and Magnusson (1968). The models used in deriving these values are described in "The Derivation of MTM-2 Time Standards", published by the Methods Time Measurement Association of the United Kingdom (1966). The derivation of the motion category GC30 is shown in Figure 2-3, from which it can be seen that GC30 was constructed from the weighted average of several other motions. Trained, experienced MTM-1 practitioners, particularly in the USA, were prepared to accept the rounding out of the MTM-GPD values; however, on the basis of the additivity of elements they seemd to be either unable or unwilling to comprehend the differences resulting from MTM-2 analysis. When MTM-3 was introduced, matters seemed to go from bad to worse and the insistence of some practitioners to attempt to detract from the new systems by comparing single values of higher level data with modal motion sequences, using MTM-1 data, was reminiscent of the behaviour of the detractors of the PMTS almost two decades earlier.

For various reasons, principally given as the doubtfulness of the MTM-2 system based upon its additivity, the MTM Association for Standards and Research, USA/Canada, did not officially accept MTM-2 and MTM-3 until 1972, and then only after the data cards had been "translated" from Metric to English Units. An attempt to justify this was presented in a paper by Eady (1972); however, it is purely a deterministic analysis, ignoring the stochastic nature of MTM-2. This whole episode provides no credit to the myopia exhibited by those managing the affairs of the MTM Association in the USA at that time.

The concepts and characteristics of MTM-2 and MTM-3, described by Appelgren et al. (1968) and Magnusson et al. (1970), respectively, met the requirements laid down by Buffa (1956, 1956) which were described earlier in this thesis. It seems, therefore, that once a base data PMTS has been accepted, the concern, with respect to the higher level data system, should be one of compatibility rather than additivity.

Figure 2-3: Construction of the MTM-2 Category GC30

DESCRIPTION - LEFT HAND	No.	LH	TMU	RH	No.	DESCRIPTION - RIGHT HAND
			11.69	R21.2C		
			8.95	G*		
			2.00	RL1		
		Total	22.64	TMU		

(Distance variable in centimeters)

The construction of the weighted Grasp G* shown above.

Grasp	TMU	Freq.	Freq. X TMU
G1B	3.5	21	73.5
G1C1	7.3	7	51.1
G1C2	8.7	1	8.7
G1C3	10.8	8	86.4
G4A	7.3	28	204.4
G4B	9.1	158	1437.8
G4C	12.9	34	438.6
Totals		257	2300.5
	Average		8.95

GC30 = 23 TMU

2.4.0 EVALUATION OF PMTS

2.4.1 Evaluation of Different PMTS

From the previous discussion, three points become evident with respect to evaluation, on a comparative basis, of PMTS of different "families"; for example, Work Factor relative to MTM. These are:

1. The lack of common concepts, definitions of motions and performance levels make any detailed comparison almost pointless.
2. There is an essential need for the researchers carrying out the studies to be skilled in systems being investigated, a point emphasized both by Bailey (1961) and Honeycutt (1962). It is unlikely that there are many researchers with these particular skills.
3. The question posed by Buffa (1956, 1956) on whether systems from different roots need to be compared must be considered. Weighing all factors, the worth of such an evaluation is hard to justify. On the other hand, since different data levels of the same system were developed with the obvious intention of being combined and interchanged, a comparison of them is easy to justify.

It is suggested, therefore, that for the research to be more meaningful and reliable, it be restricted to data systems from the same "family". Further, that only those systems in that "family" with which the investigator is trained and experienced in application, be studied. For this reason, from now on, the discussion will be restricted to:

1. MTM-1
2. MTM-2
3. MTM-3

2.4.2 Evaluation Parameters for the MTM Systems

The first discussions on the relative "value" of different levels in the MTM family centred around MTM-1 and MTM-2.

The only parameters considered at that time were:

1. Speed of Application
2. Systematic Accuracy

Later evaluation parameters proposed by Bayha, et al. (1974) and Hancock and Langolf (1974) were:

1. Complaint Threshold
2. Productivity Loss
3. Quality Loss

The work by Adams and McGrath (1979) considered the economics of the different data levels at their evaluation parameter. A novel mathematical approach was developed by Kaganowicz and Krususki (1976), specifically to develop and select optimal MTM derived procedures under various conditions of manual work.

2.5.0 SPEED OF APPLICATION OF DATA

2.5.1 Relative Speed of Application

Speed of Application was one of the specific demands set upon the MTM-2 and MTM-3 data by Appelgren (1968) and Magnusson (1970). In discussing the development of three of the higher level data systems, Magnusson (1972) stated:

> "We had observed the correlation between the speed of application and the precision in time predictions ... (and) ... we got these values in our MTM-2 test."

However, the speed of analysis of these higher level data systems or MTM-1 was not considered in print until the MTM-3 Technical Report, by Magnusson (1979), was published. In this report it was suggested that absolute speed of application of a data system would best be evaluated by means of time studies, but, recognizing the difficulties in such an approach, Magnusson used an interesting method to establish the relative speed of application of different levels of data without recourse to experimentation.

The measure of the speed of application is based upon the required TMU per decision, and is the number of TMU which will be required for each binary decision made when applying the data and values. Two assumptions are made as the basis of this method:

1. The bigger the elements are in a system, the faster the system is to use, all other factors remaining the same.
2. The greater the number of elements included in the system, the slower the system is to use, if all other factors remain the same.

The appropriate MTM analysis of the work was then considered as a decision process, where an MTM-1 motion, for example, can be REACH, GRASP, MOVE, etc. Having decided upon the motion, it is then necessary to make decisions relative to the variables affecting that motion. The analysis clearly consists of several binary decisions for each motion, each decision requiring some finite amount of time. This was shown diagramatically in a later description of this approach by Magnusson (1972) and Figure 2-4 is based upon this diagram.

To select one of two alternatives requires one binary decision, so that if there are N_b elements in the system, to calculate the number of binary decisions, n_b, the equation used is:

$$2^{n_b} = N_b \qquad \text{(Eq. 2-7)}$$

By using a decision tree to determine the frequency of certain motion sequences, the average TMU per element for a system can then be calculated. The TMU/decision is determined by:

$$\text{TMU/decision} = \frac{\text{Average TMU/element}}{n} \qquad \text{(Eq. 2-8)}$$

The relative speed of application for two PMTS, System B and System A, would be calculated as:

$$\begin{array}{c}\text{Relative Speed}\\ \text{of Application}\end{array} = \frac{\text{TMU/decision for B}}{\text{TMU/decision for A}} \qquad \text{(Eq. 2-9)}$$

The System A would be the basic system. Using this approach the relative speeds of application for MTM-1, MTM-2 and MTM-3 were calculated as part of the MTM-3 Technical Report by Magnusson (1972). The relative speeds obtained are summarized in Figure 2-5.

Figure 2-4: Binary Decision as the Basis of the Relative Speed of Application of a PMTS

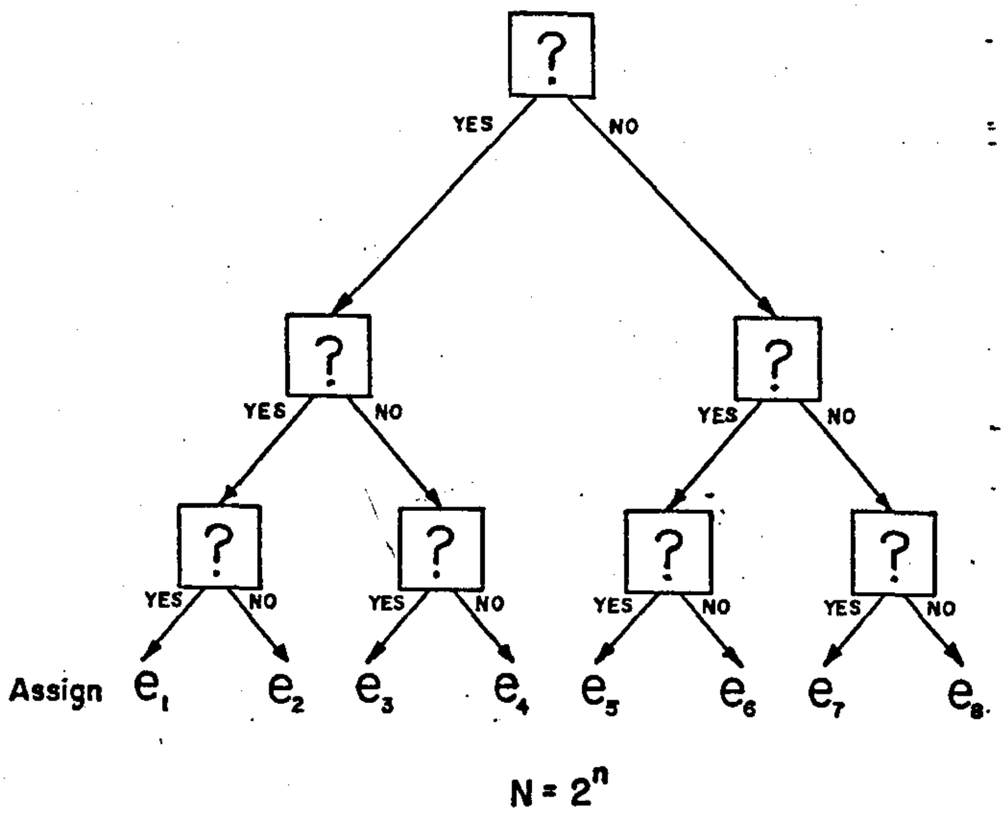


Figure 2-5: Summary of Relative Speed of Application of MTM-1, MTM-2 and MTM-3

System	Average TMU per Element	No. of Decisions	TMU per Decision	Relative Speed of Application
MTM-1	not given	not given	1.10	1.00
MTM-2	not given	not given	2.30	2.09
MTM-3	19.5	2.8	6.96	6.33

2.5.2 Absolute Speed of Application

The absolute speed of application of a data system would enable a measure to be made of the time it would take an analyst to analyse a task using that system.

Information on this measure of evaluation has been published by the MTM Association (1970, 1979), Magnusson (1972) and Zandin (1980). Their results indicated some inconsistency making comment worthwhile. The level of this inconsistency between the different authors can be seen if their results are all reduced to a basic measure of TMU analysed per hour. These values are shown in Figure 2-6.

Figure 2-6: Absolute Speed of Application for MTM-1, MTM-2 and MTM-3 Proposed by Various Authors

	TMU Analyzed per hour		
System	MTM Association (1979)	Zandin (1980)	Magnusson (1972) MTM-V (1970)
MTM-1	400	300	286
MTM-2	1000	1000	667
MTM-3	2857	3000	2000

The ways in which these values were obtained were not positively indicated by either of the authors. However, in the case of Magnusson (1972), the MTM-V Installation Manual (1970) and in light of Magnusson's comments on the use of time study, it can reasonably be assumed that there is some basis to this estimate. The MTM Association values (1979) for MTM-1 appear to have been based upon discussions with MTM Instructors, however, they do claim that the figure is reasonably conservative. Zandin (1980) indicates that his figures were obtained under Laboratory conditions and there may be a difference under actual conditions. This figure of relative speed of application is arrived at by the ratio of the absolute value of MTM-1 to that of each system.

The differences in the evaluation of these three authors is emphasized when viewed in the manner shown in Figure 2-7. Since there is an organizational relationship between the MTM Association of Standards and Research - USA/Canada, Magnusson and the Svenska MTM Foreningen some level of agreement could be expected between the values appearing in the first and third columns of Figure 2-7. Full details of the methods used in this evaluation were not published and in their absence it is not possible to determine whether the differences which do exist are due to rounding off, experimental error or real difference between the relative and absolute speed of application as defined.

Figure 2-7: Relative Speed of Application for MTM-1, MTM-2 and MTM-3 Proposed by Various Authors

System	MTM Association (1979)	Zandin (1980)	Magnusson (1972) MTM-V (1970)
MTM-1	1.00	1.00	1.00
MTM-2	2.50	3.33	2.33
MTM-3	7.14	10.00	6.99

The values of relative speed of application determined by Zandin (1980) are clearly not compatible with the remainder of those given in Figure 2-7. Does this mean that either set of results is incorrect? Not at all. It emphasizes the type of variation which can be expected if the speed of application is used as a basis of evaluation. The final result will undoubtedly depend upon:

1. The analysts's familiarity with the work task.
2. The analyst's understanding and application experience with the data level being used.

From a personal point of view, the author is completely comfortable and assured using MTM-1, MTM-2 and MTM-V. His competency, while adequate, is not so good with the MTM-3 system. Consequently, while he can achieve an absolute speed of application for MTM-3 equal to that specified by Zandin (1980) (3000 TMU per hour), in the case of MTM-1 and MTM-2 he can achieve almost twice the highest values given in Figure 2-7. Furthermore, the author has observed this same ability in many other experienced MTM practitioners.

On the basis of this, it is suggested that the measure of absolute speed is not a suitable evaluation measure. On the other hand, the relative speed of application, being less subjective may prove to be a reliable comparative measure for higher level data systems.

2.5.3 Absolute Speed of Application and Fundamental Research

When the validity of PMTS was examined by Schmidtke and Stier (1961) they pointed out that their total training in PMTS was restricted to reading the Industrial Engineering Handbook by Maynard (1956). The variations in the absolute speeds of application quoted in the tables above are also indicative of the level of training and experience of the subjects used in the experiments. This emphasizes the need for a thorough understanding of any PMTS being investigated as a prerequisite to this type of research.

2.6.0 ACCURACY OF PMTS

The problem of the accuracy of PMTS has received attention from a number of authors. A list of the most important contributors would include Hancock (1970), Evans, F. (1974), Abbruzzi (1952), Evans, P. (1980), Hancock et al. (1973), Knott (1979), MTM Association (1979), Svenska MTM Foreningen (1972), Brinkloe (1972, 1975, 1975, 1975, 1978, 1979, 1979), Alderidge (1976), Arnwine (1977, 1978) and Heacox (1978).

The confidence interval was suggested as the most suitable measure of system precision by Hancock (1970). The concept of using the confidence interval has become modified somewhat and is now expressed either as the "% Accuracy" or the "Balance Time". Both of these measures are worthy of a more detailed examination.

2.6.1 % Accuracy as an Evaluation Parameter

The percentage accuracy of a work measurement system is determined as follows:

$$\% A = \frac{Z.\sigma \times 100}{T_R} \qquad \text{(Eq. 2-10)}$$

where

A = % Accuracy of the system

Z = Number of standard deviations at the required confidence level

σ = Standard deviation of the data

T_R = Time of a reference or control period

Hancock (1973) explains that for a value A of 50%, Z in Equation 2-10 is set to 0.67, while for a value A of 95%, Z is set to a value of 1.96. He then continues to explain that in the USA the 50% value is used by most work measurement analysts, while a value of 95% is used in Europe. The value of 50% seems to have been quoted only by Hancock (1973) and no confirmation can be obtained for this value. Hancock (1973) was writing for the MTM Association when he quoted this 50% value; however, the publication gave curves for the 90% and 95% confidence levels.

Heacox (1978) in discussing the workings of MILSTD 1567 (USAF), indicates a specific requirment that:

> "... standards ... have an accuracy of at least ± 25% with a 90% confidence."

A relaxation of the supposed stringency of the work measurement accuracy is achieved in this case through the confidence limits rather than the confidence level suggested by Hancock (1973).

The accuracy concept of ± 5% on a 95% confidence level has been taken up with what amounts to blind faith by Industrial Engineers, Managers and Trade Unionists throughout the world. One must ask what the T_R in equation 2-10 refers to. Is it a motion, an element, a cycle, a task, a batch or some other reference period? Since each of these periods will result in a different answer, it is a question which should not be considered lightly.

This topic was taken up by Arnwine (1978) who was, again, discussing the behaviour of the MIL-STD 1567 (USAF). His analysis considered the simple case of reference period, T_R, being made up from N elements, each having a mean time t_i

thus

$$T_R = t_1 + t_2 + \ldots + t_i + \ldots + t_N \qquad \text{(Eq. 2-11)}$$

If the variance of each element is denoted by σ_i^2 and the variance for the reference time period by σ_{TR}^2,

$$\sigma_{TR}^2 = \sigma_1^2 + \sigma_2^2 + \ldots + \sigma_i^2 + \ldots + \sigma_N^2 \qquad \text{(Eq. 2-12)}$$

For simplicity, consider the case where

$$t = t_1 = t_2 = \ldots = t_i = \ldots t_N \qquad \text{(Eq. 2-13)}$$

and

$$\sigma_t^2 = \sigma_1^2 = \sigma_2^2 = \ldots = \sigma_i^2 = \ldots = \sigma_N^2 \qquad \text{(Eq. 2-14)}$$

From which

$$T_R = N.t \qquad \text{(Eq. 2-15)}$$

and

$$\sigma_{TR} = \sigma_t.\sqrt{N} \qquad \text{(Eq. 2-16)}$$

From Eq. 2-10

$$A.T_R = 100.Z.\sigma_{TR} \qquad \text{(Eq. 2-17)}$$

which in terms of the elements can be written as:

$$A.N.t = 100.Z.\sigma_t.\sqrt{N} \qquad \text{(Eq. 2-18)}$$

If the percentage accuracy of the elements is designated as "a" then,

$$a.t = 100.Z.\sigma_t \qquad \text{(Eq. 2-10)}$$

and combining this with Eq. 2-18

$$a.t = \frac{A\ T_R}{\sqrt{N}} \qquad \text{(Eq. 2-20)}$$

Since from Eq. 2-15, $T_R = t\,N$

$$a = A\,\frac{T_R}{t}\sqrt{\frac{t}{T_R}} \qquad \text{(Eq. 2-21)}$$

therefore,

$$a = A\sqrt{\frac{T_R}{t}} \qquad \text{(Eq. 2-22)}$$

A numerical example will clarify the significance of this relationship. Suppose an operator is required to manufacture 25 pieces, each with a standard time of 1 hour. In which case,

$t = 1$ hour

$T_R = 1 \times 25 = 25$ hours

If the accuracy required is ± 5% on the Total Time A = 5 and from Eq. 2-22

$$a = t \times \sqrt{\frac{25}{1}} = 25\%$$

Conversely, if the value of 'a' is set at 5%, then A becomes 1%. Thus, twenty five elements having been determined to an accuracy of ± 25% can be combined to produce a time with a required accuracy of 1 5%.

Without more definition than is usually given, the statement on accuracy of ± 5% on a 95% confidence level, or something similar, seems to have no real meaning.

An essential characteristic of the above approach is that for

$$\sigma^2_{TR} = \sum_{i=1}^{N} \sigma^2_i \qquad \text{(Eq. 2-23)}$$

<u>To hold true, the elements</u>, i, $1 \leq i \leq n$, <u>must be statistically independent</u>. That is, the value or occurrence of element 'i' must not be affected by either of the elements i + 1 or i - 1.

2.6.2 Balance Time as an Evaluation Parameter

In an attempt to overcome some of the disadvantages associated with the accuracy parameter, or even in total ignorance, a parameter known as the Balance Time is widely used, particularly with respect to the MTM systems. This balance time has been defined by the MTM Association (1979) as

> "The cycle time at which a given system will yield a deviation of plus or minus 5% at a stated confidence level ..."

The balance time is based upon the equation for percentage accuracy given earlier in equation 2-10. This is restated in equation 2-24, using symbols relative to the Balance Time.

$$A = \frac{Z\sigma}{T_B} \times 100 \qquad \text{(Eq. 2-24)}$$

where T_B = Balance time and other variables are as defined earlier. This equation can be transposed to

$$T_B = \frac{100\ Z\ \sigma}{A} \qquad \text{(Eq. 2-25)}$$

In comparing time data systems the confidence limit and confidence level will be the same. They will all be compared at ± 5% on a 95% confidence level for example. Thus, Z and A will be the same for all systems and the equation for Balance Time will be reduced to:

$$T_B = \text{Constant} \times \sigma \qquad \text{(Eq. 2-26)}$$

The Balance Time is, clearly, no more than a way of expressing the variance of a system, in terms which are more acceptable to practitioners with a weakness or deficiency in statistical methods.

The determination of the Balance Time for a system assumes that the one value for the standard deviation of the data system can be determined, irrespective of the conditions under which the system is operating. It will be shown subsequently that this assumption is most unrealistic.

2.6.3 Absolute and Relative Values

The total variance of a time data system is made up from two components:

1. Applicator Variance
2. System Variance

The summation of these variances then makes up the Total Variance of the system. The MTM-Association for Standards and Research (1979) identifies two types of Accuracy based upon the total variance:

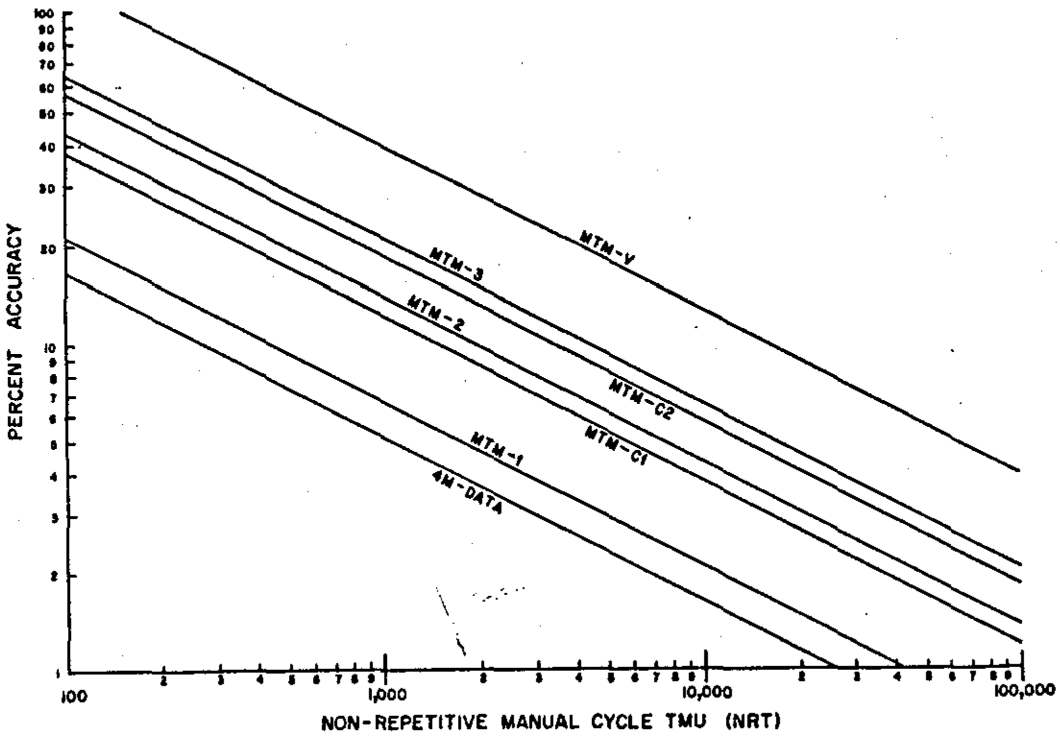
1. Absolute Accuracy - where the system is compared to the 'real time', as would be derived from a system having no system or applicator variance.
2. Relative Accuracy - where the system is compared to the results obtained by MTM-1.

2.6.4 The MTM Accuracy Curves

The idea for these curves first appeared in a publication by Appelgren, Magnusson and Skargard (1968) and were later taken up by Hancock (1970). The curves are log-linear, a typical group being shown in Figure 2-8.

To use these curves, a value known as the "Non-Repetitive Cycle Time (NRT)", which will be discussed later, is determined for the task. The total absolute accuracy which can be expected from each system considered can then be read off directly from the accuracy curve. If, for example, a task having an NRT of 6000 TMU was analysed using MTM-3, the total absolute accuracy, according to Figure 2-8, would be ± 8.0%. If a total absolute accuracy of ± 5% was required, the analyst would then check the total absolute accuracy of MTM-2 and MTM-1 to find that they were ± 5.6% and 2.6%, respectively, In this case, the use of MTM-1 would be clearly the choice of system.

Figure 2-8: The MTM Accuracy Curves



The MTM Associations throughout the world also point out that this chart can be used to determine the Balance Time of the various MTM Systems. This would be done for an Absolute Balance Time of ± 5% on a 95% Confidence Level by reading across the graph from ± 5% absolute accuracy to the curves for the various systems. In the case of MTM-1, MTM-2 and MTM-3, this would be 1600, 7200 and 15800 TMU, respectively.

These MTM Accuracy curves are clearly simple to use, so simple that many promoters of the MTM systems continually use these curves as a "sales aid". Many others have a blind faith in the truth of these curves and use them without understanding either their meaning or development. Furthermore, there is considerable difference of opinion on the values which should be used in constructing these curves. Evans (1980), in discussing the Precision of MTM-2, challenged the values of the Balance Times used in these curves. In a comment on this paper, Bayha challenged Evans' (1980) conclusions on the basis that they did not agree with accepted practice! Hardly a strong argument in this case.

This obvious misunderstanding of usage and of disagreement of values, points out the need for an examination of construction of these accuracy curves. This examination will focus upon:

1. The meaning and utility of Non-Repetitive Cycle Time (NRT)
2. The theoretical construction of these Accuracy Curves

2.6.5 The Meaning and Utility of the Non-Repetitive Cycle Time

Hancock (1970) first referred to the NRT in his early paper on the System Precision of MTM-1, where he quoted the accuracy as:

$$\pm\%A = \frac{\sigma_{MTM-1}}{NRT^{\frac{1}{2}}} \times Z \times 100 \qquad \text{(Eq. 2-27)}$$

He then defined NRT as:

> "NRT = the time sum of the MTM-1 elements used in the prediction in TMUs. This value is obtained by setting all frequencies equal to 1."

There were no other explanations or examples given in this first discussion of NRT. Consequently, if the definition is taken literally, there is a maximum NRT for the system which is equal to the sum of all of the elements appearing on the data card. Admittedly, this interpretation seems unrealistic, yet it was the only one possible at that time.

In a report to the MTM Association, Hancock, Foulkes and Miller (1973) considered the NRT in a little more detail as follows:

> "NON-REPETITIVE CYCLE TIME (NRT) is a concept that must be considered in analysing system errors. It is a requirement for statistical independence, which is necessary so that standard deviations can be used in prediction accuracy, as measured by statistical confidence intervals. Motion sequences are often repeated

in a job. The error in estimating the standards for these repeated times will be multiplied by the frequency of occurrence rather than cancelled by the averaging that occurs when independent element times are averaged.

In practice, NRT is found by taking the overall cycle time required for a given task and subtracting all times for element sequences occurring more than once. In other words, the time for each unique element sequence is counted only once. In cases where group performances are used or where different jobs are being performed by the same individual during the pay period (or the period over which performance is reviewed), the NRT is the sum of the cycles with frequencies reduced to 1.0."

The concept of statistical independence will be discussed later; however, it should be noted that the developers of the accuracy curve did recognize its importance.

The definition refers to "elements" rather than motions, but neglects to give specific examples. To illustrate the problem resulting from this, Figures 2-9 to Figures 2-11 have been developed. They have all been developed from the basic pattern in Figure 2-9.

Figure 2-9: Calculation of NRT Alternative I

DESCRIPTION - LEFT HAND	No.	LH	TMU	RH	No.	DESCRIPTION - RIGHT HAND
			11.5	R10B		
			2.0	G1A		
			10.3	M6C		
			2.0	RL1		
			11.5	R10B		
			2.0	G1A		
			10.3	M6C		
			16.2	P2SE		
			2.0	RL1		
		Total	67.8	TMU		

Freq. of all Motions in Pattern = 1

	Motion	TMU	
	R10B	11.5	
	G1A	2.0	
	M6C	10.3	
	RL1	2.0	
	P2SE	16.2	
Total	NRT	42.0	TMU

Figure 2-10: Calculation of NRT-Alternative II

DESCRIPTION - LEFT HAND	No.	LH	TMU	RH	No.	DESCRIPTION - RIGHT HAND
ELEMENT A			11.5	R10B		
			2.0	G1A		
			10.3	M6C		
			2.0	RL1		
		Total	25.8	TMU		
ELEMENT B			11.5	R10B		
			2.0	G1A		
			10.3	M6C		
			16.2	P2SE		
			2.0	RL1		
		Total	42.0	TMU		

Summary

Element	Element TMU	Freq.	Allowed TMU	NRT Elem. Freq.=1
A	25.8	1	25.8	25.8
B	42.0	1	42.0	42.0
		Total	67.8	67.8

Figure 2-11: Calculation of NRT-Alternative III

DESCRIPTION - LEFT HAND	No.	LH	TMU	RH	No.	DESCRIPTION - RIGHT HAND
ELEMENT E			11.5	R10B		
			2.0	G1A		
		Total	13.5	TMU		
ELEMENT F			10.3	M6C		
			2.0	RL1		
		Total	12.3	TMU		
ELEMENT G			10.3	M6C		
			16.2	P2SE		
			2.0	RL1		
		Total	28.5	TMU		

Summary

Element	Element TMU	Freq.	Allowed TMU	NRT Elem. Freq.=1
E	13.5	2	27.0	13.5
F	12.3	1	12.3	12.3
G	28.5	1	28.5	28.5
		Total	67.8	54.3

Two methods of breaking the motion pattern in Figure 2-9 are given in Figure 2-10 and Figure 2-11. Depending upon the analyst and local practices, both of these breakdowns can reasonably be considered to be common practice. If the method used to calculate the NRT is as implied in the original paper by Hancock (1970), then the NRT will be 42.0 TMU as given in Figure 2-9. On the other hand, if the method is that implied in Hancock's (1973) later publication, the NRT could be either 67.8 or 54.3 TMU, as shown in Figure 2-10 and Figure 2-11.

The clarity of the definition of the NRT given by the originators of the concept, makes this a confusing and impractical basis upon which to make any system evaluation. Further, the basic challenge to Hancock's original conception remains, in that it is not in agreement with the normal terminology in so far as 'Non-repetitive' is used.

A further example of the lack of utility of the NRT is in the choice of data level, since it presupposes that the NRT is known before it is measured by using one of the MTM data levels. Clearly, this becomes a circular problem.

2.6.6 Theoretical Construction of the MTM Accuracy Curves

Hancock's (1970) original analysis of the Precision of MTM-] was based upon seven assumptions, several of which are discussed elsewhere, principally in Appendix B. The four assumptions having significance in the present discussion can be summarized as follows:

1. The MTM-] data card has been determined from a continuous function producing a system variation, as described in Appendix B.
2. The frequency distribution for the occurrence of motions in a particular industry can be considered to be typical for the whole of industry.
3. Where the variance of a motion is dependent upon the distance variable, such as with Reach and Move, and average variance can be calculated by averaging long and short distance values.
4. It is possible to determine an average variance per TMU for the system which is meaningful.

The assumption 1, above, is discussed and illustrated in Appendix B, therefore further comment at this point is redundant. The criticisms relative to this assumption will be ignored at this time so as to provide the same foundation that Hancock used in his development.

Aberg (1963), published the results of an investigation into the frequency with which motions occur in different industries. His investigations covered three industries, as follows:

1. Medium Heavy Machine Production
2. Medium Heavy Assembling
3. Light Assembling

Hancock (1970) chose to consider the frequency distribution encountered in Medium Heavy Assembling as representative of the whole of industry. The tabulated form used by Hancock is reproduced in Figure 2-12.

Figure 2-12: Computation of System Variance for an Industry

Motion	Variance	Percent Occurrence	Weighted Variance
Reach	.417	12.9	.054
Move	.921	29.8	.274
Apply-Pressure	2.613	7.5	.196
Turn	4.481	.37	.016
Grasp	.284	19.7	.056
Position	4.156	11.5	.478
Release	.333	10.5	.035
Eye-Focus	4.441	.3	.013
Disengage	9.769	1.8	.176
Body Motions	19.739	5.2	1.026
Average Variance/MTM-1 Motion			2.324 TMU^2

The arithmetical errors in Figure 2-12 have been transferred directly from Hancock's (1970) paper, but will be ignored in any further calculations.

The study by Aberg (1963) also showed that the average length of MTM-1 motion used in the industry chosen as typical was 9.5 TMU. On this basis, Hancock (1970) reasoned that average system variance per TMU could be calculated for MTM-1 (σ^2_{MTM-1}) as follows:

$$\sigma^2_{MTM-1} = \frac{\text{Average Variance/MTM-1 Motion}}{\text{Average Length of MTM-1 Motion}},$$

$$= \frac{2.324}{9.5}$$

$$= 0.245\ \text{TMU}^2/\text{TMU} \qquad \text{(Eq. 2-28)}$$

and

$$\sigma_{MTM-1} = 0.495\ \text{TMU}/\sqrt{\text{TMU}} \qquad \text{(Eq. 2-29)}$$

In an attempt to determine the system accuracy of MTM-1, Hancock (1970) used this value of σ_{MTM-1} in the basic equation given in Equation 2-10. Since σ_{MTM-1} is taken as the average standard deviation per TMU for any value of NRT, if the total variance is σ, then

$$\sigma = \sqrt{\text{NRT} \times \sigma^2_{MTM-1}}$$

$$= \sigma_{MTM-1}\sqrt{\text{NRT}} \qquad \text{(Eq. 2-30)}$$

Combining Equations 2-10 and 2-30, the following results:

$$\%\ A = \frac{100\ Z\ \sigma_{MTM-1}\sqrt{\text{NRT}}}{\text{NRT}}$$

$$= \frac{100\ Z\ \sigma_{MTM-1}}{\sqrt{\text{NRT}}} \qquad \text{(Eq. 2-31)}$$

Thus, if the concept proposed by Hancock (1970) is used, the Balance Time can be considered to be a particular NRT and Equation 2-31 can be transposed to:

$$T_B = \left(\frac{100\ A\ \sigma_{MTM-1}}{A}\right)^2 \qquad \text{(Eq. 2-32)}$$

Based upon absolute precision, this would give a balance time of 376.5 TMU for MTM-1.

Apart from the criticisms of the NRT, already discussed in detail earlier, superficially, Hancock's approach is simple and acceptable. However, careful examination shows some questionable practices. These are:

1. The effects of correlation between individual motions are not adequately dealt with.
2. Averaging of Reach and Move has been used indiscriminately without justification.

2.6.7 Covariance Effects

The presence of covariance between MTM-1 motions has been discussed at length earlier. That this effect is recognized and accommodated by carefully constructed application rules has been boasted by the MTM user group for many years (although it should be acknowledged that it is unlikely that the developers recognized it as such).

Arnwine (1978) stated motion independence as a prerequisite for:

$$\sigma^2 = \sum_{i=1}^{N} \sigma_i^2 \qquad \text{(Eq. 2-33)}$$

where

$\sigma_i^2 = 1, \ldots N$

σ^2 = Total variance for all of the motions

σ_i^2 = Variance of individual motions

When motions, or elements, are not statistically independent, then,

$$\sigma^2 = \sum_{i=1}^{N} \sigma_i^2 + \text{covariance} \qquad \text{(Eq. 2-34)}$$

When the proportions of the occurrence of the different motions are not equal, Equation 2-33 no longer holds good, since

$$\sigma^2 = p_1^2\sigma_1^2 + p_2^2\sigma_2^2 + \ldots + p_i^2\sigma_i^2 + \ldots + p_N^2\sigma_N^2 \qquad \text{(Eq. 2-35)}$$

where

p_i = probability or percent occurrence of motion or element 'i'.

Equation 2-35 reduces to:

$$\sigma^2 = \sum_{i=1}^{N} p_i^2\sigma_i^2 \qquad \text{(Eq. 2-36)}$$

When the motions are not statistically independent, then the equation for summation of the variances becomes:

$$\sigma^2 = \sum_{i=1}^{N} p_i^2 \sigma_i^2 + \text{covariances} \qquad \text{(Eq. 2-37)}$$

In his early paper, considering the system precision of MTM-1, Hancock (1970) totally ignored any covariance values as is evident from the calculations associated with Figure 2-12. In a later paper on the same topic, Hancock (1973) claimed without any substantiation that, by using the NRT in the calculations, statistical independence of the elements is assured. This author is unable to agree with this line of argument. Since $p_i < 1$, the influence of the covariance can be significant and the value for σ_{MTM-1} determined by Hancock must be regarded as suspect.

2.6.8 Averaging of Values

The dependence of the variance of Reach and Move values upon the distance variable was accommodated in Hancock's (1970) calculations by:

"... averaging long and short distance values".

The motions used for this averaging were R3B, R26B, R3C, M3B5, M26B40, M3C5 and M26C40.

To check whether this assumption by Hancock was reasonable, values of variance for R-A, R-B, R-C/D and R-E were calculated over the whole distance range shown on the data card. The arguments and calculations for this appear in Appendix B. For each of these cases of Reach, a graph of its variance with respect to distance was plotted and is given in Figure B-9. Even the most cursory examination of these curves shows the assumption that an acceptable representative variance for Reach can be obtained by averaging four such widely differing values is doubtful. It is incomprehensible that either Hancock (1970, 1973), or Brinkloe (1975, 1975, 1975, 1978, 1979, 1979), who extended Hancock's ideas, were aware of this and failed to bring it to the attention of readers.

2.6.9 Assumed Frequency Distribution

The use of an assumed frequency distribution for the occurrence of motions given in Figure 2-12 must also give concern on efficacy of the approach. Relatively minor variations in the frequencies used produce major variations in the resulting balance times.

2.6.10 Applicator Accuracy

In discussing the Absolute and Relative Accuracy of a PMTS, the basic components of accuracy were noted; namely:

1. Applicator Variance (σ^2_{APP})
2. System Variance (σ^2_{SYS})

So far, our discussion has been centred around the effect of σ^2_{SYS}, yet the applicator variance is such an important component, and one which is difficult to measure, that it cannot be ignored.

Some of the sources of applicator variance in MTM-1 have been identified by Appelgren, et al. (1968) as:

1. Variations in operator performance between cycles.
2. Errors in evaluating the distance.
3. Errors in estimating the case.
4. Errors in estimating the simultaneity of two-handed work.
5. Omission of motions.

A summary of the findings of different researchers relative to the Accuracy of the MTM-1 system was published by the MTM Association for Standards and Research (1973). Figure 2-13 has been constructed from this information. The resulting balance times for the four reference studies range from 859.8 TMU to 2812 TMU. The MTM Association value determined from these studies was a balance time of 1369 TMU. This was based upon a total weighted variance of 0.8909 TMU^2/TMU. The weighted variance was calculated as:

$$S^2 = \frac{\sum_{i=1}^{4} S_i^4 T_i}{\sum_{i=1}^{4} T_i} \qquad \text{(Eq. 2-38)}$$

where

S = Total weighted variance

S_i = Variance for Study No. i

T_i = No. of TMU analyzed in study i

It may be argued that the weighted average obtained from these studies will provide a good estimate of the accuracy since the system variance suggested by Hancock (1970) seems to have been used in each study. This presupposed that Hancock's (1970) value is correct, a hypothesis which, at the present time, cannot be accepted. The validity of the MTM accuracy curves must therefore be questioned.

2.7.0 WORK TIME DISTRIBUTIONS

The natural work-time distributions displayed by operators in both paced and unpaced operations have been investigated by a number of researchers. The most important of these investigations seem to stem from a notional paper by Wiberg (1947) who suggested that the shape of these work-time distributions might give an indication of the skill and general level of motivation of the workers.

Dudley (1968) reviewed the results of the studies by Conrad (1954), Seymour (1956), Dudley (1962, 1963), Murrel (1963) and Sury (1964). These researchers were unanimous in their findings that the distributions all had a positive skew. In attempting to put parameters on these distributions, Conrad (1954) suggested that a characteristic work-time distribution would be log-normal and that approximately 66% of the work-time would be less than the average. In his studies of paced working, Sury (1964) was unable to fit a log-normal distribution to his results; however, he did find that by plotting the reciprocals of the unpaced work-times, a normal distribution was obtained.

Figure 2-13: Summary of Results of MTM-1 Validation Studies - Source MTM Association for Standards and Research (1973)

	Reference Study	Hancock et al. 1968 pp.22-23	Foulke and Hancock (1970)	Hancock et al. (1968) pp.42,7	Hancock (1969)	Weighted Value
APPLICATOR VARIATION DATA	Applicator Standard Deviation TMU/$\sqrt{TMU}$	1.26	0.8217	0.709*	0.6751	0.8036
	Applicator Variance TMU^2/TMU	1.58	0.6753	0.503	0.4564	0.6459
	TMU Analysed to Determine Values	2608	3268	16008	1278	23162
	Estimated Balance Time	2439.6	700.7	772.4	700.3	002/3
TOTAL VARIATION DATA	Total Standard Deviation TMU/$\sqrt{TMU}$	1.353	0.959	0.864	0.8364	0.944
	Total Variance TMU	1.831	0.920	0.748	0.6996	0.8909
	Estimated Balance Time	2812	1300.6	859.8	1075	1369
System Variance Calculated From Above Values		0.501	0.495	0.493	0.495	0.495

* Average of Swedish Data

Sury (1964) explained the success of this transformation on the basis that it represented the distribution of the operator work rate. In a paper relating operator fatigue to the variability of a work-time distribution, and using data collected by previous researchers as the basis of his analysis, Murrel (1963) agreed with Sury's conclusion with respect to shape of the work-time distribution.

Dudley (1962) expressed concern about the validity of PMTS in certain applications. The basis of this concern was the way in which the original data for these systems was normalised or levelled. Based upon the author's personal contact and discussion with W. Antis, the engineer who did the filming and analysis for the original studies upon which MTM was based, this concern is understandable. The MTM data was based upon operations recorded upon only 1350 feet of film. Furthermore, the camera used in taking the film was hand cranked. The levelling was based not upon individual motions but upon a series of cycles as is the standard practice with levelling. The time value for the Basic Manual Motions was then determined by means of a form of averaging. On the positive side, justifying the validity of the MTM values, it should be noted that validification was carried out under different conditions by White (1950) and were further extensively tested and proved through systematic research by Raphael (1952 to 1957).

Seymour (1956) commented on the differences in work-time distributions of different therbligs. Dudley (1968) pointed out, however, that while these observations were interesting, the size of the sample used in the research was too small to be considered conclusive.

In view of the nature of PMTS, it seems surprising that the only comments relating work-time distributions to therbligs or PMTS elements were those by Seymour (1956) cited above.

2.8.0 SUMMARY OF LITERATURE SURVEY

This literature survey has concentrated upon a limited number of aspects of PMTS. Some of the more important of these aspects are dealt with briefly below.

2.8.1 Compatability of PMTS

Compatability of PMTS requires that time standards determined by one system can be combined with or substituted for time standards developed by another system. This is one characteristic of PMTS which critics have questioned; however, there is every reason to believe that, due to commercial considerations, in the original development of these systems compatability was the last thing which was desired.

With the development of higher levels of these PMTS compatability did take on an importance. However, this was the compatability of all of the different levels of data in a total system and the basic system used. (For example, the compatability between MTM-1, MTM-2 and MTM-3.)

2.8.2 Additivity of PMTS Elements

Another characteristic of PMTS which has been challenged by critics is the concept of the additivity of elements.

The original critics, in challenging the basic system, claimed that the covariance which exists between the elements had been ignored. An examination of the application rules quickly shows that this criticism is totally unfounded.

When the higher level data systems, such as MTM-2, were introduced, there were surprising reactions from some existing users. Their criticisms were on the basis that the analysis of an operation using the higher level data system and an analysis of the same operation using the basic system would not result in the same time prediction. It is interesting that the arguments put forward by the critics of the higher level data systems were the same ones they rejected about the basic systems several years earlier.

2.8.3 Evaluation Parameters

Several measures have been proposed to evaluate different levels of PMTS. The one which is most widely promoted is by the Methods-Time Measurement Association, namely, the Balance Time.

This Balance Time is based upon a confidence interval and is related to a cycle time. The literature survey identified that the whole concept of Balance Time is poorly defined, is based upon incorrect assumptions and suspect data.

In using Balance Time to evaluate MTM systems, the user is forced to accept that the MTM-1 system is absolute and that the error of all other systems must be measured against this. Unfortunately, there does not appear to be any evidence to support this view.

2.8.4 Researcher's PMTS Skills

A disturbing feature of many of the research projects which had been carried out to evaluate PMTS was a total lack on the part of the researchers of the basic application rules and the structure of the systems which they were studying.

It seems quite acceptable for a researcher with no skills in the area to study PMTS and his/her conclusions to be considered as positive. It is interesting to speculate whether this would be considered to be good practice in other fields of academic research, such as, say, medicine!

The need for qualified, experienced practitioners of a narrow range of PMTS was, therefore, identified by the literature survey.

2.8.5 Work-Time Distributions

Several researchers have investigated the characteristics of the natural work-time distributions exhibited by operators. One of these indicated a proportion of the times which could be expected to be less than the average.

Dudley (1968) has indicated that there might be some relationship between the therbligs and the work-time distributions, but the same size used in this study was unfortunately too small to draw any reliable conclusions. There seems to be no other study in the literature which attempts to relate PMTS to these work-time distributions.

3.0.0 EXPERIMENTAL PLAN

3.1.0 OBJECTIVES AND PLAN

3.1.1 Statement of Objectives

The superiority of one form of PMTS over another has been the subject of much discussion among practitioners. Surprisingly enough, the comparison has not been restricted to competing groups of systems, such as MTM versus Work Factor, but has extended to comparisions between different data levels in the same family, such as MTM-1 verus MTM-2 versus MTM-3.

The data for the research from which the original MTM-1 system was established is no longer available. It is not possible, therefore, to examine the distribution of work-times of the research subjects to determine their natural variability. Further, since MTM-2 and MTM-3 are based upon modal MTM-1 patters collected from different sources, then analysed according to a predetermined procedure, rather than being based upon direct observations, no information exists which can be used to relate the MTM-2 and MTM-3 data to work-time distributions of the operator.

The simplification of application which occurs as higher levels of data are developed is "supposed" to make these systems less desirable as work measurement techniques when evaluated on the basis of some measure of accuracy. However, this evaluation is based purely upon an analytic approach, which is itself suspect, rather than upon direct observation. Therefore, any guidelines laid down for the selection of a particular level of PMTS, such as MTM-1, MTM-2 or MTM-3 are theoretical and are subject to question.

The doubt which must be expressed relative to the selection of the data level appropriate for a particular work measurement application must bring with it the question of whether a further simplification could be made without detriment to the work measurement results.

On this basis, the objectives of this research were

"To examine the possible superiority of any of the three principal MTM systems for the derivation of time standards, recognising the variability of actual work times arising from the natural variability of unpaced operator performance.

To consider whether the use of predetermined motion-time systems, which may be derived from MTM, might permit equally acceptable time standards to be obtained."

3.1.2 Outline of Experimental Plan

The first step in the experimental plan consisted of three decisions, as follows.

1. To select the basic data systems to be investigated.
2. To decide whether the study should be laboratory based, industry based or a combination of the two.
3. To select the plant(s) in which the studies were to be made.

The selection of MTM-1, MTM-2 and MTM-3 as the techniques to form the basis of the study was straight forward and is discussed in detail in Section 3.2.1 below.

The importance of using data from the industrial environment was established early in the study and is discussed in some detail in Section 3.2.2. The selection of the plant(s) for the study was a little more difficult but was based upon criteria which were established before the study began. The result was a decision to carry out an in-depth study in one plant rather than more superficial studies in several plants. The discussion justifying this decision appears in Section 3.2.3 below.

Initial familiarization exercises in the laboratory showed that the most effective method of collecting field data would be in three phases, as follows:

1. Video recordings of operations at the work place.
2. MTM analyses, using the video recordings and subsequently verified at the work place.
3. Timing of the work elements using the video recordings.

These three phases are described in detail in Sections 3.8.0 to 3.10.0 below.

The field data collected in this way was then subjected to extensive statistical analysis. The statistical analysis enabled conclusions to be drawn relative to the work-time distribution of the operators.also, relative to effect of simplification of the PMTS. To test the conclusions relative to the simplification, information was collected and analysed on the times predicted by MTM-1, MTM-2 and MTM-3 and other simplified systems for a further group of operations. In this latter case, no video recordings or timings were carried out.

3.2.0 SELECTION OF THE TECHNIQUES, TASKS AND SITES TO BE STUDIED

3.2.1 Selection of the Techniques to be Studied

In Chapter 2.0.0, it was identified that a fundamental weakness in the research groups studying PMTS was their lack of competency and application experience in the systems being investigated. This weakness gave rise to misapplication of the data, distortion in the results and, consequently, misleading conclusions.

With respect to the compatability* of PMTS, Chapter 2.0.0 noted that those who critisized PMTS on the basis of non-compatability failed to question whether systems such as Work Factor and MTM were even designed to have this property of compatability. In fact, the evidence points very strongly to support the opinion that they were not. On the other hand, when viewed from the aspects of theory and practical application, the need for compatability between different levels of data in the same group, for example, MTM-1, MTM-2 and MTM-3, is essential.

These two features were fundamental in the choice of systems to be studied. The author has had almost twenty years experience in applying MTM-1, MTM-2 and MTM-3 in a diversity of industries, both in Europe and North America. In addition to which, he has been engaged in directing training courses in these three techniques. The choice of MTM-1, MTM-2 and MTM-3 was, therefore, automatic.

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* In this research the term compatability is used in the sense that times from two or more systems are combinable

3.2.2 The Need for Industry Based Research

The importance of using industry based data in any PMTS research was emphasized in a preliminary study carried out in the laboratory so that familiarization with the research equipment could be established. It very quickly became evident that when unskilled operators were being used, the greatest source of variation appeared not to be due to learning effects, but to the fatigue of the operators. The subjects in this preliminary laboratory study had not developed the endurance strength in their fingers to perform the tasks in a way expected of skilled operators in industry.

Reviewing the literature in Chapter 2.0.0, it is clear that a large proportion of the research in PMTS carried out to date has been based upon a laboratory environment, using unskilled operators in that environment. Two arguments which may be put forward to support this practice are convenience and the fact that the operations used were so simple that the learning period was short enough to make the data valid.

From these considerations it was decided to restrict the study to industry based data. Furthermore, it was decided to use a set of pre-established criteria in selecting the plants to be used as candidates in the study.

3.2.3 Criteria Used in Selecting the Industrial Plants for Study

Nine plants agreed to be considered as possible sites for this study. Each plant was evaluated, based upon each of the following criteria.

1. Does the plant have a pool of stable, highly experienced operators who can be studied?
2. Is the management team dedicated to the use of some form of MTM data and would they be supportive of this research project?
3. Would the operators and Trade Union be prepared to cooperate in this project?

4. Is there a pool of skill in some MTM system available in the plant?

Of the nine plants evaluated, only one satisfied all of these criteria. Of the other eight plants, none satisfied more than two of the criteria. On this basis, it was decided that the most profitable course would be an in-depth study in one plant rather than a comparison of the results of several plants.

3.3.0 DESCRIPTION OF THE PLANT STUDIED

The plant in which the study was made is located in Lancaster, Pennsylvania, U. S. A., and has existed in that town since before the turn of the century. Within a year previous to the study being made, the company had moved from a plant which had "developed" in an unplanned manner over more than half a century. In this plant there was a great deal of wasted space, excessive materials handling and poor working conditions.

The present facility is somewhat unusual in that the company moved from the suburbs to the town centre, converting an unused modern department store to a factory. The decor, lighting and conditions may be considered to be excellent and while the layout is compact, in no way can the conditions be considered to be cramped.

3.4.0 THE PRODUCT

The company originally manufactured high quality watches and watch movements and was, in fact, considered to be a leader in this field. In the 1960's they also manufactured a range of piezzo electric watches. However, the competition generated by the cheap, low quality movements produced in the developing countries and the high technology products has completely changed the nature of the watchmaking industry in the U. S. A.

The design, manufacturing and operator skills required to produce mechanical bomb fuses are almost identical to those needed in watch manufacture. Consequently, the company responded to the change in the demands of its existing industry by entering and capturing a large portion of the market of a new industry.

3.5.0 THE PERSONNEL

The workers in the Lancaster, Pennsylvania area have a reputation for a good "work ethic" of which they are justifiably proud. In addition to this, there is a tradition of staying with one employer for long periods. The minimum length of experience of any of the operators on the job studied, for example, was three and a half years and the maximum length of experience was fifteen years.

As a result of this, the skill levels of the subjects of the tests could all be considered as extremely high.

3.6.0 WORK MEASUREMENT AND METHOD ENGINEERING HISTORY IN THE PLANT

For many years an incentive system had been in operation in the plant which had been based upon stopwatch time studies. With the passage of time, there had been considerable drifts in methods which had not been recognized, giving inconsistent time standards and an incentive scheme which was out of control.

Realizing that a change of plant would be necessary in the not-too-distant future, in early 1977 the company negotiated the introduction of MTM-1 into the plant as the basis of work measurement. It was decided the the MTM-1 system would be used to its fullest extent, not only for work measurement but as the basis of a methods improvement program.

As a result of this conscious methods improvement and work measurement program, when the company moved into the new facility in 1980, the methods had become standardized and fully recorded. The program had also resulted in a productivity improvement of over 30% in the three years from 1977 to 1980.

Having once experienced a work measurement system which had gone out of control, the company is now vigilant, and continually audits the MTM-1 based time standards.

3.7.0 WORK MEASUREMENT PERSONNEL

There were eight persons employed in the work measurement function in the plant, all of whom were certified as MTM-1 practitioners. Most of the work measurement group had been applying MTM for approximately four years, only one person having used the MTM-1 technique for less than one year. In addition to the work measurement group, several other personnel in the plant had received MTM-1 training and certification.

There was clearly an excellent pool of MTM-1 knowledge and experience from which to draw, however, in other aspects of work measurement the group had limitations. There were no graduate engineers and only one had actually used stopwatch time study in practice, and that was several years previously. The positive aspect of this, of course, was a complete reliance on, and commitment to, MTM-1.

Five of the group had been selected from the shop floor to receive MTM-1 training, one was from the previous time study department and one analyst had been recruited as a trainee from outside the company. The knowledge of the product and plant methods within the department was extremely high and the MTM-1 training which the personnel had received had clearly emphasized methods engineering equally with work measurement.

The management of the company encouraged their work measurement personnel to become actively engaged in any discussions on this research project, thereby providing an invaluable pool of knowledge and expertise, not only of MTM-1 but of the existing plant practices and methods.

3.8.0 VIDEO RECORDING

3.8.1 Video Recording Technique

The purpose of the recording was explained to the operators, shop stewards and supervisors in each area before the equipment was set up for recording. Without exception, the investigation was accepted.

The video equipment was set up at a workplace and allowed to run either for a batch of work, or until the system was causing undue interference with production. It was found that the distraction was minimized if the investigator answered any questions before setting up the equipment, then leaving the area immediately after the system was operating, eliminating any further interaction between the operator and the investigator until the study was completed. At intervals of about fifteen minutes, checks were made to ensure that the system was operating correctly. This check would be made at some distance away from the workplace merely by locating the video screen in an easily visible position.

While this approach did prevent any undue influence of the investigator on the operator, it did have attendant disadvantages. The first was that when an operator did not perform in a "workman-like manner" it was not discovered until the next phase of the data collection process, resulting in the loss of what could have been useful data. The second disadvantage was that the investigator did tend to lose some familiarity with the operation being carried out in its working environment. Fortunately, this latter disadvantage was overcome in the next phase of the data collection.

3.8.2 Video Recording Equipment

The equipment used for the on-site video recording was an RCA Type TC3250 Video Recorder coupled with an RCA Type 1010 closed circuit video camera. A photograph of the set-up is shown in Figure 3-1.

The RCA Type 3250 Video Recorder is equipped with a Time/Data Base Generator with a time lapse capability. While a ½" standard video cassette recording tape is used by this equipment, the special format required to accommodate the two features noted above preclude the use of the tapes being played back on standard equipment. To overcome this limitation, thereby making the tapes transferrable, the RCA Type TC3250 recorder was coupled directly to a JVC Vidstar VHS Color Video Cassette Recorder, Type HR-6700. A photograph of this set-up is shown in Figure 3-2.

Figure 3-1: Photograph of Set-up for On-site Video Recording

Figure 3-2: Set-up for Tape Transcription

The transcription of the tapes was carried out away from the work site and completed the video recording phase.

3.9.0 MTM ANALYSES ON FIELD DATA

3.9.1 Making the MTM-1 Analyses

Studying the video tapes, the investigator made MTM-1 analyses of all of the tasks which had been studied. Since the company provided copies of all of the MTM-1 analyses that were accepted in the plant, together with sample parts handled in the tasks, the effect of the investigator's lack of familiarity with the working environment was minimized. The investigator first made the analyses independently, only checking with the plant analyses when it was not possible to ascertain the details of a method from the video recording. The actual method and details were confirmed by observation of the tasks during a later visit to the plant.

3.9.2 Confirming the MTM-1 Analysis

A careful comparison was made between the MTM-1 analyses developed by the plant and the investigator. The reasons for any differences were established and reconciled by detailed discussions with the work measurement personnel. Most of these differences were minor and represented differences in interpretation of the MTM-1 system and resulted in differences of only several TMU in the total time value. In other cases there were major differences between the analyses made by the investigator and those in use in the plant. Where these major differences were found, they were, exclusively, the result of changes in method which had occurred and had escaped detection, in spite of the continual auditing which is carried out.

In confirming the actual MTM-1 analyses with the work measurement personnel, the concensus was achieved by first viewing the video recording as a group, then by direct observation at the workplace. The concensus was, however, based upon the method being used on the video tape. The distances were confirmed by actual measurements at the workplace.

3.9.3 MTM-2 and MTM-3 Analyses

After the MTM-1 analyses had been established, equally careful analyses of the tasks were made using MTM-2 -ad MTM-3. By the time these analyses were made, the investigator was entirely familiar with the methods and conditions existing at the workplace. Therefore, in spite of the fact that there was no backup opinion available for these analyses, it can reasonably be assumed that the errors are minimal and are within the normal levels of applicator error.

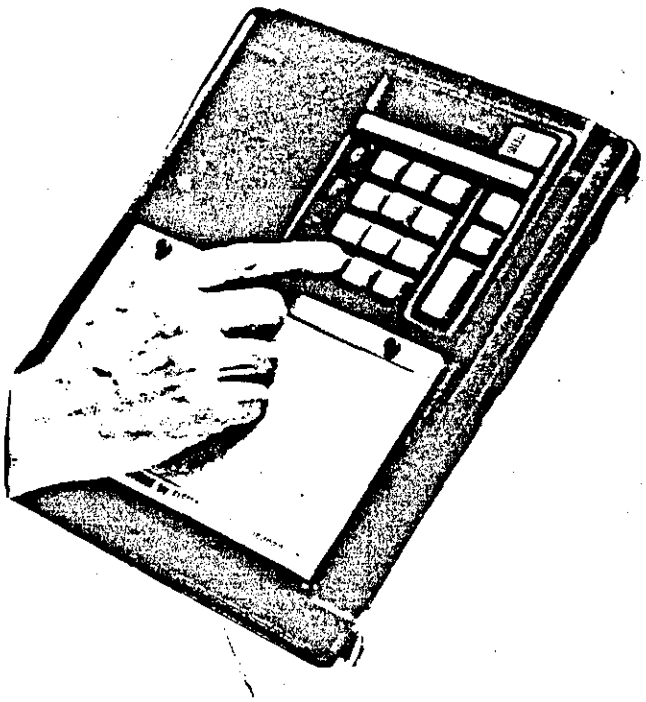
These MTM analyses not only completely defined the method but also identified the breakpoints to be used in collecting the data on the observed time taken by the operator in performing these elements.

3.10.0 TIMING THE WORK ELEMENTS

Timing the work elements was carried out by observing the video recordings and recording the work element times on a "Data-myte" data collector. A photograph of this set-up is shown in Figure 3-3 and the "Datamyte" is shown separately in Figure 3-4.

Figure 3-3: Recording Element Times Using the Datamyte Recorder

Figure 3-4: The Datamyte Recorder



The Model No. 900 "Datamyte" Data Collector is a battery powered hand held, portable instrument which fulfills three functions as follows:

1. Data Collection
2. Data Storage
3. Data Interface

As part of the data collection function, the instrument operates in a number of different input and output modes. Some of these modes include the use of an integral time generator. The time generator in the unit used in these tests was calibrated in 0.01 minutes and the operating mode was set so that an element number and time were stored in the memory of the "Datamyte" when the single key representing a particular element was pressed.

When a study was completed, the Datamyte was connected to a main frame computer via a modem and the information contained in the Datamyte memory was transferred to a computer file. This data may be transferred in a preselected format suitable for subsequent processing.

Initially it was felt that the time intervals of 0.01 minutes obtainable on the Datamyte could result in significant errors in the data. The slow playback feature of the JVC Video recorder would remove this problem. The adjustable speed control was calibrated, using a video tape of a microtimer. An operation was then timed at normal speed and at two other slower speeds. A statistical analysis showed that there was nothing to be gained numerically by carrying out a measurement of the element times at the slower speeds.

In two tasks the elements were so short and their breakpoints so difficult to detect that it was impossible to carry out the timing with any degree of confidence. It was necessary to carry out the analysis at a slow pace.

3.11.0 SELECTION OF WORK ELEMENTS

The data elements in the MTM-1, MTM-2 and MTM-3 systems are based upon them being Basic Manual Motions; that is, they contain no process time. In spite of this restriction, a practice has developed among MTM analysts to represent some short process controlled elements by an "equivalent" MTM motion. That is, the analyst estimates an MTM motion which is likely to represent the process controlled element. As an example, consider the case of a short deburring operation on a drill press, where the analyst may assign an Apply Pressure to approximate the required action.

While this practice has become accepted, there is no proof that it is acceptable with respect to the resulting time estimate. Consequently, any element which was studied and found to contain even the slightest suspicion of a process time was excluded from the analysis.

The MTM-1, MTM-2 and MTM-3 analysis of the elements, from here on referred to as job or tasks, are contained in Appendix C and the observed times for these tasks are given in Appendix D.

4.0.0 ANALYTIC MEASURES OF THE RELATIVE VALUE OF WORK MEASUREMENT SYSTEMS

4.1.0. RESEARCH DATA

The data used in the research was at the following two levels:

1. Basic Field Data
2. Proving Data

4.1.1 Basic Field Data

The Basic Field Data is comprised of twenty-six operations which were studied by video tape, analysed and then timed. These operations included:

1. Study P01/1: Grind Balance Staff and Pin Assembly - Load Part to Machine.
2. Study P01/3: Grind Balance Staff and Pin Assembly - Unload Part from Machine.
3. Study P06/1: Counterbore and Chamfer Hairspring Timer Tube - Unload Hairspring Tube.
4. Study P06/2: Counterbore and Chamfer Hairspring Timer Tube - Load Hairspring Tube.
5. Study P07/1: Assemble and Press: Plate and Spacer - Pressed Part to Bin and Assemble Three Pins.
6. Study P07/2: Assemble and Press: Plate and Spacer Assembly - Plate and Spacer Assembly into Position.
7. Study P07/3: Assemble and Press Plate and Spacer Assembly - Position Lower Plate and Shaft Assembly.
8. Study P07/4: Assemble and Press: Plate and Spacer Assembly - Assemble Lock Pin and Bottom Plate.
9. Study P09/1: Assemble Gear Train - Assemble Spacer.
10. Study P09/2: Assemble Gear Train - Assemble Interlock Detent.
11. Study P09/3: Assemble Gear Train - Assemble Interlock Indent.
12. Study P09/4: Assemble Gear Train - Assemble Escape Gear.
13. Study P09/5: Assemble Gear Train - Assemble Gear and Pinion.

14. Study P09/6: Assemble Gear Train - Assemble Lever Assembly.
15. Study P09/7: Assemble Gear Train - Assemble Rotor Assembly.
16. Study P09/8: Assemble Gear Train - Assemble Interlock Spring.
17. Study P09/9: Assemble Gear Train - Assemble Spring to Spin Detent.
18. Study P09/10: Assemble Gear Train - Assemble Bottom Plate.
19. Study P09/11: Assemble Gear Train - Parts Aside to Tray.
20. Study P10/1: Arming and Non-arming Test Fuse - Remove Part from Fixture
21. Study P10/2: Arming and Non-Arming Test Fuse - Load Part to Fixture.
22. Study P11/1: Insert Retaining Ring - Unload and Load Fuse to Fixture.
23. Study P12/1: Stake Ring - Load Fuse into Fixture.
24. Study P12/2: Stake Ring - Remove the Fuse from the Fixture and Adjust.
25. Study P13/1: Apply Silastic to Fuse Assembly - Load Fuse to Fixture.
26. Study P13/3: Apply Silastic to Fuse Assembly - Unload Fuse from Fixture.

The MTM-1, MTM-2 and MTM-3 analyses of these twenty-six operations are given in Appendix C. Reference to these analyses will enable the reader to understand fully the method used to perform each work task.

In Figure 4-1, the results of the time studies and MTM-analyses are summarized. An examination of the basic times for the field data shows that they range from around 0.02 basic minutes (43.2 TMU) to 0.10 basic minutes (209.16 TMU). It was reasoned that this range of time values was acceptable on three counts, as follows:

Figure 4-1: Table of Field Data

		Raw Time	Decimal Minutes @ 100 B.S.T.			
Job	Study	Average	Basic	MTM-1	MTM-2	MTM-3
1	P01/1	11.139	8.911	6.980	7.800	9.800
2	P01/3	5.604	4.483	2.520	2.850	3.450
3	P06/1	2.540	2.540	3.215	3.050	3.500
4	P06/2	4.229	4.224	5.890	6.100	4.000
5	P07/1	9.957	10.455	8.275	10.500	8.900
6	P07/2	2.913	3.057	3.245	3.500	3.850
7	P07/3	2.576	2.705	3.915	3.500	3.850
8	P07/4	5.990	6.230	6.755	6.850	7.450
9	P09/1	4.467	3.574	4.095	4.400	3.450
10	P09/2	2.969	2.375	2.950	2.900	2.750
11	P09/3	3.532	2.827	3.125	3.100	2.600
12	P09/4	4.465	3.572	3.095	2.900	2.800
13	P09/5	5.903	4.722	3.095	2.900	2.800
14	P09/6	3.305	2.644	3.230	2.900	2.800
15	P09/7	3.210	2.568	3.065	2.500	2.950
16	P09/8	5.984	4.782	4.945	6.300	4.900
17	P09/9	4.126	3.301	3.135	2.950	3.400
18	P09/10	7.270	5.816	6.145	4.100	6.150
19	P09/11	2.770	2.216	3.550	3.250	3.450
20	P10/1	6.673	8.341	6.645	7.300	8.100
21	P10/2	8.530	10.236	10.165	11.450	10.300
22	P11/1	3.928	4.715	4.710	5.025	6.250
23	P12/1	5.247	4.198	4.470	4.900	4.200
24	P12/2	5.094	4.095	3.925	4.150	4.800
25	P13/1	5.452	4.362	3.270	4.400	3.800
26	P13/3	3.653	2.922	2.615	3.400	3.800

(All time values in this table are expressed in 1/100 minutes.)

1. The job times were short enough to be observed efficiently in analysis, and therefore for method study purposes.
2. The range of jobs would enable the restriction of minimum cycle length of 1600 TMU for MTM-1 and 7800 TMU for MTM-3 to be broken and thus tested.
3. The work tasks selected in the field data represented a wide range of elements encountered in the plants being studied and in light industry in general.

4.2.0 MEASURES FOR EVALUATING PMTS

4.2.1 Existing Premises

Some of the measures which have been used in the past to evaluate and compare the MTM systems have been considered in different degrees of detail in Chapter 2.0.0. There is no reason to assume that the same evaluation procedures could not be applied to other PMTS.

The evaluations of the MTM systems made by the MTM association and research groups all begin with the premises that MTM-1 is the base system. It has some minimum systemic error. All systems are worse case systems compared to MTM-1 and MTM-1 is the standard system. It appears, therefore, that the evaluation criteria have evolved rather than developed to any set plan.

There is no experimental evidence to support these premises; however, for more than a decade they have formed the basis to any argument relative to the evaluation of MTM systems. It is essential that our thinking should be freed of these unproven constraints if reasoned evaluations are to be made.

4.2.2 Demands on Evaluation Criteria

PMTS are practical techniques; therefore, any criteria used to evaluate and compare alternative techniques should conform to predetermined demands which enhance this practical characteristic. It is proposed that the fundamental demands which should be placed upon these evaluation criteria are as follows:

1. The purpose for which the data is to be used should have the prime impact. Therefore, the criteria must be sensitive to this demand.
2. The criteria, wherever possible, should be quantitative. This will not only reduce any influence due to personal preferences but will also enhance the ability to compare the results from different evaluation criteria.
3. The evaluation criteria should be simple to determine, understand and apply. Criteria which are mathematically refined might be exciting in academia; however, if the same results can be obtained by means of a simpler method which fulfills these same demands, there is a greater likelihood of acceptance by the user population. There is the added spin-off that the academic and user population will have a common basis for expressing and discussing problems related to parts.

Almost without exception, one theme runs throughout the writings on work measurement; namely, that the times generated by any work measurement system should have relevancy to the work content of the job being measured. Equal with this first theme is that the times predicted for two jobs by the same work measurement system should have relevancy. Herein is implied the need for a measure of accuracy as the basis for evaluation.

4.2.3 Classifying the Purpose of PMTS

The users of the MTM systems have established MTM Associations within different countries, each pursuing separate ways to extend the use of the MTM systems, while at the same time exercising a central control through the MTM International Management Directorate (MTM-IMD). This MTM-IMD has separately generated and supported pure and applied research projects into the MTM system. The most notable research unit was operated at the University of Michigan at Ann Arbor.

In spite of the many areas of application which have been investigated by these various groups, and the resulting developments, the most convenient classification which can be used for grouping the purpose of PMTS still remains as:

1. Work Measurement
2. Methods Engineering

The principal concern of this thesis is that of Work Measurement; however, the topic of Methods Engineering will be referred to as appropriate in the discussion.

4.3.0 ANALYTIC MEASURES

4.3.1 Description of Results

The purposes for which work measurement data can be used have been enumerated in different ways by different authors. The theme which runs throughout their writings, however, is that there is a need that the time generated by the work measurement system should have relevancy to the work content of the job or task.

The work carried out by various groups associated with the MTM-IMD and the national MTM Associations, as noted previously, began with the premise that the time predicted by an MTM-1 motion pattern provided the correct time standard. There is no hard evidence to support this assumption and examination of the data shown in Figure 4-1 makes it even more questionable.

A number of disturbing inconsistencies arise in the data given in Figure 4-1. The MTM-1 value for both job No. 12 and Job No. 13 is 3.095 hundredths minutes. However, the respective Basic Times, obtained by direct measurement of these operations are 3.572 and 4.722 hundredths minutes, respectively. To examine this apparent inconsistency further, the operator's average performance on these two sample tasks can be determined using the equation:

$$\text{Operator's Average Performance} = \frac{100 \times \text{MTM-1 Time}}{\text{Average Observed Time}} \qquad \text{(Eq. 4-1)}$$

Based upon this, the operator's average performance for Job No. 12 is 69.3, and for Job No. 13 is 52.4. Yet, the operator's average performance assessed for both of these tasks by direct observation was 80. Clearly, even an untrained observer would recognize the difference between a performance of 80 and 50; therefore, the video tapes of this operation were re-examined with respect to the operator's average performance. The 80 performance for both of these was reaffirmed and the doubt on the faith in the absolute value of the times by MTM-1 strengthened.

All of the sample tasks with the Job No. prefix P09/- were performed in sequence by the same operator. Advantage was taken of this during the examination referred to above by re-ascertaining the performance level of all of these operations to be 80 BSI. Using Equation 4-1, the average operator performance level for all of these operations was determined for each MTM data level. These values are given in Figure 4-2.

Figure 4-2: Equivalent Performance Rating Levels Based Upon Average Observed Time and Time Predicted by MTM.

Job No.	Study No.	Equivalent Rating			Obs. Rating.
		MTM-1	MTM-2	MTM-3	
9	P09/1	91.7	98.5	77.2	80 B.S.I.
10	P09/2	99.4	97.7	92.6	
11	P09/3	121.1	98.8	73.6	
12	P09/4	69.3	64.9	62.7	
13	P09/5	52.4	49.1	47.4	
14	P09/6	97.7	87.7	84.7	
15	P09/7	95.5	77.9	91.9	
16	P09/8	82.6	105.3	81.9	
17	P09/9	76.0	71.5	82.4	
18	P09/10	84.5	56.4	84.6	
19	P09/11	128.2	117.3	124.5	
	Mean	90.76	83.1	82.1	
	Std. Dev.	21.73	21.26	19.2	

The inconsistency shown by MTM-1 with respect to Job No. 12 and Job No. 13 is shown throughout the jobs considered in Figure 4-2. Furthermore, this same inconsistency can be seen to exist for MTM-2 and MTM-3. It should be noted that while the standard deviations of the performances predicted by the three methods are substantially the same; the average performance, predicted by MTM-1, is higher than that predicted by MTM-2 or MTM-3.

The suspicion of the variability of the MTM-1 data is thus confirmed. The marked differences which exist in MTM-1 also exist in MTM-2 and MTM-3. Therefore, these relationships will be examined statistically.

In practice, it is relatively simple to have, or obtain, an estimate of either the average observed time for a task, from an elapsed time, or even an estimate of the basic time from the same source. Therefore, a more constructive basis of evaluating different PMTS would be either the basic time or the average observed time for the job. The method of collecting the data for this investigation enables such a comparison. However, we recognize that the average observed time will be influenced by a number of variables and the basic time influenced by a rating assessment.

To compare the predicted mean times obtained by MTM-1, MTM-2, and MTM-3 with Basic Time, we now examine three measures. It will be appreciated that the comments are directly transferable if the Average Observed Time for the Job is used. Naturally, some minor difference in the arithmetic values can be expected, nevertheless the same fundamental arguments apply in each case.

4.3.2 Mean of the Predicted Times as a Criterion

One approach, widely used by Industrial Engineers, for evaluating either PMTS or standard data systems is to determine the means of a sample of predicted times and their variance, then to compare this with the measured mean and variance of the basic time of the jobs in the sample. Thus:

$$\bar{t}_p = \frac{\sum_{i=1}^{n} t_{p_i}}{n} \qquad \text{(Eq. 4-2)}$$

and

$$s_p^2 = \frac{\sum_{i=1}^{n} \left(t_{p_i} - \bar{t}_p \right)^2}{n - 1} \qquad \text{(Eq. 4-3}$$

where:

$\bar{t}_p$ = mean predicted time

t_{p_i} = predicted time for the i^{th} job in the sample

s_p^2 = variance of the predicted times

n = number of jobs in the sample.

Similarly, if the basic time is being used as the standard of comparison

$$\bar{t}_b = \frac{\sum_{i=1}^{n} t_{b_i}}{n} \qquad \text{(Eq. 4-4)}$$

and

$$s_b^2 = \frac{\sum_{i=1}^{n} \left(t_{b_i} - \bar{t}_b\right)^2}{n - 1} \qquad \text{(Eq. 4-5)}$$

where

$\bar{t}_b$ = mean basic time

t_{b_i} = basic time for the i^{th} job in the sample

s_b^2 = variance of the basic times

n = number of jobs in the sample

In many cases these two variances are compared or rejected on an arbitrary basis. On rare occasions in the industrial environment, an analysis of variance may be performed to give some confidence in the decision.

At the best, this criterion only gives a general indication of the overall applicability of the system with respect to any bias which may exist. It does not reflect effects which may be present due to the size of individual jobs.

4.3.3 Mean Percentage Error of the Predicted Times as a Criterion

In order to reflect the size of the job being considered in the evaluation, the error of the predicted time can be expressed as a percentage of the basic time.

$$e_i = \left(\frac{t_{b_i} - t_{p_i}}{t_{b_i}}\right) \times 100 \quad \text{(Eq. 4-6)}$$

thus

$$\bar{e} = \frac{100}{n} \sum_{i=1}^{n} \left(\frac{t_{b_i} - t_{p_i}}{t_{b_i}}\right) \quad \text{(Eq. 4-7)}$$

and

$$S_e^2 = \frac{\sum (\bar{e} - e_i)^2}{n - 1} \quad \text{(Eq. 4-8)}$$

where

$\bar{e}$ = mean percentage error of the system

e_i = percentage error of the i^{th} job

S_e^2 = variance of the percentage error of sample

This mean percentage error has certain advantages over the mean of the predicted times as a criterion of evaluation. First, it incorporates not only the basic time which is being used as the standard of comparison, but also allows the size effect of the different jobs to be reflected in the evaluation. Therefore, it provides a more efficient way to compare alternative PMTS or Standard data systems.

Where this measure of evaluation is used:

$$E(e) = 0 \quad \text{(Eq. 4-9)}$$

where

$E(e)$ = expected value of the mean percentage error

Consequently, when $e > 0$ there is an indication that there may be some degree of bias in the system. Naturally, under such conditions, the statistical significance of this apparent bias can be tested.

In the industrial environment there is a tendency to accept this measure, particularly where the work measurement is providing the basis for wage incentives. It is perceived that if $E(e) \to 0$, then neither the operator nor the management is penalized by the errors in the long term.

4.3.4 Mean Absolute Percentage Error of the Predicted Times as a Criterion

The error in the system can be magnified by using the mean absolute percentage error rather than the mean percentage error. The mean absolute percentage error is calculated as follows:

$$\bar{e}_A = \frac{100}{n} \sum_{i=1}^{n} \left(\frac{|t_{b_i} - t_{p_i}|}{t_{b_i}} \right) \qquad \text{(Eq. 4-10)}$$

and its associated variance is

$$S^2_{|e|} = \frac{\sum(\bar{e}_A - e_i)^2}{n - 1} \qquad \text{(Eq. 4-11)}$$

where

$\bar{e}_A$ = mean absolute percentage error of the system

$|t_{bi}-t_{pi}|$ = absolute difference between the basic time and the predicted time

$S^2_{|e|}$ = variance of the mean absolute percentage error of the system

This gives a truer value of the errors introduced by the system, although some industrial users of PMTS and standard data might argue against this.

4.3.5 Justification of These Three Measures

No absolute measure of the work content of a task has yet been developed. To choose one system arbitrarily as the standard and relate other systems to it is questionable; however, when the chosen system exhibits the inconsistencies demonstrated in Figure 4-2, it is clearly unacceptable. This is another factor which substantiates the doubt on the Balance Time or any other measure based upon a Coefficient of Variation of the data.

The advantage of using the three measures of evaluation of MTM systems proposed in sections 4.3.2, 4.3.3 and 4.3.4 is that in neither case is an absolute standard ascertained. A comparison of the variance within the results for a particular measure is the basis of the evaluation.

5.0.0 ANALYSIS OF THE THREE GENERAL LEVELS OF MTM DATA

5.0.1 Defining a General Time Data Level

A general level of time data can be considered one which can be applied equally successfully to a clerical task and a machine shop. It can be applied in New York, London or Hong Kong. A general level of time data can be used to carry out work measurement irrespective of work place layout, location or operator.

It has always been claimed that MTM-1 is a general level of time data and, judging from the wide range of applications over more than thirty years, it would seem to be justified.

Within the MTM range there are several levels of data, all having varying degrees of detail in describing the method. Of these different data levels, only MTM-2 and MTM-3 are considered to have this property of "generality". Both MTM-2 and MTM-3 were developed from MTM-1 data.

It is these three general levels of MTM data which will be considered in Chapter 5.0.0. For those readers unfamiliar with these systems, there is a brief description of each in Appendix K. The theoretical structure of these systems is not given in Appendix K; the reader requiring this information should refer to the various research reports given in the list of References.

5.1.0 USING REGRESSION ANALYSIS TO COMPARE THE GENERAL LEVELS OF MTM DATA

5.1.1 Comparing the General Levels of MTM Data with Each Other

A better understanding of the nature of the general levels of MTM relative to the basic time can be achieved by means of simple regression analyses.

Using the SAS Computer Package, linear regression analyses were made on all combinations of MTM-1, MTM-2 and MTM-3. These regression analyses were performed with the restriction that the line must go through the origin. The justification for this restriction is that when either of the two variables being considered has a value of zero then the value of the other variable must also be zero. Any other case is clearly illogical.

The graphs for the three combinations are shown in Figure 5-1 to Figure 5-3. Each of these figures shows three relationships. The first is a dotted line which indicates the case where the relationship is perfect. The other two lines indicate the relationships of the variables where each in turn is the independent variable.

The statistical analyses associated with these regressions are given in Appendix L, as Figures L-1 to L-6. The correlation coefficients and regression coefficients for these analyses are summarized in Figure 5.4 and Figure 5-5.

From these summaries we find that the correlation coefficients are all in excess of 96%, comfirming the linearity of the relationships between these three general levels of MTM. Further, the regression coefficients of these relationships, given in Figure 5-5, are so close to 1.000 that the small differences can reasonably be assumed to be due to experimental error. The coefficients will be taken as 1.000.

Figure 5-1: Regression of MTM-1 and MTM-2 on Each Other

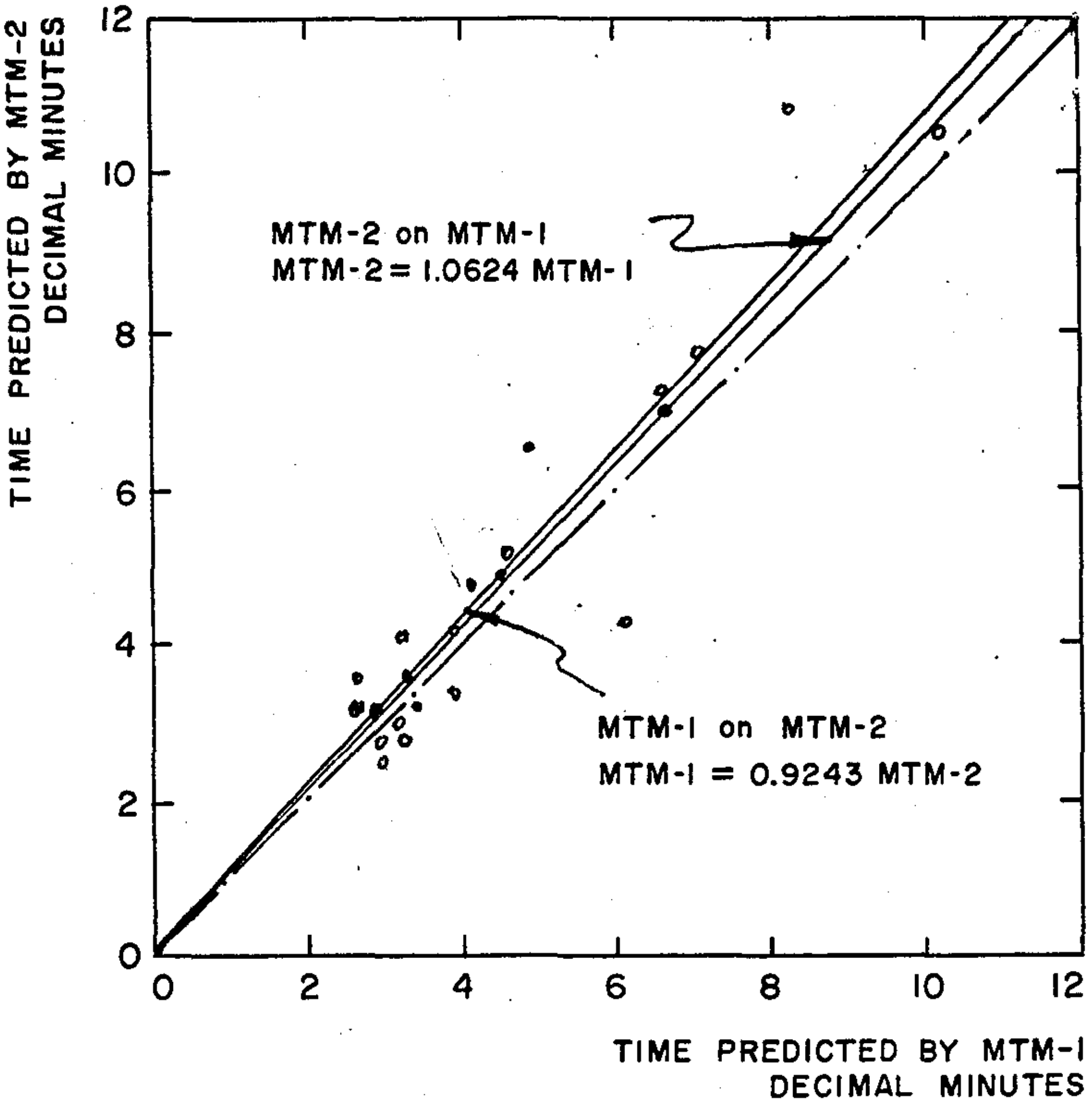


Figure 6-2: Regression of MTM-1 and MTM-3 on Each Other

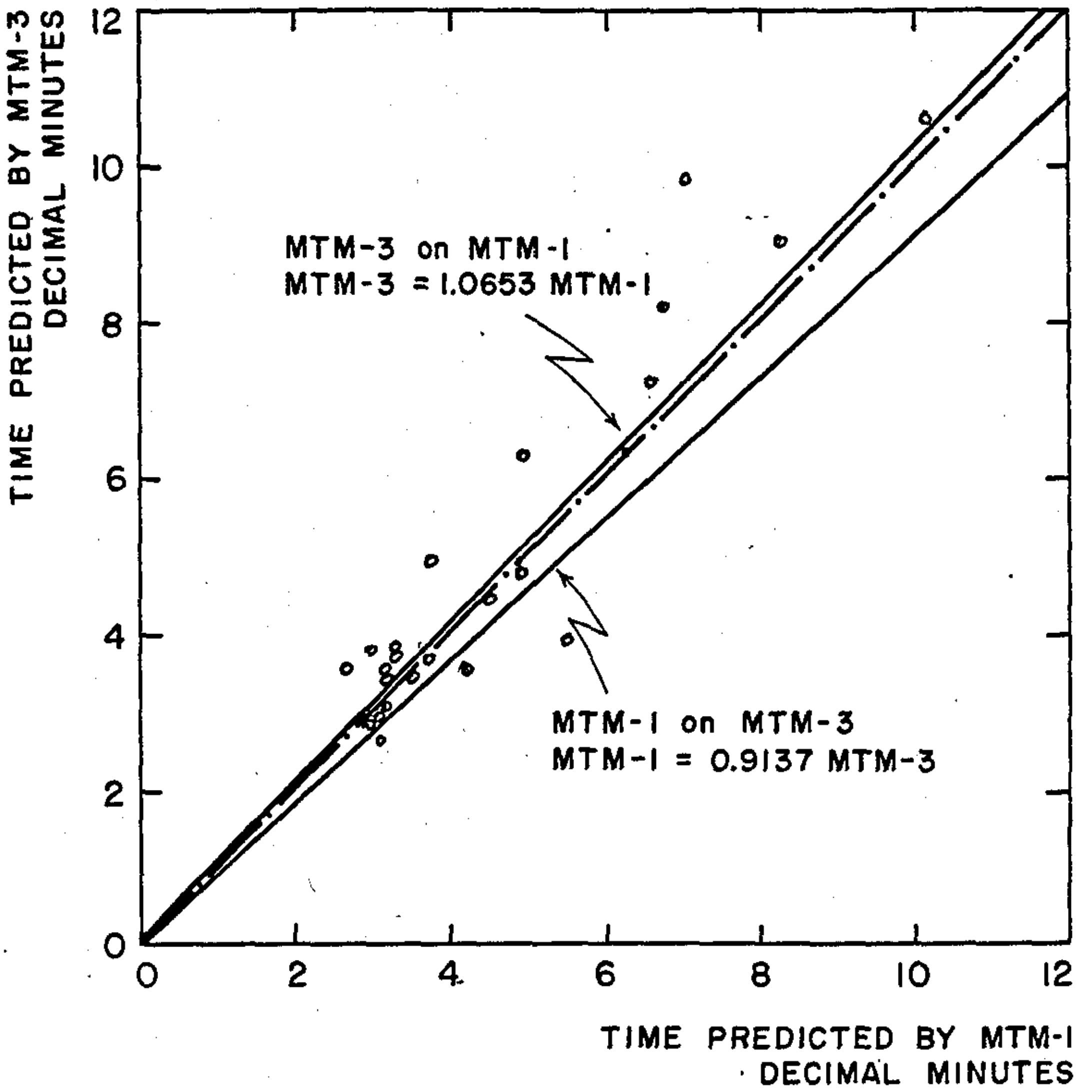


Figure 5-3: Regression of MTM-2 and MTM-3 on Each Other

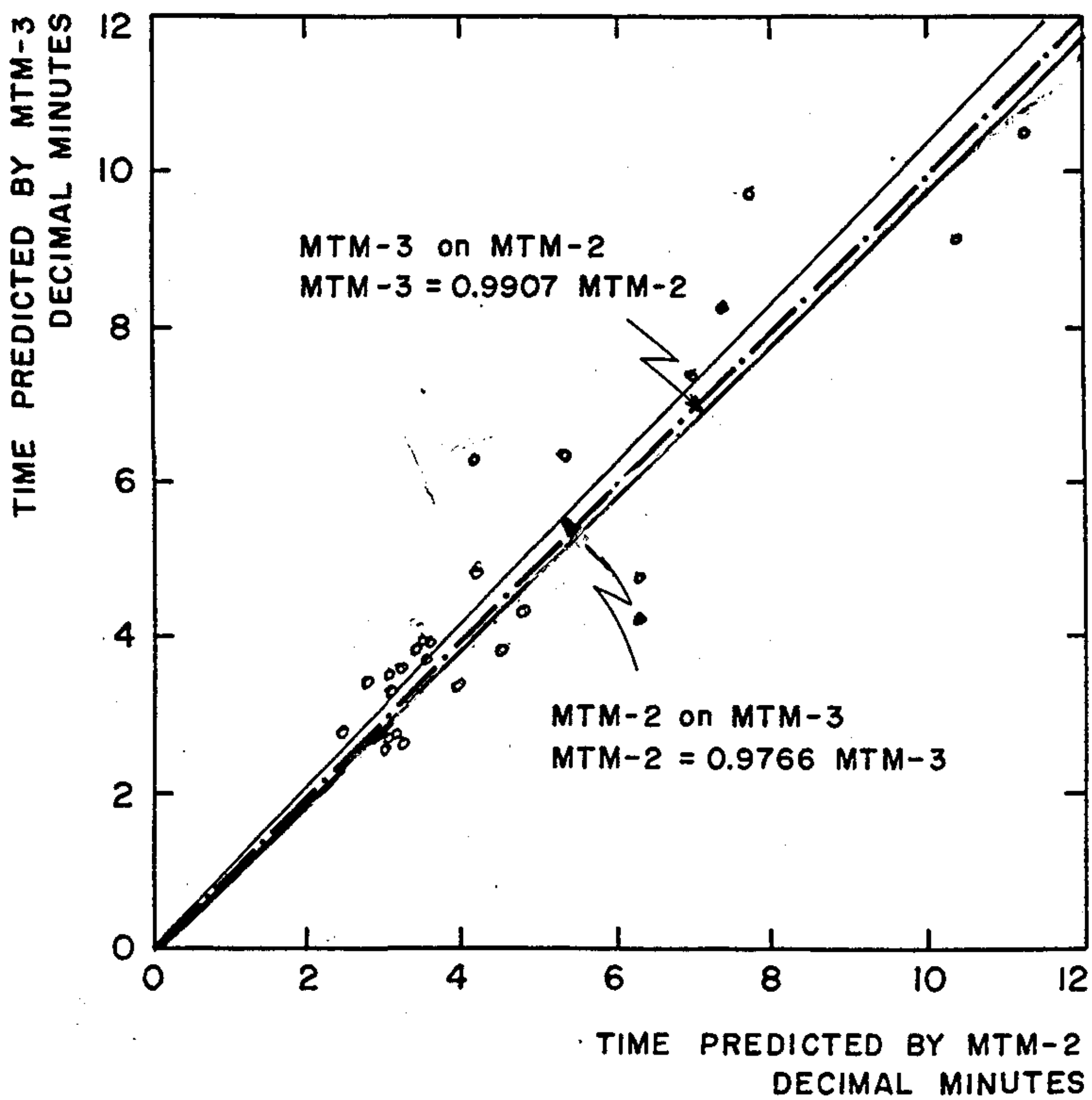


Figure 5-4: Table of Correlation Coefficients for Comparison of the General MTM Systems

		DEPENDENT VARIABLE		
		MTM-1	MTM-2	MTM-3
INDEPENDENT VARIABLE	MTM-1	X	0.9820	0.9734
	MTM-2	0.9820	X	0.9675
	MTM-3	0.9734	0.9675	X

Figure 5-5: Table of Regression Coefficients for Comparison of General MTM Systems

		DEPENDENT VARIABLE		
		MTM-1	MTM-2	MTM-3
INDEPENDENT VARIABLE	MTM-1	X	1.0624	1.0653
	MTM-2	0.9243	X	0.9907
	MTM-3	0.9137	0.9766	X

5.1.2 Comparing MTM-1, MTM-2 and MTM-3 With the Basic Time

An analysis, similar to that just described, was made to compare the MTM general systems with the basic time. The same restriction, that the curves should go through the origin, was placed upon the analysis and linearity was assumed. The graphs of these relationships are shown in Figure 5-6 to Figure 5-8 and the tables of the Regression Analysis Data appear in Appendix L as Figure L-7 to Figure L-12. The correlation coefficients and regression coefficients for these analyses are summarized in Figure 5-9 and Figure 5-10, respectively.

Figure 5-6: Regressions of MTM-1 and Basic Time Upon Each Other

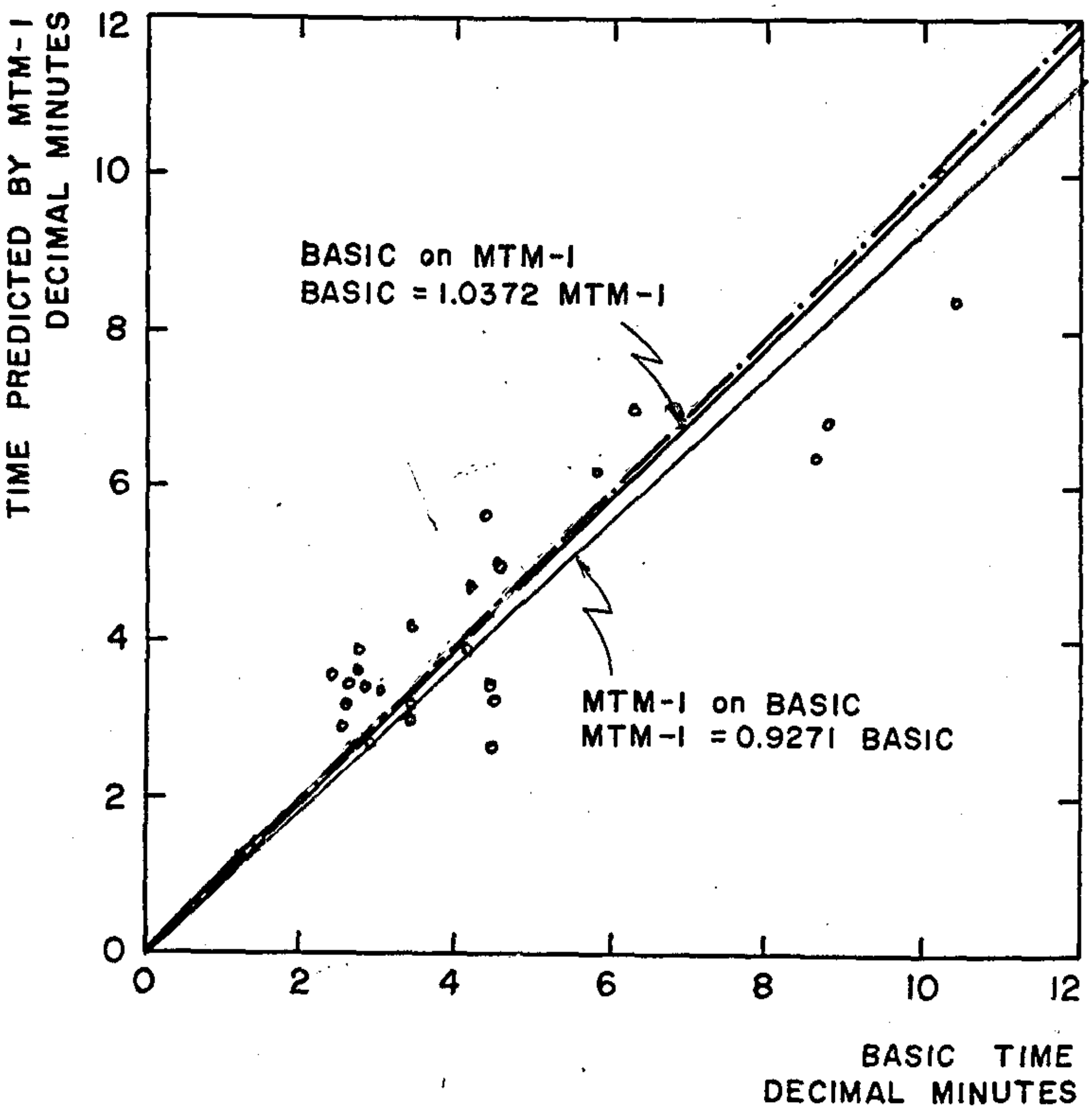


Figure 5 -7: Regression of MTM-2 and Basic Time
Upon Each Other

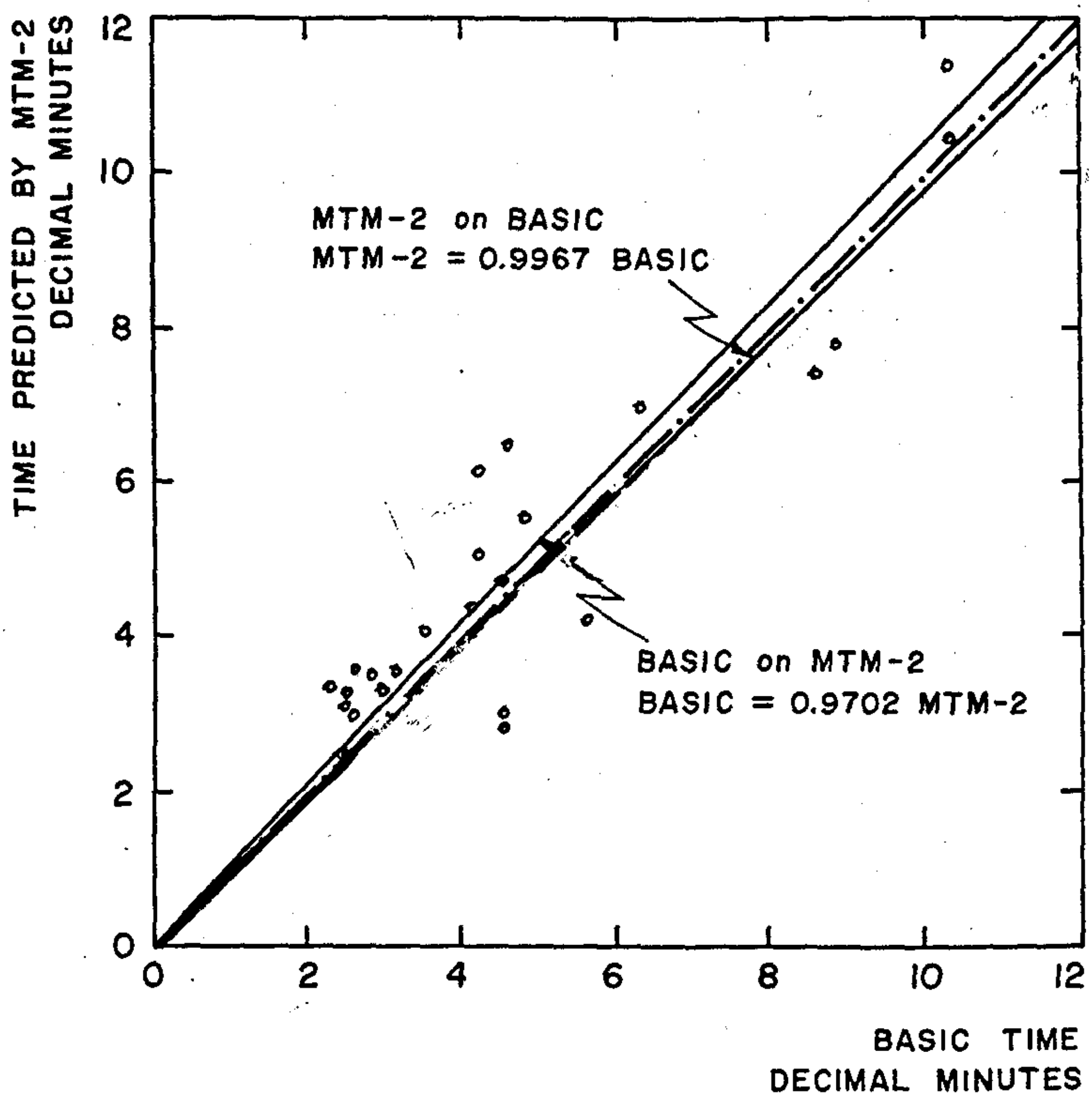


Figure 5-8: Regression of MTM-3 and Basic Time Upon Each Other

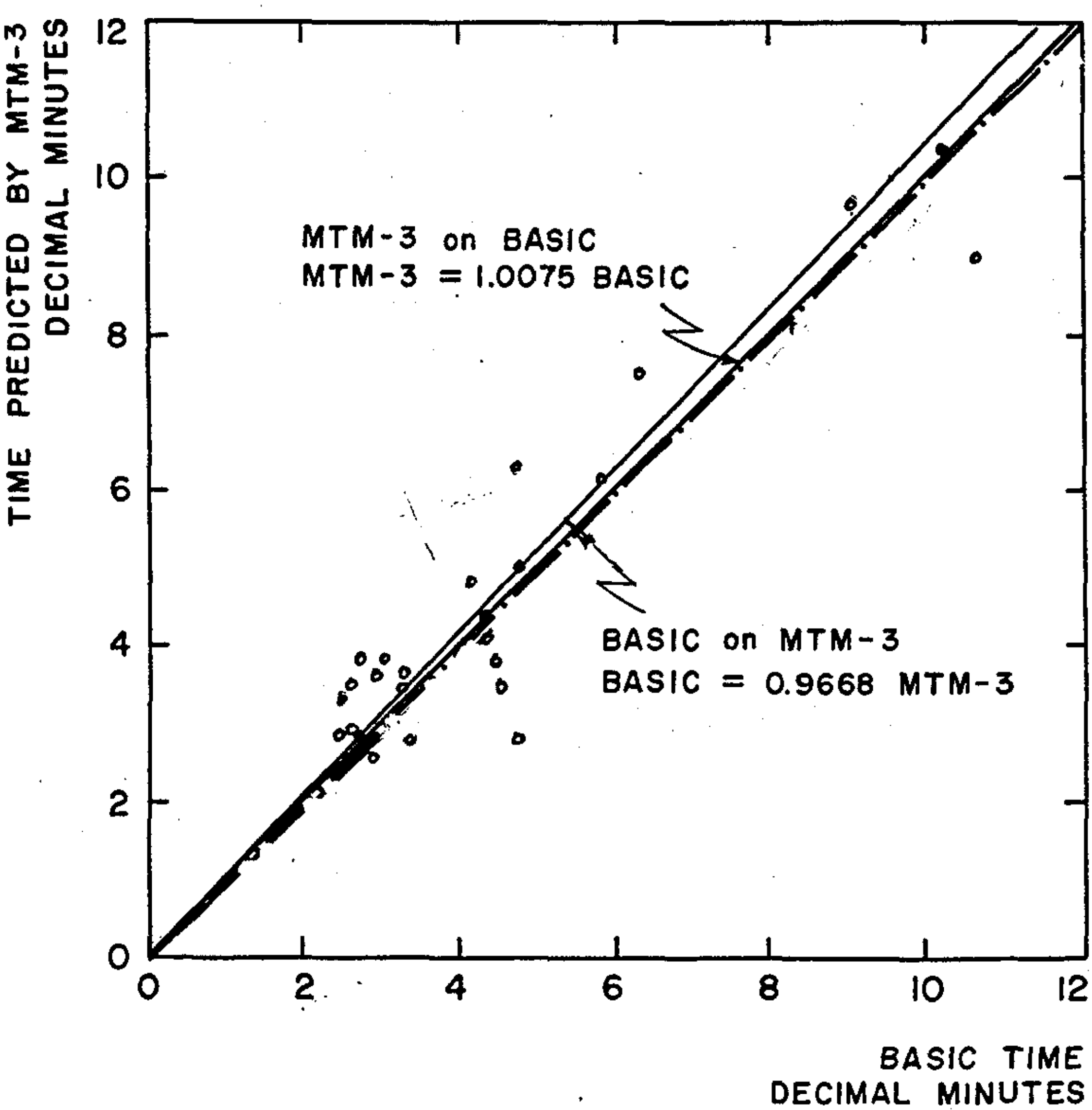


Figure 5-9: Table of Correlation Coefficients for Comparison of Basic Time with General MTM Systems

		DEPENDENT VARIABLE			
		BASIC	MTM-1	MTM-2	MTM-3
INDEPENDENT VARIABLE	BASIC		0.9615	0.9669	0.9740
	MTM-1	0.9615			
	MTM-2	0.9669			
	MTM-3	0.9740			

Figure 5 -10: Table of Regression Coefficients for Comparison of Basic Time with General MTM Systems

		DEPENDENT VARIABLE			
		BASIC	MTM-1	MTM-2	MTM-3
INDEPENDENT VARIABLE	BASIC		0.9721	0.9966	1.0075
	MTM-1	1.0372			
	MTM-2	0.9702			
	MTM-3	0.9668			

The results of these analyses are summarised as Figures 5 -9 and Figure 5-10. From these summaries we can see that, again, all of the correlation coefficients have a value greater than 96%, confirming the linearity of the relationship between these three general MTM data levels and the Basic Time.

The regression coefficients for these analyses are again all very close to 1.000 as can be seen in Figure 5-10 and any deviations from this value could be considered to be due to experimental error.

From an examination of the distribution of the data points on Figures 5-6 to 5-8 it is not possible for one system to predict times better than another system for different cycle times.

5.1.3 Comparison of the Average Observed Time with MTM-1, MTM-2 and MTM-3

The ease with which an estimate of a performance qualified actual time can be obtained in practice requires a consideration of the relationship of the Average Observed Time and the general MTM Systems. A series of linear regression analysis, similar to those described above, were carried out on the Average Observed Time, MTM-1, MTM-2 and MTM-3. The lines for these analyses are shown in Figure 5-11 through Figure 5-13 and linearity is supported by statistical analysis. The interpretation of these lines is the same as described above. The Statistical Analysis Data for these regression curves is given in Appendix L, Figures L-13 to L-18, inclusive. The correlation and regression coefficients for these analyses are summarized in Figure 5-14 and Figure 5-15, respectively.

As would be expected, the correlation coefficients relating actual times with MTM-1, MTM-2 and MTM-3 times do not indicate a fit so good as for the Basic Times. Nevertheless, these correlation coefficients are high.

The regression coefficients shown in Figure 5-15 also show some difference from those obtained from the Basic Times in Figure 5-10. While this result is not unexpected, it is interesting to note that the differences between the values in the two tables is greatest for the MTM-1 values and least for the MTM-3 values suggesting that perhaps the MTM-3 level is not as sensitive to changes in performance levels as MTM-1.

Figure 5-11: Regression of Average Observed Time and MTM-1 Time on Each Other

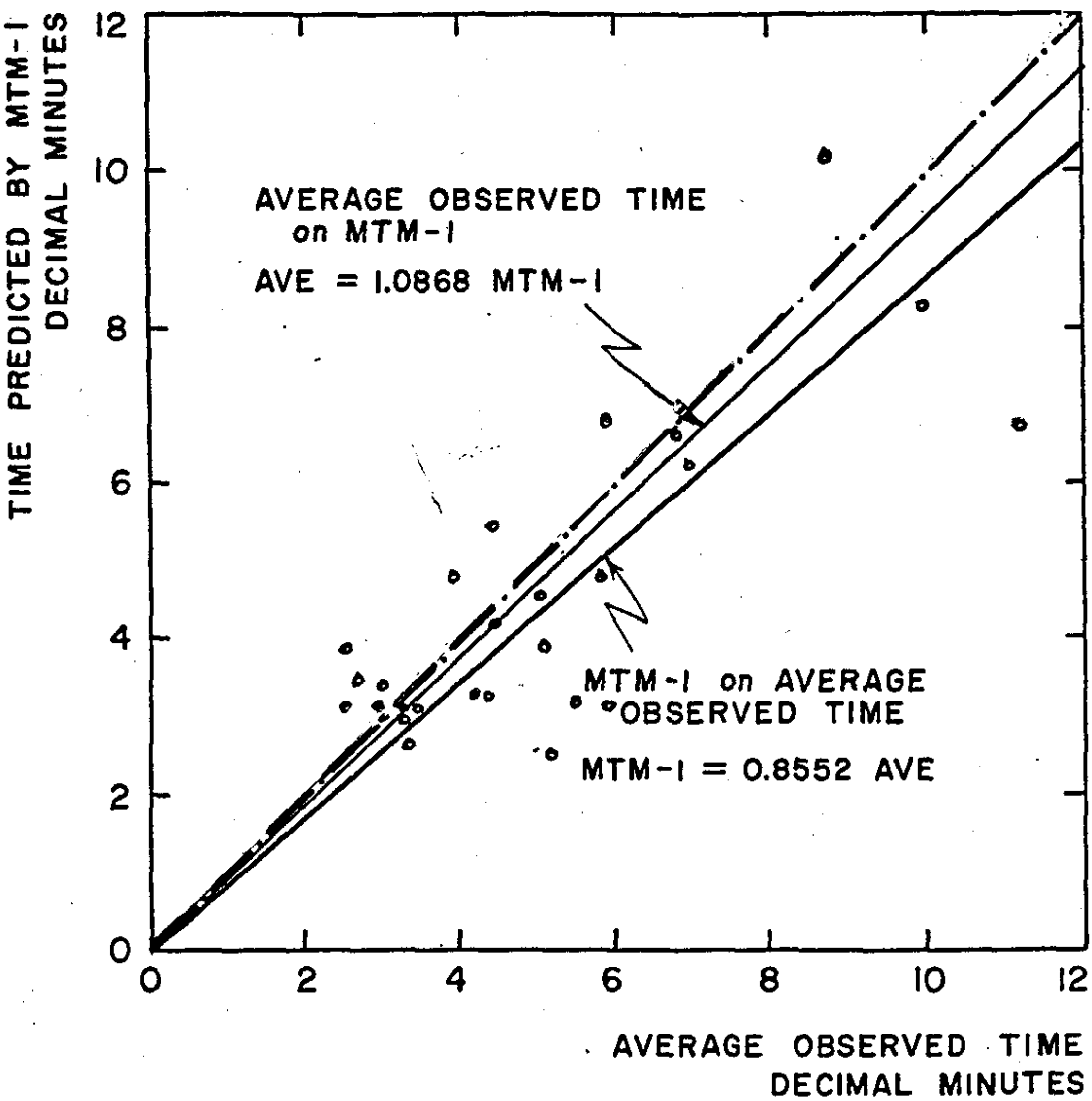


Figure 5-12: Regression of Average Observed Time and MTM-2 Time on Each Other

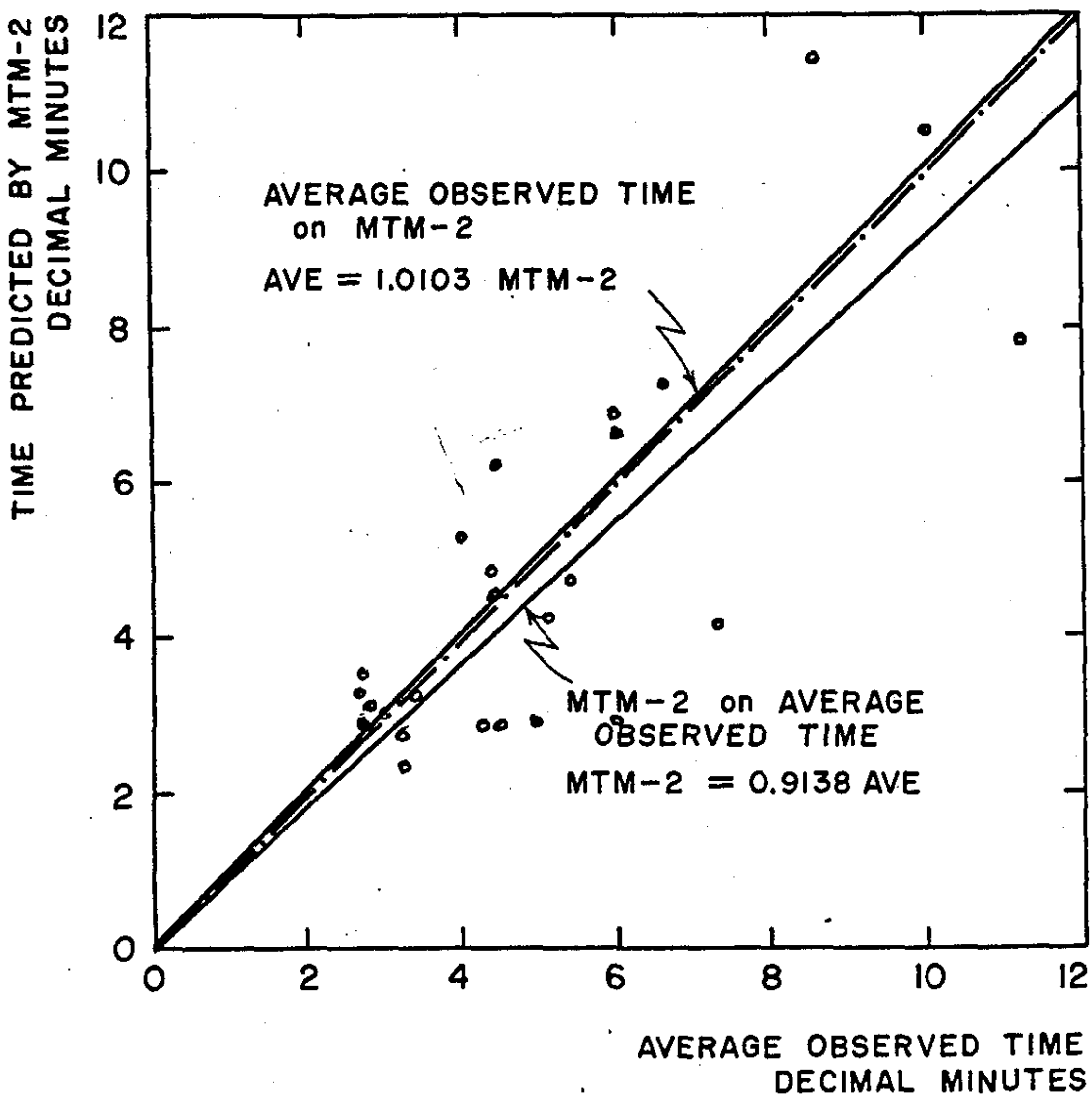


Figure 5-13: Regression of Average Observed Time and MTM-3 Time on Each Other

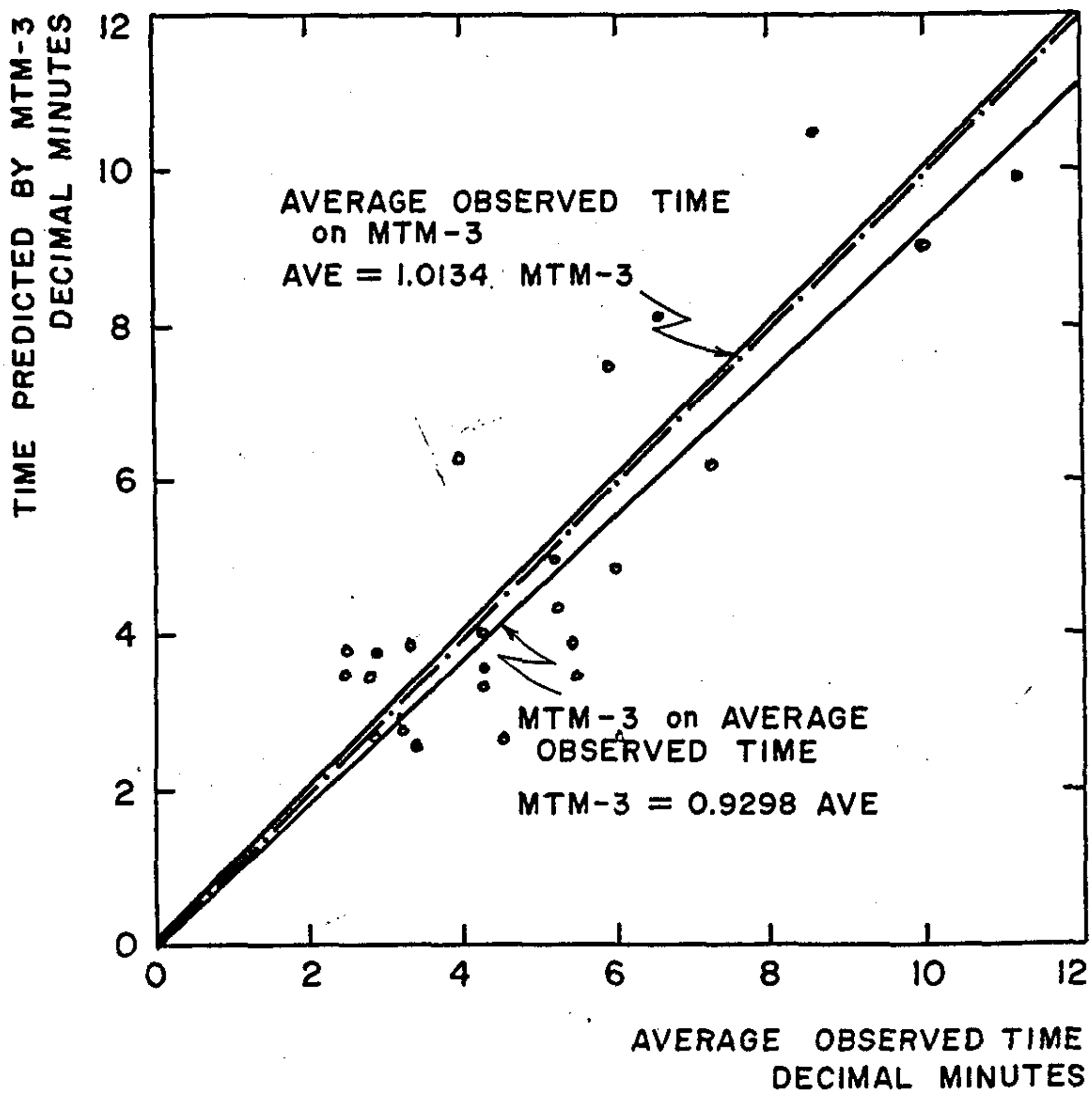


Figure 5-14: Table of Correlation Coefficients for Comparison of Average Observed Time With MTM-1, MTM-2 and MTM-3

		DEPENDENT VARIABLE			
		AVERAGE	MTM-1	MTM-2	MTM-3
INDEPENDENT VARIABLE	AVERAGE		0.9294	0.9231	0.9243
	MTM-1	0.9294			
	MTM-2	0.9231			
	MTM-3	0.9243			

Figure 5-15: Table of Regression Coefficients for Comparison of Average Observed Time With MTM-1, MTM-2 and MTM-3

		DEPENDENT VARIABLE			
		AVERAGE	MTM-1	MTM-2	MTM-3
INDEPENDENT VARIABLE	AVERAGE		0.8552	0.9138	0.9298
	MTM-1	1.0868			
	MTM-2	1.0103			
	MTM-3	1.0134			

5.1.4 Variance About the Regression Line

The high correlation coefficients indicate the high probability of a direct linear relationship between the Basic Time and the time predicted by any one of the three levels of MTM data, MTM-1, MTM-2 and MTM-3. It can be equally claimed, therefore, that the additivity of these systems is also supported.

The consistent claim of the MTM-IMD that MTM-1 is the standard with which the other data levels are to be compared, since it has a higher level of precision, is challenged when the variance about the regression lines of the MTM data systems on Basic Time is examined. The variances about the regression lines are summarized in Figure 5-16, where it will be seen that whether the MTM systems are considered as the dependent or independent variables, the MTM-3 system has in the order half of the variance of the MTM-1 system.

The times for the tasks used in the field data sample are very much lower than the lowest values for application of MTM-1 and MTM-2 recommended by the MTM-IMD. In view of this, the unexpected inversion of values of variances must cast considerable doubt on the lowest time restrictions set down by the MTM-IMD and the claim of greater precision of MTM-1 over the other MTM general data levels.

Figure 5-16: Variances About the Regression Lines of Basic Time Versus MTM-1, MTM-2 and MTM-3

		DEPENDENT VARIABLE			
		BASIC	MTM-1	MTM-2	MTM-3
INDEPENDENT VARIABLE	BASIC		0.9162	0.8945	0.6588
	MTM-1	1.1466			
	MTM-2	0.8477			
	MTM-3	0.5237			

5.2.0 EVALUATING THE GENERAL LEVELS OF MTM DATA

5.2.1 Analysis of Variance Using Basic Time

The power of the regression analyses performed so far is limited as the basis of any evaluation. It is proposed to use Analysis of Variance, with the three evaluation criteria described earlier, to compare MTM-1, MTM-2 and MTM-3 with the Basic Time.

5.2.2 Analysis of Field Data

The results of the Basic Times, MTM-1, MTM-2 and MTM-3 time values for field data tasks are reproduced in Figure 5-17. In this figure, the means and standard deviations for each method of time determination have been calculated. This allows the mean value of time prediction by each system to be used as the basis of comparing them.

The value of the mean time predicted by the MTM-1 system is slightly lower than that predicted by the Basic Time. On the other hand, the times predicted by both MTM-2 and MTM-3 are higher than the Basic Time. These differences are almost certainly due to experi-experimental errors.

A single factor analysis of variance carried out on the data given in Figure 5-18 showed that no statistically significant difference exists between the four sets of results obtained from the field data, when the predicted time value is used as the basis of comparison.

Figure 5-18: ANOVA Tableau: Comparison of the Three General Level Data Systems of MTM With the Basic Time

Source	d.f	Sum of Squares	Mean Square	F_{exp}
Between Systems	3	1.171	0.390	0.076
Error	100	511.218	5.112	
Total	103	512.389		

No significant difference.

Figure 5-17: Comparison of Basic Times Based upon Direct Time Study, MTM-1, MTM-2 and MTM-3.

Job	Study	Basic	MTM-1	MTM-2	MTM-3
1	P01/1	8.911	6.980	7.800	9.800
2	P01/3	4.483	2.520	2.850	3.450
3	P06/1	2.540	3.215	3.050	3.500
4	P06/2	4.224	5.890	6.100	4.000
5	P07/1	10.455	8.275	10.500	8.900
6	P07/2	3.057	3.245	3.500	3.850
7	P07/3	2.705	3.915	3.500	3.850
8	P07/4	6.230	6.755	6.850	7.450
9	P09/1	3.574	4.095	4.400	3.450
10	P09/2	2.375	2.950	2.900	2.750
11	P09/3	2.827	3.125	3.100	2.600
12	P09/4	3.572	3.095	2.900	2.800
13	P09/5	4.722	3.095	2.900	2.800
14	P09/6	2.644	3.230	2.900	2.800
15	P09/7	2.568	3.065	2.500	2.950
16	P09/8	4.782	4.945	6.300	4.900
17	P09/9	3.301	3.135	2.950	3.400
18	P09/10	5.816	6.145	4.100	6.150
19	P09/11	2.216	3.550	3.250	3.450
20	P10/1	8.341	6.645	7.300	8.100
21	P10/2	10.236	10.165	11.450	10.300
22	P11/1	4.715	4.710	5.025	6.250
23	P12/1	4.198	4.470	4.900	4.200
24	P12/2	4.095	3.925	4.150	4.800
25	P13/1	4.362	3.270	4.400	3.800
26	P13/3	2.922	2.615	3.400	3.800
	MEAN	4.613	4.501	4.730	4.773
	STD. DEV.	2.385	1.947	2.383	2.300
	$\sum X$	119.931	117.025	122.975	124.100
	$\sum (X^2)$	695.415	621.541	723.568	724.615

5.2.3 Percentage Error of Predicted Time as an Evaluation Criterion

The Percentage Error of the Basic Time of the times predicted by MTM-1, MTM-2 and MTM-3 have been calculated and are shown in Figure 5-19 and the associated ANOVA Tableau is shown in Figure 5-20.

The analysis of variance shows no significant difference in the percentage difference between the Basic Time and the times predicted by either MTM-1, MTM-2 and MTM-3.

Figure 5-20: ANOVA Tableau Comparing the Percentage Error of the Predicted Times by the Three General Level Data Systems of MTM with the Basic Times

Source	d.f.	Sum of Squares	Mean Square	F_{exp}	
Between Systems	2	175.681	87.841	0.1678	NS
Error	75	39248.587	523.314		
Total	77	39424.268			

Figure 5-19: Percentage Error of Basic Times of General MTM Systems

Job	Study	Basic	MTM-1	MTM-2	MTM-3
1	P01/1	8.911	21.672	12.470	-9.974
2	P01/3	4.483	43.790	36.429	23.046
3	P06/1	2.540	-26.575	-20.079	-37.795
4	P06/2	4.224	-39.276	-44.242	5.415
5	P07/1	10.455	20.850	3.812	14.872
6	P07/2	3.057	-6.093	-14.430	-25.873
7	P07/3	2.705	-44.743	-29.400	-42.340
8	P07/4	6.230	-7.401	-8.912	-18.451
9	P09/1	3.574	-14.590	-23.125	3.459
10	P09/2	2.375	-24.200	-22.095	-15.780
11	P09/3	2.827	-10.596	-9.711	7.984
12	P09/4	3.572	13.354	18.813	21.613
13	P09/5	4.722	34.461	38.591	40.108
14	P09/6	2.644	-22.163	-9.682	-5.900
15	P09/7	2.568	-19.354	2.648	-14.875
16	P09/8	4.782	-3.296	-31.601	-2.356
17	P09/9	3.301	5.023	10.628	-3.005
18	P09/10	5.816	-5.657	29.505	-5.743
19	P09/11	2.216	-60.199	-46.661	-55.686
20	P10/1	8.341	20.336	12.483	2.892
21	P10/2	10.236	0.694	-11.860	-0.625
22	P11/1	4.715	0.076	-6.606	-32.595
23	P12/1	4.198	-6.489	-16.733	-0.057
24	P12/2	4.095	3.686	-1.835	-17.786
25	P13/1	4.362	25.028	-0.880	12.876
26	P13/3	2.922	10.519	-16.343	-30.030
		Mean	-3.509	-5.721	-7.157
		Std. Dev.	24.401	22.155	21.993
		$\sum X$	-91.230	-148.756	-186.096
		$\sum (X^2)$	15205.784	13122.024	13423.971

5.2.4 Absolute Percentage Error of the Predicted Time as an Evaluation Criterion

The values of the absolute percentage errors of the time predicted by MTM-1, MTM-2 and MTM-3 relative to the Basic Time for each task is shown in Figure 5-21 and the associated ANOVA tableau is shown in Figure 5-22.

Figure 5-22: ANOVA Tableau Comparing the Absolute Percentage Error of the Predicted Times by the Three General Level Data Systems of MTM with the Basic Times

Source	d.f.	Sum of Squares	Mean Square	F_{exp}	
Between Systems	2	45.378	22.689	0.1091	NS
Error	75	15598.083	207.974		
Total	77	15643.461			

The analysis of variance, using absolute percentage difference from Basic Time as the evaluation criterion, shows that there is no significant difference in the times predicted by MTM-1, MTM-2 and MTM-3.

Figure 5-21: Absolute Percentage Error of Basic Times of MTM General Systems

Job	Study	Basic	MTM-1	MTM-2	MTM-3
1	P01/1	8.911	21.672	12.470	9.974
2	P01/3	4.483	43.790	36.429	23.046
3	P06/1	2.540	26.575	20.079	37.795
4	P06/2	4.224	39.276	44.242	5.415
5	P07/1	10.455	20.850	3.872	14.872
6	P07/2	3.057	6.093	14.430	25.873
7	P07/3	2.705	44.743	29.400	42.340
8	P07/4	6.290	7.401	8.912	18.451
9	P09/1	3.574	14.590	23.125	3.459
10	P09/2	2.375	24.200	22.095	15.780
11	P09/3	2.827	10.596	9.711	7.984
12	P09/4	3.572	13.354	18.813	21.613
13	P09/5	4.722	34.461	38.591	40.708
14	P09/6	2.644	22.163	9.682	5.900
15	P09/7	2.568	19.354	2.648	14.875
16	P09/8	4.782	3.296	31.601	2.356
17	P09/9	3.301	5.023	10.628	3.005
18	P09/10	5.816	5.657	29.505	5.743
17	P09/11	2.216	60.199	46.661	55.686
20	P10/1	8.341	20.336	12.483	2.892
21	P10/2	10.236	0.694	11.860	0.625
22	P11/1	4.715	0.076	6.606	32.595
23	P12/1	4.198	6.489	16.733	0.057
24	P12/2	4.095	3.686	1.835	17.786
25	P13/1	4.362	25.028	0.880	12.876
26	P13/3	2.922	10.519	16.343	30.030
		MEAN	19.235	18.448	17.374
		STD. DEV.	15.168	13.076	14.929
		$\sum X$	500.121	479.659	451.736
		$\sum (X^2)$	15371.801	13123.181	13420.762

5.3.0 SUMMARY OF THE COMPARISON OF MTM-1, MTM-2, MTM-3 AND THE BASIC TIME

In Chapter 5.0.0, three measures which could be used as the basis of evaluation were discussed in detail. In this chapter, these measures have been used to compare the times predicted by MTM-1, MTM-2 and MTM-3 with the Basic Times for the tasks collected as field data.

The MTM Associations have continually emphasized that the MTM-2 system should not be used on tasks where the cycle time is less than 1600 TMU, or, MTM-3 where the cycle time is less than 7800 TMU. These two values were established based upon calculation of their respective "Balance Times". The MTM Associations have continued to support this official position, even though many practitioners used the systems in place of MTM-1 on extremely short cycles, with excellent results. The results presented in this chapter show that there is no evidence of statistically significant differences between the systems. Therefore, the "coarser" work measurement systems can clearly be used with a greater confidence than was generally believed up to this time.

6.0.0 DEVELOPING AND EVALUATING ALTERNATIVE DATA SYSTEMS

6.1.0 TESTING THE VALUES OF THE EXISTING MTM SYSTEMS

6.1.1 Comparison between frequency of MTM-1 Motions in Developing MTM-2 and the Frequency of the Motions in the Present Study.

The MTM-2 model was based upon the premise that by selecting an industry and determining the distribution of MTM-1 Basic Manual Motions in that industry, high level data systems could be developed. Further, it was argued that these higher level data systems would then be universal in application. Aberg (1963) investigated the distribution of Basic Manual Motions for several industries and the distribution for Medium Heavy Assembling was chosen as the basis for developing MTM-2.

The universality of data based upon this premise was questioned in Chapter 2.0.0. However, this was based upon the equally questionable measure of Balance Time.

The distribution of the Basic Manual Motions in the field data was tested against the data used in developing MTM-2 data card times. The results of this test are given in Figure 6.1, where it can be seen that there is a statistically significant difference between the two distributions. In spite of this, using each of three evaluation criteria discussed earlier, there was no statistically significant difference between the basic time and the times predicted by each of the general levels of MTM. This result opens up many opportunities for the investigation of data development and its evaluation.

The approach used in the work which follows was

1. An attempt to verify the data values for the three general levels of MTM, using Multiple Regression Analysis (MRA) on its field data.
2. Using the frequency of occurrence of motion elements in the MTM-2 and MTM-3 values of the field data, new data systems were developed and tested.

Figure 6-1: Comparison of the Distribution of Motion Times Between the Field Data and That Used in the Development of MTM-2

Basic Manual Motion	% Field Data (0)	% MTM Data (E)	$\frac{(0-E)^2}{E}$
Reach	17.92	12.90	1.9535
Move	35.55	29.80	1.1095
Apply Pressure	5.20	7.50	0.7053
Turn	0.58	0.37	0.1192
Grasp	10.98	19.70	3.8600
Position	8.09	11.50	0.5878
Release	20.23	10.50	9.0165
Eye Action	0	0.30	0.3000
Disengage	1.45	1.80	0.0681
Body Motion	0	5.20	5.2000
		χ^2	22.9199

Degrees of Freedom = 9

p	95	97.5	99	99.9
χ^2	3.33	2.70	2.09	1.73

There is a highly significant difference between the two distributions.

(The frequency of occurence of the Basic Manual Motrons was obtained from Appendix E)

6.1.2. Testing the MTM-1, MTM-2 and MTM-3 Data Card Values

The distribution of the Basic Manual Motions, categories and actions for MTM-1, MTM-2 and MTM-3 are given in Appendices E, F and G, respectively. We therefore set out to derive alternative sets of values to those normally accepted as MTM-1, MTM-2 and MTM-3, using the motion distributions given in the aforementioned appendices. It is a simple matter to construct matrices of the data given in these appendices as follows:

$$\left[a_j \; X_i\right] = \left[Y_j\right] \qquad \text{(Eq. 6-1)}$$

where

X_i = the time value of a particular motion element in a data system

a_j = the frequency with which element a_j occurs in a task j

Y_j = the basic time of the task j

This matrix clearly lends itself to solving for X_i using MRA. The values used in a general MTM data level, such as MTM-1, MTM-2, or MTM-3, can thus be compared to the value of X_i and tested for the work area being studied.

Another way in which this solution may be viewed is as an alternative set of values to those accepted as the MTM data level being reviewed.

In several tasks, even though the motion patterns were the same, it has been pointed out that there exists considerable difference in the basic times. The differences in these cases were obviously too great to be explained by differences in performance level.

An MRA was carried out on each of the three general levels of data, and since, logically, negative values were not possible, the analysis was performed so that there would be zero intercept. Due to the high variation in the task times, it was found to be impossible to carry out a satisfactory analyses for either MTM-1 or MTM-2 from the field data. On the other hand, useful and interesting results were obtained for the MTM-3 system.

The results of the statistical analysis relative to MTM-3 are given in Figure 6-2. For the purpose of identification, the values obtained in this analysis will be referred to as System 1. Any PMTS consists of a series of time values which are applied according to a specific set of rules. System 1 uses the same application rules as MTM-3. The high statistical significance of these results, in Figure 6-2, will be noted, giving a good confidence to any potential user of the system.

Figure 6-2: Estimated Values for a System Using Eight Values, Based on the MTM-3 Model and Basic Times: Identified as System 1.

DATA ELEMENT	ESTIMATED DEC. MIN.	T FOR HO: PARAMETER=0	PR > |T|	STD. ERROR OF ESTIMATE
TB80	0.9620	2.72	0.0140	0.3536
TA80	1.4027	3.09	0.0075	0.4656
HB80	2.7138	11.18	0.0001	0.2428
HA80	1.7505	2.88	0.0100	0.6084
TB15	1.0917	5.51	0.0001	0.1981
TA15	0.3542	2.93	0.0090	0.1211
HB15	1.6309	5.90	0.0001	0.2762
HA15	0.5403	2.91	0.0094	0.1860

One immediate and reasonable criticism of the results given in Figure 6-2 which may be expressed by anyone with knowledge of PMTS would be relative to the values of TB80 and TA80. Since the Case B motion requires a higher level of control than a Case A motion, the TB80, conventionally, should have a greater value than the TA80. In spite of the high statistical significance of the results, this inconsistency could easily cause System I to prove to be unacceptable in the industrial environment.

6.1.3 Testing the Values Determined as System I

In Figure 6-3, the data card values for MTM-3, converted to decimal minutes at 100 BSI, and the System I values are compared.

To provide some other basis than actual values for comparison, the difference between the two values has been expressed as a % of the MTM-3 values. The extremes of these values range from -41.682% to +43.967%. Superficially, such a variation must give some concern about the validity of the new system.

Figure 6·3: Comparison of MTM-3 Data Card Values and the Values Determined for System I (Data Values in Decimal Minutes at 100 BSI)

CODE	MTM-3 (DEC. MIN)	SYSTEM I (DEC. MIN.)	ACTUAL ERROR (DEC. MIN.)	% ERROR
TB80	1.4500	0.9620	0.4880	33.655
TA80	0.8000	1.4027	-0.6027	-41.682
HB80	2.4000	2.7138	-0.3138	-13.075
HA80	1.7000	1.7505	-0.0505	-2.971
TB15	1.0500	1.0917	-0.0417	-3.971
TA15	0.3500	0.3542	-0.0042	-1.200
HB15	1.7000	1.6309	0.0691	4.065
HA15	0.9000	0.5403	0.3957	43.967

The first analysis made to test for any similarity of results arising from these two sets of data was a X^2 test, the results of which are given in Figure 6-4. From this analysis there is no evidence of a satistically significant difference between the two sets of results. Any differences which may occur could be due to statistical errors in each data set.

The acid test of comparison of MTM-3 against System 1 can be made by an analysis of variance of the field data. In fact, three analyses of variance were made, the evaluation criteria in each case being the three criteria discussed earlier.

The basic time for each task, together with the predicted time for that task using MTM-3 and System 1 are given in Figure 6-5. Some consistency, not necessarily agreement, between times with the same motion pattern predicted by MTM-3 and System 1 can be seen in jobs number 12 through 14, for example. The Basic Time for these jobs shows considerable variation, however; a variation which cannot be explained. The Analysis of Variance Tableau relative to this data is given as Figure 6-6. The results of this Analysis of Variance indicate clearly that no statistically significant difference exists between the Basic Time and times predicted by MTM-3 and System I.

Figure 6-4: χ^2 Test on the Data Values of MTM-3 and System I

SYSTEM I (O)	MTM-3 (E)	$\frac{(O-E)^2}{E}$
0.9620	1.4500	0.1642
1.4027	0.8000	0.4541
2.7138	2.4000	0.0410
1.7505	1.7000	0.0015
1.0917	1.0500	0.0017
0.3542	0.3500	0.0000
1.6309	1.7000	0.0028
0.5403	0.9000	0.1416
	χ^2	0.8069

Degrees of Freedom = 7

P	.95	.975	.99	.999
χ^2	2.167			1.239

There is no statistically significant difference between the two sets of values.

Figure 6-5: Basic Times and Predicted Times by MTM-3 and System I for Field Data Tasks (Decimal Minutes)

Job	Study	Basic	MTM-3	System I
1	P01/1	8.911	9.8000	9.487
2	P01/3	4.483	3.450	3.743
3	P06/1	2.540	3.500	3.024
4	P06/2	4.224	4.000	3.963
5	P07/1	10.455	8.900	9.892
6	P07/2	3.057	3.850	3.066
7	P07/3	2.705	3.850	3.066
8	P07/4	6.230	7.450	7.168
9	P09/1	3.574	3.450	3.806
10	P09/2	2.375	2.750	2.694
11	P09/3	2.827	2.600	2.171
12	P09/4	3.572	2.800	2.892
13	P09/5	4.722	2.800	2.892
14	P09/6	2.644	2.800	2.892
15	P09/8	2.568	2.950	2.525
16	P09/8	4.782	4.900	4.157
17	P09/9	3.301	3.400	3.262
18	P09/10	5.816	6.150	5.397
17	P09/11	2.216	3.450	3.806
20	P10/1	8.341	8.100	8.182
21	P10/2	10.236	10.300	9.921
22	P11/1	4.715	6.250	4.973
23	P12/1	4.198	4.200	4.030
24	P12/2	4.095	4.800	4.040
25	P13/1	4.312	3.800	4.160
26	P13/3	2.922	3.800	4.160
Mean		4.613	4.773	4.591
Std. Dev.		2.385	2.300	2.329
$\sum X$		119.931	124.100	119.369
$\sum (X^2)$		695.415	724.615	683.629

Figure 6-6: ANOVA on Basic, MTM-3 and System I Times

Source	d.f	Sum of Square	Mean Square	F_{esp}
Between Systems	2	0.515	0.2575	0.0144
Error	23	409.485	17.084	
Total	25			

The percentage error of the predicted time relative to the basic time was also tested on the same basis. The table of these values is shown in Figure 6-7 and the Analysis of Variance Tableau is shown in Figure 6-8. The final test was based on the absolute percentage error of these two predicted times relative to the Basic Time. The raw data and Analysis of Variance Tableau for this criterion is shown in Figure 6-9 and Figure 6-10, respectively. For each of these comparisons, there is again no evidence of a significant difference between the two data systems.

Figure 6-8: ANOVA on Percentage Difference Between Basic Time and Times Predicted by MTM-3 and System I

Source	d.f	Sum of Square	Mean Square	F_{exp}
Between Systems	1	326.726	326.726	0.340
Error	24	23032.017	959.667	
Total	25	23358.743		

Figure 6-7: Percentage Error Between Basic Time and Times Predicted by MTM-3 and System I

Identification		Dec.Min.	% Error	
Job	Study	Basic	MTM-3	System I
1	P01/1	8.911	-9.974	-6.456
2	P01/3	4.483	23.046	16.058
3	P06/1	2.540	-37.795	-19.039
4	P06/2	4.224	5.415	6.032
5	P07/1	10.455	14.872	5.385
6	P07/2	3.057	-25.873	-0.230
7	P07/3	2.705	-42.340	-13.343
8	P07/4	6.230	-18.451	-13.963
9	P09/1	3.574	3.459	-6.489
10	P09/2	2.375	-15.780	-13.401
11	P09/3	2.827	7.984	23.160
12	P09/4	3.572	21.613	19.043
13	P09/5	4.722	40.708	38.764
14	P09/6	2.644	-5.900	-9.372
15	P09/7	2.568	-14.875	1.659
16	P09/8	4.782	-2.356	13.156
17	P09/9	3.301	-3.005	1.182
18	P09/10	5.816	-5.743	7.199
19	P09/11	2.216	-55.686	-71.728
20	P10.1	8.341	2.892	1.904
21	P10/2	10.236	-0.625	3.077
22	P11/1	4.715	-32.595	-5.499
23	P12/1	4.198	-0.057	3.993
24	P12/2	4.095	-17.786	0.866
25	P13/1	4.312	12.876	4.629
26	P13/3	2.922	-30.030	-42.338
		Mean	-7.157	-2.144
		Std. Dev.	21.993	20.919
		$\sum X$	-186.096	-55.751
		$\sum (X^2)$	13423.971	11059.579

Figure 6-9: Absolute Percentage Error Between Basic Time and Times Predicted by MTM-3 and System I

Identification		Dec.Min.	Absolute % Error	
Job	Study	Basic	MTM-3	System I
1	P01/1	8.911	9.974	6.456
2	P01/3	4.483	23.046	16.058
3	P06/1	2.540	37.795	19.039
4	P06/2	4.224	5.415	6.032
5	P07/1	10.455	14.872	5.385
6	P07/2	3.057	25.873	0.230
7	P07/3	2.705	42.340	13.343
8	P07/4	6.230	18.451	13.963
9	P09/1	3.574	3.459	6.489
10	P09.2	2.375	15.780	13.401
11	P09/3	2.827	7.984	23.160
12	P09/4	3.572	21.613	19.043
13	P09/5	4.722	40.708	38.764
14	P09/6	2.644	5.900	9.372
15	P09/7	2.568	14.875	1.659
16	P09/8	4.782	2.356	13.156
17	P09/9	3.301	3.005	1.182
18	P09/10	5.816	5.743	7.199
19	P09/11	2.216	55.686	71.728
20	P10/1	8.341	2.892	1.904
21	P10/2	10.236	0.625	3.077
22	P11/1	4.715	32.595	5.499
23	P12/1	4.198	0.057	3.993
24	P12/2	4.095	17.726	0.866
25	P13/1	4.362	12.876	4.629
26	P13/3	2.922	30.030	42.338
		Mean	17.374	13.383
		Std. Dev.	14.929	16.003
		$\sum X$	451.736	347.965
		$\sum (X^2)$	13420.762	11059.579

Figure 6-10: ANOVA on Absolute Percentage Difference Between Basic Time and Times Predicted by MTM-3 and System I

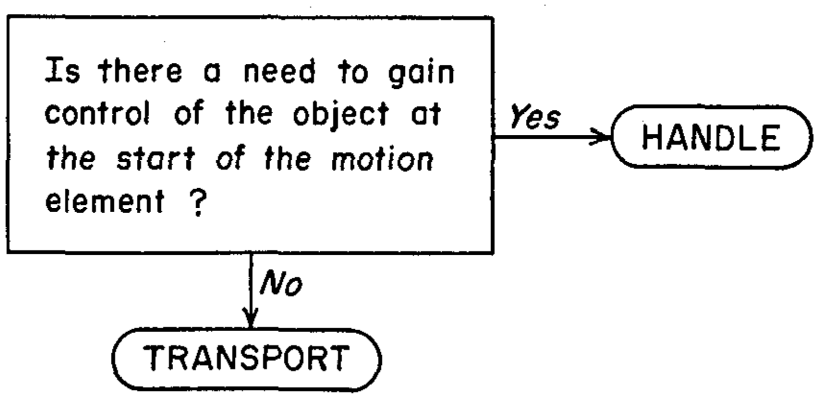
Source	d.f	Sum of Squares	Mean Square	F_{esp}
Between Samples	1	207.085	207.085	0.415
Error	24	11974.762	498.948	
Total	25	12181.847		

6.2.0 VARIATIONS ON THE MTM-3 CONCEPT

The wide variations between the MTM-3 data card values and the System I values seen in Figure 6-3 raise the question as to how far a particular system can be extended and still produce final results which are acceptable. To investigate this, the MTM-3 data was chosen as a starting point.

The MTM-3 system recognizes two motion elements, namely, Transport and Handle. The way in which these elements are recognized is described in detail by Knott and Goodall (1970), however the algorithm in Figure 6-11 summarizes these requirements.

Figure 6-11: Algorithm for Recognizing the MTM-3 Motion Elements



These two motion elements are each affected by only two variables, as follows.

1. Distance
2. Case

The algorithms which are used to establish the values of these variables are shown in Figure 6-12 and Figure 6-13, respectively.

Figure 6-12: Algorithm for Determining the Distance Variable for the MTM-3 Motion Elements

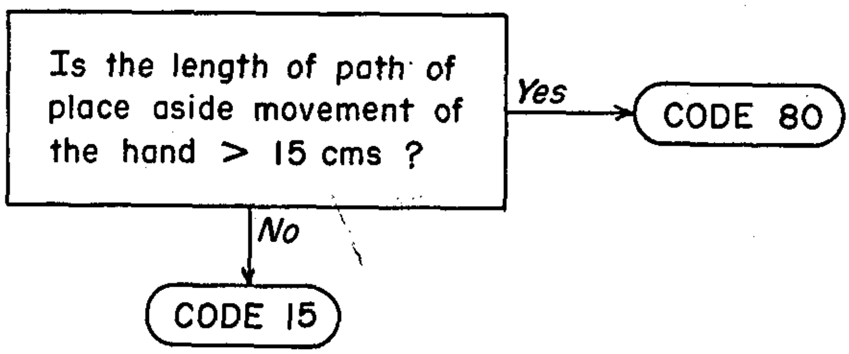
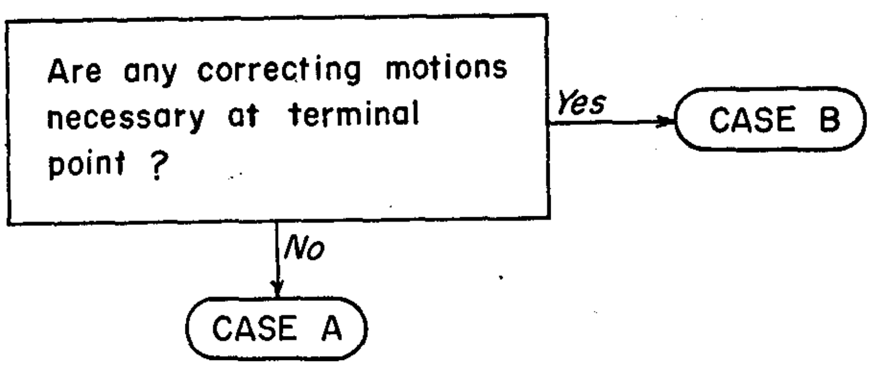


Figure 6-13: Algorithm for Determining the Case of the MTM-3 Motion Elements



The obvious simplification using the MTM-3 concept and Basic task times is to have a system in which the motion elements have only one variable. Two systems were used to meet this and are described below.

6.2.1 Description of System II

The first of the two systems based upon the MTM-3 concepts and Basic task times will be referred to as System II. It is characterized by having only two motion elements, which, in order to distinguish them from the MTM-3 motion elements, will be called

1. Carry (C)
2. Deposit (D)

The algorithm for recognising the System II motion elements is given in Figure 6-14. Comparison will show that, apart from the names of the elements, it is the same as Figure 6-11.

The case of the motion element in System II uses exactly the same algorithm as MTM-3. The symbols used to identify a motion element in System II will be as illustrated in Figure 6-15 and Figure 6-16.

Figure 6-14: Algorithm for Recognizing System II Motion Elements

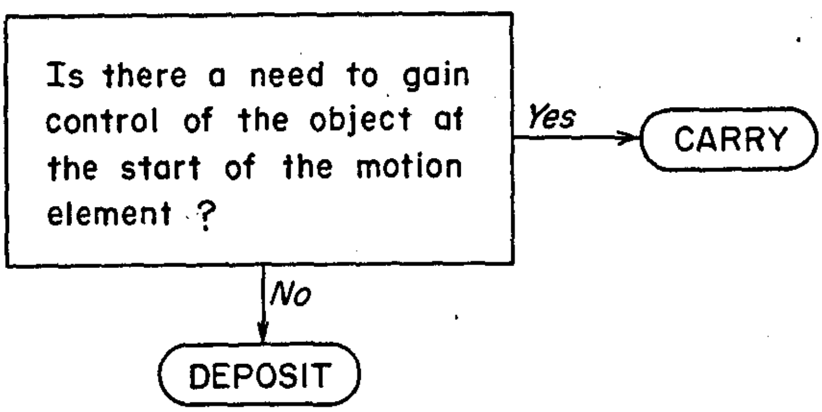
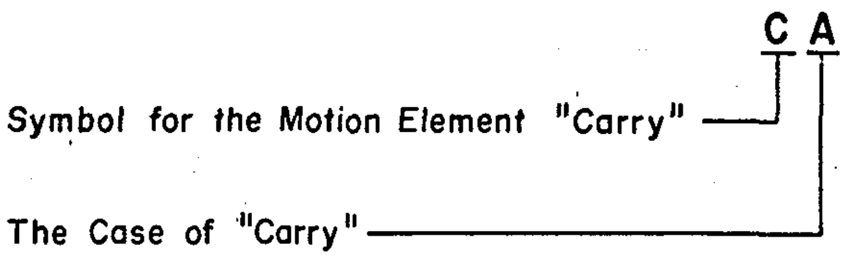
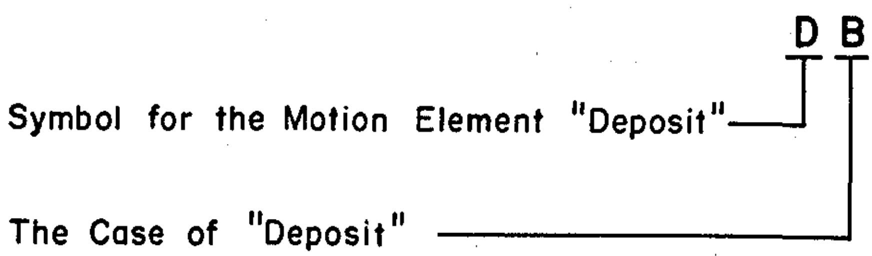


Figure 6-15: Symbol for the System II Motion Element Carry



Description: Operator has to gain control of object at beginning of motion and places aside without correction motions at terminal point of the action.

Figure 6-16: Symbol for the System II Motion Element Deposit



Description: Operator has control of the object at beginning of motion and places aside with correcting motions at terminal point of the action.

The frequency of each System II motion element in each job in the field data is given in Figure 6-17. These frequencies were obtained in the following way, where f indicates the frequency of a particular motion element.

$$f_{DA} = f_{TA15} + f_{TA80} \quad \text{(Eq. 6-2)}$$

$$f_{DB} = f_{TB15} + f_{TB80} \quad \text{(Eq. 6-3)}$$

$$f_{CA} = f_{HA15} + f_{HA80} \quad \text{(Eq. 6-4)}$$

$$f_{CB} = f_{HB15} + f_{HB80} \quad \text{(Eq. 6-5)}$$

Figure 6-17: Frequency of System II Motion Elements in Field Data Jobs

JOB	STUDY	DA	DB	CA	CE	BASIC
1	P01/1	10	3	3	0	8.9112
2	P01/3	3	1	1	0	4.4832
3	P06/1	1	0	3	0	2.5400
4	P06/2	2	0	1	1	4.2290
5	P07/1	0	0	1	3	10.4548
6	P07/2	1	0	2	1	3.0586
7	P07/3	1	0	2	1	2.7048
8	P07/4	3	2	2	1	6.2895
9	P09/1	0	1	0	1	3.5736
10	P09/2	3	0	0	1	2.3752
11	P09/3	0	0	1	1	2.8256
12	P09/4	2	2	0	0	3.5720
13	P09/5	2	2	0	0	4.7224
14	P09/6	2	2	0	0	2.6440
15	P09/7	1	0	1	1	2.5680
16	P09/8	1	1	2	1	4.7872
17	P09/9	0	0	0	2	3.3008
18	P09/10	3	0	3	1	5.8160
19	P09/11	0	1	0	1	2.2160
20	P10/1	8	0	3	1	8.3412
21	P10/2	5	3	2	1	10.2360
22	P11/1	4	3	1	0	4.7136
23	P12/1	1	1	0	1	4.1976
24	P12/2	1	3	1	0	4.0752
25	P13/1	1	1	0	1	4.3616
26	P13/3	1	1	0	1	2.9224

An MRA carried out on this data produces values for a new data system, the values for which are given in Figure 6-18. Again, the restriction that there should be zero intercept was applied. The estimated times for the motion elements of this system meet with the expected logic that the higher the case of the motion, then the higher its time value. In each case, PR > |T| is less than 3%, giving the potential user a relatively high confidence in the motion element values.

It is proposed to carry out further evaluation of this system at a later stage.

Figure 6-18: Estimated Values for a System Using Four Motion Elements with No Distance Variable; Based on the MTM-3 Model and Basic Times: Identified as System II

Data Element	Estimated	\T for Ho: Parameter=H	PR > |T|	Std. Error of Estimate
DA	0.4587	3.55	0.0018	0.1297
DB	1.0743	5.41	0.0001	0.1986
CA	0.5678	2.37	0.0269	0.2395
CB	2.4116	9.99	0.0001	0.2414

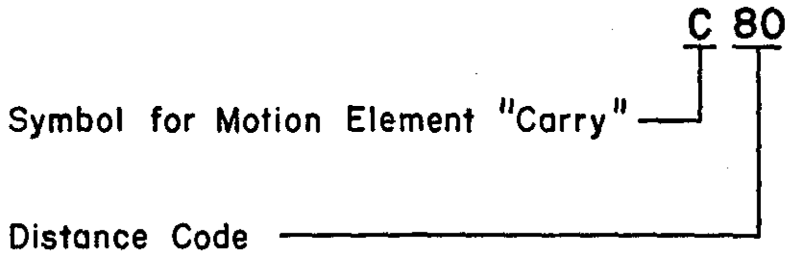
6.2.2 Description of System III

The second of the systems developed on the MTM-3 concept and the Basic Times will be identified as System III. As in the case of System II, there will only be two motion elements, Carry and Deposit. These two elements will be recognized in exactly the same way as in System II ard the same algorithm, Figure -14, will apply.

The variable affecting the motion elements in System III is the Distance, which is established in accordance with the algorithm given in Figure 6-12.

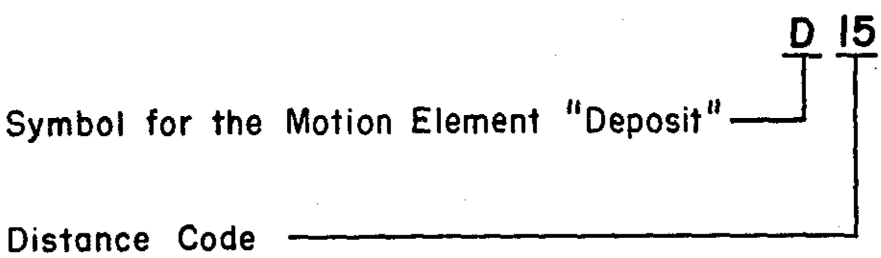
The symbols used in System III are summarized in Figure 6-19 and Figure 6-20.

Figure 6-19: Symbol for the System III Motion Element Carry



Description: Operator has to gain control of object at beginning of motion. Place aside movement > 15 centimetres.

Figure 6-20: Symbol for the System III Motion Element Deposit



Description: Operator has control of object at beginning of motion. Place aside movement $\leq$ 15 centimetres.

The frequency of each System III motion element in each job in the field data is given in Figure 6-21. These frequencies were obtained in the following way, where f indicates the frequency of a particular motion element.

$$f_{D15} = f_{TA15} + f_{TB15} \qquad \text{(Eq. 6-6)}$$

$$f_{D80} = f_{TA80} + f_{TB80} \qquad \text{(Eq. 6-7)}$$

$$f_{C15} = f_{HA15} + f_{HB15} \qquad \text{(Eq. 6-8)}$$

$$f_{C80} = f_{HA80} + f_{HB80} \qquad \text{(Eq. 6-9)}$$

Figure 6-21: Frequency of Distribution of System III Motion Elements in Field Data Jobs

JOB	STUDY	D15	D15	C80	C80	BASIC
1	P01/1	12	3	1	0	8.9112
2	P01/3	3	1	1	0	4.4832
3	P06/1	0	3	1	0	2.5400
4	P06/2	2	1	0	1	4.2290
5	P07/1	0	0	0	4	10.4548
6	P07/2	1	3	0	0	3.0586
7	P07/3	1	3	0	0	2.7048
8	P07/4	5	2	0	1	6.2895
9	P09/1	1	0	0	1	3.5736
10	P09/2	3	1	0	0	2.3752
11	P09/3	0	2	0	0	2.8256
12	P09/4	4	0	0	0	3.5720
13	P09/5	4	0	0	0	4.7224
14	P09/6	4	0	0	0	2.6440
15	P09/7	1	2	0	0	2.5680
16	P09/8	2	3	0	0	4.7872
17	P09/9	0	2	0	0	3.3008
18	P09/10	3	3	0	1	5.8160
19	P09/11	1	0	0	1	2.2160
20	P10/1	6	4	2	0	8.3412
21	P10/2	7	1	1	2	10.2360
22	P11/1	5	1	2	0	4.7136
23	P12/1	1	0	1	1	4.1976
24	P12/2	3	1	1	0	4.0752
25	P13/1	2	0	0	1	4.3616
26	P13/3	2	0	0	1	2.9224

An MRA carried out on this data produces values for a new data system, which are given in Figure 6-22. The restriction of zero intercept was applied to the analysis of the data. As one would expect, the time values of the motion element increase as the distance variable increases. Further, in each case, the value of PR > $|T|$ is low, although as distinct from System II, for one motion element the value is almost 7%. In spite of this, a potential user should have a relatively high confidence in these estimated values.

As in the case of System II, further analysis will be delayed until a later time.

Figure 6-22: Estimated Values for a System Using Four Motion Elements with No Case Variable, Based on the MTM-3 Model and Basic Times: Identified as System III

Data Element	Estimated Dec. Min.	T For Ho: Parameter=0	PR > |T|	Std. Error of Estimate
T15	0.5757	7.62	0.0001	0.0756
T80	0.6790	1.90	0.0699	0.3564
H15	0.8415	6.31	0.0001	0.1334
H80	2.4743	12.66	0.0001	0.1954

6.2.3 Comparison of MTM-3, System I, System II and System III

From the algorithms used to identify the motion elements in MTM-3, System I, System II and System III, it must be accepted that these four systems are closely related. Therefore, to complete the evaluation of System II and System III, it is proposed to carry out the analysis of variance on these four systems at one time. The three basic evaluation criteria described earlier will be used.

The actual values of Basic Times and the four systems being considered are given in Figure 6-23, the percentage errors in Figure 6-24 and the absolute percentage errors in Figure 6-25. The Analysis of Variance Tableau for these criteria appear as Figure 6-26 to Figure 6-28, respectively.

The three analyses given in Figure 6-26 to Figure 6-28 provide an important example of why it is necessary to use more than one criterion to evaluate a work measurement system. To delineate which of these two systems shows a significant difference in the mean percentage error, a Duncan's Multiple Range Test was performed. The results of this test are shown in Figure 6-29. Examination of the mean values in Figure 6-24 suggests that if there is one system which has a significant difference from the other, it would be System III, and this is confirmed by the results of the Duncan's Multiple Range Test.

Figure 6-23: Basic Times and Predicted Times by MTM-3, System I, System II and System III

Job	Study	Basic	MTM-3	System I	System II	System III
1	P01/1	8.911	9.800	9.487	9.487	9.788
2	P01/3	4.483	3.450	3.743	3.018	3.248
3	P06/1	2.540	3.500	3.024	2.612	2.879
4	P06/2	4.224	4.000	3.963	3.897	4.305
5	P07/1	10.455	8.900	9.892	7.803	9.897
6	P07/2	3.057	3.850	3.006	4.006	2.613
7	P07/3	2.705	3.850	3.066	4.006	2.613
8	P07/4	6.230	7.450	7.168	7.071	6.711
9	P09/1	3.574	3.450	3.806	3.450	3.050
10	P09/2	2.375	2.750	2.694	3.788	2.406
11	P09/3	2.827	2.600	2.171	2.980	1.358
12	P09/4	3.572	2.800	2.892	3.066	2.303
13	P09/5	4.722	2.800	2.892	3.066	2.303
14	P09/6	2.644	2.800	2.892	3.066	2.303
15	P09/7	2.568	2.950	2.525	3.438	1.934
16	P09/8	4.782	4.900	4.157	5.080	3.189
17	P09/9	3.301	3.400	3.262	4.823	1.358
18	P09/10	5.816	6.150	5.397	5.491	6.239
17	P09/11	2.216	3.450	3.806	3.486	3.050
20	P10/1	8.341	8.100	8.182	7.785	7.854
21	P10/2	10.236	10.300	9.921	9.064	10.450
22	P11/1	4.715	6.250	4.973	5.626	5.241
23	P12/1	4.198	4.200	4.030	3.945	3.892
24	P12/2	4.095	4.800	4.040	4.250	3.248
25	P13/1	4.362	3.800	4.160	3.945	3.626
26	P13/2	2.922	3.800	4.160	3.945	4.467
Mean		4.613	4.773	4.591	4.702	4.397
Std. Dev.		2.385	2.300	2.329	1.959	2.376
$\sum X$		119.931	124.100	119.369	122.248	114.325
$\sum (X^2)$		695.415	724.615	683.629	670.710	643.804

Figure 6-24: Percentage Error Between Basic Times and Times Predicted by MTM-3, System I, System II and System III

Identific'n		Dec.Min.	% Error			
Job	Study	Basic	MTM-3	System I	System II	System III
1	P01/1	8.911	-9.974	-6.456	-6.760	-9.840
2	P01/3	4.483	23.046	16.058	32.675	27.554
3	P06/1	2.540	-37.795	-19.039	-2.850	-13.327
4	P06/2	4.224	5.415	6.032	7.823	-1.795
5	P07/1	10.455	14.872	5.385	25.367	5.333
6	P07/2	3.057	-25.873	-0.230	-30.978	14.575
7	P97/3	2.705	-42.340	-13.343	-48.111	3.401
8	P07/4	6.230	-18.451	-13.963	-12.443	-6.706
9	P09/1	3.574	3.459	-6.489	3.210	14.649
10	P09/2	2.375	-15.780	-13.401	-59.469	-1.314
11	P09/3	2.827	7.984	23.160	-5.447	51.939
12	P09/4	3.572	21.613	19.043	14.166	35.521
13	P09/5	4.722	40.108	38.764	35.075	51.228
14	P09/6	2.644	-5.900	-9.372	-15.961	2.890
15	P09/7	2.568	-14.875	1.659	-33.886	24.696
16	P09/8	4.782	-2.356	13.156	-6.125	39.393
17	P09/9	3.301	-3.005	1.182	-46.122	58.858
18	P09/10	5.816	-5.743	7.199	5.581	-7.268
19	P09/11	2.216	-55.686	-71.728	-57.306	-37.640
20	P10/1	8.341	2.892	1.904	6.669	5.843
21	P10/2	10.236	-0.625	3.077	11.452	-2.576
22	P11/1	4.715	-32.595	-5.499	-19.348	-11.189
23	P12/1	4.198	-0.057	3.993	6.027	7.290
24	P12/2	4.095	-17.786	0.866	-4.277	20.301
25	P13/1	4.312	12.876	4.629	9.561	16.868
26	P13/3	2.922	-30.030	-42.338	-34.978	-52.868
		Mean	-7.157	-2.144	-8.710	9.454
		Std. Dev.	21.993	20.919	26.148	25.910
		$\sum x$	-186.096	-55.751	-226.455	245.815
		$\sum (x^2)$	13423.971	11059.579	19065.114	19106.854

Figure 6-25: Absolute Percentage Error Between Basic Times and Times Predicted by MTM-3, System I, System II and System III

Identific'n		Dec.Min.	Absolute % Error			
Job	Study	Basic	MTM-3	System I	System II	System III
1	P01/1	8.911	9.974	6.456	6.960	9.840
2	P01/3	4.483	23.046	16.058	32.675	27.554
3	P06/1	2.540	37.795	19.039	2.850	13.327
4	P06/2	4.224	5.415	6.032	7.823	1.795
5	P07/1	10.455	14.872	5.385	25.367	5.333
6	P07/2	3.057	25.873	0.230	30.978	14.575
7	P07/3	2.705	42.340	13.343	48.111	3.401
8	P07/4	6.230	18.451	13.963	12.443	6.706
9	P09/1	3.574	3.459	6.489	3.210	14.649
10	P09/2	2.375	15.780	13.401	59.469	1.314
11	P09/3	2.827	7.984	23.160	5.447	51.939
12	P09/4	3.572	21.613	19.043	14.166	35.521
13	P09/5	4.722	40.708	38.764	35.075	51.227
14	P09/6	2.644	5.900	9.372	15.961	2.890
15	P09/7	2.568	14.875	1.659	33.886	24.696
16	P09/8	4.782	2.356	13.156	6.125	39.393
17	P09/9	3.301	3.005	1.182	46.122	58.858
18	P09/10	5.816	5.743	7.199	5.581	7.268
19	P09/11	2.216	55.686	71.728	57.306	37.640
20	P10/1	8.341	2.892	1.904	6.669	5.843
21	P10/2	10.236	0.625	3.077	11.452	2.576
22	P11/1	4.715	32.595	5.499	19.348	11.189
23	P12/1	4.198	0.057	3.993	6.027	7.290
24	P12/2	4.095	17.786	0.866	4.277	20.301
25	P13/1	4.312	12.876	4.629	9.561	16.868
26	P13/3	2.922	30.030	42.338	34.978	52.868
		Mean	17.374	13.383	21.103	20.956
		Std. Dev.	14.929	16.003	17.766	18.105
		$\sum x$	451.736	347.965	548.667	544.862
		$\sum(x^2)$	13420.762	11059.579	19469.252	19612.847

Figure 6-26: ANOVA Tableau for Comparison of Basic Time and Predicted Times by MTM-3, System I, System II and System III

Source	df	Sum of Squares	Mean Square	F_{esp}
Between Systems	4	2.085	0.521	0.101
Error	125	647.096	5.177	
Total	129	649.181		

No significant difference between systems.

Figure 6-27: ANOVA Tableau for Comparison of Percentage Difference Between Basic Time and MTM-3, System I, System II and System III

Source	df	Sum of Squares	Mean Square	F_{esp}
Between Systems	3	5271.977	1757.326	3.088
Error	100	56907.545	569.075	
Total	103	62179.522		

Significant difference between systems on 95% confidence level.

Figure 6-28: ANOVA Tableau for Comparison of Absolute Percentage Difference Between Basic Time and MTM-3, System I, System II and System III

Source	df	Sum of Square	Mean Square	F_{esp}
Between Systems	3	1037.506	345.835	1.232
Error	100	28060.320	280.603	
Total	103	29097.826		

No significant difference between systems.

Figure 6-29: Duncan's Multiple Range Test on the Mean Percentage Error for the Third Generation Systems (5% Confidence Level)

System	System II	MTM-3	System I
System III	Signif.	Signif.	Signif.
System I	Not sig.	Not sig.	
MTM-3	Not sig.		

The absence of some evaluation of case only occurs in System III and therefore, it becomes reasonable to suspect that the case of the motion is the important variable when higher level data systems are being used to determine time standards.

6.3.0 ALTERNATIVE SYSTEMS BASED UPON THE MTM-2 MODEL

The term <u>model</u>*is used in a different sense here from that used in the research reports on the development of the MTM-2 by Appelgren (1968) and MTM-3 by Magnusson (1970). In considering System I, System II and System III, for example, the actions Carry and Deposit were used. These two actions, on even the most cursory examination, could be seen to be the Handle and Transport actions of MTM-3.

It was decided to use a similar approach to that described earlier, but with the motion categories being recognized in a manner similar to the MTM-2 categories, hence, based upon the MTM-2 model.

It has already been noted that it was not possible to develop the system parallel of System I to MTM-3 for the MTM-2 system. Nevertheless, it was argued that the apparent importance of the case variable rather than the distance variable made it desirable to make simplification based on the MTM-2 model. Two alternate systems were developed on this basis and will be identified as System IV and System V.

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* The MTM-2 model consists of weighted averages of MTM-1 motions. The models used in this research are based on the frequency of occurence of MTM-2 categories

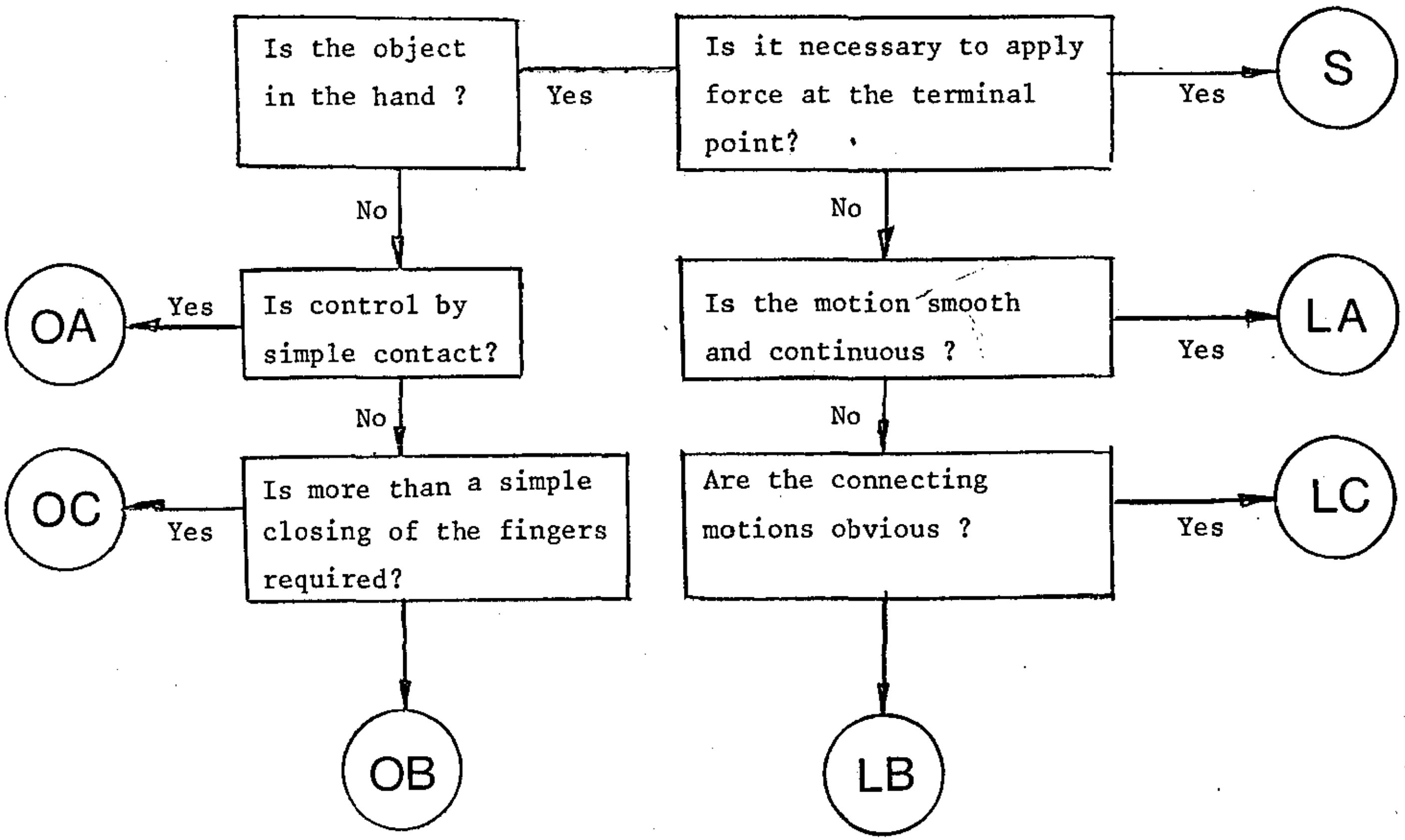


Figure 6-30: System Description Algorithm for System IV

6.3.1 Description of System IV

System IV recognizes three motion categories, in which the only variable is the case. The algorithm in Figure 6-30 enables a complete simplified system description to be seen. The motion categories in the system are identified as:

1. Obtain
2. Locate
3. Seat

The frequency of each category in System IV was constructed from the frequencies of the MTM-2 categories in the field data (Appendix F) using the following equations:

$$f_{OA} = f_{GA5} + f_{GA15} + f_{GA30} + f_{GA45} + f_{GA80} \quad \text{(Eq. 7-10)}$$

$$f_{OB} = f_{GB5} + f_{GB15} + f_{GB30} + f_{GB45} + f_{GB80} \quad \text{(Eq. 7-11)}$$

$$f_{OC} = f_{GC5} + f_{GC15} + f_{GC30} + f_{GC45} + f_{GC80} \quad \text{(Eq. 7-12)}$$

$$f_{LA} = f_{PA5} + f_{PA15} + f_{PA30} + f_{PA45} + f_{PA80} \quad \text{(Eq. 7-13)}$$

$$f_{LB} = f_{PB5} + f_{PB15} + f_{PB30} + f_{PB45} + f_{PB80} \quad \text{(Eq. 7-14)}$$

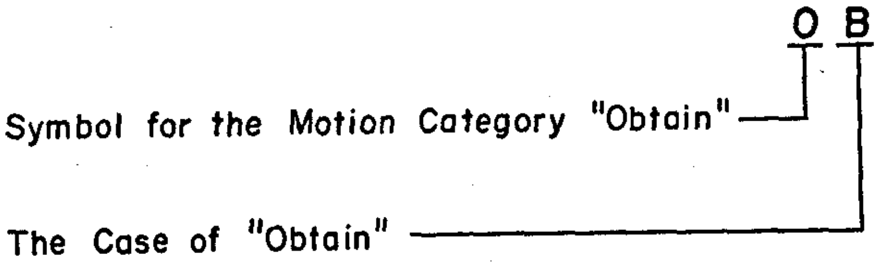
$$f_{LC} = f_{PC5} + f_{PC15} + f_{PC30} + f_{PC45} + f_{PC80} \quad \text{(Eq. 7-15)}$$

$$f_{S} = f_{A} + f_{GW5} \quad \text{(Eq. 7-16)}$$

The motion category SET has no variables and therefore its symbol is simply S. The symbols used for Obtain and Locate are possibly self-evident. Nevertheless, Figure 6-31 and Figure 6-32 have been included to ensure that this is completely established.

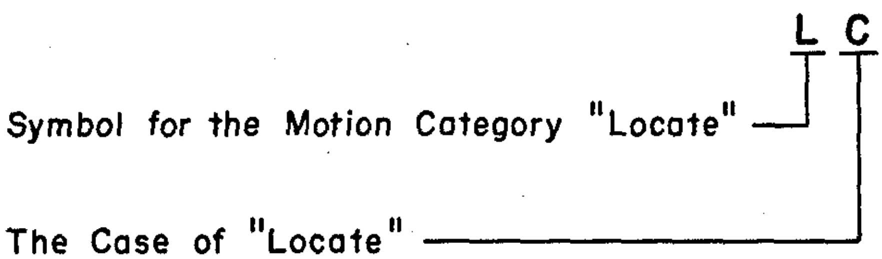
The frequency with which these System IV motions categories occur in the field data jobs, together with their respective Basic Times are given in Figure 6-33. These have been constructed directly from the data appearing in Appendix F.

Figure 6-31: Symbol for System IV Motion Category Obtain



Description: Operator gains control of object by simple closing of the fingers.

Figure 6-32: Symbol for System IV Motion Category Locate



Description: Operator moves object to new location, with obvious correcting motions at the terminal point of the motion.

An MRA was carried out on the data given in Figure 6-33, the results of which are summarized in Figure 6-34. The constraint that there should be no intercepts was placed on the analysis. For this system, it will be seen that the logic that ranks order of the time values should be the same as the case of the motions was followed. The value of PR > $|T|$ for OA, OB and LB was, however, at a level which must give rise to concern on the reliability of the values for the motion categories.

Figure 6-33: Frequency of System IV Motion Categories in Field Data Jobs

JOB	STUDY	OA	OB	OC	LA	LB	LC	S	BASIC	AVERG
1	P01/1	0	3	0	12	0	3	0	8.9112	11.139
2	P01/3	0	1	0	3	0	1	0	4.4832	5.604
3	P06/1	2	1	0	4	0	0	0	2.5400	2.540
4	P06/2	0	1	1	3	0	0	3	4.2290	4.229
5	P07/1	0	0	4	1	0	3	0	10.4548	9.957
6	P07/2	0	1	1	1	0	1	0	3.0586	2.913
7	P07/3	0	1	1	1	0	1	0	2.7048	2.576
8	P07/4	1	2	0	3	0	3	1	6.2895	5.990
9	P09/1	0	0	2	0	0	2	0	3.5736	4.467
10	P09/2	0	0	1	0	0	1	0	2.3752	2.969
11	P09/3	0	2	1	1	0	1	0	2.8265	3.532
12	P09/4	0	0	0	2	0	2	0	3.5270	4.465
13	P09/5	0	0	0	2	0	2	0	4.7224	5.903
14	P09/6	0	0	0	2	0	2	0	2.6440	3.305
15	P09/7	0	3	0	1	0	1	0	2.5680	3.210
16	P09/8	0	0	3	0	0	2	1	4.7822	5.984
17	P09/9	0	0	2	0	0	1	0	3.3008	4.126
18	P09/10	0	3	0	2	0	1	1	5.8160	7.270
19	P09/11	0	1	0	0	0	2	0	2.2160	2.770
20	P10/1	0	4	0	7	1	0	5	8.3412	6.673
21	P10/2	2	4	0	5	2	2	4	10.2360	8.530
22	P11/1	0	1	0	5	2	1	1	4.7136	3.928
23	P12/1	1	1	0	0	0	1	1	4.1976	5.247
24	P12/2	0	1	0	2	2	1	0	4.0952	5.094
25	P13/1	0	1	0	1	0	2	0	4.3616	5.452
26	P13/3	0	1	0	1	0	1	0	2.9224	3.653

Figure 6-34: Estimated Values for a System Using Seven Motion Categories with No Distance Variable Based on the MTM-2 Model and Basic Times - Identified as System IV

DATA ELEMENT	ESTIMATED DEC. MIN.	T FOR HO: PARAMETER=0	PR > |T|	STD. ERROR OF ESTIMATE
OA	0.2582	0.59	0.5608	0.4361
OB	0.4237	1.58	0.1306	0.2682
OC	0.9961	3.32	0.0036	0.3003
LA	0.3251	2.74	0.0129	0.1185
LB	0.3957	0.96	0.3493	0.4123
LC	1.4780	6.08	0.0001	0.2433
S	0.77o6	3.00	0.0074	0.2574

6.3.2 Description of System V

System V is a further simplification based upon the MTM-2 model. System V recognizes only two motion categories, each of which is subject to one variable, namely, the case. The motion categories in the system are, again,

1. Obtain
2. Locate

Figure 6-35 is an algorithm which provides a complete simplified system description. It will be seen that there has been a considerable simplification in this system. The motion category set has been enumerated by combining it with another element. The reduction of the number of cases to either

1. Easy (E)
2. Difficult (D)

has also resulted in significant system simplification. The method of coding these motions by symbols is given in Figure 6-36 and Figure 6-37.

Figure 6-35: System Description Algorithm for System V

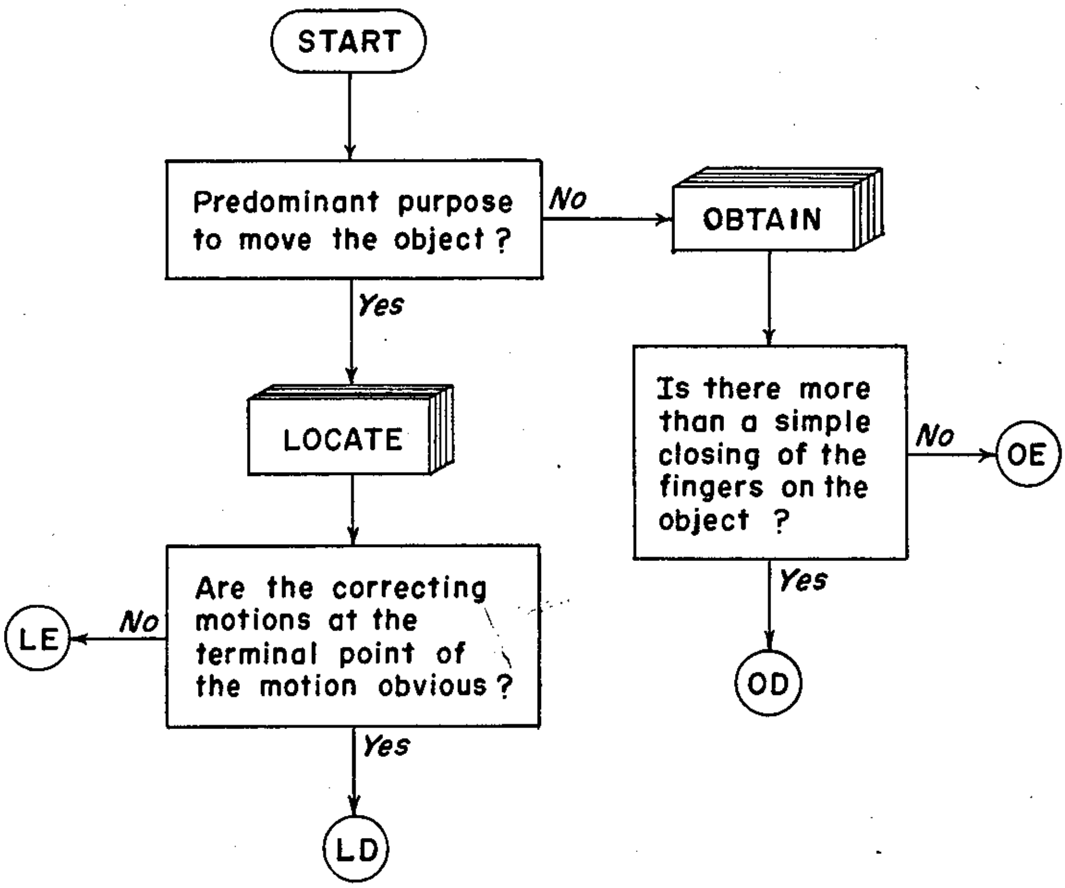
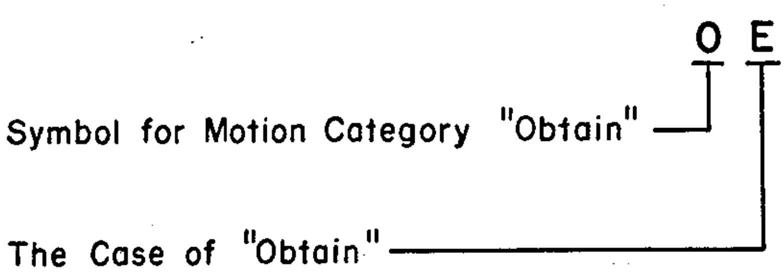
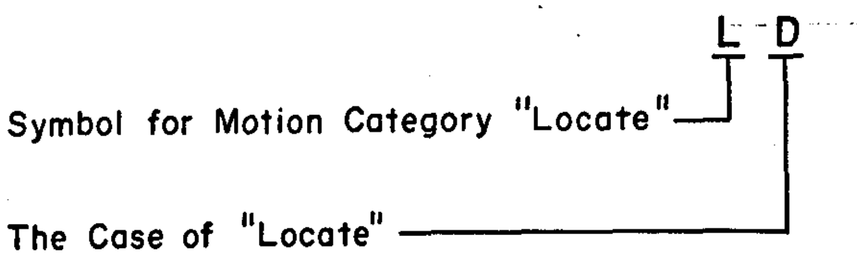


Figure 6-36: Symbol for System V Motion Category Obtain



Description: Operator obtains control of object, Case Easy, with simple contact or closing of Fingers.

Figure 6-37: Symbol for System V Motion Category Locate



Description: Operator moves object to a new location, Case Difficult, requiring obvious correcting motions at termination of movement.

The frequency with which these System V motion categories occur in the field data jobs is given, together with the Basic Times for the jobs in Figure 6-38. This figure has been constructed directly from the data appearing in Appendix F. The equations used to construct these System V motion categories are as follows:

$$f_{OE} = f_{GA5} + f_{GB5} + f_{GA15} + f_{GB15} + f_{GA30} + f_{GB30} + f_{GA45} + f_{GB45} + f_{GA80} + f_{GB80} \quad \text{(Eq. 6-17)}$$

$$f_{OD} = f_{GC5} + f_{GC15} + f_{GC30} + f_{GC45} + f_{GC80} + f_{GW}^{5} \quad \text{(Eq. 6-18)}$$

$$f_{LE} = f_{PA5} + f_{PB5} + f_{PA15} + f_{PB15} + f_{PA30} + f_{PB30} + f_{PA\,45} + f_{PB45} + f_{PA80} + f_{PB80} \quad \text{(Eq. 6-19)}$$

$$f_{LD} = f_{PC\,5} + f_{PC15} + f_{PC30} + f_{PC45} + f_{PC80} + f_{A} \quad \text{(Eq. 6-20)}$$

An MRA was carried out on the data given in Figure 6-38, the results of which are summarized in Figure 6-39. The constraint that there should be no intercepts was placed on this analysis. For this system it will be seen that the logic, relative to the rank order of motion action times and their cases is not followed; however, the value of PR > |T| for each motion action is less than 10T and in three out of the four cases, less than 1%. Therefore, in spite of the failure in logic, the values can be treated with some confidence.

Figure 6-38: Frequency of System IV Motion Categories in Field Data Jobs

JOB	STUDY	OB	OC	LA	LC	BASIC	AVERG
1	P01/1	3	3	12	3	8.9112	11.139
2	P01/3	1	0	3	1	4.4832	5.604
3	P06/1	3	0	4	0	2.5400	2.540
4	P06/2	1	1	3	0	4.2290	4.229
5	P07/1	0	4	1	3	10.4548	9.957
6	P07/2	1	3	1	1	3.0586	2.913
7	P07/3	1	3	1	1	2.7048	2.576
8	P07/4	3	1	3	3	6.2895	5.990
9	P09/1	0	2	0	2	3.5736	4.467
10	P09/2	0	4	0	1	2.3752	2.969
11	P09/3	2	1	1	1	2.8265	3.532
12	P09/4	0	0	2	2	3.5270	4.465
13	P09/5	0	0	2	2	4.7224	5.903
14	P09/6	0	0	2	2	2.6440	3.305
15	P09/7	3	0	1	1	2.5680	3.210
16	P09/8	0	6	0	2	4.7822	5.984
17	P09/9	0	2	0	1	3.3008	4.126
18	P09/10	3	2	2	1	5.8160	7.270
19	P09/11	1	0	0	2	2.2160	2.770
20	P10/1	4	0	7	1	8.3412	6.673
21	P10/2	6	0	5	4	10.2360	8.530
22	P11/1	1	0	5	3	4.7136	3.928
23	P12/1	2	0	0	1	4.1976	5.247
24	P12/2	1	0	2	3	4.0952	5.094
25	P13/1	1	0	1	2	4.3616	5.452
26	P13/3	1	0	1	1	2.9224	3.653

Figure 6-39: Estimated Values for a System Using Four Motion Categories with No Distance Variable: Based on the MTM-2 Model and Basic Times - Identified as System V

DATA ELEMENT	ESTIMATED DEC. MIN.	T FOR HO: PARAMETER=0	PR > |T|	STD. ERROR OF ESTIMATE
OE	0.6667	2.83	0.0096	0.2354
OD	0.5216	2.96	0.0072	0.1762
LE	0.2651	1.83	0.0803	0.1446
LD	1.1314	5.25	0.0001	0.2506

6.3.3 Comparison of MTM-2, System IV and System V

It is now proposed to perform analyses on MTM-2, System IV and System V similar to those carried out on what was referred to earlier as the third generation systems, due to their relationship to MTM-3. For the present analysis, it seems reasonable to refer to the group as the second generation systems. The basic evaluation criteria which will be used are the actual times, the percentage error and the absolute percentage error of the predicted times relative to the Basic Time.

The actual Basic Times and their times predicted by MTM-2, System IV and System V are shown in Figure 6-40. The percentage errors for this data are given in Figure 6-41 and the absolute percentage errors in Figure 6-42. The Analysis of Variance Tableau associated with each of these three sets of data appear as Figure 6-43 to Figure 6-45, respectively.

The only significant difference shown in the comparison of these second generation systems is for System V where the criterion of evaluation being used is the absolute percentage error of the difference from Basic Time.

6.3.4 Comparing the Eight Data Systems

To assist the reader at this point the characteristics of the five alternative systems are summarized as follows:

1. System I: The system is an exact replica of MTM-3, however, the data values have been developed based upon the Basic Time Values from the field data.
2. System II: The system uses a model similar to MTM-3, in that the motion categories are the same and the case of motion is determined in the same way. The distance variable and simultaneous motions are not recognized in System II.

Figure 6-40: Basic Times and Predicted Times by MTM-2, System IV and System V

Job	Study	Basic	MTM-1	System IV	System V
1	P01/1	8.911	7.800	9.606	10.689
2	P01/3	4.483	2.850	2.877	2.776
3	P06/1	2.540	3.050	2.240	3.061
4	P06/2	4.224	6.100	3.715	1.984
5	P07/1	10.455	10.500	7.747	6.294
6	P07/2	3.057	3.500	3.223	3.811
7	P07/3	2.705	3.500	3.223	3.811
8	P07/4	6.230	6.850	7.287	7.260
9	P09/1	3.574	4.400	3.952	3.672
10	P09/2	2.375	2.900	2.474	3.401
11	P09/3	2.827	3.100	3.647	3.434
12	P09/4	3.572	2.900	3.606	3.159
13	P09/5	4.722	2.900	3.606	3.159
14	P09/6	2.644	2.900	3.606	3.159
15	P09/7	2.568	2.500	3.075	3.519
16	P09/8	4.782	6.300	6.716	5.758
17	P09/9	3.301	2.950	3.470	2.357
18	P09/10	5.816	4.100	4.172	4.888
19	P09/11	2.216	3.250	3.380	3.925
20	P10/1	8.341	7.300	8.227	5.837
21	P10/2	10.236	11.450	10.673	10.528
22	P11/1	4.715	5.025	5.091	5.935
23	P12/1	4.198	4.900	2.932	2.648
24	P12/2	4.095	4.150	3.344	5.140
25	P13/1	4.312	4.400	3.705	3.560
26	P13/2	2.922	3.400	2.227	2.246
Mean		4.613	4.730	4.532	4.464
Std. Dev.		2.385	2.383	2.322	2.257
$\sum x$		119.931	122.975	117.821	116.071
$\sum(x^2)$		695.415	723.568	668.724	645.518

Figure 6-41: Percentage Error Between Basic Time and Times Predicted by MTM-2, System IV and System V

Identific'n		Dec.Min.	% Error		
Job	Study	Basic	MTM-2	System IV	System V
1	P01/1	8.911	12.470	-7.799	-19.953
2	P01/3	4.483	36.429	35.824	38.077
3	P06/1	2.540	-20.079	11.417	-20.512
4	P06/2	4.224	-44.242	12.050	53.030
5	P07/1	10.455	3.872	25.901	39.799
6	P07/2	3.057	-14.430	-5.430	-24.665
7	P07/3	2.705	-29.400	-19.150	-40.887
8	P07/4	6.230	-8.912	-15.851	-15.421
9	P09/1	3.574	-23.125	-10.576	-2.742
10	P09/2	2.375	-22.095	-4.168	-43.200
11	P09/3	2.827	-9.711	-29.006	-21.472
12	P09/4	3.572	18.813	-0.952	11.562
13	P09/5	4.722	38.591	23.634	33.100
14	P09/6	2.644	-9.682	-36.384	-19.478
15	P09/7	2.568	2.648	-19.743	-39.369
16	P09/8	4.782	-31.601	-40.443	-20.410
17	P09/9	3.301	10.628	-4.961	28.597
18	P09/10	5.816	29.505	28.999	15.956
19	P09/11	2.216	-46.661	-58.984	-77.121
20	P10/1	8.341	12.483	1.367	30.020
21	P10/2	10.236	-11.860	-4.269	-2.852
22	P11/1	4.715	-6.606	-7.269	-25.875
23	P12/1	4.198	-16.733	30.157	36.922
24	P12/2	4.095	-1.835	18.339	-25.519
25	P13/1	4.312	-0.880	15.062	18.386
26	P13/3	2.922	-16.343	23.785	23.135
		Mean	-5.721	-3.710	-2.724
		Std. Dev.	22.155	23.593	32.491
		$\sum X$	-148.756	-96.448	-70.822
		$\sum(X^2)$	13122.024	14273.270	26584.535

Figure 6-42: Absolute Percentage Error Between the Basic Time and the Times Predicted by MTM-2, System IV and System V

Identific'n		Dec.Min.	Absolute % Error		
Job	Study	Basic	MTM-2	System IV	System V
1	P01/1	8.911	12.470	7.799	19.953
2	P01/3	4.483	36.429	35.824	38.077
3	P06/1	2.540	20.079	11.417	20.512
4	P06/2	4.224	44.242	12.050	53.030
5	P07/1	10.455	3.872	25.901	39.799
6	P07/2	3.057	14.430	5.430	24.665
7	P07/3	2.705	29.400	19.150	40.887
8	P07/4	6.230	8.912	15.851	15.421
9	P09/1	3.574	23.125	10.516	2.742
10	P09/2	2.375	22.095	4.168	43.200
11	P09/3	2.827	9.711	29.006	21.472
12	P09/4	3.572	18.813	0.952	11.562
13	P09/5	4.722	38.591	23.634	33.100
14	P09/6	2.644	9.682	36.384	19.478
15	P09/7	2.568	2.648	19.743	39.369
16	P09/8	4.782	31.601	40.443	20.410
17	P09/9	3.301	10.628	4.961	28.597
18	P09/10	5.816	29.505	28.999	15.956
19	P09/11	2.216	46.661	58.984	77.121
20	P10/1	8.341	12.483	1.367	30.020
21	P10/2	10.236	11.860	4.269	2.852
22	P11/1	4.715	6.606	7.269	25.875
23	P12/1	4.198	16.733	30.157	36.922
24	P12/2	4.095	1.835	18.339	25.519
25	P13/1	4.312	0.880	15.062	18.386
26	P13/3	2.922	16.343	23.785	23.135
		Mean	18.448	18.905	28.002
		Std. Dev.	13.076	14.095	15.738
		$\sum X$	479.659	491.520	728.06
		$\sum (X^2)$	13123.181	14272.800	26579.361

Figure 6-43: ANOVA Tableau for Comparison of Basic Times and Predicted Times by MTM-2, System IV and System V

Source	df	Sum of Squares	Mean Square	F_{esp}
Between Systems	3	1.019	0.3397	0.062
Error	100	546.210	5.462	
Total	103	547.299		

No significant difference

Figure 6-44: ANOVA Tableau for Comparison of Percentage Difference of MTM-2, System IV and System V Relative to Basic Time

Source	df	Sum of Squares	Mean Square	F_{esp}
Between Systems	2	121.366	60.683	0.087
Error	75	52578.047	701.641	
Total	77	52699.413		

No significant difference

Figure 6-45: ANOVA Tableau for Comparison of Absolute Percentage Difference of MTM-2, System IV and System V Relative to Basic Time

Source	df	Sum of Squares	Mean Square	F_{esp}
Between Samples	2	1510.191	755.096	3.666
Error	75	15447.033	205.960	
Total	77	16957.224		

Significant on 95% level

3. System III: The system uses a model similar to that in MTM-3, in that the categories are the same and the distance variable is determined in the same way. The case of motion and simultaneous motions are not recognized in System III.
4. System IV: Three motion categories are recognized in the system. Namely, Obtain, Locate and Seat. The only variable recognized in this system is that of the case of the motion categories and the algorithm for selecting the case is that used in MTM-2. No consideration is given to distance or to simultaneous motions.
5. System V: Only two motion categories are recognized by the system, each having only one variable, the case. There are only two cases and there are no simultaneous motions recognized.

As a further test, the three general MTM systems, namely MTM-1, MTM-2 and MTM-3, and the five alternative generated systems were tested as a group using the three criteria which have been used previously. The data and results of these analyses are given in Figure 6-46 to Figure 6-51, inclusive. It was only in the case of using the mean percentage error as the criterion where any statistically significant difference in the systems was detected. We investigated this difference further by carrying out a Duncan's Multiple Range Test upon the data. The results of this test are given in Figure 6-52, where it can be seen that only System III shows any statistically significant difference from the other systems.

The only developed alternative system from which the case of motion was excluded as a variable was System III. This suggests that in any simplification of a PMTS, the case of the motion element is of greater importance than its distance variable and should, therefore, be considered carefully before exclusion. Furthermore, the effect of simplifying this variable should be tested.

A further implication of these results is that data developed by all of the systems, with the exception of System III, are compatible. Thus, the time for any elements determined by one of these compatible systems can be added to a time for any other element determined by any of the other systems (excluding System III) to determine a total time value.

Figure 6-46: Comparison of the Basic Times with the Times Predicted by Eight Different Systems

Job	Study	Basic	MTM-1	MTM-2	MTM-3	System I	System II	System III	System IV	System V
1	P01/1	8.911	6.980	7.800	9.800	9.487	9.532	9.788	9.606	10.689
2	P01/3	4.483	2.520	2.850	3.450	3.743	3.018	3.248	2.877	2.776
3	P06/1	2.540	3.215	3.050	3.500	3.024	2.612	2.879	2.240	3.061
4	P06/2	4.224	5.890	6.100	4.000	3.963	3.897	4.305	3.715	1.984
5	P07/1	10.455	8.275	10.500	8.900	9.892	7.803	9.897	7.747	6.294
6	P07/2	3.057	3.245	3.500	3.850	3.066	4.006	2.613	3.223	3.811
7	P07/3	2.705	3.915	3.500	3.850	3.066	4.006	2.613	3.223	3.811
8	P07/4	6.230	6.755	6.850	7.450	7.168	7.071	6.711	7.287	7.260
9	P09/1	3.574	4.095	4.400	3.450	3.806	3.459	3.050	3.952	3.672
10	P09/2	2.375	2.950	2.900	2.750	2.694	3.788	2.406	2.474	3.401
11	P09/3	2.827	3.125	3.100	2.600	2.171	2.980	1.358	3.647	3.434
12	P09/4	3.572	3.095	2.900	2.800	2.892	3.066	2.303	3.606	3.159
13	P09/5	4.722	3.095	2.900	2.800	2.892	3.066	2.303	3.606	3.159
14	P09/6	2.644	3.230	2.900	2.800	2.892	3.066	2.303	3.606	3.159
15	P09/7	2.568	3.065	2.500	2.950	2.525	3.438	1.934	3.075	3.579
16	P09/8	4.782	4.945	6.300	4.900	4.157	5.080	3.189	6.716	5.758
17	P09/9	3.301	3.135	2.950	3.400	3.262	4.823	1.358	3.470	2.357
18	P09/10	5.816	6.145	4.100	6.150	5.397	5.491	6.239	4.172	4.888
19	P09/11	2.216	3.550	3.250	3.450	3.806	3.486	3.050	3.380	3.925
20	P10/1	8.341	6.645	7.300	8.100	8.182	7.785	7.854	8.227	5.837
21	P10/2	10.236	10.165	11.450	10.300	9.921	9.074	10.450	10.673	10.528
22	P11/1	4.715	4.710	5.025	6.250	4.973	5.626	5.241	5.091	5.935
23	P12/1	4.198	4.470	4.900	4.200	4.030	3.945	3.892	2.932	2.648
24	P12/2	4.095	3.924	4.150	4.800	4.040	4.250	3.248	3.344	5.140
25	P13/1	4.312	3.270	4.400	3.800	4.160	3.945	3.626	3.705	3.560
26	P13/3	2.922	2.615	3.400	3.800	4.160	3.945	4.467	2.227	2.246
Mean		4.613	4.501	4.730	4.773	4.591	4.702	4.397	4.532	4.464
Std. Dev.		2.385	1.947	2.383	2.300	2.329	1.959	2.376	2.322	2.257
$\sum X$		119.931	117.025	122.975	124.100	119.369	122.248	114.325	117.821	116.071
$\sum (X^2)$		695.415	621.541	723.568	724.615	683.629	670.710	643.804	668.724	645.518

Figure 6-47: Comparison of the Percentage Error of the Predicted Times to the Basic Times Using Eight Different Systems

Job	Study	Basic	MTM-1	MTM-2	MTM-3	System I	System II	System III	System IV	System V
1	P01/1	8.911	21.672	12.470	-9.974	-6.456	-6.760	-9.840	-7.799	-19.953
2	P01/3	4.483	43.429	23.046	16.058	32.675	27.554	35.554	35.824	38.077
3	P06/1	2.540	-26.575	-20.079	-37.795	-19.039	-2.850	-13.327	11.417	-20.512
4	P06/2	4.224	-39.276	-44.242	5.415	6.032	7.823	-1.795	12.050	53.030
5	P07/1	10.455	20.850	3.872	14.872	5.385	25.367	5.333	25.901	39.799
6	P07/2	3.057	-6.093	-14.430	-25.873	-0.230	-30.978	14.575	-5.430	-24.665
7	P07/3	2.705	-44.743	-29.400	-42.340	-13.343	-48.111	3.401	-19.150	-40.887
8	P07/4	6.230	-7.401	-8.912	-18.451	-13.963	-12.443	-6.706	-15.851	-15.421
9	P09/1	3.574	-14.590	-23.125	3.459	-6.489	3.210	14.649	-10.576	-2.742
10	P09/2	2.375	-24.200	-22.095	-15.780	-13.401	-59.469	-1.314	-4.168	-43.200
11	P09/3	2.827	-10.596	-0.711	7.984	23.160	-5.447	51.939	-29.006	-21.472
12	P09/4	3.572	13.354	18.813	21.613	19.043	14.166	35.521	-0.952	11.562
13	P09/5	4.722	34.461	38.591	40.708	38.764	35.075	51.228	23.645	33.100
14	P09/6	2.644	-22.163	-9.682	-5.900	-9.372	-15.961	12.890	-36.384	-19.478
15	P09/7	2.568	-19.354	2.648	-14.875	1.659	-33.886	24.696	-19.743	-39.369
16	P09/8	4.782	-3.296	-31.601	-2.356	13.156	-6.125	39.393	-40.443	-20.410
17	P09/9	3.301	5.023	10.628	-3.005	1.182	-46.122	58.858	-4.961	28.597
18	P09/10	5.816	-5.657	29.505	-5.743	7.199	5.581	-7.268	28.999	15.956
19	P09/11	2.216	-60.199	-46.661	-55.686	-71.728	-57.306	-37.640	-58.984	-77.121
20	P10/1	8.341	20.336	12.483	2.892	1.904	6.669	5.843	1.367	30.020
21	P10/2	10.236	0.694	-11.860	-0.625	3.077	11.452	-2.576	-4.269	-2.852
22	P11/1	4.715	0.076	-6.606	-32.595	-5.499	-19.348	-11.189	-7.269	-25.875
23	P12/1	4.198	-6.489	-16.733	-0.057	3.993	6.027	7.290	30.157	36.922
24	P12/2	4.095	3.686	-1.835	-17.786	0.866	-4.277	20.301	18.339	-25.519
25	P13/1	4.312	25.028	-0.880	12.876	4.629	9.561	16.868	15.062	18.386
26	P13/3	2.922	10.519	-16.343	-30.030	-42.338	-34.978	-52.868	23.785	23.135
	Mean		-3.509	-5.721	-7.157	-2.144	-8.710	9.454	-3.710	-2.724
	Std. Dev.		24.401	22.155	21.993	20.919	26.148	25.910	23.593	32.491
	$\sum X$		-91.230	-148.756	-186.096	-55.751	-226.455	245.815	-96.448	-70.822
	$\sum(X^2)$		15205.784	13122.024	13423.971	11059.579	19065.114	19106.854	14273.270	26584.535

Figure 6-48: Comparison of Absolute Percentage Error of Predicted Times Relative to the Basic Times Using Eight Different Systems

Job	Study	Basic	MTM-1	MTM-2	MTM-3	System I	System II	System III	System IV	System V
1	P01/1	8.911	21.672	12.470	9.974	6.456	6.760	9.840	-7.799	19.953
2	P01/3	4.483	43.790	36.429	23.046	16.058	32.675	27.554	35.824	38.077
3	P06/1	2.540	26.575	20.079	37.795	19.039	2.850	13.327	11.417	20.512
4	P06/2	4.224	39.276	44.242	5.415	6.032	7.823	1.795	12.050	53.030
5	P07/1	10.455	20.850	3.872	14.872	5.385	25.367	5.333	25.901	39.799
6	P07/2	3.057	6.093	14.430	25.873	0.230	30.978	14.575	5.430	24.665
7	P07/3	2.705	44.743	29.400	42.340	13.343	-48.111	3.401	19.150	40.887
8	P07/4	6.290	7.401	8.912	18.451	13.962	12.443	6.706	15.851	15.421
9	P09/1	3.574	14.590	23.125	3.459	6.489	3.210	14.649	10.576	2.742
10	P09/2	2.375	24.200	22.095	15.780	13.401	59.469	1.314	4.168	43.200
11	P09/3	2.827	10.596	9.711	7.984	23.160	5.447	51.939	29.006	21.472
12	P09/4	3.572	13.354	18.813	21.613	19.043	14.166	35.521	0.952	11.562
13	P09/5	4.722	34.461	38.591	40.708	38.764	35.075	51.228	23.634	33.100
14	P09/6	2.644	22.163	9.682	5.900	9.372	15.961	2.890	36.384	19.478
15	P09/7	2.568	19.354	2.648	14.875	1.659	33.886	24.696	19.743	39.369
16	P09/8	4.782	3.296	31.601	2.356	13.156	6.125	39.393	40.443	20.410
17	P09/9	3.301	5.023	10.628	3.005	1.182	46.122	58.858	4.961	28.597
18	P09/10	5.816	5.647	29.505	5.743	7.199	5.581	7.268	28.999	15.956
19	P09/11	2.216	60.199	46.661	55.686	71.728	57.306	37.640	58.984	77.121
20	P10/1	8.341	20.336	12.483	2.892	1.904	6.669	5.843	1.367	30.020
21	P10/2	10.236	0.694	11.860	0.625	3.077	11.452	2.576	4.269	2.852
22	P11/1	4.715	0.076	6.606	32.595	5.499	19.348	11.189	7.269	25.875
23	P12/1	4.198	6.489	16.733	0.057	3.993	6.027	7.290	30.157	36.922
24	P12/2	4.095	3.686	1.835	17.786	0.866	4.277	20.301	18.339	25.519
25	P13/1	4.312	25.028	0.880	12.876	4.629	9.561	16.868	15.062	18.386
26	P13/3	2.922	10.519	16.343	30.030	42.338	34.978	52.868	23.785	23.135
	Mean		19.235	18.448	17.374	13.383	21.103	20.956	18.905	28.002
	Std. Dev.		15.168	13.076	14.929	16.003	17.766	18.105	14.095	15.738
	$\sum X$		500.121	479.659	451.736	347.965	548.667	544.862	491.520	728.06
	$\sum (X^2)$		15371.801	13123.181	13420.762	11059.579	19469.252	19612.847	14272.800	26579.365

Figure 6 -49: ANOVA Tableau for Comparison of the Basic Time and Predicted Times of all Eight Systems

Source	df	Sum of Square	Mean Square	F_{esp}
Between Systems	8	3.392	0.424	0.083
Error	225	1145.987	5.093	
Total	233	1149.379		

No significant difference

Figure 6-50: ANOVA Tableau for Comparison of Percentage Difference in Basic Times and Predicted Times Using all Eight Systems

Source	df	Sum of Square	Mean Square	F_{esp}
Between Systems	7	5563.230	794.747	27.818
Error	200	5714.284	28.57	
Total	207	11277.514		

Very highly sigificant difference

Figure 6-51: ANOVA Tableau for Comparison of Absolute Percentage Differences in Basic Times and Predicted Times Using all Eight Systems

Source	df	Sum of Square	Mean Square	F_{esp}
Between Systems	7	3130.022	447.146	1.816
Error	200	49254.139	246.271	
Total	207	52384.141		

Figure 6.52: Results of Duncan's Multiple Range Test on Percentage Error Between Basic Time and Times Predicted by All Eight Systems

	System II	MTM-3	MTM-2	System IV	MTM-1	System IV	System I
System III	S	S	S	S	S	S	S
System I	NS	NS	NS	NS	NS	NS	
System V	NS	NS	NS	NS	NS		
MTM-1	NS	NS	NS	NS			
System IV	NS	NS	NS				
MTM-2	NS	NS					
MTM-3	NS						

S = Significant difference between systems.

NS = No significant difference between systems.

6.4.0 TESTING THE ALTERNATIVE DATA SYSTEMS

6.4.1 Establishing the Need for Testing the Alternative Developed Data Systems

In spite of the exhaustive analyses carried out in the previous sections and the implications in the results, two essential questions remain unanswered. They are:

1. Are these systems transferable to tasks outside the field data, but within the immediate work area of the test site?
2. Are these systems transferable to tasks outside the test site?

In order to test the concepts of system simplification used in this research, data was collected from two sources:

1. Fifteen tasks from the site of the investigations.
2. Eleven tasks from a maintenance environment.

The Behaviour of Systems II and IV were considered with respect to these two work areas since they produced the best results in previous analyses and some limitation on the length of the investigation was felt to be desirable.

6.4.2 Application to Tasks at the Test Site

The fifteen tasks for which data was collected from the test site were as follows:

Task T1: Load Springs into Magazines
Task T2: Hand Load Detonators to Magazines
Task T3: Insert S-A Retainer into Fuse Body
Task T4: Handle Fuses
Task T5: Assemble and Stamp Torque Module
Task T6: Apply Tape Seal to S-A
Task T7: Assemble Body and Washer to Fuse
Task T8: Assemble and Crimp Detonator Support
Task T9: Assemble Timer Spacers and Retainer
Task T10: Assemble and Stake Trigger Assembly
Task T11: Torque (3) Posts
Task T12: Assemble Starting Spring
Task T13: Burnish Slot
Task T14: Assemble Pin Option Arm
Task T15: Assemble and Form Key Assembly

Each of these tasks was analyzed using MTM-1, MTM-2, MTM-3, System II and System IV. The complete analyses appear in Appendices M to Q, inclusive. Based upon MTM-1, the cycle times for these tasks ranged from approximately 0.04 minutes to approximately 0.63 minutes. The table of time values for these tasks is given in Figure 6-53:

Figure 6-53: Table of Cycle Times for Test Tasks from Test Site (Times in 0.01 Minutes)

Task	MTM-1	MTM-2	MTM-3	System II	System IV
T1	6.740	6.200	5.370	2.6256	4.2539
T2	5.465	7.115	8.760	7.5339	5.5116
T3	18.895	13.510	17.490	14.3488	13.8413
T4	4.450	5.475	6.050	5.2491	3.6213
T5	4.145	5.250	4.800	4.2823	3.8034
T6	8.400	9.270	9.530	7.1385	6.4981
T7	12.640	12.100	12.250	11.4806	9.0188
T8	8.655	8.725	7.420	5.8767	6.7019
T9	19.315	21.725	17.015	24.1687	19.1611
T10	63.005	63.760	64.590	60.9039	57.4973
T11	16.050	15.950	13.900	12.2460	16.3019
T12	25.025	25.150	20.000	11.0778	20.9384
T13	9.770	11.200	16.650	18.3835	16.0995
T14	38.030	36.150	30.050	31.1474	30.1415
T15	8.780	9.950	9.300	2.4116	8.2769
Total	244.365	251.080	243.175	218.874	221.6669
Mean	16.291	16.379	16.212	14.5916	14.778

The mean values obtained by the two systems does suggest that derived systems may produce time values which, on average, may be less than those expected from MTM-1, MTM-2 and MTM-3. We carried out an Analysis of Variance to test if this was the case and from the results, given in Figure 6-54, it will be seen that no *statistically significant difference can be detected in the five* systems being tested.

Based upon these analyses, we may conclude that Systems II and IV could be applied for setting standards in the associated work areas at the test site without any significant change in the overall predicted work content.

6.4.3 Application to Maintenance Type Tasks Outside the Test Site

The investigator developed time standards using MTM-1, MTM-2,MTM-3. System II and System IV for maintenance type tasks in a totally different environment to the test site. This represented eleven tasks, as follows:

Task T16: Assemble and Remove a Small, Easy to Handle Part or Pipe (Less than or Equal to 6'-0" long) into a Bench Vice, Pipe Vice or Wood Vice.

Task T17: Assemble and Remove a Large or Heavy Part or Pipe (Over 6'-0" long) into a Bench Vice, Pipe Vice or Wood Vice

Task T18: Assemble and Remove a Spring Clamp

Task T19: Assemble and Remove Vice Grip Pliers

Tasl T20: Assemble C-Clamp (6" or less) - Easy to Place. Little or No Alignment

Task T21: Assemble C-Clamp (6" or Less) - Difficult to Place. More Exacting Alignment

Task T22: Assemble C-Clamp (Over 6") - Easy to Place. Little or no Alignment

Task T23: Assemble C-Clamp (Over 6") - Difficult to Place. More Exacting Alignment.

Task T24: Remove C-Clamp (All Classifications)

Task T25: Assemble Wood Hand-Screw Clamp

Task T26: Remove Wood Hand-Screw Clamp

The detailed analyses for these tasks in MTM-1,MTM-2,MTM-3, System II and System IV are given in Appendices R to V respectively and the relevant time standards are summarized in Figure 6-55.

Figure 6-54: Analysis of Variance on Five Systems for Tasks in Test Site

Source	df	M.S.	S.S.	F_{exp}
Between	4	56.498	14.125	0.0618 (N.S.)
Error	70	15996.565	228.522	
Total	74	16053.063		

Figure 6-55: Table of Cycle Times for Test Tasks for Maintenance Tasks (Times in 0.01 Minutes)

	MTM-1	MTM-2	MTM-3	System II	System IV
T16	20.630	21.165	21.250	13.088	12.128
T17	25.000	23.515	22.075	14.471	13.187
T18	3.540	4.150	5.150	3.586	3.527
T19	18.315	23.800	23.950	11.980	14.658
T20	24.880	21.500	20.900	12.725	12.381
T21	31.960	31.450	30.150	14.417	20.687
T22	30.715	35.600	33.915	23.233	19.431
T23	39.335	44.000	39.415	27.121	24.683
T24	9.020	8.875	8.100	4.402	4.888
T25	22.525	20.600	26.000	16.454	19.039
T26	8.815	8.250	9.600	7.870	9.845
Total	234.735	243.390	240.505	149.304	154.454
Mean	21.340	22.126	21.864	13.571	14.041

A comparison of the distance variables for MTM-1, MTM-2 and MTM-3 for the field data tasks, and for the maintenance tasks being considered here will quickly explain the difference in the average time values for the MTM-1, MTM-2 and MTM-3 studies and the System II and System IV studies in Figure 6-55. For the sake of consistency, however, we carried out an Analysis of Variance on the data, the results of which are given in Figure 6-56.

Figure 6-56: Analysis of Variance on Five Systems for Maintenance Type Tasks

Source	df	SS	MS	F_{exp}
Between	4	843.1046	210.776	2.2258 (Sig)
Error	50	4734.788	94.696	
Total	54	5577.8926		

There was a statistically significant difference detected between the times predicted by the systems when applied to this work area. It should be noted, however, that this significance was only on a 90% level. While it was obvious, by examination, that the two derived systems were different from MTM-1, MTM-2 and MTM-3, it was confirmed quantitatively by means of a Duncan's Multiple Range Test.

6.5.0. *DISCUSSION ON DERIVED SYSTEMS*

In this chapter the use of developing new PMTS through existing system models, multiple regression analysis and field data has been demonstrated. Several important points are revealed with respect to this approach and are discussed below.

The development of System I, based upon the same classification of motion elements as MTM-3 and the basic times of the field data tasks, tested the premise that the data card values for a particular data system were not exclusive. That is, that other sets of data card values, when developed in an appropriate manner, could be used for setting time standards without disturbing the average prediction of work content.

In developing System I the same breakdown of elements as in MTM-3 was used. The possibility of using this same approach for simplifying elements was investigated by developing System II to System V, inclusive. These alternative systems were based upon both MTM-2 and MTM-3 with simplification being achieved by combining elements to eliminate the variable of either case or distance. The results of the analysis indicated that the recognition of the case of the motion elements is of greater importance than the distance variable when simplifying PMTS for use in the same work environment as which the data was derived.

This can, perhaps, account for some of the success of MTM-2 and MTM-3 even though considerable reductions in the choice of distance codes were made over MTM-2.

The question of transferability of data systems from one work environment to another is always of great importance. Unfortunately this is a subject which has been transcended by commercial consideration. In the late 1960's and early 1970's in the United

Kingdom, several "Data Consortiums" were set up to reduce the costs of work measurement. The argument put forward by the proponents of these groups was that there was no need to develop standards in one plant when they already existed elsewhere. Therefore, there could be significant economies of scale by pooling efforts. Consultants work on similar lines, excepting that they keep the data banks and extend upon them as they carry out assignments. To evaluate this practice of transferring data, tasks within the test site, but not the field tasks, together with tasks from work of a different type were studied and two of the developed systems, System II and System IV, respectively, were used to predict the times. These times were then compared with the values obtained from analyses made using MTM-1, MTM-2 AND MTM-3.

Within the test site the tasks had similar characteristics and, though the derived systems appeared to produce a slightly lower average value than MTM-1, MTM-2 or MTM-3, it was not possible to detect any statistically significant differences between them. When applying the derived systems to the maintenance time tasks, however, a statistically significant difference was found between the derived systems and the MTM-1, MTM-2 and MTM-3 average times. Thus, these tests demonstrated that the data from the two systems under test was not completely transferable between sites, but was applicable to tasks in the work area. As a result of this analysis, one should be aware of the dangers of indiscriminately transferring standard time data between work sites.

7.0.0 ANALYSIS OF OPERATOR WORK-TIME DISTRIBUTIONS

7.0.1 The Importance of Work-Time Distributions

Hancock (1970) proposed the concept of the Balance Time of a PMTS as a means for evaluating alternative MTM systems. This Balance Time, which has been discussed at length is Section 2.6.0 and Appendix B of this thesis, is based upon an assumed "average variance" of the system. A slight variation to Hancock's approach was used by Brinklow (1975,1975,1975,1978,1979,1979) while trying to prove the superiority of the proprietory system MOST (Maynard Operation Sequence Technique) over other MTM based PMTS. Brinklow chose to ignore the incorrect assumptions and questionable averaging used by Hancock and in doing so added little to the body of knowledge and considerably to the confusion surrounding the practice of PMTS.

The Balance Time of MTM-2 was considered by Peter Evans (1980) who also became involved in an extensive statistical approach to prove the superiority of this technique. As with the authors noted above Evans was pre-occupied with the variance of the system and the analyst.

The original study data used in the development of MTM was far too small to be used to study the effects which may result from the natural variation in time which occurs when operators perform unpaced manual tasks. In any case, considering the reasons for developing MTM it is unlikely that the originators even considered this aspect of application. Certainly, in reading the MTM Research Reports which appeared in the 1950's and in private discussions with the authors of these reports, there is every reason to assume that this was the case.

It must be recognised that the variance referred to with respect to the Balance Time is associated with the MTM data itself and not with the natural variation in work-times exhibited by the operator. (For a fuller review refer to Section 2.6.0 and Appendix B of this thesis). The authors who have written on this "average variance" have not made this point sufficiently clear, consequently many users of the MTM systems assume the results to refer to the operator variance, rather than the system variance.

This intuitive association of the measure of variance of the system with the variance of the work-time distribution of an operator indicates the desirability of some such measure. The variance must of course be related to the range of the operator's performance and the variability associated also with the level of skill demonstrated, the motivation brought to bear on the task and the level and standardisation present in the task.

The possible influence of work-time distributions on the application of PMTS was considered by Dudley (1962) in questioning the validity of these systems. However, there are no reports in the technical literature which have attempted to relate the characteristics of MTM to the natural variability of an operator's motion time distribution. This is surprising, since one would assume that breakdown and classification of the motions would provide a natural basis for such an analysis.

The method of data collection used in the current research lends itself to analysing the nature of the work time distributions and their possible relationship to the MTM systems.

7.0.2 Relationship Between Variance of the Operator Variation and the Job Time.

The results of each cycle of each element studied in the field data appears in Appendix D. The histograms for each of these field data jobs have been constructed and are given as Figure H-2 to Figure H-26 in the Appendix H. The variance of the operator variability has been calculated for each of the field data jobs as follows:

$$V_{op} = \frac{\Sigma\,(\bar{t} - t_i)^2}{n - 1} \qquad \text{(Eq.7-1)}$$

where

where. V_{op} = variance of the operator work-time variation

$\bar{t}$ = mean observed time for the task

t_i = observed time for observation i

n = number of observations in the sample.

The variance of the operator work-time distribution is calculated for each job in the field data and the results are given in Figure 7.1

Figure 7-1: Variance of Operator Cycle Time Distribution and Various Estimated Times for Field Data (Time Units in Decimal Minutes)

Job	Study	Basic	MTM-1	MTM-2	MTM-3	Average	Op. Var.
1	P01/1	8.911	6.980	7.800	9.800	11.139	14.868
2	P01/3	4.483	2.520	2.850	3.450	5.604	5.542
3	P06/1	2.540	3.215	3.050	3.500	2.540	0.346
4	P06/2	4.224	5.890	6.100	4.000	4.229	1.141
5	P07/1	10.455	8.275	10.500	8.900	9.957	4.582
6	P07/2	3.057	3.245	3.500	3.850	2.913	2.772
7	P07/3	2.705	3.915	3.500	3.850	2.576	2.105
8	P07/4	6.290	6.755	6.850	7.450	5.990	4.084
9	P09/1	3.574	4.095	4.400	3.450	4.467	5.929
10	P09/2	2.375	2.950	2.900	2.750	2.969	0.776
11	P09/3	2.827	3.125	3.100	2.600	3.532	1.080
12	P09/4	3.572	3.095	2.900	2.800	4.465	2.091
13	P09/5	4.722	3.095	2.900	2.800	5.903	3.356
14	P09/6	2.644	3.230	2.900	2.800	3.305	1.182
15	P09/7	2.568	3.065	2.500	2.950	3.210	2.091
16	P09/8	4.782	4.945	6.300	4.900	5.984	3.201
17	P09/9	3.301	3.135	2.950	3.400	4.126	2.816
18	P09/10	5.816	6.145	4.100	6.150	7.270	4.137
19	P09/11	2.216	3.550	3.250	3.450	2.770	1.130
20	P10/1	8.341	6.645	7.300	8.100	6.673	3.873
21	P10/2	10.236	10.165	11.450	10.300	8.530	3.404
22	P11/1	4.715	4.710	5.025	6.250	3.928	2.849
23	P12/1	4.198	4.470	4.900	4.200	5.247	2.158
24	P12/2	4.095	3.925	4.150	4.800	5.094	1.523
25	P13/1	4.312	3.270	4.400	3.800	5.452	4.322
26	P13/3	2.922	2.615	3.400	3.800	3.653	0.964

Figure 7-2: Summary of Coefficients of Variation of Operator Work-Cycle Distribution

Job	Study	Basic	MTM-1	MTM-2	MTM-3	Average	Op. Var.
1	P01/1	0.433	0.552	0.494	0.393	0.346	14.868
2	P01/3	0.525	0.934	0.826	0.628	0.420	5.542
3	P06/1	0.232	0.183	0.193	0.168	0.232	0.346
4	P06/2	0.253	0.181	0.175	0.267	0.253	1.141
5	P07/1	0.204	0.259	0.204	0.241	0.215	4.582
6	P07/2	0.545	0.513	0.476	0.432	0.572	2.772
7	P07/3	0.536	0.371	0.414	0.377	0.563	2.105
8	P07/4	0.321	0.299	0.295	0.271	0.337	4.084
9	P09/1	0.681	0.595	0.553	0.706	0.545	5.929
10	P09/2	0.377	0.299	0.303	0.302	0.297	0.776
11	P09/3	0.368	0.333	0.335	0.400	0.294	1.080
12	09/4	0.405	0.467	0.498	0.516	0.324	2.091
13	P09/5	0.388	0.592	0.632	0.654	0.310	3.356
14	P09/6	0.411	0.337	0.375	0.388	0.329	1.182
15	P09/7	0.563	0.472	0.578	0.490	0.452	2.091
16	P09/8	0.374	0.362	0.284	0.365	0.299	3.201
17	P09/9	0.274	0.272	0.306	0.266	0.219	2.816
18	P09/10	0.350	0.331	0.496	0.331	0.263	4.137
19	P09/11	0.480	0.299	0.327	0.308	0.384	1.130
20	P10/1	0.236	0.296	0.270	0.243	0.295	3.873
21	P10/2	0.180	0.182	0.161	0.179	0.216	3.404
22	P11/1	0.358	0.358	0.336	0.270	0.430	2.849
23	P12/1	0.350	0.329	0.300	0.350	0.280	2.158
24	P12/2	0.301	0.314	0.297	0.257	0.242	1.523
25	P13/1	0.477	0.636	0.472	0.574	0.381	4.322
26	P13/3	0.336	0.375	0.289	0.258	0.269	0.964

In this same figure the Basic Times have been derived by Time Study, MTM-1, MTM-2 and MTM-3. The average observed time is also given.

Since the coefficient of variation relates the standard deviation to the mean, it provides an excellent basis for comparing distributions with different units and different means. In Figure 7-2 the coefficient of variation has been determined based upon the Basic Times established by Time Study, MTM-1, MTM-2, MTM-3 and upon the Average Observed Time.

The usefulness of being able to relate the variance of the operator work-time distribution to the length of cycle as predicted by a particular work measurement technique is clear. To illustrate however, let us assume that it would be possible to establish a reasonable estimate of the average coefficient of variation, then the variance of the operator work-time distribution at a particular cycle time would be estimated as follows:

$$v = \frac{\sqrt{V_{op}}}{t} \qquad \text{(Eq.7-2)}$$

where

v = average coefficient of variation

t = predicted task time

V = estimated variance of operator work-time distribution

therefore

$$V_{op} = (t\ v)^2 \qquad \text{(Eq.7-3)}$$

and

$$\sigma_{op} = t\ v \qquad \text{(Eq.7-4)}$$

where σ_{op} = the estimated standard deviation of the operator work-time distribution at a specified task time, t.

In order to investigate the possibility of establishing a relationship between the average observed time and the coefficient of variation of the work-time distribution, the graph shown in

Figure 7-3: Coefficient of Variation Versus Observed Mean Time for Job Nos. Indicated.

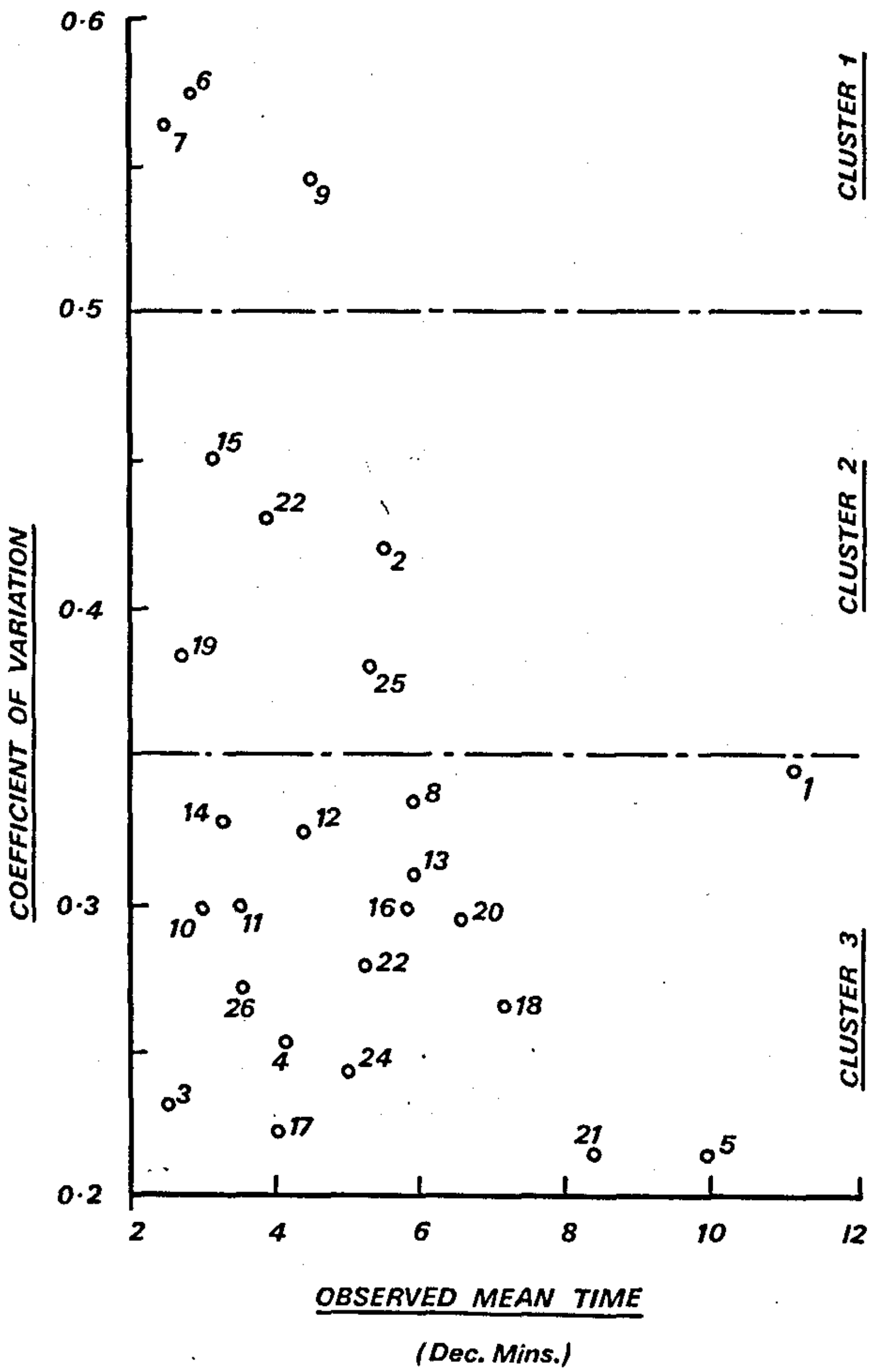


Figure 7-3 was constructed. The numbers shown by the data points refer to the job No. listed in Section 4.4.1. Even a cursory examination shows that it would be unacceptable to use an average coefficient of variation in any calculation.

Further examination of the data shows that the spread of the data points also precludes the development of any acceptable general relationship,other than an average, between the coefficient of variation and the observed mean time. Although there is a suggestion that there may be three clusters of data, Job Nos. 6, 7 and 9, for example, form one such possible cluster. A careful examination of the MTM-1,MTM-2 and MTM-3 motion patterns, together with the characteristics of the processes used in each job failed to produce any basis which could be used to group or classify the jobs for further analysis.

We are therefore faced with the problem of not being able to predict with assurance the coefficient of variation of the work-time distribution from MTM derived standards.

7.0.3 Developing an Average Work-Time Distribution

An examination of the histograms in Appendix H shows a considerable difference in their individual shapes. Several different approaches were used to develop some classification or relationship to the variables of the motion pattern. A goodness of fit, X^2 test, was used testing the actual work-time distributions against Log Normal, Gamma and Beta. None of these showed any statistically significant agreement. The reciprocals of the actual times, as suggested by Sury (1964) were also considered since this ratio represented the work rate. Again, goodness of fit tests were carried out, but this time the Normal distribution was also considered in the comparisons. Again, no statistically significant agreement was shown between the observed data and the common parametric distributions.

In the absence of such a relationship it is tempting to develop an approximate distribution of work-times by pooling data. It is proposed to illustrate a method which was used to do this then, in Sections 7.0.4 and 7.0.5 show the dangers which are attendant upon such a practice.

The first step was to construct the cumulative frequency distribution for each job in the field data. These distributions are given as Figure J-1 through J-26 in Appendix J. On each of these cumulative frequency distributions five ordinates have been constructed, namely $\bar{X}-2\sigma$, $\bar{X}-\sigma$, $\bar{X}$, $\bar{X}+\sigma$ and $\bar{X}+2\sigma$
The points at which these ordinates intercept the cumulative frequency curve were estimated and have been summarised in Figure 7-4. Where it was not possible to obtain an estimate for the $\bar{X}-2\sigma$ ordinate the value was ignored. This was found to occur on thirteen occasions. Therefore, the mean value for this ordinate was based upon thirteen observations.

By plotting the mean cumulative frequency values for these five ordinates and drawing a smooth curve through them, an estimated average cumulative frequency curve for work-time distributions was generated. It is a simple mechanical procedure to draw an average work-time distribution for unpaced operations from this cumulative frequency curve. The cummulative frequency curve and the frequency distribution are shown in Figure 7-5 and Figure 7-6 respectively. The characteristics of the distribution are as follows:

1. The distribution has a positive skew
2. The mode of the distribution occurs at approximately $\bar{X} - 0.6\hat{\sigma}$ where $\hat{\sigma}$ is the variance of the average operator work-time distribution.
3. For approximately 45% of the cycle the operator will perform the task in less than the modal time.
4. For 73% of the cycles the operator will perform the task in less than the average time.
5. An estimated distribution of the motion times due to the natural variation of the operator is described by the following table:

Std.Devs. From Mean	-2.0	-1.5	-1.0	-0.5	0	0.5	1.0	1.5	2.0
% Cum. Frequency	4	11	24	45	73	84	92	95	98

Where the standard deviation is calculated as 0.38 of the predicted mean cycle time.

Figure 7-4: Summary of Cumulative Frequency Distributions on Specified Ordinates for the Field Data Jobs

Job	Study No.	Ordinate				
		$\bar{X}-2\sigma$	$\bar{X}+\sigma$	$\bar{X}$	$\bar{X}-\sigma$	$\bar{X}-2\sigma$
1	P01/1	94	86	71	26	2
2	P01/3	96	93	71	10	-
3	P06/1	99	97	75	44	7
4	P06/2	98	89	76	26	4
5	P07/1	97	90	65	14	5
6	P07/2	96	93	80	22	-
7	P07/3	97	94	85	10	-
8	P07/4	97	92	74	18	1
9	P09/1	97	92	80	6	-
10	P09/2	97	94	82	33	7
11	P09/3	98	88	70	35	-
12	P09/4	97	93	71	26	-
13	P09/5	97	93	70	13	2
14	P09/6	97	92	80	30	3
15	P07/7	96	90	76	27	-
16	P07/8	97	90	67	23	2
17	P09/9	98	93	76	18	-
18	P09/10	96	90	69	24	2
19	P09/11	97	95	85	46	-
20	P10/1	97	93	73	13	1
21	P10/2	98	91	72	16	3
22	P11/1	97	92	67	25	-
23	P12/1	97	91	72	21	2
24	P12/2	95	90	77	35	-
25	P13/1	98	91	64	27	-
26	P13/2	99	93	60	25	-
Mean		97	91.73	73.385	23.577	3.154
Std. Dev.		1.095	2.290	6.31	9.96	2.03
Conf. Lts. 95%		.421	0.880	2.425	3.829	1.104

Figure 7-5: Cumulative Frequency Distribution of Work Time Distributions in Unpaced Work

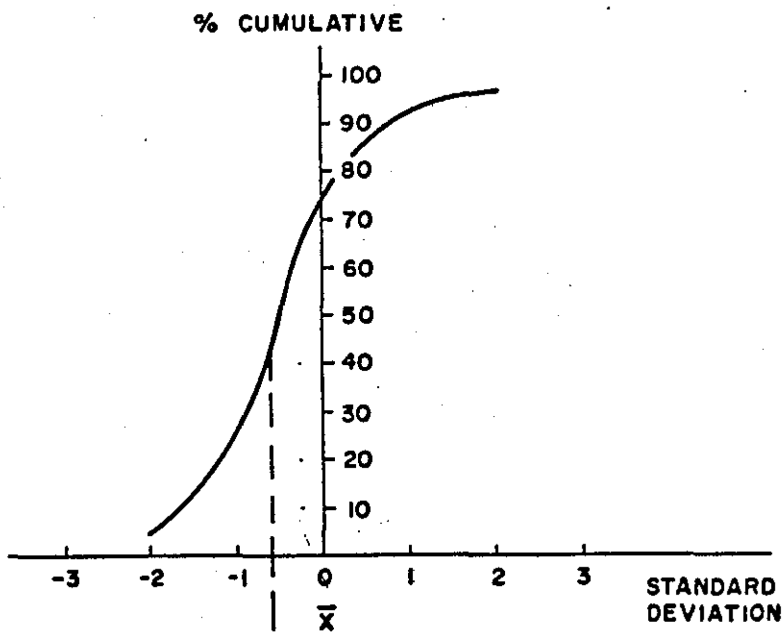
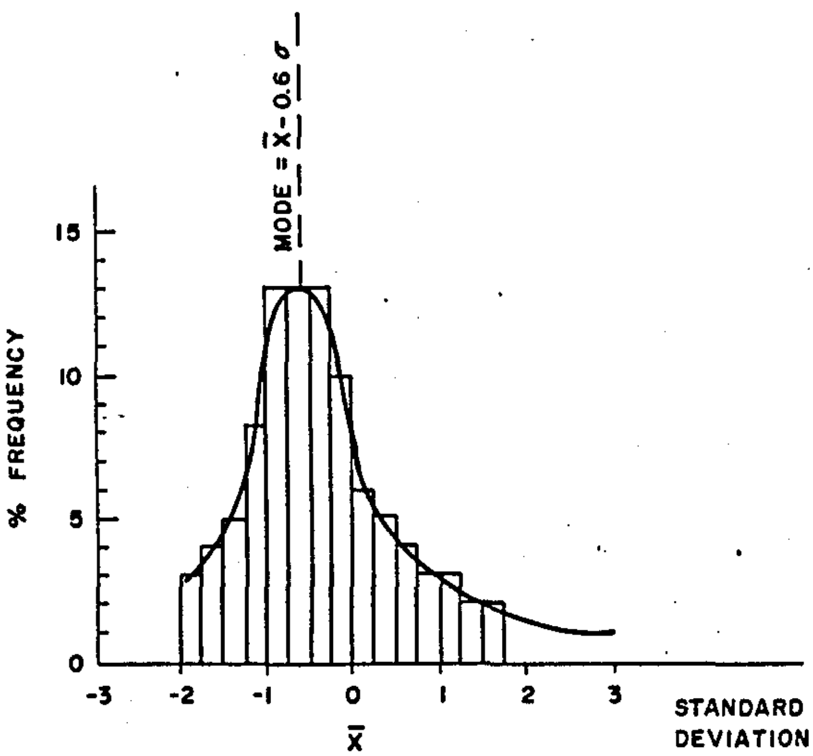


Figure 7-6: General Curve of Frequency Distribution of Work Time Distributions in Unpaced Work.



7.0.4 Skew as a Measure of the Distribution

The skew of a distribution is a measure of its asymmetry and is supplied by the different between the mean and the mode. To make this measure dimensionless, this different is divided by the standard deviation of the distribution. Thus,

$$\text{Skewness} = \frac{\text{Mean} - \text{Mode}}{\sigma} \qquad \text{(Eq. 7-5)}$$

Where

$\hat{\sigma}$ = the estimated standard deviation of the operator work-time distribution.

Since it is easier to determine the Median than the Mode, in practice the alternative equation used to calculate the skewness is

$$\text{Skewness} = \frac{\text{Mean} - \text{Median}}{\hat{\sigma}} \qquad \text{(Eq.7-6)}$$

To see if there is any agreement between the average work-time distribution developed in Section 7.0.3 and the work-time distributions of the individual tasks, the skewness of these distributions were compared.

At the end of Section 7.0.3, five characteristics of the average work-time distribution were stated. One of these was that the mode od the distribution occurs at is the variance of this average work-time distribution. Thus, if the relationship

$$\text{Mode} = \text{Mean} - 0.6\hat{\sigma} \qquad \text{(Eq.7-7)}$$

is substitued into equation 7-5 the skewness of the average work-time distribution is calculated as

$$\text{Skewness} = \text{Mean} - (\text{Mean} - 0.6\hat{\sigma})$$
$$= 0.6\hat{\sigma} \qquad \text{(Eq.7-8)}$$

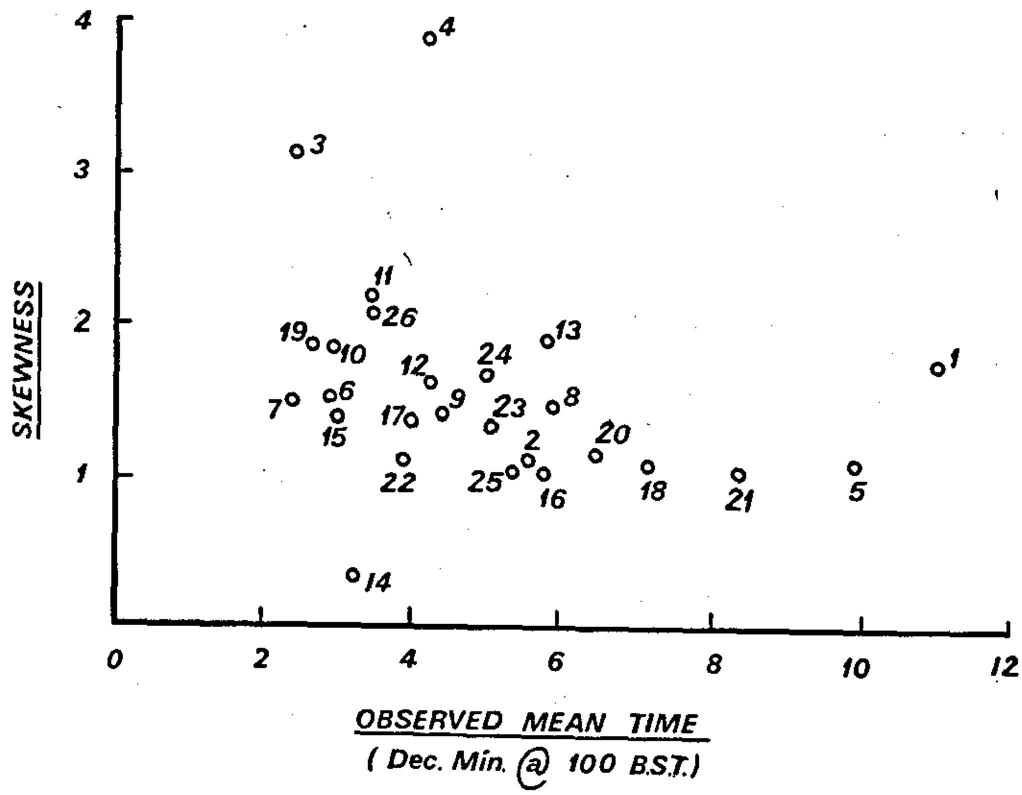
This simplification is attractive, particularly since it appears to agree closely with the findings of Conrad (1955) that some two thirds of the cycle times will be ar or shorter than the mean. However, when the skewness of individual jobs are examined this becomes suspect.

Figure 7-7 Skewness of Work Time Distributions

Job	Study No.	Decimal Min.@ 100 BSI		Standard Deviation	Skew
		Observed Mean	Observed Median		
1	P01/1	11.139	9.833	3.338	1.174
2	P01/3	5.604	4.613	2.354	1.263
3	P06/1	2.540	1.908	0.588	3.224
4	P06/2	4.229	3.133	1.068	3.886
5	P07/1	9.957	9.081	2.141	1.227
6	P07/2	2.913	2.068	1.665	1.523
7	P07/3	2.576	1.858	1.451	1.484
8	P07/4	5.990	5.070	2.021	1.366
9	P09/1	4.467	3.295	2.435	1.444
10	P09/2	2.969	2.432	0.881	1.829
11	P09/3	3.532	2.790	1.039	2.142
12	P09/4	4.465	3.698	1.446	1.591
13	P09/5	5.903	4.738	1.832	1.908
14	P09/6	3.305	3.197	1.087	0.298
15	P09/7	3.210	2.520	1.446	1.432
16	P09/8	5.984	5.362	1.789	1.043
17	P09/9	4.126	3.378	1.678	1.337
18	P09/10	7.270	6.461	2.034	1.193
19	P09/11	2.770	2.133	1.063	1.797
20	P10/1	6.673	5.914	1.968	1.157
21	P10/2	8.530	7.833	1.845	1.052
22	P11/1	3.928	3.325	1.688	1.072
23	P12/1	5.247	4.604	1.469	1.313
24	P12/2	5.094	4.402	1.234	1.682
25	P13/1	5.542	4.750	2.079	1.013
26	P13/2	3.653	2.958	0.982	2.123

The mean, median and standard deviation for each of the work-time distributions was determined and, from this, the skew calculated. The summary of these results is given in Figure 7-7. In Figure 7-8 these skewness values were plotted against the observed mean times in an attempt to establish any trends, or basis, for classification of jobs based upon skewness and motion characteristics.

Figure 7-8 Skewness versus Observed Mean Time for Jobs Indicated.



It is clear from Figure 7-8 that there is no relationship between the skewness of the work-time distribution of individual tasks and their observed mean time. As was carried out with respect to the relationship existing between the co-efficient of variation and the observed mean, the nature of the outliers on the graph were examined in attempt to establish the basis for grouping the skew values of the distribution, but, unfortunately no basis was found.

7.0.5 Summary of the Study of Work-Time Distributions

In all of the jobs studied the work-time distributions exhibited the positive skew reported by the previous researchers. There was, however, a marked difference in the degree of skewness and hence the shape of the work-time distributions of the different tasks.

In spite of a detailed study it was not possible to find any relationship between the coefficient of variation of the work-time distribution and any of the characteristics of the job or its motion pattern. Therefore, although it is possible to make a prediction of the Basic Time for a task, this study was unable to develop any way in which the variance of the work-time distribution could also be predicted with assurance by MTM analysis.

By pooling certain characteristics of the individual work-time distribution an average work-time distribution was developed. The general form of this distribution confirmed the findings of Conrad (1954) that on approximately two thirds of the occasions the task would be completed in less than its mean time. The usefulness of the average work-time distribution ends here, since, in order to make any analysis we need to have at least an estimate of its standard deviation. As was noted earlier in this section we have no means of determining this.

A further point of interest, and warning, arises when comparing the skew of the individual work-time distributions with the average. The skewness values of individual distributions range from approximately 0.3 to approximately 3.9 but with almost 90% of them having a value between 1.0 and 2.0. The average distribution developed in Section 7.0.3 on the other hand has a skew of only 0.6. Clearly then any interpretations based on the average distribution must be viewed with great reservation.

8.0.0 CONCLUSIONS AND SUGGESTIONS FOR FURTHER RESEARCH

This research study has been confined to Methods-Time Measurement Systems which have been used in a close examination of a sample of operations in a specific plant. The extent to which the conclusions may be used in general must therefore benefit from further testing. The methodology developed in this study assists both the wider examination within individual industrial units and the development of further simplified work measurement systems. These systems may be MTM based or derived from direct time study.

8.1.0. CONCLUSIONS

The following are specific conclusions arrived at as a result of this research:

1. The comparison of the basic times as derived from MTM-1, MTM-2 and MTM-3 showed marked differences. However, these differences were not consistent or statistically significant.

2. In reasoning that the higher level data systems such as MTM-2 and MTM-3, would not be so responsive as MTM-1 to the effect of changes in method on the predicted time, the MTM Associations recommend that MTM-2 should not be used where the cycle time is less than 0.9604 minutes (1600 TMU) and for MTM-3, 4.4819 minutes (7800 TMU). In this research operation durations of about 0.11 basic minutes were studied. It was argued that if a statistically significant difference was found between the times predicted by MTM-1, MTM-2 and MTM-3, then it would be necessary to study longer operations. This would enable a minimum time value to be established experimentally. On the other hand, the absence of such statistically significant differences in the predicted times would indicate that these minimum time restrictions serve no useful purpose. The results of this study indicate that the minimum restrictions on the cycle times recommended by the MTM Associations cannot be sustained.

3. A distinct lack of similarity exists between the character of the industrial studies used by the MTM Association to compile the MTM-2 data values and those used in this research study. This difference cannot only be seen by visual examination of

the tasks but confirmed by comparing the frequency of distribution of MTM-1 basic manual motions. Despite this no statistically significant difference was found between the times predicted between MTM-1, MTM-2 and MTM-3. The transferability of MTM-2 and MTM-3 data values was therefore found to be equal to that of MTM-1.

4. The lack of statistically significant differences between MTM-1 basic times and those derived by the higher level systems, MTM-2 and MTM-3, has encouraged consideration of further simplification. Four simplifications have been conceived, two of which were based upon MTM-2 and two upon MTM-3. The simplifications, identified as Systems II, III, and IV and V, were carried out in regard to the motion definitions and their basic times obtained by direct observations in the factory studies (See Section 6.3.5). It was only in System III in which any statistically significant difference was detected compared to the results using MTM-1, MTM-2 or MTM-3.

5. The further simplified systems II and IV were used to predict basic times for operations similar to those encompassed in the first major stage of the study. No significant differences were found between the basic times derived by MTM-1, MTM-2 and MTM-3 and those obtained from further simplified systems II and IV. However, this does not mean that such simplification of MTM systems could be used with assurance outside the work environment in which they were derived.

6. Testing the use of Systems II and IV with studies of maintenance tasks in an entirely different environment (Section 6.4.3) showed a statistically significant difference in the predicted basic times of these derived systems. An examination of the motion patterns suggests that this could be due principally to a difference in the distance variable of the motions involved.

7. Where simplification of a work measurement data system is sought the method described in Section 6.0.0 can be recommended as the basis of testing the acceptability of such simplifications; its use would be markedly quicker and more economical in training and industrial application.

8. Although no consistent statistically significant superiority in predicting basic time has been found for any of the systems tested, there is an indication that the case of the motion elements has a far greater influence than the distance elements in a specific work environment. Bearing in mind the more specific nature of MTM-2 oriented method description, it is recommended that any further simplified system definition be based on the MTM-2 model as with the system IV described in Section 6.3.1.

9. The lack of statistically significant differences in the predicted times by MTM-1, and MTM-3 supports the MTM Association's claim of compatability of these three systems. Furthermore, compatability can be expected between these systems and the systems II to IV described in Section 6.2.1., 6.2.2., 6.3.1., and 6.3.2.

10. Analysis of the work-time distributions of the jobs studied in this research failed to detect any basis for a consistent relationship between either the overall time or motion pattern characteristics with any of the work-time distribution parameters.

11. The work-time distributions of all of the jobs studied showed positive skewness but this skewness varied markedly. By pooling the results of these distributions it was possible to develop an average work-time distribution. (Section 6.0.3) This distribution is in line with that expressed by previous researchers insofar as two thirds of the frequency of times lie below the average time. However, the use of this average value could be misleading in some circumstances due to the wide differences encountered in regard to skewness and variance in the range of operations studied.

8.2.0. RECOMMENDATIONS FOR FURTHER RESEARCH

8.2.1. Additivity of Motion Times

The results of this research have done nothing to answer the long-standing questions on the additivity of motions. In fact, a lack of additivity of the motions may account for some of the apparently conflicting values. A detailed study to establish this concept would provide the basis for understanding the nature of human motions in terms of time.

8.2.2. Complaint and Productivity Indices

The approximation of the operator cycle-time distribution which resulted from this research opens up areas of study into line balancing, incentive design, etc. The concept of a Productivity Index and Complaint Index proposed by Hancock (1974) takes on a far more realistic form when based upon a distribution which approximates what happens more clearly. The influence of the natural variation of the operator upon these problem areas using the proposed motion time distribution should be investigated.

8.2.3 Delineation of Factors Affecting Operators' Natural Variability

In spite of the approximation developed for the motion time distribution of the operators, it is readily admitted that enough variation exists between the distributions of the individual field data tasks for many questions to be still unanswered. Since the completion of this research, it has come to the author's attention that the availability of a computer program to analyze and classify the non-parametric distributions is imminent. This opens up the possibility of an investigation which would delineate and quantify those factors which affect this variation. Such an investigation could provide a better understanding of those motions which require most attention in methods engineering, training and productivity improvement.

8.2.4 Factors Affecting Transferability of Standard Data Systems

Comment was made in Chapter 6.0.0 on the practice of indiscriminately transferring time data between work areas without any real validation. A quantitative statement of the effect of those factors which influence the transferability of standard data systems would be a significant contribution to the more effective development and application of those systems.

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